ISSN 2409-9066. Sci. innov., 2019, 15(4), 21—28 https://doi.org/10.15407/scine15.04.021

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ORGANIZATION OF SUPERVISION OVER CONSTRUCTION WORKS USING UAVs AND SPECIAL SOFTWARE

Introduction. *Innovative approaches to supervising over the life cycle of construction projects at the stages of engineering surveys and design works, underground and earthworks, construction of building superstructures and further operation and maintenance using UAVs and special software give the Ukraine construction sector companies a unique chance to realize their potential during the digital revolution and take their rightful place among the world leaders.*

Problem statement. *Due to the lack of actual, accurate data and indicators which describe the status of the construction site, building corporations face such problems as the lack of up-to-date information on the project implementation progress, late detection of delays in the progress of works from the original works program, uncontrolled human factor effect on checking the quantities and quality of works performed by contractors, insufficient communication between project stakeholders. Subsequently, these factors lead to an increase in the budget and extension of works time.*

Purpose. *To implement innovative approaches to supervision over infrastructure construction projects.*

Materials and Methods. *Applied research using UAV DJI Phantom 4 PRO, software DroneDeploy, Pix4D, and Virtual Surveyor as part of supervising over the implementation of for solid waste landfill rehabilitation project in Pidhirtsi, Obukhiv District, Kyiv Oblast.*

Results. *Based on the data obtained using UAVs, orthophotomaps and topographical map of the area with a constantly varying surface have been built. With the help of the mentioned maps, the parameters and characteristics of the construction project have been analyzed for making decisions at different stage of the project implementation.*

Conclusions. *UAVs have proved themselves to be an efficient monitoring and supervision tool for organizing and managing the solid waste landfill rehabilitation project.*

Keywords: UAVs, cloud technologies in construction, 3D model, orthophotomap, remote control, construction organization, monitoring, and construction project management.

In 2017, the digital revolution entered a crucial phase as one in two inhabitants of the Earth connected to the Internet. According to the McKinsey Global Institute (MGI) [1], as soon as in the next 20 years, up to 50% of works in the world can be automated, and this process will be comparable to the industrial revolution of the 18th — 19th centuries.

The Industrial Revolution allowed individual countries to achieve impressive rates of economic growth, and, for many decades, they took the lead in the world economy. Today, corporations that operate in various industries have a unique chance to realize their potential thanks to the digital revolution and to take their rightful place among the world leaders. For example, *Shimizu* Corporation (Japan) [2] has presented a series of construction robots designed to address one of the most crucial problems of the country, the shortage of labor. The robotic conveyor, the robotic loader, and the robotic welder have successfully passed trials at the construction site during the construction of a high-rise hotel in Osaka. By 2025, *Shimizu* Corporation intends to assign 10% of all construction operations to robots.

The key precondition for growing corporations and national economies as a whole is a significant increase in labor productivity. One of the most important ways to achieve this growth for construction companies around the world is to organize real-time integrated operational control and production management using digital tools.

The relevance of the topic is explained by the fact that because of the lack of reliable operational information that describes the status of the process at the construction site, corporations face such problems as late detection of deviations of the parameters of works performed from the design documentation, the lack of data necessary for making management decisions, insufficient communication between the project stakeholders, etc. These factors lead to budget overrun, extension of project deadlines, and improper quality of works. Addressing these problems requires additional scientific and practical substantiation and research using advanced analytical tools, which, in turn, creates the need to refine the existing tools in the field of construction management.

One of the possible ways to solve the problems described above is to introduce such a digital tool as an unmanned aerial vehicle (UAV), or drones, in combination with special software into the daily activities of construction corporations.

The aim of this research is to study the benefits of using drones on construction sites, in particular, in *The Rehabilitation of Solid Household Waste Landfill no. 5 in the Village of Pidhirtsi, Obukhiv District of Kyiv Oblast* project.

According to statistics from *DroneDeploy*, the developer and integrator of software designed for industrial use of UAVs, construction is an industry where drones have been used most widely even as compared with agriculture and mining. According to *DroneDeploy*, in 2017, in the United States, a growth in the use of drones in the construction sector reached 240%.

However, in Ukraine, there is a different situation. Here, drones have been most widespread in agriculture. In 2014, only the largest agroindustrial holdings were interested in using UAVs, although in 2015, small and medium-sized farms started applying this technology. In total, today, in Ukraine, drone surveys have covered over 6% (3 million hectares) of agricultural land. At the same time, UAVs are increasingly used for the implementation of construction projects in Ukraine.

Today, drones are a safe and cost-effective tool for monitoring and controlling the construction and assembly works. In addition to photo and video recording, UAVs enable to create high-precision metric orthophotomaps and 3D models of the construction site. Comprehensive analysis of the data allows corporations to improve the organization and management of construction, to monitor the progress of works, to optimize the use of materials and machinery, to carry out surveys and inspections of individual areas, buildings, and structures as a whole, to improve communication between project stakeholders, to detect deviations in the progress of works from the design documentation at an early stage, as well as to improve labor protection and industrial safety at the construction site. So, the implementation of the UAV technology leads to an increase in the number of effective management decisions, a reduction in the costs of remedial works and in time required for individual project stages, improvement of quality and efficiency of supervision over contractors.

The Table below shows the opportunities and benefits from using drones at different stages of construction projects.

Today, there is a trend among advanced construction and development companies to implement software systems for improving construction organization and management processes by concentrating all project data in one database for their subsequent analysis (Bluebeam, *Procore Autodesk BIM 360*). Drones are a means of collecting valuable operational data from the construction site for further processing using the abovementioned software packages. Data collected by UAVs are easily integrated into the existing data collection process in organizations and do not require any fundamental transformations of business processes in companies.

From December 2017 to April 2018, within the framework of the cooperation between the Kyiv National University for Civil Engineering and Architecture and the Research Institute of Construction Production (RICP) of the Ministry of Regional Development of Ukraine, a pilot project for surveying a solid landfill site (the solid waste landfill no. 5 in the village of Pidhirtsi, Obukhiv District, Kyiv Oblast) was implemented with *DronNadzor* specialists involved. The aim of the project was to conduct a comprehensive visual and analytical monitoring of progress in forming smooth slopes and covering the landfill with soil, measuring the length, areas, and volumes of various large-scale elements of the landfill, as well as comparing the results of the UAV topographic surveys and the tacheometric surveys.

The first survey was performed on December 8, 2017, using a *DJI Phantom 4 PRO* drone. The orthophotomap, a digital elevation model, a 3D model of 23 ha terrain and a preliminary topographic map were created within one working day (Fig. 1).

The *Virtual Surveyor* software [3] has enabled building triangulations based on a 3D model with different characteristics: a different step between surface points (from 0.5 m to 15 m) and a complex algorithm that calculates the most significant terrain points. This has allowed us to build topographic maps with different detail elaboration.

The obtained model has made it possible to measure any distances, areas and volumes of both individual sections and the entire landfill as a whole in a matter of seconds. The total volume of the waste heap within the survey limits is 2 520 873 m^3, the area is 229 727 m^2.

The results of topographic surveys made using UAV and a total station have been compared by superimposing in *AutoCAD* [4]. In the process of comparison, there were identified problems caused by incorrect imposition, which have been solved. The preliminary topographic map obtained using UAV has coincided with the results of the tacheometric survey.

The second survey was made on April 4, 2018, its area increased to 47 ha. It was pegged to three ground points with known horizontal and vertical coordinates, which enabled creating a high-precision 3D model of the landfill and getting the vertical coordinates of any point of the model. This function was used to provide the vertical coordinates of the points for drilling wells for geological surveys, thereby eliminating the need to obtain well elevations by the tacheometric method.

When comparing orthophotomaps of the first and the second surveys, a progress of works on

Opportunities and Advantages of Using UAVs at Different Stages of Construction

Opportunities	Advantages
Stage 1. Survey	
Orthophotomaps, 3D model; digital surface model; preliminary topographic plan	Obtainment of detailed data for assessing the main characteristics of the land plot, identification of risks and hidden defects; time saving on preliminary surveys
Stage 2. Design	
Site topographic map; 3D-model of site	Time saving on design works; high accuracy of data; the ability to visualize the 3D model of the building on the site
Stage 3. Construction and assembly works	
Orthophotomap of the site; metric 3D platform model; progress report; report on deviations of the actual works performed from the design; report on the quantities of earthworks, landscaping works, and installation of engineering networks	A powerful tool for operational control and communication; supervision over contractors, quick obtainment of accurate data on quantities and quality of works performed; reduced costs due to regular detection of defects in the works
Stage 4. Operation and maintenance	
Detailed photo report on the actual condition of buildings and structures; report on heat losses of buildings using a thermal imager	Fast and safe access to hard-to-reach places of buildings and structures; quick obtainment of comprehensive data on heat losses of buildings

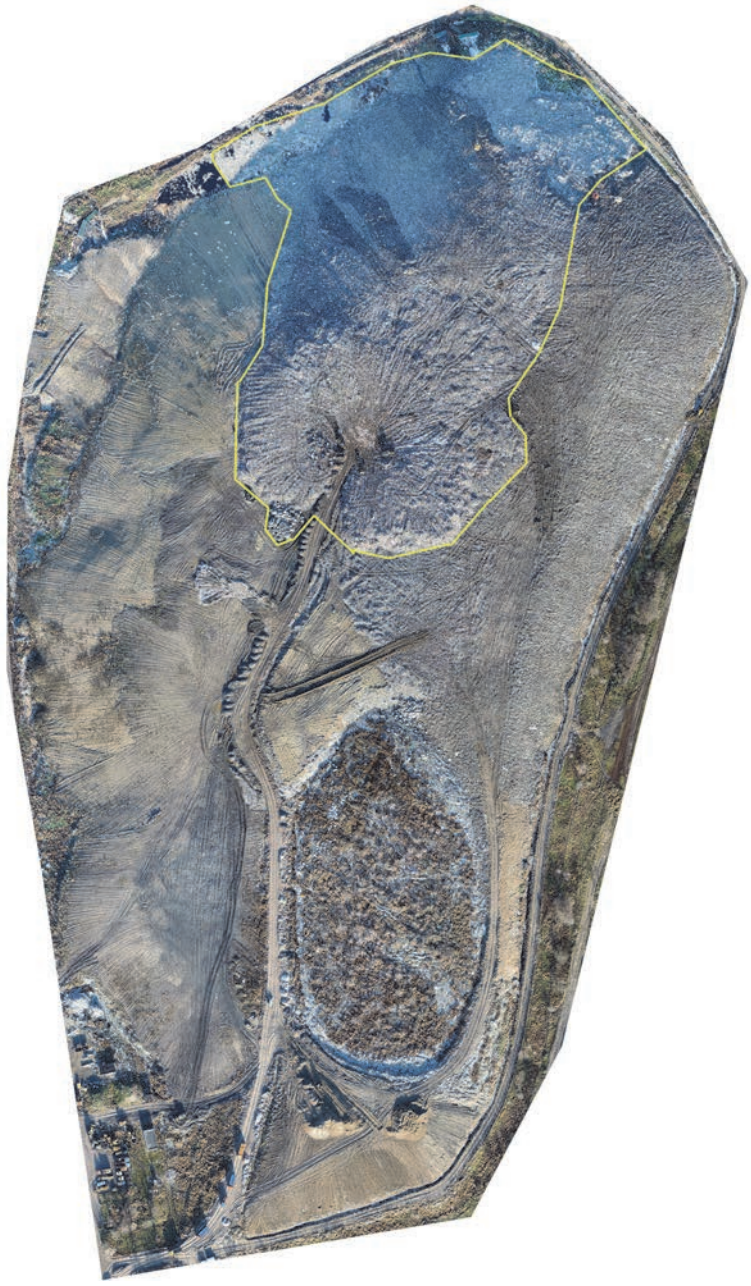

Fig. 1. Orthophotomap of landfill No. 5, survey dated 08.12.2017

covering the landfill with soil is visually observed. At the same time, it is clearly seen that in the central part of the landfill waste continues to be supplied and stored (Fig. 2, yellow contour).

The established factor causes the problem of impossibility of conducting an operational tacheometric survey of this area of the landfill because of constant changes in the waste heap relief. However, it has been promptly solved with the use of UAV. The survey was done in 2 hours, and the materials were processed in 5 hours, with 5-hour subsequent processing of the 3D model.

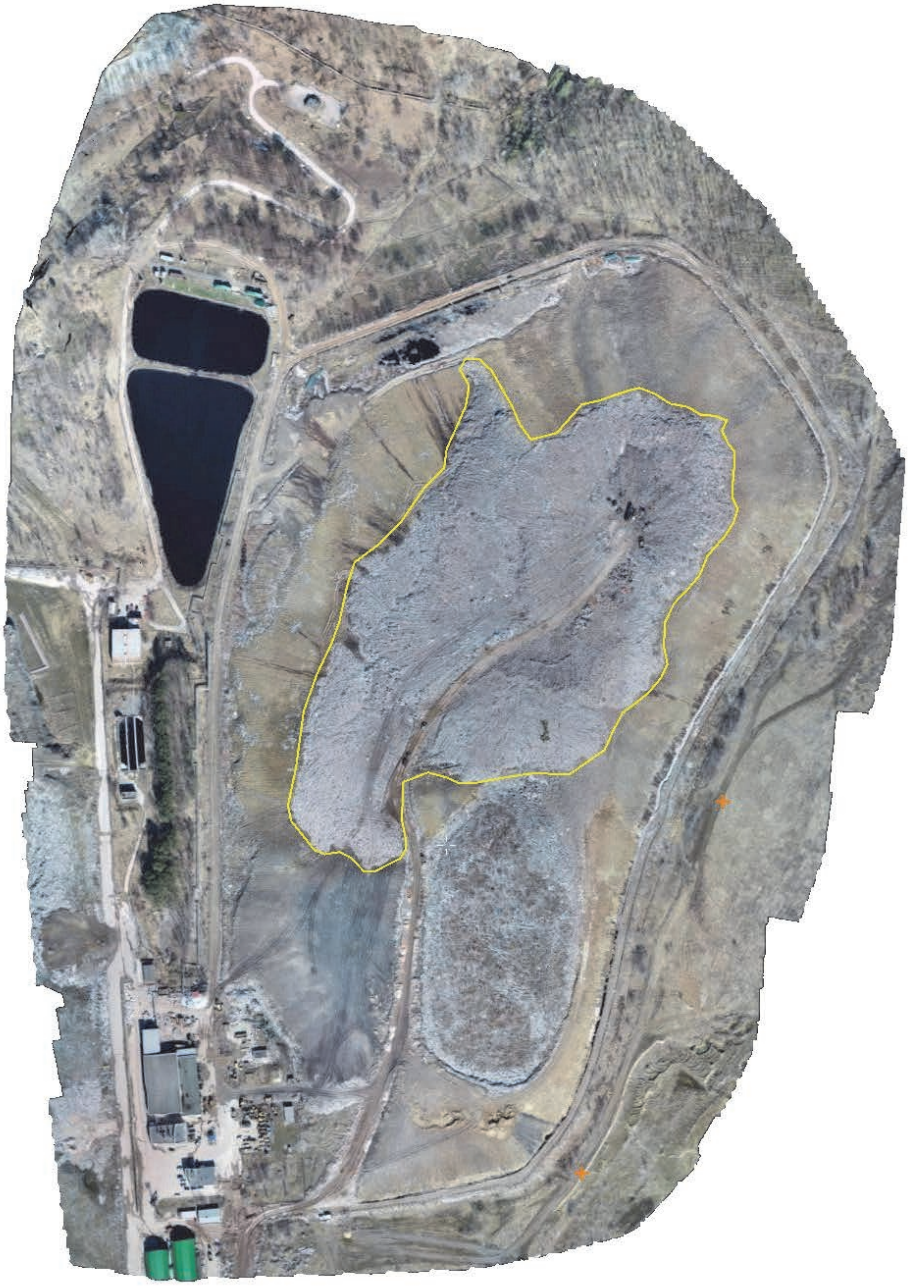

Fig. 2. Orthophotomap of landfill No.5, survey dated 04.04.2018

The 3D model is operated using special software. It has been cleaned from foreign objects that can distort the terrain (vehicles, containers). As a result, two options of topographic maps of the landfill site based on 1) the most significant points of the surface created using the software algorithm and 2) on the basis of triangulation created by points on the surface, which are located at a distance of 5 m from each other have been obtained.

The second option has been found the most suitable for being combined with the tacheo-

metric survey of the rest of the landfill made by RICP staff.

When combining the tacheometric survey and the topographic map of the landfill site created using the UAV data, point mismatches of vertical coordinates within 20 cm have been identified, which is a good result considering the characteristics of the surface surveyed.

Also, with the help of the software, the area of the surveyed site has been calculated using the 3D model in 2 minutes. Measurements were required to calculate the quantity of film for covering the upper part of the landfill. The estimated surface area of the waste heap was 66,400 m^2.

During the survey, the required measurements have been carried out, the progress of rehabilitation works has been monitored, and an accurate topographic map of the waste heap surface has been obtained.

It should be noted that the data obtained are based on the two surveys of the landfill and, accordingly, regular (weekly) landfill surveys for monitoring and evaluation of the progress of the project, early detection of problems in the works, and quick and accurate measurements can provide the project stakeholders with a powerful tool for supervision, organization, and management of construction works.

Today, the mentioned technology for supervision over construction and assembly works is used by *DronNadzor* for the following projects:

- construction of a medical diagnostic cardiology center, Vinnytsia;
- reconstruction of water supply and sewage networks, Kropyvnytskyi;
- reconstruction of Kirovohrad wastewater treatment plant, Kropyvnytskyi;
- reconstruction of the Dnieper water treatment plant, Svitlovodsk.

The obtained positive results have allowed us to formulate the directions for the further research as follows:

- development of an integrated information system for designing the organization and monitoring of progress in construction works, which combines tools for organizational and structural support of the construction works;
- development of a system for checking the quantities of works and cost control;
- creation of a system for quality control and early detection of defects in the course of works. The system can be based on such software systems as *Autodesk BIM 360, Procore, Bluebeam* and supplemented with algorithms for automatic data analysis using machine learning and artificial intelligence. The development of the very system and the creation of algorithms for its implementation in the operation of construction sector will be a powerful incentive for digitization of construction and will result in a significant increase in labor productivity and efficient use of materials, labor, and financial resources.

A parallel direction of research is the creation of automated flight procedures for data collection without human input and the introduction of a new type of compact drones designed to collect information inside buildings and structures.

Also, Resolution of the Cabinet of Ministers of Ukraine No. 461 as amended on 07.06.2017 on the handover to operation of completed construction projects requires photo and video recording for the preparation of technical dossier and certificate of the technical condition of the object. This job can be done using UAVs, with high resolution and accuracy, since buildings and structures have many hard-to-reach places for man with camera (for example, enclosing structures and protective covers).

Thus, drones have proven their effectiveness as a tool for monitoring and supervision over the organization and management of construction sites, in particular, in the project for the rehabilitation of the solid waste landfill No. 5 in the village of Pidhirtsi, Obukhiv District, Kyiv Oblast. High-resolution orthophotomaps with records of progress of works on the entire area of the landfill, as well as the 3D model based on the drone-collected data have underlain a comprehensive analysis of the construction project.

Considering the above, drones enable real-time monitoring of continuous changes at the construction site in the course of earthworks, control of the quantities of transported earth masses with a high accuracy, reliable assessment of needs in materials, and accurate planning of the scope of works. This allows construction corporations to use paperless, accurate, and fast methods for monitoring and managing the capital-intensive phase of earthworks.

Also, drones enable organizing a system of remote monitoring and control of projects and, consequently, fundamentally modifying the methodology for monitoring the construction process.

Further studies of the application of research technology will be focused on analyzing the areas of effective use of drones at different stages of the life cycle of construction projects, improving the organizational and technological solutions for construction production using UAVs and cloud technologies, organizing on-line remote monitoring and quality control of construction works using drones, as well as on utilizing the capabilities of drones in the implementation of various projects, including, the construction of civil, residential, and industrial buildings, as well as linear objects (utility facilities and roads).

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Received 06.11.18
Revised 05.12.18
Accepted 26.12.18

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ОРГАНІЗАЦІЯ КОНТРОЛЮ ВИКОНАННЯ БУДІВЕЛЬНИХ РОБІТ
З ВИКОРИСТАННЯМ ДРОНІВ І СПЕЦІАЛЬНОГО ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ

Вступ. Інноваційні підходи до контролю життєвого циклу будівельних проектів на етапах вишукувальних та проектних робіт, нульового циклу, зведення надземної частини та подальшої експлуатації з використанням дронів і спе-

ціального програмного забезпечення дають компаніям будівельного сектора України унікальний шанс реалізувати свій потенціал в ході цифрової революції і зайняти гідне місце серед світових лідерів.

Проблематика. Через нестачу оперативних, достовірних даних і показників, які описують стан будівельного майданчика, виникають проблеми відсутності у керівництва актуальної інформації про прогрес реалізації проекту, пізнього виявлення фактичного відхилення ходу виконання робіт від проектної документації, неконтрольованого впливу людського фактора в процесі перевірки обсягів і якості робіт, виконаних підрядними організаціями, недостатньої комунікації між учасниками проекту, що згодом призводить до перевитрат бюджету і порушення розрахункових термінів виконання проекту.

Мета. Впровадження інноваційних підходів до контролю будівельних проектів інфраструктурного призначення.

Матеріали й методи. Прикладне дослідження з використанням безпілотного літального апарату *DJI Phantom 4 PRO*, програмного забезпечення (ПО) *DroneDeploy*, *Pix4D*, *Virtual Surveyor* в рамках моніторингу реалізації проекту з рекультивації Полігону зберігання твердих побутових відходів № 5 в с. Підгірці Обухівського району Київської області.

Результати. Базуючись на даних, отриманих за допомогою дрону, побудованої ортофотоплани полігону та топографічний план частини полігону з мінливим рельєфом поверхні, за якими виконано аналіз параметрів і характеристик будівельного проекту на різних етапах робіт для прийняття подальших управлінських рішень.

Висновки. Використання дронів довело свою ефективність як інструменту моніторингу та контролю в рамках процесу організації й управління проектом з рекультивації Полігону зберігання твердих побутових відходів.

Ключові слова: дрон, хмарні технології в будівництві, 3D-модель, ортофотоплан, дистанційний контроль, організація будівництва, моніторинг, управління будівельним проектом.

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ОРГАНІЗАЦІЯ КОНТРОЛЮ ВИКОНАННЯ БУДІВЕЛЬНИХ РОБІТ З ВИКОРИСТАННЯМ ДРОНІВ І СПЕЦІАЛЬНОГО ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ

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