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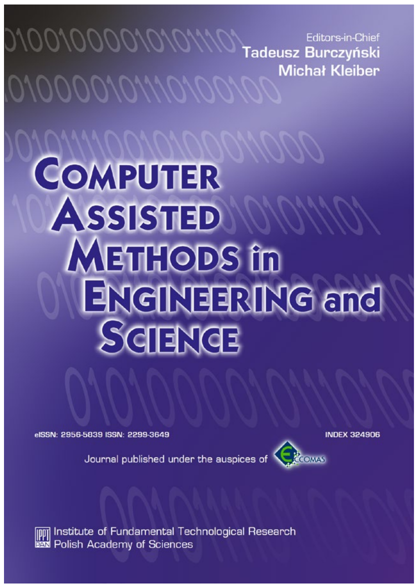

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DOI: https://doi.org/10.24423/cames.2025.273

Journal: *Computer Assisted Methods in Engineering and Science*

ISSN: 2299-3649, e-ISSN: 2956-5839

Publication status: In press

Received: 2019-11-14

Revised: 2025-12-23

Accepted: 2025-12-23

Published pre-proof: 2025-12-23

Please cite this article as:

Łabędź P., Ozimek P., Possibilities of obtaining terrain models, orthophoto maps and point clouds with the use of multirotor, *Computer Assisted Methods in Engineering and Science*, 2025, https://doi.org/10.24423/cames.2025.273

Possibilities of obtaining terrain models, orthophoto maps and point clouds with the use of multirotor

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In the paper a method for acquiring spatial data using unmanned aerial vehicles was presented. In this work the UAV is a hexacopter equipped with a high-end camera that allows recording of 4K movies and high-detailed pictures registering.
The first step in data acquisition is to make a flight over the analyzed object, which can be both land and construction object. During the flight a series of photographs or film footage is recorded. In a later process this recordings are transformed with the use of appropriate software. This processing consists of several steps. In the first of them recorded photos are arranged according to the place of their shooting and then stitched properly. On this basis a dense point cloud is created, where it is possible to build a mesh with an adjustable number of vertices. In addition, the polygons' textures are retrieved from the photographs taken.
According to this approach, it is possible to obtain high quality data on both terrain and architectural objects. The obtained point cloud can serve as a starting point for performing a variety of analyzes or inventories, provide the basis for high-precision models or for supplementing existing clouds of lower density.

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

1. Introduction

In the era of Geographic Information Systems (GIS), Building Information Models (BIM), Computer Integration of Manufacturing (CIM) used to carry out various spatial analyses, spatial planning, architectural and urban design or landscape architecture the data of adequate quality and amount are required. Modern computers and workstations are able to process large data sets, although specialized software is rarely able to use these capabilities.

There are many research programs to acquire spatial data, which led to a situation where it is possible to create terrain models, its coverage, individual objects, vegetation or individual trees. These data are obtained using satellites, planes, drones or terrestrial scanners. Thanks to the existence of programs such as Copernicus [1], Sentinel [2], in which data is obtained using satellites, huge amounts of them have been accumulated that can be used, e.g. to measure subsidence of buildings in the event of mining damage. They are very accurate and can be updated on an ongoing basis. The mentioned programs are carried out with considerable resources and so far their effects are not used to the extent that justifies these expenditures. The environment of landscape architects, people involved in spatial planning and urban planners should make the most of this data.

In the databases of geodesy and cartography centers, there are spatial data represented in different densities. These data concern both land models and coverage. For many data formats such as a systematic point grid, the 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]. To simplify, they contain sets of points specified by x, y, z coordinates and color in the additive color model (RGB) [4]. In addition, the points in these files are classified into four layers: ground, building, water and high vegetation. As part of the ISOK [5] project, a surface scan of Poland was carried out, resulting in a point cloud in two density standards, that covers 93% of the country's area. These data, however, age and become outdated. Relatively often there is a need to supplement them. In this case, space scanning technology can be useful with the help of a multirotor equipped with a precise camera.

2. Technology

Filling in gaps or updating spatial data should be performed with the use of native formats, which are appropriate to 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 as a result of scanning limited areas or specific objects. Each point should have coordinates in the correct layout and standard color information. This type of structure is possible to obtain in photogrammetric technology. In this technology, eye-level photographs could be used, however, more complete information will be obtained thanks to the use of the drone. To make precise photos from specific points in space, multirotors are used that can hover anywhere in the air and fly at very low speeds.

In the research, the hexacopter equipped with the Lumix GH-4 mirrorless camera was used. This camera is mounted on a 3-axis brushless gimbal[1], which ensures perfect stabilization of the recorded image. The camera can record photos up to 4608 x 3456 pixels and movies in 4096 x

[1] gimbal - stabilizer enabling independent rotation of the camera from the carrier's rotation, in this case the multirotor

2160 pixels (4K standard) at 25 fps. Hexacopter and gimbal are controlled individually using radio equipment. This separation of the functions of the aircraft operator and camera operator allows greater steering precision, however it involves the need for two people to control it. According to Polish law, flights performed with unmanned aerial vehicles that do not take place for recreational purposes require operators to have a qualification certificate issued by the Civil Aviation Office. It is also necessary to insight the layout of the airspace in the area of planned flights. In some zones, it is necessary to obtain the consent of the administrator of a given space, e.g. an area near the airport, strategic industrial facilities or national parks.

Data acquisition consists of performing a flight over the object with simultaneous photographic registration. Attention should be paid to the aspects of proper recording - the proper sensitivity of the sensor, white balance, setting the focus point and the aperture value and exposure time of a single frame. The type of flight depends on the type of the object. An architectural object should be registered from a small altitude with a camera set horizontally or at a slight angle of inclination in relation to the object. On the other hand, the terrain should be registered from the higher altitude with the camera set vertically down. The specific flight altitude depends on the type of airspace in which the flight is performed.

During the flight, a series of photographs are taken, which should be made in such a way that the neighboring shots contain a common fragment of the photographed object. This requires that the multirotor be stopped in places suitable for taking the picture. Another approach is to record the footage during the whole flight. The recorded sequence should be divided into single frames, as they are the starting point for further processing. Neighboring frames should, as in the case of a series of photographs, contain a common fragment of the analyzed object and also be correctly registered. This applies in particular to the blur effect, which often becomes evident during too fast flight. Thanks to the high-quality gimbal used in the multirotor, it is possible to minimize the distortion of photographs coming from the unstable flight of the aircraft. The stabilization of the gimbal combined with the stabilization of the lens in the used camera almost completely reduces the vibrations associated with the flight, even in adverse weather conditions (gusts of wind).

The presented article uses the second method - the recording of film material. The recorded video is then automatically divided into individual frames, from which some of them are selected for the further process. Classification of frames for further processing can be carried out by the operator, assisted by the initial automatic selection of frames with numbers being a multiple of a given value (e.g. every 25, corresponding to 1 second of the video). The discussion of criteria for the selection of frames was carried out in the final part of the 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 previously prepared frames. They are then analyzed to have sufficient EXIF[2] data, such as the focal length of the camera. 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 searched and on this basis the position and spatial orientation of the camera are determined. 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). It is a relatively small number, which is why its usability is limited, but it can be exported to external programs and further processed at this stage.

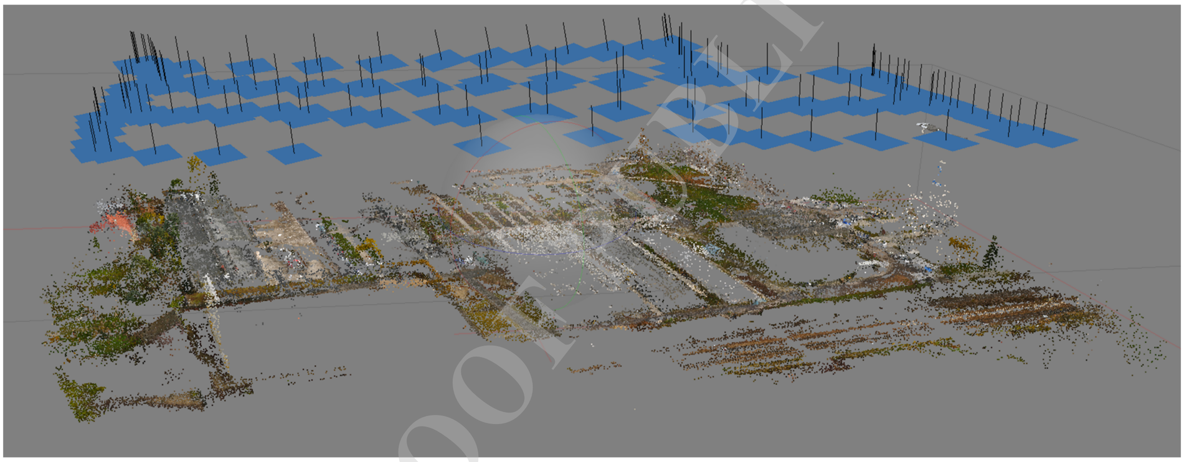

Figure 1 - An example of a sparse point cloud (containing 130,000 points) with visible designated camera positions.

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 may already form the basis for further editing or analysis. It is also possible to classify the points of the created cloud, e.g. based on the color criterion.

[2] Exchangeable Image File Format - metadata standard for image and sound files

Figure 2 - An example of a dense point cloud containing over 53 million points.

Both a dense and sparse point cloud can become a starting point to create 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 be arbitrarily determined by the user. Thanks to properly calibrated photographs it is possible to obtain the model structure as well as the information about the color of individual polygons, which can be saved in the form of texture.

4. Case studies

During the research, attempts were made to obtain data of three different facilities - open area, built-up area, and a detached building. Each of these cases required an individual approach to the problem of 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 with bushes and trees on the slopes. In this case the acquisition of data involved the flight on the altitude of 100 m AGL[3] - the maximum available height in the given area. The camera lens of the aircraft

[3] Above Ground Level

was directed vertically downwards and three flights were made in parallel stripes of space, several meters apart (fig. 3).

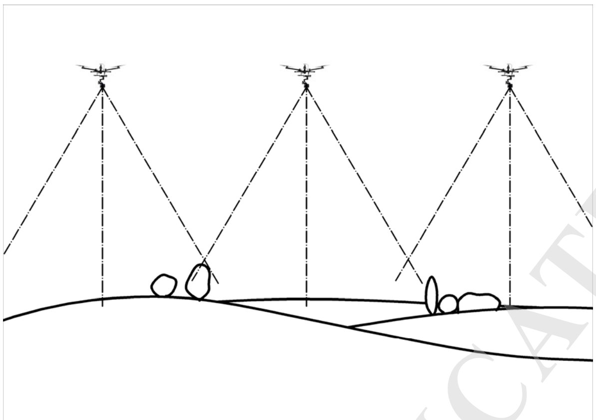

Figure 3 - Data acquisition in open areas.

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

Figure 4 - A 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 in the blank spaces, it is essential to accurately photograph a given object, especially from the side of their occurrence (fig. 5).

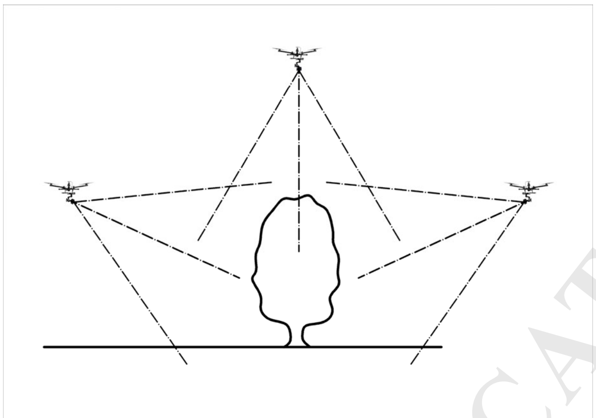

Figure 5 - Filling in the blank spaces of a single object.

Based on stitched photos, it is also possible to obtain a highly detailed orthophoto map. If it has a georeference as well, it can be used as a GIS layer (fig. 6).

Figure 6 - Fragment of an orthophoto map generated on the basis of stitched photos.

4.2. Case 2 - built-up area

As a case study, the built-up area of the University of Agriculture in Krakow was selected. The campus is located a short distance north of Krakow's city centre 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, marked by simple geometric forms and minimal decorative elements. Acquisition of data using a multirotor in built-up areas requires detailed knowledge of the specificity of the area being analyzed. First of all, it is necessary to take the already mentioned legal restrictions regarding the flight in a given airspace into account. It is also necessary to analyze the distribution of all types of terrain and construction obstacles, such as trees, high buildings, overhead transmission lines, chimneys or construction cranes. The acquisition of data in the analyzed case involved the flight at an altitude of about 50 m AGL, which was motivated by the weather conditions prevailing at the time. The camera lens was directed vertically downwards, similarly to the acquisition of data in an open area. The recording of the film material took place in parallel stripes of space.

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

The obtained point cloud was characterized by high detail of all those elements of the terrain, which were clearly visible directly from above, such as roofs, ground or parked cars. However, the surfaces of building walls have been reproduced very poorly or even not at all (fig.

7). Again, this is related to the registration method. Supplementing data on building walls would require a different approach, described in the next section. Certain inaccuracies also occurred in the case of objects covered largely by a transparent material, such as greenhouses.

4.3. Case 3 - detached building

The Houston teaching and administration building, located on Warszawska Street and forming part of the Krakow University of Technology (PK), was selected as the representative detached structure. It accommodates dean's offices, laboratories, and lecture halls, making it a significant component of the PK 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 lens pointing down is also necessary to record the details of the roof of the object, it is more important to collect information about its walls. In addition to the threats described in previous cases, the additional element to be taken into account during the flight is the proximity of other buildings. Their location can significantly hinder or even prevent the right data acquisition. The construction of the multirotor and the way of its control forces the use of a camera with a fixed focal length. The only way to change the cropping is in this case changing the position of the camera, and thus also the multirotor itself. The method of registration required a flight around the analyzed object with a lens directed towards its walls. Correct registration of the roof edge requires such a framing that at the same time both the roof and the part of the wall beneath it are visible. This forces the diagonal adjustment of the camera lens relative to the object (fig. 8).

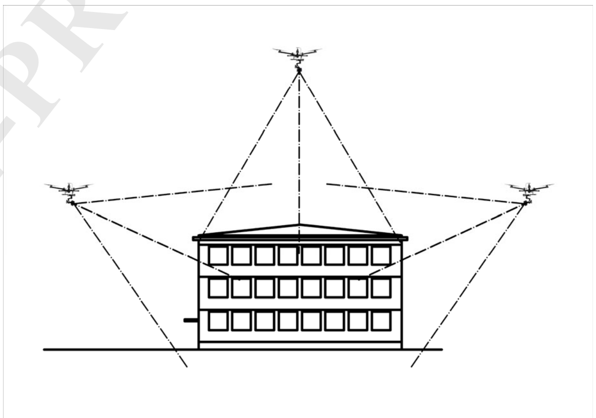

Figure 8 - Data acquisition of an architectural object.

In the case of an architectural object, one of the main requirements is to obtain the highest possible level of detail reproduction. The problem, in this case, is the presence of relatively small (in relation to the whole building) elements protruding from the main structure, such as antennas, chimneys or air conditioning installations. While the overall shape of the building's body has been reproduced satisfactorily, the above-mentioned details not in every case (fig. 9).

Figure 9 - A fragment of a dense point cloud of an architectural object (about 7 million points).

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

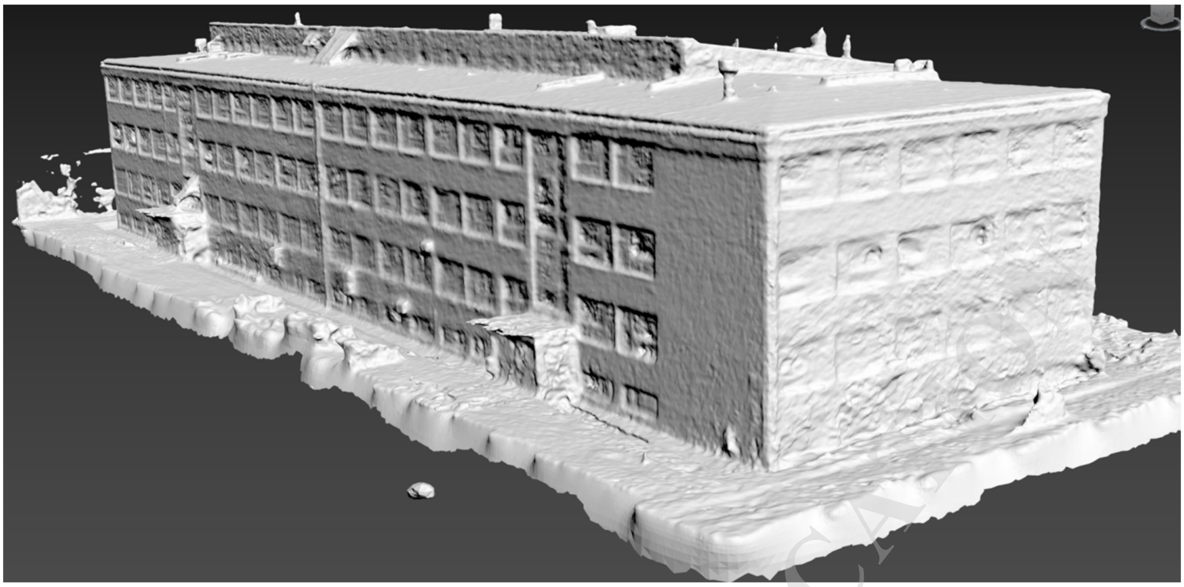

Figure 10 - A polygon mesh generated based on a dense cloud with an arbitrarily fixed number of polygons.

Transforming a point cloud into a polygon mesh reveals further problems that were not clearly visible previously. While during the point cloud observation most of the surface appears to be uniform, the polygon mesh model exposes significant inequalities, located mainly in places where transparent surfaces such as windows are present (fig. 11).

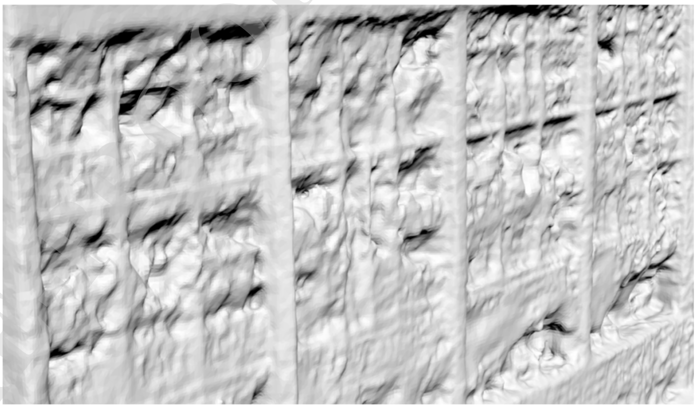

Figure 11 - Problems seen when processing objects that contain transparent and reflective surfaces.

5. Supplementing point clouds

The presented methods have been used to supplement the 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 cloud of one of the facades was obtained, containing over 2 million points (fig. 12).

Figure 12 - A dense point cloud of the facade of the Royal Palace in Łobzów.

The resulting cloud was then scaled using the reference section and matched by the rotations to the existing point cloud containing data about the neighborhood. After completing the alignment, both clouds have been combined and can function as one data structure (fig. 13).

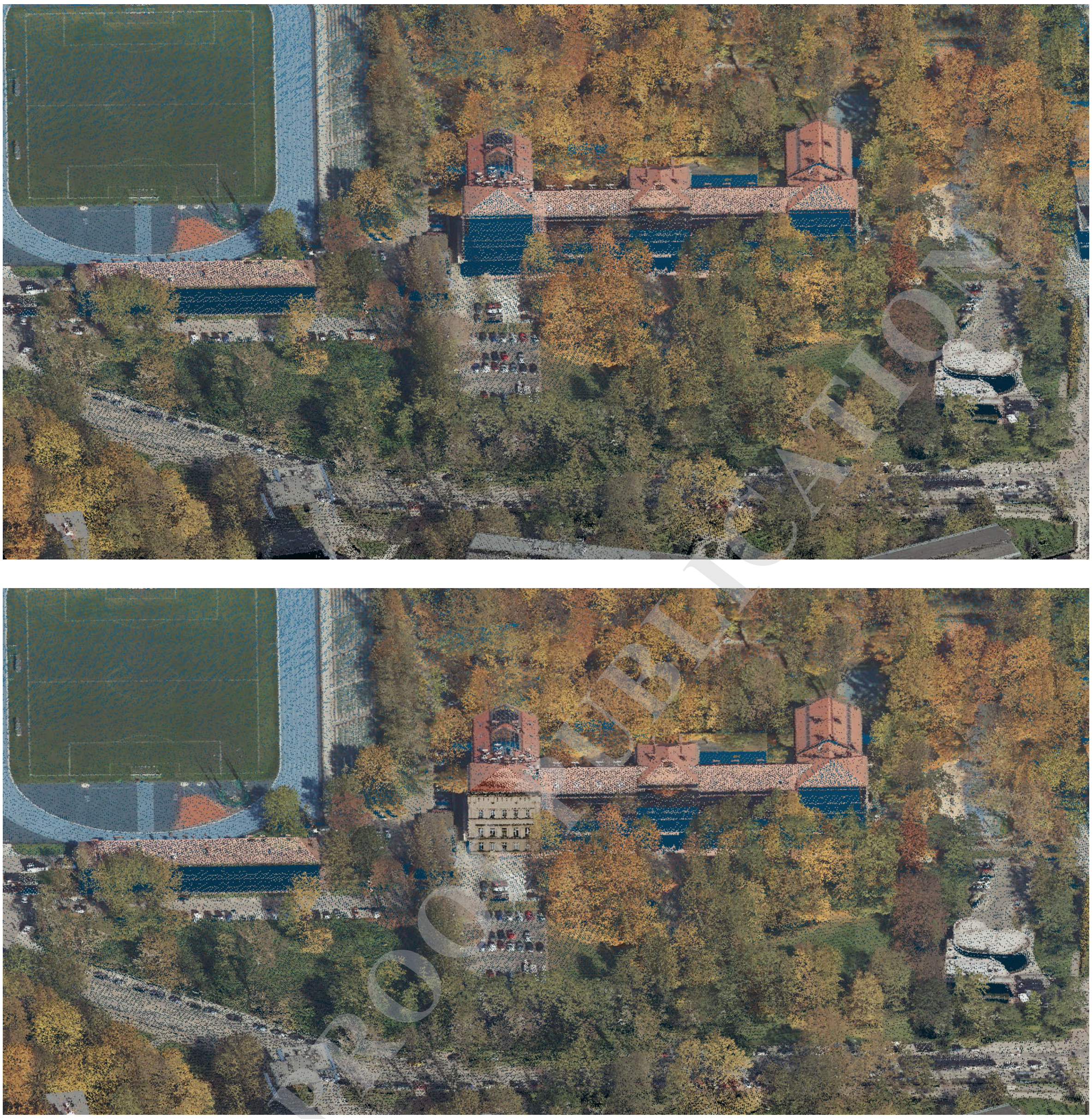

Figure 13 - Original (above) and supplemented (below) point cloud of the neighborhood of the Royal Palace in Łobzów.

The obtained point cloud is much denser than the existing data, which is most visible at close-up (fig. 14).

Figure 14 - A close-up of the point cloud of the neighborhood of the Royal Palace in Łobzów.

6. Discussion

The article presents a method allowing to acquire spatial data using unmanned aerial vehicles. The presented procedure shows the process of building a point cloud without having ground control points and a given path of a flight. Using the presented methods, it is possible to supplement the point cloud acquired using remote sensing methods with detailed data regarding smaller areas. It is possible to create both a sparse and dense point clouds, a polygon mesh with appropriate textures as well as an orthophoto map.

The methods presented in the paper are not devoid of imperfections. After processing the data obtained during the flight over the open area, there was a certain amount of blank spaces associated with the registration method. They required a separate supplementation by another method, which entails the necessity of another field visit, as such errors appear only in the process of data processing. During the data processing of the architectural object, errors related to the structure itself were visible - the accuracy of registration of small, angular elements, and problems with the generation of a polygon mesh for transparent and reflective surfaces.

The procedure of recording film / photographic material also matters. The correct exposure of single frames has a very large impact on the final quality of the generated point cloud. At present, research is underway on the impact of initial processing of input images on the final quality of the generated model. In the presented work, movie frames were chosen arbitrarily every 25 seconds (every 1 second of flight). It seems necessary to develop a method allowing automatic selection of appropriate frames in order to create a point cloud of optimal quality. One of the indicators that could be used for this purpose is the Tanimoto coefficient. Its application and comparison with other methods of non-systematic frame selection are described in [6]. Such a procedure would also have to assess the suitability of specific photographs from the point of view of both exposure and focus based on objective measures.

In the presented paper, the joining of two point clouds was performed manually. In order to make the most of the possibilities of supplementing existing data, a procedure should be devised to allow an automated joining. It is necessary to have spatial coordinates of the created cloud, which in the case of generation based on film material is not trivial.

Spatial data in the form of point clouds are updated as part of the ISOK program and also thanks to the initiative of local space managers. However, the update does not keep pace with changes in urban space that are happening particularly fast in big cities. In addition, the purpose of these projects is usually obtaining data about the area for flood protection. In the case of projects with a small spatial extent, e.g. a single building or a square, higher density data may be very useful. The method described in the article allows to supplement the data available in geodetic institutions, harmonize them and use in precise design in a specific context.

References

[1] Copernicus [online], https://www.copernicus.eu/en (access: 26.10.2025).

[2] Sentinel Online [online], https://sentinel.esa.int/web/sentinel/home (access: 05.11.2025).

[3] Ptak A., *LiDAR w wielkim mieście*. “Geodeta : Magazyn Geoinformacyjny “ May 2017

[4] Ozimek A., *Miara krajobrazu. Obiektywizacja oceny widoków i panoram wspomagana narzędziami komputerowymi,* Wydawnictwo PK, Kraków 2019

[5] Informatyczny System Osłony Kraju [online], http://www.isok.gov.pl/ (access: 28.10.2025).

[6] Krzysztof Skabek, Piotr Łabędź, Paweł Ozimek, Konrad Bober, Agnieszka Ozimek, Piotr Zając (2025). Selecting images from UAV sequences for photogrammetric reconstruction, ECMS 2025, Proceedings Edited by: Marco Scarpa, Salvatore Cavalieri, Salvatore Serrano, Fabrizio De Vita, European Council for Modelling and Simulation. doi:10.7148/2025-0653