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Considerations on the use of UAV technology in monitoring civil constructions during the execution phase

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Abstract. The use of UAV technology (Unmanned Aerial Vehicles) in the monitoring of constructions during the execution phase represents an innovative, modern, and efficient approach in the field of civil engineering. This method enables the rapid and accurate collection of large volumes of high-resolution geospatial data, thereby contributing to the real-time assessment of potential structural deformations, deviations from the design, and other critical factors that may impact the quality and safety of the construction. By providing detailed and up-to-date information, UAV technology supports the decision-making process of engineers and specialists, thus facilitating efficient resource management and the prevention of potential errors that could cause delays in project execution. The aim of this research is to highlight the types of data obtained through photogrammetry that can be effectively used for monitoring constructions during the execution phase. The study involves the identification and analysis of the products delivered by UAV technology (orthophotos, 3D models of the structures) and the evaluation of their potential for detecting possible non-conformities with the technical design, in the context of digitization and sustainability of civil engineering projects.

Keywords: technology, UAV, monitoring, construction.

1. Introduction

Monitoring of constructions represents an essential component in the assessment of their structural behaviour over time [1]. According to the specialized literature, existing research mainly focuses on monitoring structures during the operational phase, in the context of the occurrence of degradations or as a result of events that have generated structural damage (earthquakes, landslides, accidental overloads).
An analysis carried out on the studies published on this topic shows an increasing

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interest in the safety of constructions [2]. At the national level, in Romania, the interest in construction monitoring has grown from year to year [2], and the approaches range from the use of classical technologies to modern technologies with small AI (Artificial Intelligence) influences.
The transition from classical construction monitoring technologies, such as optical levelling, theodolites and conventional total stations, to modern solutions based on terrestrial and airborne LiDAR scanners, photogrammetric UAV systems, high-precision GNSS sensors and integrated BIM platforms, marks a significant leap towards increasing accuracy, efficiency and capacity for real-time data integration.
Photogrammetry, as an engineering science, has a particular applicability in the activity of monitoring the behaviour over time of construction deformations, by precisely determining the displacements and constant or temporary deformations occurred in an objective under the action of disturbing factors and static and dynamic loads [3].
The increasingly frequent use of UAV (Unmanned Aerial Vehicles – term used in the specialized literature since 1980) technology is due to its ability to provide high-precision and high-resolution geospatial data, at a significantly lower cost compared to similar methods, an aspect that generates substantial savings in terms of financial resources, execution time and the labour force involved [4,5,9].
Among the major advantages are the high spatial and temporal resolution, the low operational costs for projects with moderate extensions, as well as the superior accuracy of the obtained data, due to the minimal influence of atmospheric factors on the acquisition process [6,7].
The present paper presents the data that can be obtained by applying the monitoring activity during the construction execution stage, using UAV (Unmanned AerialVehicles) technology. Within the study, both the advantages of this method, in terms of accuracy, efficiency and adaptability to various technical conditions, are analysed. The contribution of the paper consists in deepening the potential of UAV technology for construction monitoring, offering relevant perspectives for optimising its applicability in the field of civil engineering.

2. Materials and methods

Photogrammetry, as a technical science, is part of modern topo-geodetic technologies that deal with and provide information regarding the Earth's surface, the environment, and fixed, mobile, or deformable objects [1].
In order for the resulting plans, the orthophoto maps, to provide a variety of information, it is necessary that the obtained images, namely the photograms, meet certain essential criteria for proper processing: they must be clear, taken during the time of day when the light is appropriate, and they must be centered on the investigated object.
The main advantage of the photogrammetric method [8,9] is represented by the depiction of the construction in its natural aspect. Also, another advantage would be obtaining details about constructions and terrain that are difficult to access, where the application of classical measurement methods would be impossible.

In order for the resulting orthophoto map to present the necessary accuracy and to allow the collection of specific data, a series of steps must be taken prior to obtaining the orthophoto map and the 3D model.

2.1. Flight plan development

The first stage of the process consists in developing the flight plan through specialized software compatible with the UAV platform used. This type of software allows the configuration of essential operational parameters, such as flight altitude, degree of image overlap, capture angle, and optimized trajectory, with the aim of obtaining high-quality photogrammetric datasets. The main objective is to collect precise and consistent data, necessary for the reconstruction of a three-dimensional digital model with high geometric accuracy and a detailed level of representation, suitable for the structural analysis of the monitored objective.
In the present study, the flight plan was generated using the DroneDeploy application, compatible with the DJI Mavic 2 Pro UAV, with parameters configured as shown in Figure 1. The drone performed an autonomous flight at an altitude of 20 meters, its camera being set at a perfect 90-degree angle, and the image overlap was set to 80%, providing a total of 84 images. This image overlap results in capturing multiple images of the same detail, ultimately producing an image with a clearer perspective.

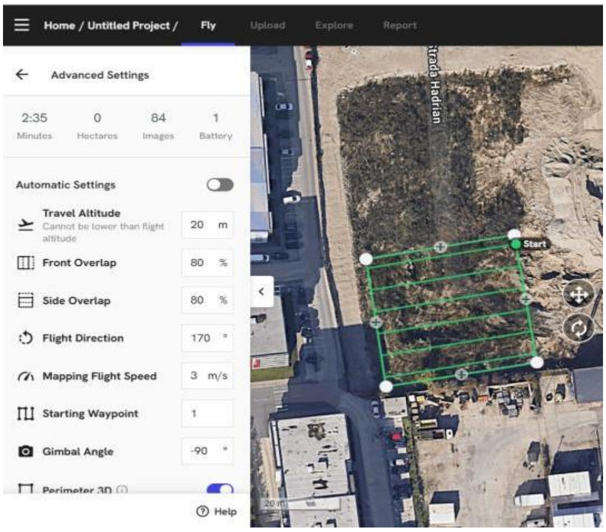


Fig. 1. Flight plan configuration.

2.2. Flight performance

Before the actual initiation of the flight, it is essential to establish ground control points, which will serve as reference points for increasing the accuracy of the digital model. To ensure the highest possible accuracy of the collected data, it is recommended that these control points be either generated from the support network or selected from the existing points of this network, thus guaranteeing a correct alignment of the images in the photogrammetry process.

To obtain a high-quality digital model, it is necessary to complement the autonomous flight, established according to the flight plan, with additional manual flights. These allow the capture of detailed images of specific elements of the construction, thus ensuring a representation as faithful as possible of the geometry and textures of the analyzed surfaces. This combined approach contributes to improving accuracy and reducing possible errors in the three-dimensional reconstruction of the monitored objective.

2.3. Photogram processing

The processing of the images captured during the UAV flight involves going through specific stages, depending on the software used, with the final objective of obtaining a high-precision digital model. In this case, we used the AgiSoft Professional software as the processing tool, which requires the following main steps to be completed:

1. Importing the images into the processing software – The captured images are uploaded into the specialized program, where they will be analyzed and processed according to the established criteria.
2. Sorting the images based on the quality index – A filtering process is carried out to remove frames that do not meet the necessary criteria for the correct reconstruction of the model.
3. Aligning the images – The photographs are correlated and overlapped to determine the relative position of each image in three-dimensional space.
4. Generating the dense point cloud – Based on the aligned images, a dense set of points is obtained, defining the geometry of the scanned surface.
5. Graphic cleaning of the point cloud – Erroneous points or anomalies that may affect the accuracy of the model are removed.
6. Identifying and georeferencing the control points – The ground control points are located and integrated into the model to ensure geospatial accuracy. In this stage, the reference system is also set, namely Dealul Piscului 1970 (Stereographic Projection 1970).
7. Improving the density of the point cloud – Algorithms are applied to increase the resolution and details of the model.
8. Creating the Digital Elevation Model (DEM) – A digital representation of the elevation variations of the terrain or construction is generated.
9. Applying textures and generating the orthophoto mosaic – Textures and colors are overlaid on the 3D model for a more detailed representation.
10. Generating contour lines – Contour lines are extracted, useful in topographic and geospatial analysis.
11. Obtaining the orthophoto map – An orthorectified image is created, combining the geometric accuracy of a map with the photographic details of the aerial image.

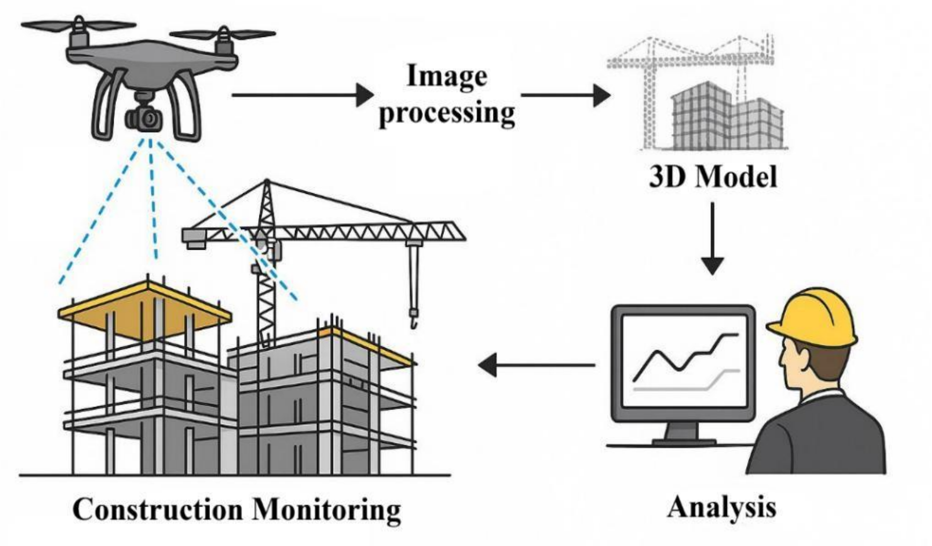


Fig. 2. Staging of the monitoring process.

This workflow allows the obtaining of precise digital models, usable in construction monitoring activities. The data resulting from the UAV flight, namely the orthophoto map (Figure 3) and/or the 3D digital model of the objective, can be used as materials for this study.

Fig. 3. Orthophoto of the studied area

3. Results and discussions

By using the 3D digital model obtained through UAV technology and photogrammetry, it is possible to measure and identify the compliance of the construction's structural elements with the design specifications. This method allows the detection of possible deviations from the project and provides a clear view of the quality of the structural execution.

By using the digital model as study material, it is possible to overlay the structural axes in the two fundamental directions, horizontal and vertical, in order to determine any deviations from the technical project.

3.1. Vertical axis overlap

This method allows the verification of the deviations of the structural elements with respect to verticality, by analyzing their continuity from one level to another, as shown in Figures 4 and 5. Finally, it is possible to evaluate the total deviation of the main structural elements, from level 0 up to the top level provided in the project

Fig. 4. Vertical axis overlap.

Through this analysis, any possible tilting of the support pillars or other structural non-conformities can be identified.

The identified displacements are summarized in the chart in Figure 6 and fall within the standard deviations mentioned in the P-100 and NP 068 regulations (Romania). The chart shows the verticality errors obtained from the measurements carried out to determine the verticality of the marginal columns, which are most often subject to execution errors. The measurements were performed starting from the base of the column, plotting its exact position using stereographic coordinates. Using the total station, the horizontal movement was locked, and by vertical movements of the telescope, the bases of the columns and the upper parts on each executed floor were measured. According to Figure 6, it can be observed that the deviations increase as the construction progresses vertically. The deviations range in value between 0 and 2 cm. The columns located at the corners of the slabs were chosen for monitoring because they are the most difficult to execute in terms of formwork placement.

Fig. 5. Checking the verticality of the structure

The result of this procedure reflects the deviations between the verticality of the executed columns and the designed verticality according to the technical project.

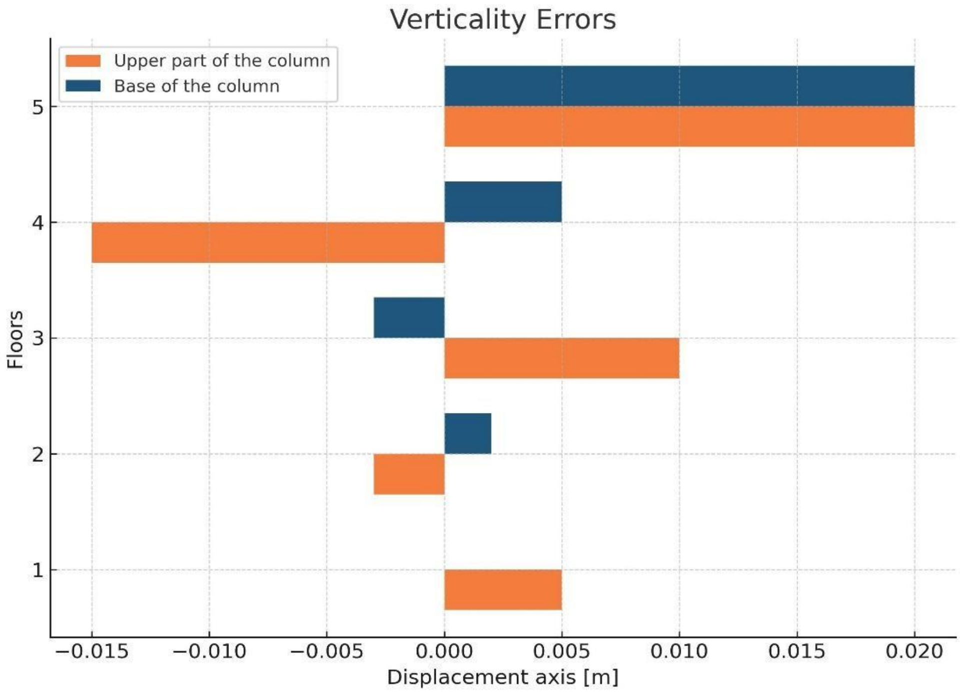


Fig. 6. Travel graph.

3.2. Horizontal axis overlap

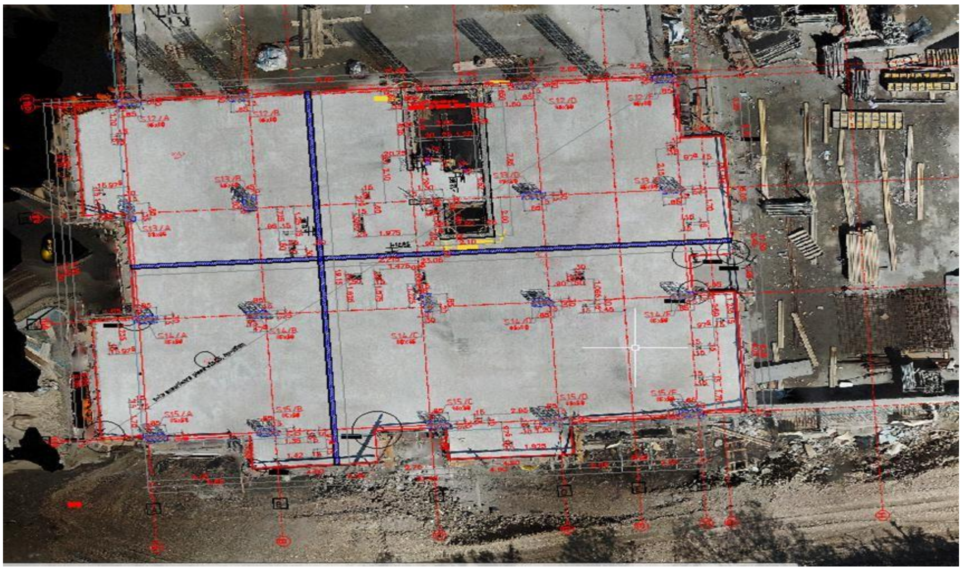
Using the “AutoCAD Map” software, we georeferenced the orthophoto map over the axes of the designed construction (Figure 6) with the purpose of comparing the georeferenced plan with the designed plan in order to check for possible errors that may have occurred during the execution stage. The application of this method provides precise information regarding the planimetric position of the executed structural elements, including the positioning of the load-bearing columns, slabs, and technological openings (for example, for elevators or installations).

Overlaying the structural plan onto the orthophoto map obtained from the processing of UAV images allows the identification of deviations between the executed structure and the designed one, as shown in Figure 7.

After performing the overlays using the specialized software, we highlighted the errors that occurred during the execution phase. These show deviations in three categories of elements:

1. Slab closures (blue color, values approximately between 0.03 m and 0.05 m);
2. Staircase (green color, values approximately between 0.02 m and 0.026 m);
3. Elevator (red color, values approximately between 0.002 m and 0.018 m);

The data show deviations ranging between 0 and 5 cm, given that they are identified through measurements on the orthophoto map.



g. 7. Overlapping plane.

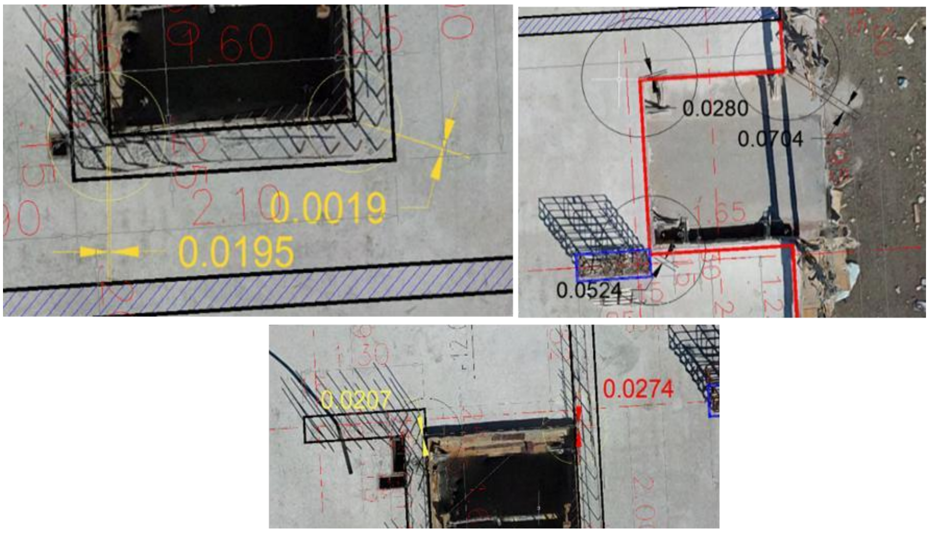


Fig. 8. Highlighting deviations.

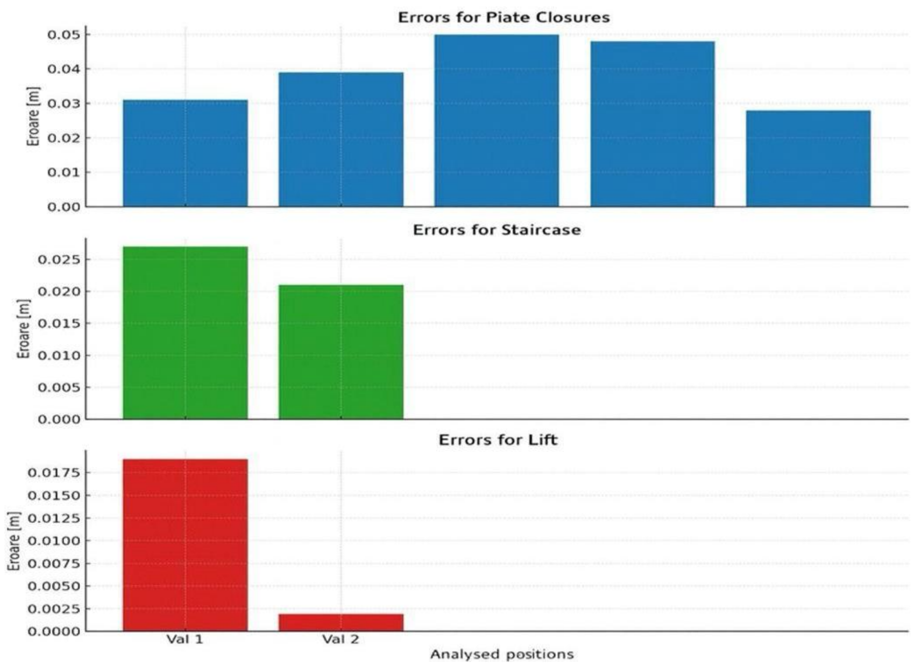


Fig. 9. Deviation graph.

The overlay of the plans led to the identification of other execution errors regarding the openings in the slabs required for the installations project. These are not marked using precision instruments, and therefore such differences occur as a result of cumulative measurement errors made with a tape measure or a carpenter's ruler.

4. Conclusions

The use of drones in the field of civil engineering represents an essential tool in monitoring constructions during the execution phase, due to their ability to collect high-resolution images and data that allow for detailed inspections and the early identification of non-conformities. The captured aerial images make it possible to detect fine defects, deviations from the design, or surface imperfections that might escape visual observation [10,11].

By correlating the obtained data with the execution plans or the three-dimensional models of the construction (e.g., BIM), geometric deviations or execution errors can be quickly identified. This early detection capability enables timely corrective interventions, contributing to compliance with the quality standards imposed by the project.

Regarding the monitoring of the execution process, UAV technology allows for an accurate and continuous assessment of the progress of works throughout the entire project life cycle. Through periodic aerial captures or automated photogrammetric missions, drones provide up-to-date spatial data that can be compared with the planned execution schedule [12–15]. This overlap between the actual site conditions and the technical project facilitates the rapid identification of structural deviations.

Real-time monitoring supports proactive decision-making regarding resource allocation and the prioritization of activities.

In carrying out the measurements with UAV equipment, several aspects were identified that can influence the processing of the resulting photograms (images). Some of these aspects refer to:

- Atmospheric conditions – these can affect the flight activity.
- Flight altitude – this can affect the clarity of the orthophoto map. Also, the greater the distance, the more difficult it is to accurately determine a characteristic point.
- Number of images – the number of images resulting from the flight is essential in obtaining the planimetric plan, and especially in obtaining the 3D model. A larger number of images provides greater overlap of elements, which leads to obtaining a much clearer 3D model with more essential details.
- Manual flight – performing a manual flight is essential in obtaining data related to the facades. Most of the time, performing an automatic flight around the objective is obstructed by various obstacles.
- Drone equipment – for works that require a certain accuracy and high clarity of photograms, it is necessary for drones to be equipped with modern cameras, RTK systems, and LiDAR.
- Image processing – the software used in the image processing stage plays an important role both in terms of the quality of the result and the duration of image processing.

In both cases presented above, the data provided by the analysis of the 3D digital model highlight the execution deviations relative to the technical project, thus facilitating the implementation of the corrective measures necessary for ensuring the compliance of the construction.

As UAV technology evolves rapidly, it is expected that these systems will play an increasingly decisive role in transforming practices in the field of civil engineering. The advanced integration of drones into planning, execution, and especially monitoring processes will enable increased productivity, reduced operational risks, and the assurance of superior quality control of the executed works.

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