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Drones capabilities and use in post remediated landfill sites development plans

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ABSTRACT

Post-remediated old landfill site development is a complex process. It requires long-term monitoring of the impact of continuously changing mechanical, biological and physiochemical conditions of the landfill body. Particular issues occur on the embankment-type landfill of an extensive area. To fit the scale of the structure when surveying the area, a useful data collecting tool in the monitoring process of changes taking place in such structures is a drone, called an unmanned aerial vehicle (UAV). Equipped with dedicated sensors they can provide useful information, allowing assessment of the structure conditions, and its environmental impact and help in the design of associated engineering structures. Drones collected data support the structure investigation and allow expanding the investigation area efficiently. Precise data and information, revealing even the smallest aberrations and changes, are crucial in the decision-making process in structure development planning. The research presents capabilities and examples of UAV collected data utilisation in reclamation progress monitoring of restored landfill sites. To present the capabilities of engaging UAV for survey data collection the Radiowo landfill case study is presented. The landfill has been already closed and is located between the urban area and environmentally protected zones, like two nature reserves and National Kampinoski Park. The remediated landfill of 20 ha area and 60 m high will be transformed into a recreational and winter complex park. The drones' collected data was used directly in planning the future development of the landfill area.

Keywords: drone, unmanned aerial vehicle, landfill, development plans, LiDAR, photogrammetry

1 INTRODUCTION

An unmanned aerial vehicle (UAV), commonly referred to as a drone, is a device that has settled into our everyday life for good. Drones are increasingly used in many socio-economic areas, including the military, paramedics, agriculture, the energy sector, environmental protection and construction engineering (Tkáč and Mésároš, 2019; Merkert and Bushell; 2020). The UAVs used in the civil engineering sector serve structure data acquisition purposes mainly, especially for cubature investments. These high-tech tools are used for a variety of tasks in the construction process, from site survey and mapping to inspection and monitoring. The drone equipped with the appropriate sensors can provide much valuable information about the surveyed structure, which would be difficult or in some cases even impossible to obtain using traditional methods. One of the biggest advantages of using drones in construction is their ability to access hard-to-reach locations. Drones can easily fly over and around buildings, bridges and other structures, providing detailed images and survey data.

This enables better planning and project execution process. It also helps detect and fix potential issues before they become major hazards (Anwar et al., 2018). Drones collected data is obtained efficiently and in a non-invasive way - without the need to interrupt construction works. The images are of high spatial resolution, due to the low altitude and frequent measurements. Depending on the size of the mapped area the scanning can be repeated on a daily basis. The advantage of drones is also the ability to use real-time data. Live footage can help identify issues immediately and make necessary adjustments. This can help reduce delays and expenses, ensuring that projects are completed on time and on budget (Sreenath et al., 2020).

The range of drone applications usually depends on the sensors that are mounted on their decks. There are a number of additional instruments that could be attached these are RGB cameras, multispectral cameras, hyperspectral cameras, thermal cameras and laser scanners. Each of the sensors generates a different type of data that could be utilised depending on the specific project requirements. Measurement results can be presented in the form of orthophoto maps, point clouds, Digital Terrain Models (DTM), Digital Surface Models (DSM) or hyperspectral and thermal images. The collected data is used for visual analysis and investigation interpretation by applying algorithms and computational methods. These data can be used in Structural Health Monitoring, geodetic surveys (geometry and volume measurements), building inventory, vegetation cover analyses, temperature measurements or even in designing and structures development planning (Gordan et al., 2021).

Due to the advantages of using UAVs in the construction sector, their potential can also be applied in the landfill reclamation process or in planning the development of remediated landfill sites. The development of former landfills varies due to site conditions, development capabilities and legal regulations set for a particular country. The landfill reclamation process concerns natural, economic and social factors (Bhunia et al., 2021; Koda et al., 2023). The main purpose of such works is to restore the contaminated area to bring back the surrounding environment to its original condition. Often, as compensation for the long-term negative impact of the landfill on the nearest neighborhood (ecosystems), they are adapted to serve public functions including recreational, sports, museums or exhibition services. Spatial development planning of remediated land involves detailed analyzes of (1) analysis of the spatial characteristics of the area and its surroundings, (2) analysis of environmentally valuable areas, (3) inventory analysis of vegetation cover, facilities and transport accessibility, (4) analysis of the urban composition, (5) analysis of the visual and aesthetic effect (Koda, et al., 2022a). Detailed data for this type of analysis can be obtained timely and efficiently by drones equipped with appropriate sensors. The results of such detailed analyzes become principal guidelines for new development plans.

The aim of the paper is to present the capabilities of drones in the context of obtaining data for the post-reclamation development plan on the example of the Radiowo landfill located in Warsaw (Poland). The paper presents the analyses and the results of an aerial investigation performed using UAV for the purposes of monitoring the development progression at the restored landfill site. The work also describes the opportunities of extending the survey by proposing additional sensors that can be successfully used while investigating such sites. The data obtained would indicate the future directions for landfill site development. The research work also discusses the advantages and limitations associated with drone land surveying methods.

2 STUDY AREA

The research area concerns the Radiowo landfill located in Warsaw (Poland), where reclamation works has been already progressing. The site sets between the urban area and environmentally protected zones, such as two nature reserves and the Kampinos National Park. It is an embankment-type landfill with an area of approximately 20 ha. The height of the structure is approx. 60 m (Figure 1.). The unsorted municipal waste has been disposed of there for years. Combined with the specific unfavourable geotechnical conditions (wetlands) and the lack of established rules for waste disposal management on landfills, in the 1980s and early 1990s resulted in the occurrence of numerous landslides and fires (Mohammad et al., 2023). During 1999-2017, there have been a number of reclamation works implemented at the landfill. They were aimed at protecting the landfill body from landslides and limiting the impact on the adjacent areas. To improve the geotechnical conditions at the landfill, it was decided to start disposing of only ballast waste from the production of compost from the

Radiowo composting plant. The waste composition included: foils, tires, textiles, and scrap metal with a reduced amount of organic waste (5-15%). The works also included the slopes reengineering to reshape the landfill body, paying major attention to the stability conditions. Another step was to construct proper drainage and degassing systems, a vertical cut-off barrier within the landfill boundary, and supporting additional embankments were constructed as part of the mineral capping (Koda et al., 2013; Koda et al., 2020). In 2017, the landfill was closed and the structure was started to be re-engineered to adapt the site for recreational and winter sports park purposes, with downhill for skiers, snowboarders and sledders. Bicycle paths and landscape viewpoints have also been designed at the landfill crown. According to Polish legal regulations (Regulation of the Minister of Environment, 2013) the construction of facilities on the top of the landfill could only be started after fifty years from the date of its closure. However, this time can be shortened depending on geotechnical and sanitary investigation results, determining whether the site poses a threat to human life and health or to the environment. Until then, the landfill should be frequently monitored, for this purpose the drones can be successfully applied (Sliusar et al., 2022; Guo et al., 2022).

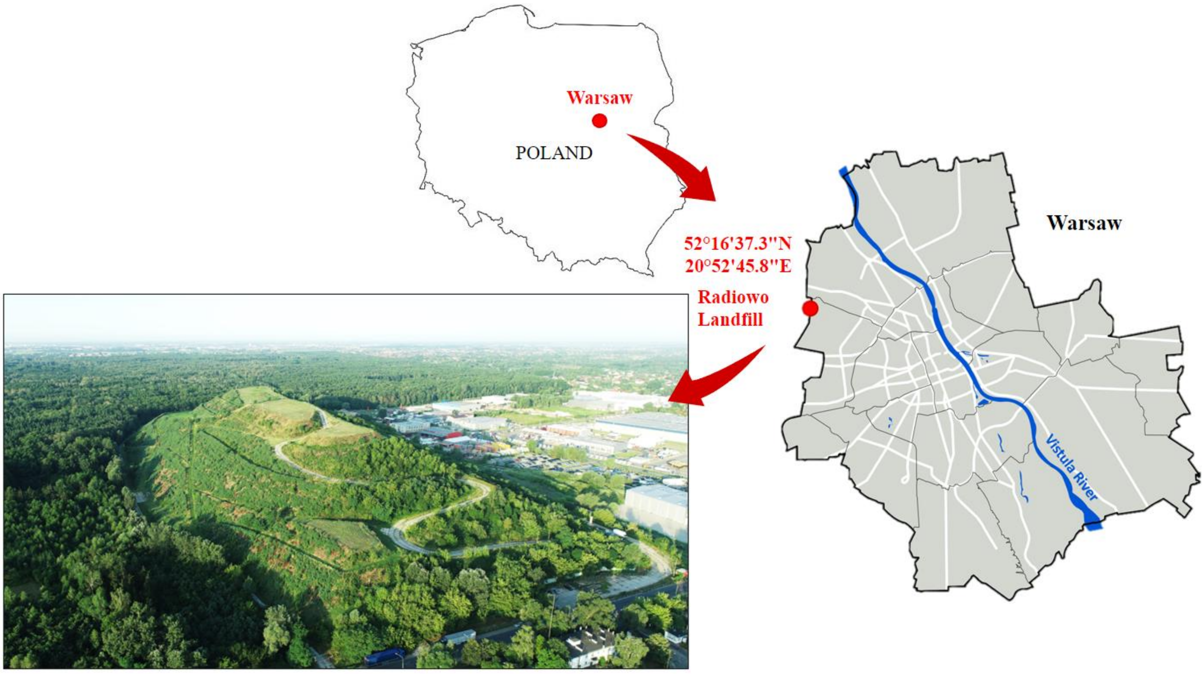

Figure 1. *View of the Radiowo Landfill from the North-East side (left). Localization map (right).*

3 MATERIALS AND METHODS

In order to make an inventory of the actual conditions at the Radiowo landfill, a wide range of investigations were performed using drones. The UAV were used to design plans for the facilities' development. There were three UAV sets were used for the survey: DJI Phantom 4 Pro V2 with RGB camera, DJI Matrice M600 with LiDAR system and DJI Matrice M600 with a thermal camera (Figure 2). These instruments allowed landfill geometry data collection and visual assessment of the technical condition of the infrastructure elements located within the area. As part of the working plan, an orthophoto map of the landfill and adjacent areas was created, in addition, a Digital Terrain Model (DTM) and a Digital Surface Model (DSM) as well as thermal imaging were built. These data were used in spatial analyzes for the purposes of the future development plan of the landfill area. The investigation was possible to be performed despite the proximity of the Warsaw-Bemowo airport, which made the entire survey process even more complex and challenging.

Figure 2. *DJI Phantom 4 PRO V2 (left). DJI Matrice M600 (right).*

The condition of degassing system infrastructure located at the landfill was assessed based on recordings of a video camera and a thermal camera that the drone was attached with. A thermal camera was used to detect possible damage to the degassing infrastructure and the mineral capping of the landfill. In case of a gas leak, the breached spots could be detected based on increased temperature zones. The video camera allowed for a remote visual assessment of any potential damage on the landfill surface. In this case, the survey did not reveal any issues with the mineral capping.

There were two principal methods used to measure the landfill geometry: the photogrammetric method and the LiDAR (Light Detection and Ranging) laser scanning method. The photogrammetric method is based on the analyses of digital photos captured with a large overlapping, which makes it possible to determine homologous points on adjacent photos. Properly processed data obtained from the UAV made it possible to obtain high-resolution 3-D models and orthophoto maps. The accuracy of the method depends on the resolution of the camera and the flight altitude from which the photos are taken. The disadvantage of this method for landfill monitoring is the vegetation cover that influences the precision of reading and image data interpretation. It is certainly the case with reclaimed landfills of lush vegetation cover (Baiocchi et al., 2019; de Sousa Mello et al. 2022). What distinguishes the LiDAR method used on the Radiowo landfill distinguish from the photogrammetric method is it utilises an active sensor which sends a laser beam. The laser beam reflected from the measured object is then recorded by the detector. The measurement is therefore independent of the access to light, which is an undoubted advantage. As a result of the scanning, the so-called point cloud is created, i.e. a set of points in the XYZ coordinates representing the measured object. In addition to the location of the points, we also receive data on the intensity of reflection, angle of reflection and the number of reflections of each laser beam. These data allow for more accurate filtering of point clouds, e.g. in order to separate vegetation cover from the ground surface. An undoubted advantage of this method is also the ability to penetrate the vegetation, i.e. reaching the ground surface. This is an advantage over the photogrammetric method in the context of monitoring and mapping the landfill surface (de Sousa Mello et al., 2022; Pasternak et al., 2023).

4 RESULTS

Periodical landfill body volume change measurements allow monitoring of structural deformations caused by mechanical, biological and physicochemical processes taking place inside the landfill, such as: oxidation, combustion, fermentation, leaching or compaction and consolidation of the waste bed caused by its compression (Koda and Zakowicz, 1998). In order to determine the impact of these processes on the amount of surface subsidence, in addition to data obtained from drones, also data generated from Airborne Laser Scanning (ALS) were used in the analyses. ALS allow tracking the changes in geometry at the Radiowo landfill in the years 2012–2022 (Figure 3). Based on a summary of deformation differences in the landfill geometry three cross-sections for different periods were created (Figure 4). Data from obtained in 2012 is marked in blue, data from 2018 (right after the landfill was closed) is represented by red colour and data from 2022 is marked in green. The largest changes can be observed between 2012 and 2018. During this time, the landfill was re-engineered. The most intensive exploitation took place during that time which is also a reason for recording the most significant increase in landfill volume. There are no such large deformations observed between 2018 and 2022, but subsidence of the landfill crown caused by the slow mechanical creep of waste and the deformation of slopes towards the outside can be noticed. Such observation is confirmed by geodetic measurements of benchmarks installed on the crown and slopes of the landfill (Pasternak, 2022). The advantage of recorded data is the ability to generate sections anywhere in the area of the entire facility, which is in contrast to classic geodetic measurements, where only individual point monitoring is possible. This type of analysis can be a key element in slope stability analyses and the decision-making process regarding the need for slope reinforcement and risk assessment.

Figure 3. *Data acquisition timeline.*

Among the other sensors used in drones, multispectral and hyperspectral cameras deserve particular attention, as they can be used to monitor the condition of vegetation cover on the landfill site. These cameras allow the registration of spectral channels in a much wider range than visible light. Particularly important in the context of vegetation cover inventory is the measured near-infrared radiation range. Monitoring the condition of plant species and changes in their biomass using remote sensing methods consists in determining the so-called vegetation chlorophyll index, which allows the determination of the amount of chlorophyll in their green parts. The vegetation cover condition can be assessed, e.g. using different vegetation indexes: NDVI (Normalize Difference Vegetation Index), SR (Simple Ratio), PVI (Perpendicular Vegetation Index), SAVI (Soil Adjusted Vegetation Index), or NLI (On-linear Vegetation Index) (Zeng et al., 2022). These methods are based on the images captured in the near-infrared NIR band and images in the visible RGB bands. The most frequently used index, due to the ease of calculations, is NDVI, which is an indicator based on the ratio of selected spectral channels and is expressed by the formula (1).

$$NDVI=\frac{NIR\text{-}Red}{NIR+Red} \quad (1)$$

where:
NIR – near infrared band,
Red – infrared band.

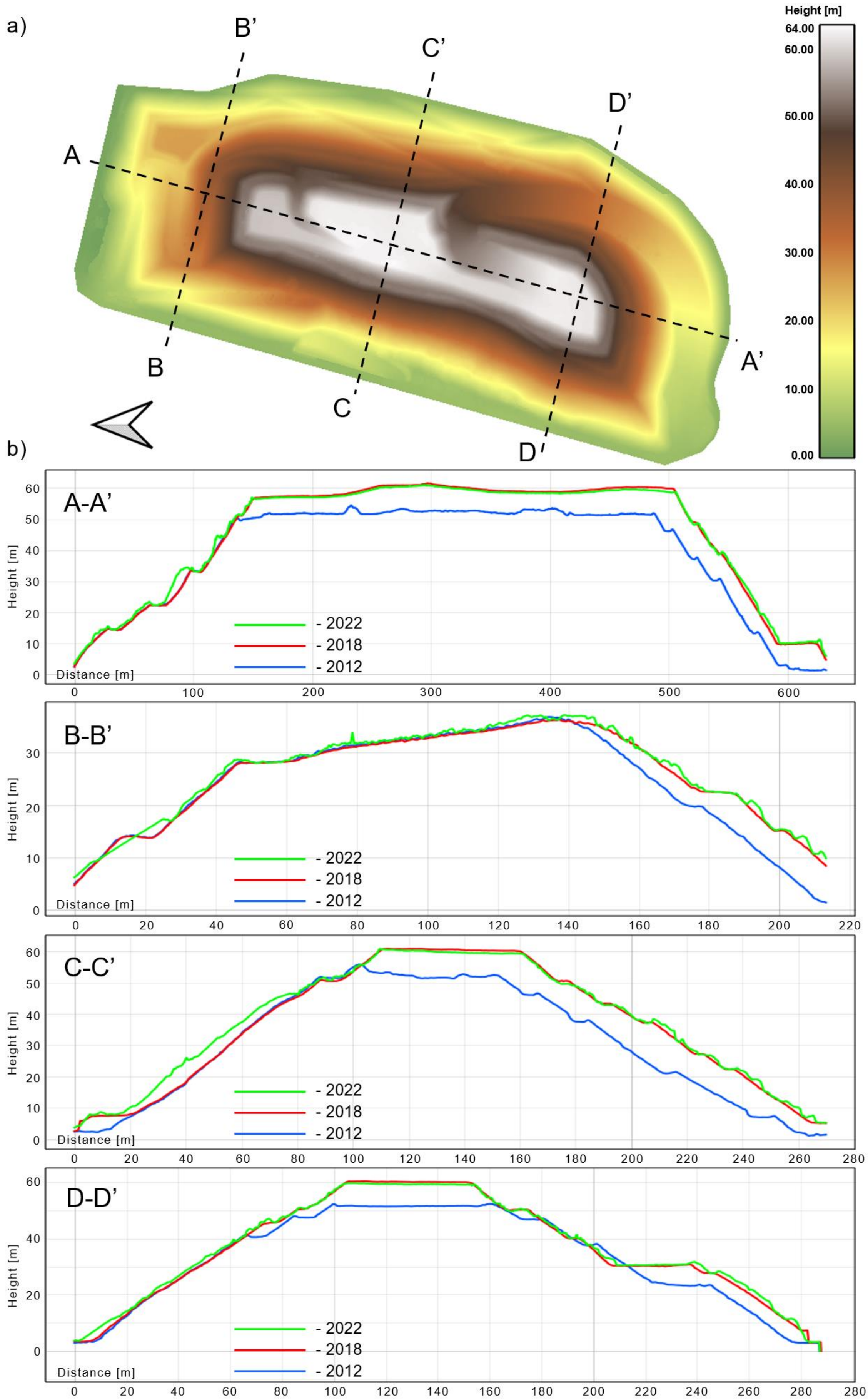

Figure 4. *Elevation model with marked cross-sections (a). Cross-sections (b).*

The NDVI index is based on the value of the contrast between the largest reflection (in the NIR band) and the absorption in the Red band and contains in a range of values from -1 to 1. The value of the NDVI index increases as the reflection in the NIR band increases and the reflection in the Red band decreases. A high value of the index corresponds to areas covered with lush vegetation of good biological condition. This index is used to collect information on the intensity of photosynthesis and to forecast yields or the amount of biomass produced by the ecosystem (Wang et al., 2004). In the context of monitoring vegetation in landfills, these indexes are also an excellent tool for fire risk assessment in zones covered with lush vegetation. Areas covered with dry vegetation, with a low vegetation rate, will constitute a flammable material that increases the risk of a possible fire. A low NDVI may also indicate issues resulting from leaks in the mineral landfill capping or leaks in degassing systems. Gas leakage or leachate collecting system failure can negatively affect the development of plants (Koda et al., 2022b; Ran et al., 2020).

5 DISCUSSION AND CONCLUSIONS

The drones application in the construction sector continues to expand and has the potential to revolutionize the industry. With the ability to access hard-to-reach areas and to provide detailed images and data, drones can help professionals in better planning, design and execution of construction projects. Additionally, the use of drones can help reduce construction delays and manage the budget more effectively. This would allow for completing the investment on time and within budget. As technology continues to advance and sensor downscaling works are progressing, it is likely that drones will become an even more important tool in the construction industry.

The particular potential of drones application is presented for the process of remediated landfill sites monitoring. Data obtained from sophisticated sensors, that drones are equipped with, can be used in analyzes aimed at investigating the abnormalities in the landfill body, identifying emergency cases, and future development plans design. These include utilising geometry changes and displacements data, vegetation cover assessment and landfill technical infrastructure check-ups. The drone gives the opportunity to timely obtain much more valuable information about the structure, which could be challenging to achieve using traditional methods. Drone-based monitoring of such structures can also be of great importance in decision-making processes. Drones allow for collecting data of high spatial and frequency resolution. It enables real-time investigation over an extensive area, which results in a faster decision-making process and increases the efficiency of applying safety measures.

Despite the benefits, there are still some challenges associated with the use of drones. It needs to be emphasised that drone operators must be properly trained and certified. They must also comply with the strict aviation regulations in force in particular countries. This is to ensure the safety of both air traffic and civilians present in the vicinity of the surveyed area. Depending on the location of the landfill, in a number of cases, the use of drones may be limited.

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