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Research paper

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The use of modern photogrammetric techniques in the inventory of historical monuments – focus on the Potocki Palace in Krzeszowice

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Summary

The study presents advanced measurement methods used in the inventory of historic buildings, focused on the Potocki Palace in Krzeszowice. The paper addresses two main measurement methods that led to obtaining comprehensive and accurate documentation. The first technique was terrestrial laser scanning, using specialised laser scanners to collect data. In order to represent the actual colours and texture of the object under study, the scanning method was supported by photogrammetry. The second method was low-ceiling photogrammetry, which provided even more accurate data about the Palace. Data processing resulted in a three-dimensional (3D) solid, consisting of a multi-million-point cloud. This was followed by a vectorisation process, which made it possible to obtain a full-dimensional representation of the studied object. The results facilitated a detailed analysis of the Potocki Palace, including the identification of damage and changes occurring over the years. The resulting documentation provides a solid basis for future conservation, modernisation and research work related to the building.
The paper also points out the potential applications of contemporary technologies in order to visualize inventoried objects. The technique of Virtual Reality (VR) and showing the object in 3D that has been popular so far, has recently found even broader application, providing input for the construction of the so-called Augmented Reality (AR).

Keywords

photogrammetry • laser scanning • inventory of monuments • virtual reality • Potocki Palace in Krzeszowice

1. Introduction

Historical objects constitute an integral part of our environment. They bear witness to previous eras and, due to their significant historical, aesthetic, and architectural value, they are usually considered part of our national cultural heritage. Because of their immense historical value, they also require special attention and care from heritage conservators. To preserve the splendour of these structures, constant maintenance and monument conservation is necessary. One of the tools allowing us to understand the exact technical condition of these buildings is the process of architectural (building) inventory.

Photogrammetric methods based on terrestrial or low-level photography complemented by laser scanning technology seem to work best for the stated purpose. Added to this are the latest solutions for 3D visualization of inventoried objects in the form of virtual models or augmented reality [Mikrut et al. 2018].

1.1. Building inventory

Building inventory is a process of documenting, describing, and recording the technical condition of a building. It involves an examination of the state of the structure, including all structural elements, interior furnishings, and existing installations. The gathered information facilitates the creation of precise documentation, including the detailing of damage, recommended repairs, or information about the necessity of replacing elements that pose a threat. The knowledge obtained in this manner brings many benefits to property owners, managers (heritage conservators), and potential users of the building. By knowing the technical condition of the property, the owner can plan any necessary conservation, modernization, or renovation work. Systematic documentation of the building's condition also allows early detection of damage or failures, which can save time, and often also money, while ensuring the safety of users.

Technological advancements over the years have led to the development of several modern building inventory methods. In addition to the long-standing manual measurements using traditional measuring tools (such as rulers, protractors, measuring tapes, etc.), application of methods such as scanning, thermographic analysis, geodetic methods, laser scanning, and photogrammetry is on the rise. The choice of the appropriate method depends on a number of different factors, such as the location of the object, its geometry, and the requirements of the investor. Regardless the chosen method, it is essential to accurately replicate the object, its technical condition, dimensions, shapes, surface types, and location.

This is essential for the protection, conservation, modernization, and research related to the building [Prarat 2016]. An interesting approach involves the use of computer object visualization, as described in research papers by Sadjadi [2019] and professors from the University of Zaragoza [Quintilla-Castán et al. 2022]. In their articles, they emphasize the importance of integrating photogrammetry with 2D and 3D models in the reconstruction of culturally significant sites. Additionally, the creation of digital documentation brings numerous benefits to conservation specialists, property owners, and tourists.

Monument inventory methods and the latest techniques are widely described in the literature, including: Pierdicca at al. [2023], Balloni et al. [2023], Gorgoglione et al. [2023], Malinvierni et al. [2024]. Effective presentation of the inventory results by the virtual and augmented reality methods mentioned in the introduction is also becoming a key element [Olko et al. 2021].

1.2. Surveying method

The surveying method involves measuring the position, shape, and dimensions of a building and its immediate surroundings using specialized geodetic equipment. Field measurements are commonly conducted with instruments such as levels and theodolites. The geodetic method is particularly useful for buildings with complex geometry and decorative elements. Accurately determining the dimensions of individual building components facilitates creation of precise documentation and planning any necessary property renovations or modernizations. However, this method can be time-consuming, especially for large structures, and it may be impractical in hard-to-reach areas due to the size of the geodetic instruments [Prarat 2016].

1.3. Laser scanning

Laser scanning is an advanced measurement technique that involves measuring objects using a laser scanner [Kurczyński 2014, Mitka et al. 2016]. This technology offers precise knowledge of the shape, dimensions, and surfaces of the scanned building objects. The result of the laser scanning process, after data processing and interpretation, is the creation of a three-dimensional visualization of the inspected object in the form of a 3D model. Laser scanning is most commonly used for buildings with complex geometry and irregular decorative elements, where other methods may be insufficient.

1.4. Photogrammetry

Photogrammetry involves measurements and analysis of objects and surfaces based on photographs or images [Kubalska et al. 2014]. Through appropriate processing, it is possible to obtain information about the shape, dimensions, or location of objects. This is particularly useful while conducting inventory in large areas where other measurement methods would be excessively time-consuming and costly. The photogrammetry process begins with collecting a set of photographs or images of a given area. Then, characteristic points on each photo are identified, allowing the determination of their precise spatial coordinates. Additionally, camera calibration is necessary because it enables the accurate determination of camera parameters, such as focal length, distortion, and position [Doroszuk et al. 2022]. Knowing these parameters is essential for converting points into real spatial coordinates. Stereovision techniques are often applied, using multiple photos from different camera positions to create a three-dimensional effect. The final stage of the photogrammetry process is data processing to create maps or 3D models of the studied area.

A very common solution is to combine both techniques, i.e. photogrammetry and laser scanning [Mikrut et al. 2014, Markiewicz et al. 2016].

1.5. New visualisation methods (VR and AR)

There are two main components in a virtual reality system that work closely together to enable VR technology (Virtual Reality). The first is the software, which is responsible for generating the virtual 3D image. The second component, responsible for direct contact with the user and providing the effects necessary for immersion, is specialised electronic equipment. The latter can be divided into design devices and those intended for interaction [Olko et al. 2021, Pająk et al. 2011].

Virtual Reality (VR) allows the user to take a virtual walk using special hardware and software. This allows the user to experience the virtual world as if it were the real world. In Augmented Reality (AR), the user sees the real world, but with additional virtual elements (e.g. additional tourist information).

The dynamic development of multimedia technology makes various VR and AR solutions possible. Nowadays, there are more or less advanced devices, whose differentiation in price and quality is related to the way they are displayed - the cheaper equipment has one screen (the one in which a smartphone plays the role of a display), the professional one has two. A detailed analysis in terms of the availability of different solutions, mainly allowing use for heritage inventory purposes, is presented in the literature [Olko et al. 2021].

2. Characteristic of the object

The historical object under examination is the Potocki Palace in Krzeszowice (Fig. 1). It is located on a small hill in the Krzeszowice City Park [Krzeszowice 2024]. This 19th-century building, which has been left unused for many years, has lost its former splendour. The impact of weather conditions, moisture and vandalism by third parties has brought the palace to a state of ruin. To restore its former glory, it is necessary to create precise documentation that will facilitate its renovation. However, this process is quite complex due to the fact that the building has been designated as a historical monument and is a subject to special oversight. The necessary stock taking process requires extremely precise measurements that will not affect the condition of the building but will accurately represent its shape, with particular emphasis on decorative elements.

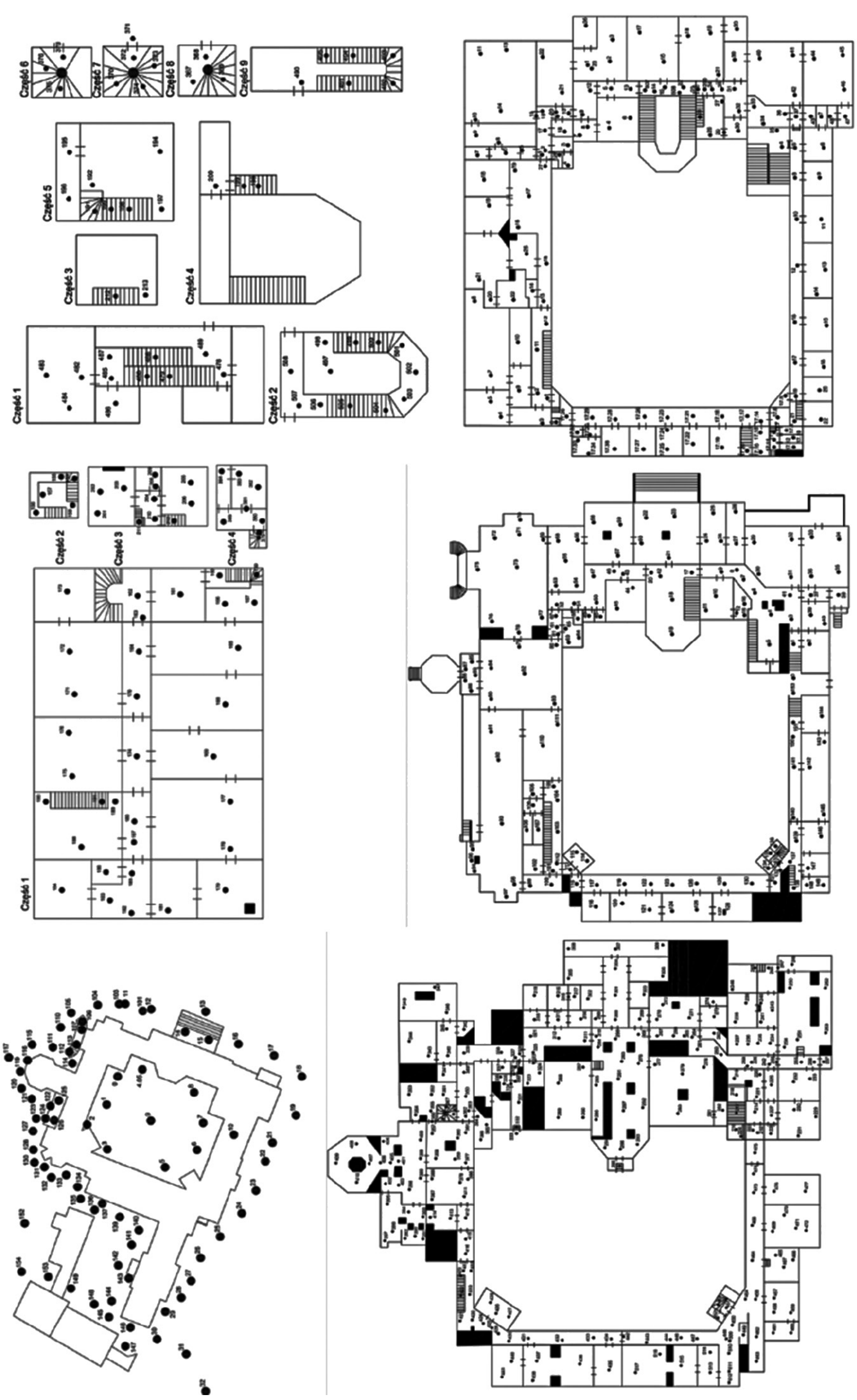
Source: Author's own study

Fig. 1. Potocki Palace in Krzeszowice (view from the South)

3. Data acquisition

During the inventory process, scanners and drones were used. Scanners are complex devices consisting of several components. Before commencing the scanning process, it was necessary to plan the layout of measurement stations and control points to minimize the risk of creating so-called 'dead zones' (Fig. 2). The next step preceding the scanning process was to determine the parameters under which the measurement would be performed.

The laser scanning measurement procedure was conducted using two phase-shift scanners. The first was the Z+F IMAGER 5010 model [ZF 2024], and the second was by FARO, the Faro Focus S120 model. Both scanners are very small in weight and size, which renders them highly mobile [FARO 2013]. They also proved to be highly effective for measurements in hard-to-reach, tight spaces. These scanners are characterized by a wide field of view and high measurement speed, which significantly facilitated and expedited the inventory process. To obtain all the necessary information to determine the condition of the Potocki Palace, laser scanning was complemented with photogrammetry (Table 1). During the scanning process, photographs of the entire residence were taken. This allowed the generated point cloud to be colorized (RGB), giving each element the appropriate texture. Because the obtained scans partially overlap, they can be merged in suitable software and used for various analyses and representations.



Source: Author's own study

Fig. 2. Schematic representation of the layout of measurement stations

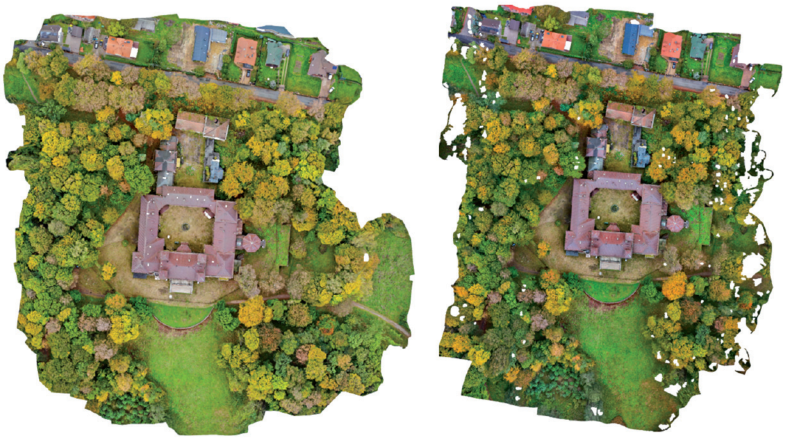
Table 1. Number of scans performed for different areas of the Potocki Palace in Krzeszowice

	Object	Scanning area	Part	Number of scans	Sum
1	Palace from outside	Courtyard in the middle of the palace		**11**	78
2		Façade of the palace		**67**	
3	Palace indoors	Dungeons		**248**	653
4		Ground floor		**148**	
5		First floor		**147**	
6		Second floor		**57:**	
7			Part 1	33	
8			Part 2	8	
9			Part 3	11	
10			Part 4	5	
11		Staircases:		53:	
12			Part 1	11	
13			Part 2	12	
14			Part 3	2	
15			Part 4	3	
16			Part 5	8	
17			Part 6	3	
18			Part 7	5	
19			Part 8	3	
20			Part 9	6	
Total					731

As previously mentioned, two drones were used in the inventory process. The first one was the DJI Mavic Air, and the second one was the DJI Mavic Air 3. Drones are remotely controlled using radio transmitters that transmit signals from the person controlling the flight on the Earth's surface to the drone.

The inventory process using low-ceiling photogrammetry began with planning the drone mission [Tsoraeva et al. 2021]. During this process, the study area was defined, and flight parameters such as altitude, speed, and flight path were set. After adequate preparation and obtaining the necessary permissions, the aerial measurement was initiated. Once the flight was completed, the data collected by the drone in the form of photographs were reviewed and subjected to further processing. This method led to obtaining the shape and dimensions of the roof, complementing the terrestrial laser scanning.

By using this method, an orthophotomap was obtained, and the impact of the flight procedure on its quality was evaluated. The first method involved meticulous planning of the drone's route for the aerial survey, while the second method applied Waypoints to determine the drone's flight path. It was noted that the second method yielded poorer results. This was due to imprecise placement of the survey points and insufficient terrain coverage on the generated orthophotomap, resulting in gaps and deficiencies. Consequently, the first method proved to be more efficient, despite the lower resolution of the camera (Fig. 3).



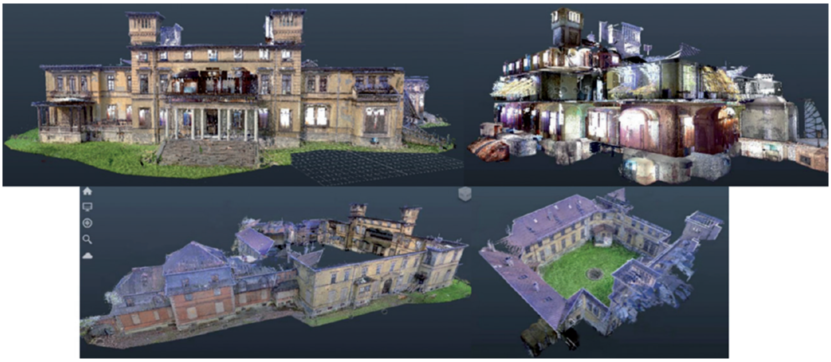
Source: Author's own study

Fig. 3. Orthophotomap created using the DJI Mavic Air and DJI Mavic Air 3 drones

The inventory process also involved special backpacks equipped with appropriate sensors and technology. Data collection took place throughout the city park where the Potocki Palace is located. Owing to special 360-degree cameras and LIDAR technology, it became possible to create three-dimensional maps. Additionally, outfitting the backpacks with GPS receivers enabled the tracking of location and terrain properties. It is worth mentioning that modern technologies used for inventorying offer numerous benefits. They save time and increase measurement accuracy, which is particularly important when dealing with large and complex resources [Su et al. 2020].

4. Data processing

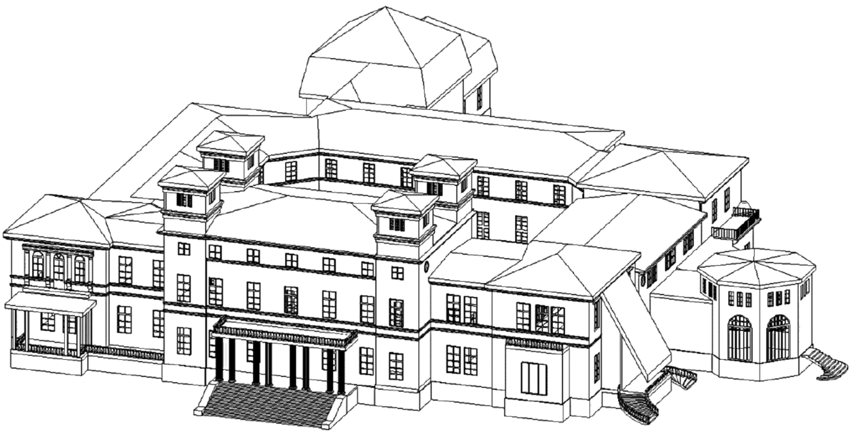
For the analysis and data processing, various software applications were employed, resulting in the creation of a 3D model of the Potocki Palace. The generated 3D model accurately replicated the geometry of the object, making it a fully measurable entity. This allowed straightforward analysis of shapes, dimensions, and an assessment of the overall condition of the entire structure, as well as of each component thereof. Additionally, the 3D model served as a valuable source of information about the texture and the details, namely, the architectural embellishments of the building, which significantly facilitated the inventory process, particularly in the context of monument conservation efforts (Fig. 4).



Source: Author's own study

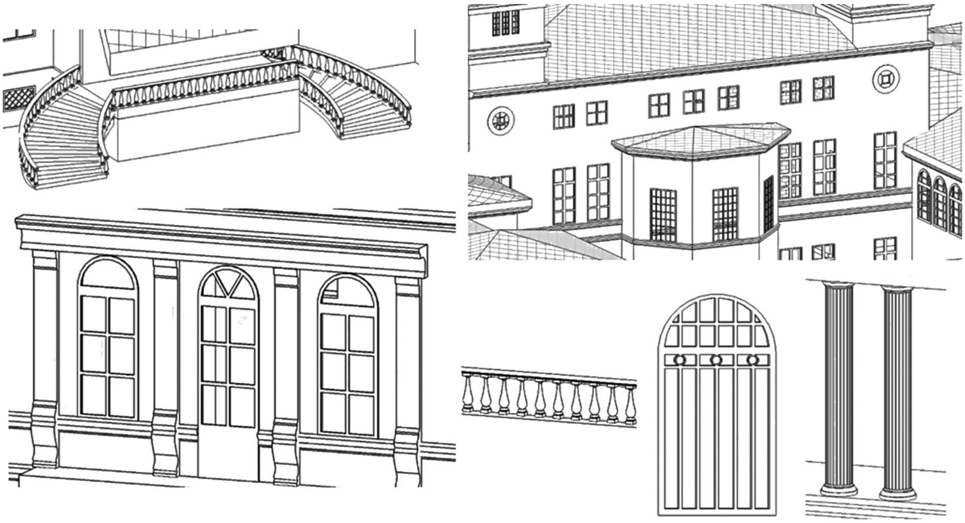
Fig. 4. Three-dimensional (3D) model of the Potocki Palace in Krzeszowice

During further analysis of the acquired data, vectorization of the Potocki Palace was performed. The vectorization process was based on a point cloud. This stage was a crucial step in the analysis and documentation of the object, which required detailed inventorying and preservation. Vectorization involved converting the points of the point cloud into a vector form, ultimately providing accurate geometric data of the object. The obtained vector layers also facilitate the creation of precise plans, maps, and documentation of the object (Fig. 5, Fig. 6).



Source: Author' own study

Fig. 5. Vector Model of the Potocki Palace in Krzeszowice



Source: Author's own study

Fig. 6. Sample elements subjected to the vectorization process

5. Visualisation of the object in virtual reality (VR)

As part of the facility's inventorying, we are also planning to use the latest multimedia techniques related to its visualisation. The data acquired will help develop a comprehensive 3D visualisation of the facility, both the interior and the exterior. In the first stage, the data on the courtyard of the building was compiled (scanning and photogrammetry) and a virtual model was created to enable multimedia visualisation. This is the first step towards creating a visualisation of the entire building.

Autodesk ReCap Pro software was used for the tasks of importing and combining laser-scanning data, displaying and pre-cleaning the point cloud, and exporting the output.

Agisoft Metashape software was used to process the image data, then generate and clean the cloud to get rid of redundant points, followed by assembling a coherent object model (Fig. 7).

Unity Hub and Unity Editor were then used to create the design, import the 3D model, and develop a virtual tour of the site. The Oculus App allowed a wireless connection between the Oculus VR goggles and a smartphone. The configuration of these devices is necessary to use the goggles. Figure 8 shows a section of the virtual model generated from the data acquired in the project. A more extensive description can be found in the paper [Olko et al. 2021].

The next step will be to use augmented reality (AR) technology to launch virtual walks with tourist information.

Source: Author's own study

Fig 7. View of the palace as a coloured point cloud

Source: Author's own study

Fig. 8. The main corridor of the facility overlooking the courtyard in the virtual model

6. Conclusions

Owing to the methodology that combines laser scanning enriched with photogrammetry and drone photogrammetry, a comprehensive three-dimensional (3D) model of the Potocki Palace in Krzeszowice was successfully created. In addition, an orthophotomap was obtained, allowing even more detailed data acquisition. The data acquisition and processing demonstrated that objects with complex shapes and surfaces can be accurately inventoried using the methods described above. The created 3D model is fully dimensional, enabling further analysis, monitoring, and comparison of the damage sustained by the building over the years. The acquired information not only allows the assessment of the condition of each element of the object but also provides detailed data on the structure and texture of the surfaces under investigation. This is particularly useful for irregularly shaped elements, such as decorative features or surface damage. Additionally, vectorization of the object based on the point cloud was carried out, resulting in an even more detailed representation of the Potocki Palace. These data serve as an extremely valuable source of information for future conservation, modernization, and revitalization efforts. With precise documentation that includes the dimensions and technical condition of individual elements, it becomes possible to accurately plan and execute work on the object. The created 3D model and the acquired data form the basis for further analysis, actions, and management of the Potocki Palace in Krzeszowice.

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References

Balloni E., Gorgoglione L., Paolanti M., Mancini A., Pierdicca R. 2023. Few shot photogrammetry: a comparison between NERW and MVS-SFM for the Documentation of Cultural Heritage. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-M-2-2023, 155–162.

Doroszuk K., Markiewicz J. 2022. The possibility of using close-range photogrammetry in the inventory of historic complex basements – case study. Sensors and Machine Learning Applications. 1. 10.55627/smla.001.02.0014.

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.

Kubalska J.L., Preuss R. 2014. Wykorzystanie danych fotogrametrycznych do inwentaryzacji zieleni na terenach zurbanizowanych. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 26, 75–86.

Kurczyński Z. 2014. Fotogrametria. Wydawnictwo Naukowe PWN, Warszawa.

Malinverni E.S., Di Stefano F., Gorgoglione L. 2024. Rivoluzione Digitale nel Patrimonio Culturale: Impatti e Innovazioni della Stampa 3D. Rocca di Senigallia. (Ri)conoscere, Gestire, Valorizzare. Gangemi Editore. Collana Antico/Futuro (in printing).

Markiewicz J., Zawieska D., Salach A. 2016. Integration of point clouds from terrestrial laser scanning and image-based matching for generating high-resolution orthoimages. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 399–404.

Mikrut S., Marmol U., Moskal A. 2014. Images and scanning data integration on selected example. Image Processing & Communications: International Journal, 19, 2–3, 37–44.

Mikrut S., Papuci-Wladyka E., Strus A., Głowienka E., Konstantinowski Puntos J. 2018. The Use of Photogrammetry in Archaeology and Multimedia Open-Air Performance in the Castle Square of Kato Paphos. Proceedings. Baltic Geodetic Congress, BGC-Geomatics.

Mitka B., Makuch M., Gawronek P. 2016. Zastosowanie intensywności wiązki odbicia w ocenie stanu powierzchni budowli zabytkowych. Episteme, 32, 11–24.

Olo K., Słowiak M. 2021. Opracowanie modelu 3D w wirtualnej rzeczywistości na przykładzie dziedzińca Pałacu Potockich w Krzeszowicach. Praca dyplomowa, AGH.

Pająk E., Dudziak A., Górski F., Wichniarek R. 2011. Techniki przyrostowe i wirtualna rzeczywistość w procesach przygotowania produkcji. Wydawnictwo Promocja, Poznań.

Pierdicca R., Gorgoglione L., Martuscelli M., Usmanov S. 2023. Challenging Architectures: an Integrated and Multipurpose Survey for the Complete Mapping of the Emir Palace in Kogon (Uzbekistan). Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-M-2-2023, 1225–1232.

Prarat M. 2016. Wykorzystanie tachimetrii i fotogrametrii w dokumentacji zabytków architektury na przykładzie inwentaryzacji pomiarowo-rysunkowej wybranych kamienic toruńskich. AUNC_ZiK, 46, 509–531.

Quintilla-Castán M., Martínez-Aranda S., Hernández L. 2022. Digital 3D Inventory for the Promotion and Conservation of the Architectural Heritage. ISPRS ‑ International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences, XLVIII-4/W1-2022, 379–385.

Sadjadi S. 2019. Using Digital Terrestrial Photogrammetry in Cultural Heritage Case Study: The Great Wall of Gorgan in Iran. ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XLII-4/W16, 555–561.

Su Y., Guo Q., Jin S., Guan H., Sun X., Ma Q., Hu T., Wang R., Li Y. 2020. The Development and Evaluation of a Backpack LiDAR System for Accurate and Efficient Forest Inventory. IEEE Geoscience and Remote Sensing Letters, 1–5.

Tsoraeva E., Gadzhiev R., Kuchiev S., Pekh A., Mezhyan S. 2021. Application of photogrammetric methods in architecture, construction, and land management. Materials Science and Engineering, 1083(1), 012052.

Online sources

Krzeszowice 2024. Pałac Potockich, Zabytek.pl. https://zabytek.pl/pl/obiekty/krzeszowice-palac-potockich

FARO 2013. laserscanning-europe.com. https://www.laserscanning-europe.com/sites/default/files/redakteur_images/TechSheet_Laser%20Scanner_Focus3D.pdf.

ZF 2024. Z + F. GmbH. zofre.de. https://www.zofre.de/laserscanner/3d-laserscanner/z-f-imagerr-5010