ONLINE FIRST February 2, 2026

Computer Assisted Methods in Engineering and Science
***, https://doi.org/10.24423/cames.2025.273

Possibilities for Obtaining Terrain Models, Orthophoto Maps, and Point Clouds with the Use of a Multirotor UAV

Piotr Łabędź, Paweł Ozimek*

Cracow University of Technology, Kraków, Poland
* *Corresponding Author:* *pawel.ozimek@pk.edu.pl*

In this paper, a method for acquiring spatial data using unmanned aerial vehicles (UAVs) is presented. In this work, the UAV is a hexacopter equipped with a high-end camera capable of recording 4K video and capturing high-resolution photographs.

The first step in data acquisition involves conducting a flight over the analyzed object, which can be either a land area or a construction site. During the flight, a series of photographs or video footage is recorded. In a later stage, these recordings are processed with the use of appropriate software. This processing consists of several steps. First, the recorded photos are arranged according to their location of capture and then properly stitched together. Based on this, a dense point cloud is created, from which it is possible to build a mesh with an adjustable number of vertices. In addition, the polygons' textures are extracted from the photographs taken.

According to this approach, it is possible to obtain high-quality data for both terrain and architectural objects. The resulting point cloud can serve as a starting point for performing a variety of analyses or inventories, provide the basis for high-precision models or supplement existing lower-density point clouds.

Keywords: landscape architecture, terrain modeling, orthophoto map, point cloud, multirotor.

1. Introduction

In the era of geographic information systems (GIS), building information models (BIMs), and computer integration of manufacturing (CIM), which are used to carry out various spatial analyses, spatial planning, architectural and urban design, or landscape architecture, adequate quality and quantity data are required. Modern computers and workstations are capable of processing large datasets, although specialized software rarely takes full advantage of these capabilities.

There are many research programs aimed at acquiring spatial data, which has made it possible to create terrain models, represent land coverage, individual objects, vegetation, or even individual trees. These data are obtained using satellites, planes, drones, or terrestrial scanners. Thanks to the existence of programs such as Copernicus [1] and Sentinel [2], which collect data by using satellites, vast amounts of information have been accumulated that can be used, e.g., to measure building subsidence in areas affected by mining activity. These datasets are very accurate and can be updated continuously. However, the mentioned programs are carried out with considerable resources, and so far their effects have not been used to the extent that would justify the investment. The environment of landscape architects, professionals involved in spatial planning, and urban planners should make full use of these data.

In the databases of geodesy and cartography centers, there are spatial data available at different densities. These data concern both terrain models and land coverage. For many data formats, such as systematic point grids, point clouds are obtained using various remote sensing methods. Landscape files that are interesting for landscape architects are LAS files containing point clouds acquired using LIDAR [3]. Simply put, these files contain sets of points specified by x, y, and z coordinates, along with color information in the additive red, green, and blue (RGB) model [4]. In addition, the points in these files are classified into four layers: ground, building, water, and high vegetation. As part of the Informatyczny System Osłony Kraju (ISOK – National Protection Information System) project [5], a surface scan of Poland was carried out, resulting in a point cloud in two density standards covering 93 % of the country's area. These data, however, age and become outdated. Relatively often, there is a need to supplement them. In such cases, spatial scanning technology can be useful, especially when using a multirotor UAV equipped with a high-precision camera.

2. Technology

Filling in gaps or updating spatial data should be performed with the use of native formats that are appropriate for the given environment. Point clouds should be supplemented with sets of points included in this structure. Therefore, it is necessary to obtain such a set by scanning limited areas or specific objects. Each point should have coordinates in the correct layout and standard color information. This type of structure can be obtained using photogrammetric technology. In this technology, while eye-level photographs can be used, more complete information is obtained through the use of drones. To capture precise images from specific points in space, multirotors are used, as they can hover anywhere in the air and fly at very low speeds.

In this research, a hexacopter equipped with a Lumix GH-4 mirrorless camera is used. This camera is mounted on a 3-axis brushless gimbal (a stabilizer that enables the camera to rotate independently of the carrier's movements; in this case, the carrier is the multirotor), which ensures perfect stabilization of the recorded image. The camera can record photos up to 4608×3456 pixels and videos in 4096×2160 pixels (4K standard) at 25 fps. The hexacopter and gimbal are controlled separately using radio equipment. Although this separation of the aircraft operator and camera operator functions allows for greater precision in flight and camera control, it involves the need for two operators to control it. According to Polish law, flights performed with UAVs for purposes other than recreational require operators to have a qualification certificate issued by the Civil Aviation Office. It is also necessary to review the airspace layout in the area of planned flights. In some zones, it is necessary to obtain consent from the administrator of the given space, e.g., in areas near airports, strategic industrial facilities, or national parks.

Data acquisition consists of performing a flight over the object while simultaneously taking photographs. Attention should be paid to the aspects of proper recording parameters – sensor sensitivity, white balance, focus point, aperture value, and exposure time for each frame. The type of flight depends on the type of object being surveyed. An architectural object should be registered from a low altitude with the camera set horizontally or at a slight angle of inclination relative to the object. On the other hand, terrain should be recorded from a higher altitude with the camera pointing vertically downward. The specific flight altitude also depends on the type of airspace in which the flight is performed.

During the flight, a series of photographs is taken, which should be made in such a way that neighboring shots contain a common fragment of the photographed object. This requires the multirotor to pause in places suitable for taking each picture. Another approach is to record the footage continuously throughout the whole flight. The recorded sequence should be divided into individual frames, as they are the starting point for further processing. Neighboring frames, as in the case of a series of photographs, should contain a common fragment of the analyzed object and also be correctly registered. This applies in particular to avoid the blur effect, which often occurs during flights at excessive speed. Thanks to the high-quality gimbal used on the multirotor, it is possible to minimize distortions of photographs caused by the unstable flight of the aircraft. The stabilization of the gimbal, combined with the stabilization of the lens in the camera, almost completely reduces vibrations associated with flight, even under adverse weather conditions such as gusts of wind.

In this study, the second method is employed – the recording of video material. The recorded video is then automatically divided into individual frames, from which some of them are selected for further processing. Frame selection for further processing can be carried out by the operator, assisted by an initial automatic selection of frames at regular intervals (e.g., every 25 frames, corresponding to 1 second of video). The criteria for selecting frames are discussed in the final part of this article.

3. Model generation procedure

The Agisoft Metashape software was used to create the point cloud and 3D model. The first step in the creation procedure is to import the previously prepared frames. These frames are then analyzed to ensure that sufficient EXIF (exchangeable image file format – a metadata standard used for storing information about image and sound files, including camera settings, date, time, and location) data, such as the focal length of the camera, are available. When this data is not available, the program assumes that the photo was taken using an equivalent focal length of 50 mm. The imported photos must then be aligned. During this phase, common points appearing in the analyzed pictures are identified, and the position and spatial orientation of the camera are determined based on these matches. The result is a set of reconstructed positions of each photograph taken and a sparse point cloud, usually containing tens or hundreds of thousands of points (Fig. 1). Although this is a relatively small number of points and limits its usability, the sparse cloud can be exported to external programs and further processed at this stage.

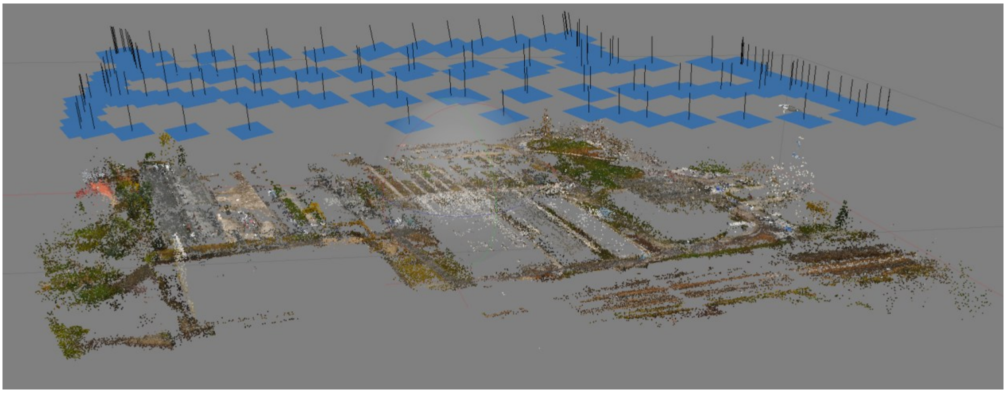

Fig. 1. Example of a sparse point cloud (containing 130 000 points) with visible designated camera positions.

The next stage of the procedure is the construction of a dense point cloud (Fig. 2). In this phase, the software calculates depth information based on the information obtained from the estimated shooting position. It is possible to generate a very dense cloud containing tens of millions of points. Such a cloud

Fig. 2. Example of a dense point cloud containing over 53 million points.

may already form a basis for further editing or analysis. It is also possible to classify the points in the generated cloud, e.g., based on color information.

Both dense and sparse point clouds can become starting points for creating a 3D mesh. The number of polygons in this mesh can be defined automatically as a fraction of the number of points in the cloud or can be arbitrarily determined by the user. Thanks to properly calibrated photographs, it is possible to capture the geometric structure of the model but also the color information of individual polygons, which can be saved in the form of texture.

4. Case studies

During the research, attempts were made to obtain data for three different facilities – an open area, a built-up area, and a detached building. Each of these cases required an individually tailored approach to data acquisition.

4.1. Case 1 – open area

As an example of an unbuilt area, a fragment of the open area near Skotnicka Street in Kraków was chosen. This area is a small hill covered with grass on the ridge and bushes and trees on the slopes. For this case, the acquisition of data involved flights at an altitude of 100 m above ground level (AGL) – the maximum available height in the given area. The camera of the UAV was directed vertically downward, and three flights were conducted along parallel strips of space, several meters apart (Fig. 3).

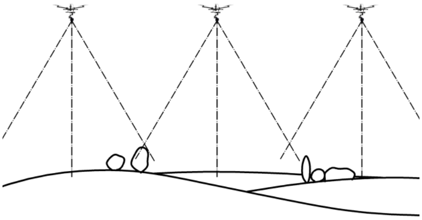

Fig. 3. Data acquisition in open areas.

This method of acquisition allowed the registration of both the terrain details and its coverage (Fig. 4). The accuracy of vegetation registration, however, depends on the way it is spatially arranged. Shrubs growing close to each other, forming coppices, were recorded correctly, while vegetation elements growing as individual objects often contained blank spaces. This limitation is associated with the acquisition method used.

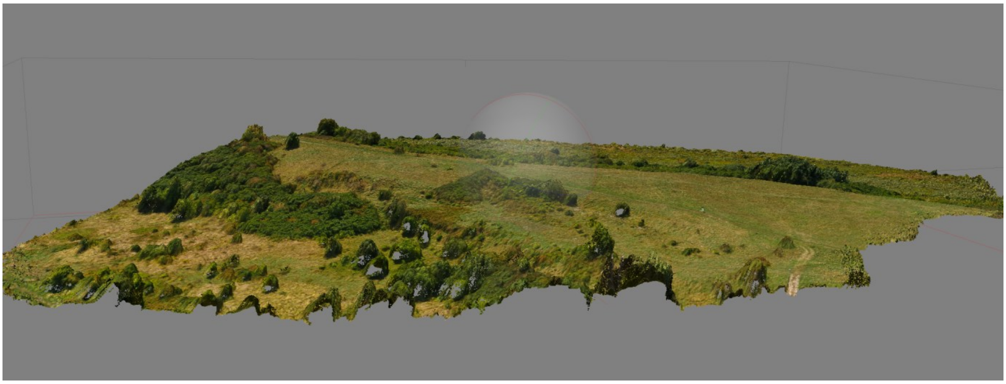

Fig. 4. Fragment of a dense point cloud of the open area (about 5 million points). The illustration clearly shows blank spaces.

If it is necessary to fill these blank spaces, it is essential to accurately photograph the given object, especially from the side where the gaps occur (Fig. 5).

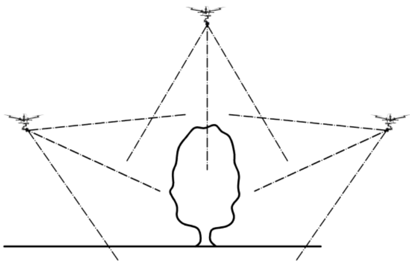

Fig. 5. Filling in the gaps of a single object.

Based on stitched photos, it is also possible to obtain a highly detailed orthophoto map. If the map is georeferenced, it can be used as a GIS layer (Fig. 6).

Fig. 6. Fragment of an orthophoto map generated from stitched photos.

4.2. Case 2 – built-up area

As a case study, the built-up area of the University of Agriculture in Kraków was selected. The campus is located a short distance north of Kraków's city center and comprises research and teaching facilities, student dormitories, a sports hall, and specialized infrastructure such as a greenhouse and crop plots. The architectural ensemble dates to the second half of the 20th century and reflects a modernist style, characterized by simple geometric forms and minimal decorative elements. Data acquisition using a multirotor in built-up areas requires detailed knowledge of the specific characteristics of the area being analyzed. First of all, as already mentioned, legal restrictions regarding flights in the given airspace must be taken into account. It is also necessary to analyze the distribution of all types of terrain and construction obstacles, such as trees, tall buildings, overhead transmission lines, chimneys, or construction cranes. Data acquisition in the analyzed case involved flights at an altitude of about 50 m AGL, which was determined by weather conditions prevailing at the time. The camera was directed vertically downward, similar to the data acquisition procedure in the open area. Video recording took place along parallel strips of space.

The obtained point cloud was characterized by great detail of all elements of the terrain, clearly visible directly from above, such as roofs, the ground or parked cars. However, the surfaces of building walls were reproduced very poorly or not captured at all (Fig. 7). Again, this limitation is related to the chosen acquisition method. Supplementing data for building walls would require a different approach, described in the next section. Certain inaccuracies were also observed for objects largely covered with transparent material, such as greenhouses.

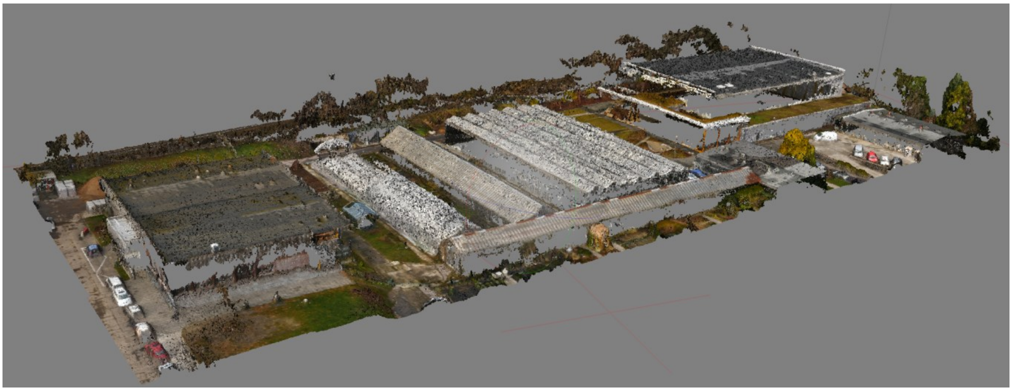

Fig. 7. Fragment of a dense point cloud of the built-up area (about 23 million points).

4.3. *Case 3 – detached building*

The Houston teaching and administration building, located on Warszawska Street and forming part of Cracow University of Technology (CUT), was selected as the representative detached structure. It accommodates the dean's offices, laboratories, and lecture halls, making it a significant component of the CUT campus. Obtaining data on the whole structure of a single architectural object requires a slightly different approach than those presented in the previous two cases. Although a flight directly above the object with the camera pointing downward is necessary to record the details of the roof of the object, it is more important to collect information about the building's walls. In addition to the hazards described in the previous cases, another important element to be taken into account during the flight is the proximity of surrounding buildings. Their location can significantly hinder or even prevent proper data acquisition. The construction of the multirotor and its control system necessitates the use of a camera with a fixed focal length. The only way to change the cropping, in this case, is to change the position of the camera, and thus reposition the multirotor itself. Consequently, the registration method required flying around the analyzed object with the camera directed towards its walls. Correct registration of the roof edge requires framing that simultaneously captures both the roof and the part of the wall beneath it. This forces a diagonal orientation of the camera relative to the object (Fig. 8).

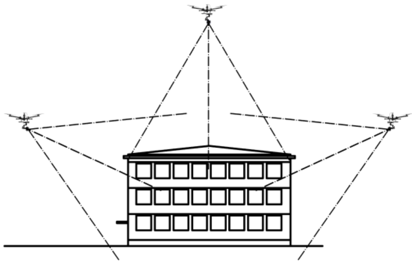

Fig. 8. Data acquisition of an architectural object.

In the case of an architectural object, one of the main requirements is to obtain the highest possible level of detail in reproduction. The problem, in this case, is the presence of relatively small elements (in relation to the whole building size) protruding from the main structure, such as antennas, chimneys, or air-conditioning installations. While the overall shape of the building was reproduced satisfactorily, the above-mentioned details were not captured consistently in all cases (Fig. 9).

Fig. 9. Fragment of a dense point cloud of an architectural object (about 7 million points).

From each point cloud, a polygon mesh can be obtained as well. This mesh may be based on either a sparse or a dense cloud, and the number of polygons it consists of can be determined arbitrarily (Fig. 10).

Transforming a point cloud into a polygon mesh reveals further issues that are not always clearly visible. While during point cloud inspection, most surfaces appear to be uniform, the polygon mesh model exposes significant surface irreg-

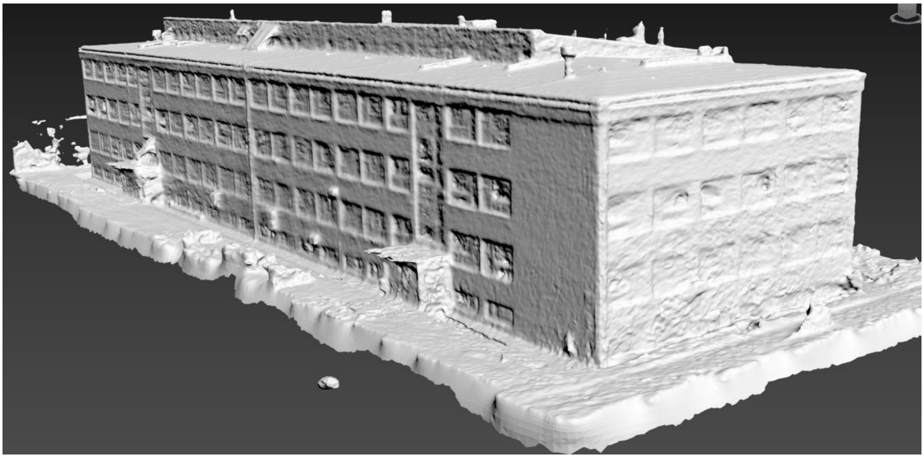

Fig. 10. Polygon mesh generated based on a dense cloud with an arbitrarily defined number of polygons.

ularities, located mainly in areas where transparent surfaces such as windows are present (Fig. 11).

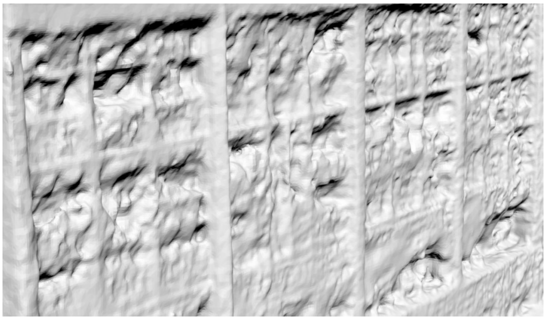

Fig. 11. Problems observed when processing objects that contain transparent and reflective surfaces.

5. Supplementing point clouds

The presented methods were used to supplement a point cloud containing scanned data obtained as part of the ISOK project. As an example, a fragment of the building of the Royal Palace in Łobzów was selected. After the procedures described in the previous paragraphs were carried out, a dense point cloud of one of the facades was obtained, containing over 2 million points (Fig. 12).

The resulting cloud was then scaled using a reference section and aligned through rotations with the existing point cloud containing data on the surrounding areas. After completing this alignment, both clouds were merged and can function as a single data structure (Fig. 13).

Fig. 12. Dense point cloud of the facade of the Royal Palace in Łobzów.

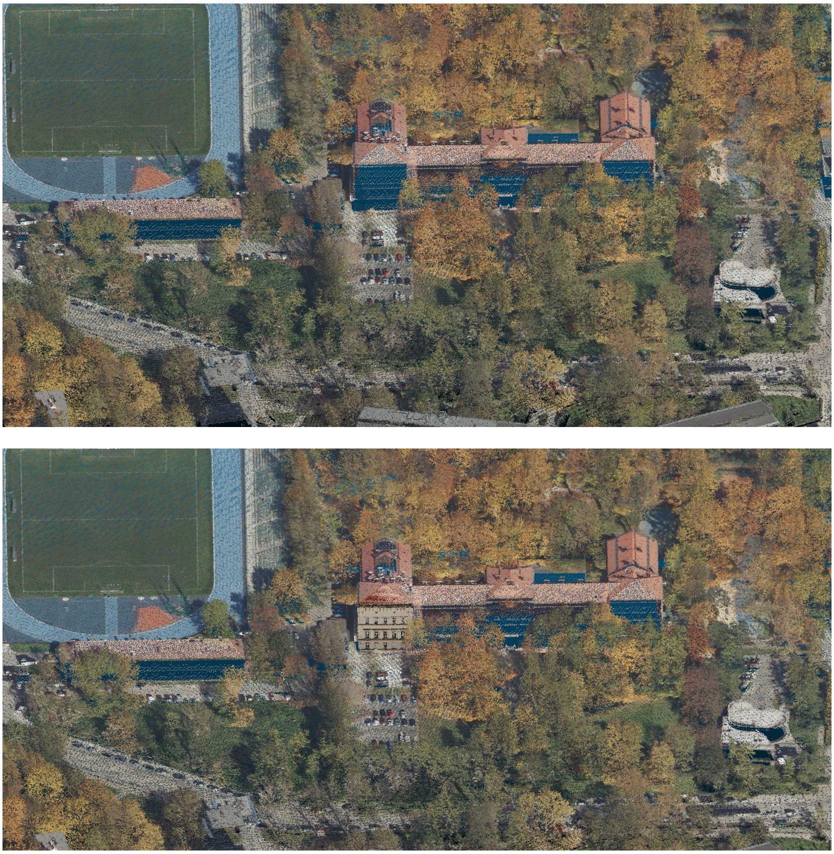

Fig. 13. Original (top) and supplemented (bottom) point cloud of the neighborhood of the Royal Palace in Łobzów.

The supplemented point cloud is denser than the original dataset, which is most evident in close-up views (Fig. 14).

Fig. 14. Close-up view of the point cloud of the neighborhood of the Royal Palace in Łobzów.

6. Discussion

This article presented a method for acquiring spatial data using UAVs. The presented procedure shows the process of building a point cloud without using ground control points or a predefined flight path. Using the presented methods, it is possible to supplement point clouds acquired using remote sensing methods with detailed data for smaller areas. The workflow enables the creation of both sparse and dense point clouds, polygon meshes with appropriate textures, as well as orthophoto maps.

The methods presented in the paper are not devoid of imperfections. During the processing of data obtained during the flight over the open area, there was a certain amount of blank spaces associated with the chosen acquisition method. These gaps required additional supplementation using another method, which in turn necessitated an additional field visit, as such errors only become apparent during data processing. In the case of architectural objects, errors related to the structure itself were visible, including reduced accuracy in the registration of small, angular elements, and problems in generating polygon meshes for transparent and reflective surfaces.

The procedure for recording video and photographic material also matters. Proper exposure of individual frames has a very large impact on the final quality of the generated point cloud. At present, research is underway to assess the impact of initial processing of input images on the final quality of the generated models. In the presented work, video frames were chosen arbitrarily at intervals of 25 frames (corresponding to 1 second of flight). It seems necessary to develop a method for the automatic selection of appropriate frames in order to generate point clouds of optimal quality. One potential indicator that could be used for this purpose is the Tanimoto coefficient. Its application, along with comparisons to other methods of non-systematic frame selection are described in [6]. Such a procedure would also have to assess the suitability of specific photographs in terms of both exposure and focus, based on objective measures.

In this study, the merging of two point clouds was performed manually. In order to make the most of possibilities of supplementing existing datasets, a procedure should be devised to allow an automated alignment and merging. This would require having spatial coordinates for the newly created cloud, which is not trivial when the cloud is created from video material.

Spatial data in the form of point clouds is updated as part of the ISOK program and also through initiatives undertaken by local spatial management authorities. However, these updates do not keep pace with rapid changes of urban space, particularly in big cities. In addition, the purpose of such projects is usually to obtain data about the area for flood protection purposes. In the case of projects with a limited spatial extent, e.g., a single building or an urban square, higher-density data may be very useful. The method described in this article allows to supplement and harmonize the data available in geodetic institutions, and supports their use in precise context-specific design.

References

1. Copernicus, https://www.copernicus.eu/en [access: 26.10.2025].
2. Sentinel Online, https://sentinel.esa.int/web/sentinel/home [access: 05.11.2025].
3. Ptak A., LiDAR w wielkim mieście, *Geodeta: Magazyn Geoinformacyjny*, **12**: 28–29, 2014.
4. Ozimek A., *Miara krajobrazu. Obiektywizacja oceny widoków i panoram wspomagana narzędziami komputerowymi*, Wydawnictwo PK, Kraków, 2019.
5. Informatyczny System Osłony Kraju, http://www.isok.gov.pl/ [access: 28.10.2025].
6. Skabek K., Łabędź P., Ozimek P., Bober K., Ozimek A., Zając P., Selecting images from UAV sequences for photogrammetric reconstruction, [In:] *ECMS 2025 Proceedings*, M. Scarpa, S. Cavalieri, S. Serrano, F. De Vita [Eds.], pp. 1–8, European Council for Modelling and Simulation, 2025, https://doi.org/10.7148/2025-0653.

Received November 14, 2019; revised December 23, 2025; accepted December 23, 2025; available online December 23, 2025; version of record February 2, 2026.