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RESEARCH

Development and actualization of brownfields database with the use of unmanned aerial vehicles - the case of Upper Silesia, Poland

Aleksandra Zgórska[1] · Adam Hamerla[1] · Jan Bondaruk[2] · Paweł Zawartka[1]

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Abstract

This paper presents the assumptions and the preliminary results of the project entitled "Extension of the system for management of post-mining areas in the Silesian province - OPI TPP 2.0". The overall objective of the project is to develop and implement a new e-service in the form of an open-access information system on post-mining areas in the Silesia Voivodeship. The range of information and tools planned to be made available is dedicated to assessing the possibilities and potential for economic and social reuse of these areas. The basic and extremely important stage of the project was to identify and collect data on post-industrial sites located in the Silesia Province. The information contained in this article illustrates the activities that were carried out in the initial phase of the project in which unmanned aerial vehicles (UAV) were used to identify and acquire information on brownfields (including post-mining sites) entered into the developed common database. The article assesses the possibility of using drones in an enterprise of such a large scale and also points out the advantages of using this method. The article describes the methodology and scope of work related to the acquisition of data that can be collected using unmanned aerial vehicle (UAV) covering surface infrastructure and land use of brownfields, allowing for the identification of negative phenomena on their site as well as monitoring of naturally occurring processes. Based on fieldworks experience and the results of numerous analyses carried out for different types of brownfields (e.g. post-mining areas, former transport bases, settling ponds, etc.), paper presents the advantages and benefits of drones (UAN) over other data sources used to monitor changes in an area. The article is based on the results of an inventory of over 600 brownfields located in Upper Silesia region (Silesia Voivodeship, Poland).

Keywords Unmanned aerial vehicle · Brownfields · Post-industrial sites · Databases · Drones

1 Introduction

The economic development of European countries, especially in the EU, has resulted in the disappearance of traditional industrial regions. From a global perspective, the functioning of mining enterprises is determined by many factors, the most important of which is the directions of the energy policy and countries pushing towards a low-carbon economy (Li 2021). Currently, the transformation process concerns the largest coal mining region in the EU - Upper Silesia in Poland. Among the many social, economic and environmental consequences in the spatial aspect, the emergence of a large number of brownfields. The importance of the problem is given by the fact that the total area of degraded and devastated land in Poland is approximately 3,463,374 ha (2017), which gives an area of 16.3 m^2 per Polish citizen (GUS 2017). In Silesia Voivodeship alone, the area of degraded and devastated terrains exceeded 11,300 ha, including more than 6000 ha in the central part of the region. According to the literature data 7000 ha of the total value, are the areas occupied by brownfields (Gasidło 2019). However, the studies have shown that the actual area occupied by brownfields in the region is much larger.

The process of remediation and redevelopment of brownfields requires the creation of a complex organizational and financial system. The base to start restoring the role of these sites in socio-economic context is the information base including characteristics of these sites. The problem

✉ Aleksandra Zgórska
azgorska@gig.eu

[1] Department of Water Protection, Central Mining Institute, Plac Gwarków 1, 44-166 Katowice, Poland

[2] Deputy Director for Environmental Engineering Central Mining Institute, Plac Gwarków 1, 44-166 Katowice, Poland

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of access to information on brownfields does not concern only Poland, but also other European countries with industrial history. In Belgium, for example, there is no reliable quantitative data on brownfield sites. Only in Wallonia has such an inventory been carried out, which includes formerly economically active sites. Registered sites include sites suspected of being contaminated and sites with little or no contamination but in need of remediation (Maes et al. 2007). In Europe, the need for an inventory of brownfields is also indicated by researchers outside the European Union, who indicate the need to develop a database of degraded sites at the national level, taking into account the geographical location, status and land use. Experts also highlight the role of public access to these data as a first step in solving the problem of revitalization of brownfields and degraded areas (Ignjatić et al. 2017; Vujičić and Tijana 2017).

For local governments acquire zero-one information about the presence or absence of brownfields in the region is not a problem in itself. The problem is the lack of a unified, generally accessible system (open success database), which would gather all the brownfields occurring in the region with their full characteristics. The knowledge about these areas based on reliable and up-to-date information enables decision-makers and investors deciding on the form of land development including aspects of spatial management and investment profitability (Tan et al. 2021; Al-Sa'd et al. 2019). At the stage of characterisation site a particularly important role is played by the inventory, which is the only way to check the current state of sites with the information obtained by the traditional methods such as *desk research*, community interviews, official reports and documents obtained from the site manager. The possibility of conducting a quick inventory of areas that are difficult to access, which certainly include post-industrial areas (difficulty due to the relief of the terrain and the potential risks for researchers and often required permits for entry) is currently provided by drones (Villarreal et al. 2021; Young et al. 2021).

Numerous of scientific papers have overviewed applications of UAV technique. For example, small UAV have been successfully used to track the progress and scale of damage caused by e.g. natural disasters (Fabbroni et al. 2016). The drone-based pre- and post-disaster remote sensing has become the subject of numerous works. The authors provides information about the hazard-specific of UAV technique applications relating to: mass movements and land-slides (process modelling, risk assessment, detection, monitoring, impact assessment etc.), floods risk (flood risk assessment, modelling, impact assessment, protection structure inspection, etc.); earthquakes risk (reconstruction monitoring, fault zone mapping, impact and risk assessment, etc.), volcanoes activity (termal mapping, topographical analysis, lava flow monitoring, etc.), as well as wildfires monitoring (Bravo and Leiras 2015; Gomez and Purdie 2016; Antoine et al. 2020).

A systematic literature performance conducted Kucharczyk by using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses methodology, resulting, indicated that, of the 635 studies, 87% performed mitigation- and recovery-related remote sensing. Where the most frequently analyzed hazard type was the mass movements (38% of studies) (Kucharczyk et al. 2021). In the aspect of post-industrial and post-mining areas, the drones have been used, among others, in research conducted by Nádudvari et al. 2021, which aims to create a classification index for self-heating intensity in coal waste dumps using Landsat-, ASTER- and thermal-infrared camera acquisition from a drone using Landsat 4–5 TM, ETM+, and ASTER images.

Available work also considers UAV technology applications in the process of electrical and renewable energies inspection, mapping and 3D modeling (Ramirez et al. 2022). The possibilities of using drones were also described in agriculture (half condition, growth efficiency, assessment of fertilizer application efficiency, etc.) as well as in the construction industry. The UAVs are widely used for agricultural purpose in case for monitoring the crops, manage the plants, and supports crop-spraying. The data collected from drones recording fields help farmers plan their planting and treatments to achieve the best possible yields. Drone usage helps to boost up the efficiency and effectiveness of farmers as well as drone pilots (Meivel and Maheswari 2021). The application of very-high resolution spatial data acquired using UAV technology proved to be quite efficient for the water and ecological environmental monitoring of wetland, which makes its large-scale application reliable and efficient The overarching aim of the authors' research was to use UAV orthomosaics and digital elevation models to carry out seasonal monitoring, simulate the water flow in the areas of hydric-contribution and inland flooding, and validate the flooding simulations(Furlan et al. 2021). Additionally, the opportunities for use the unmanned aerial vehicles (UAV) technology in land administration system were also rated and reported. For example, Casiano et al. (2020) promotes the use of new technologies, such as unmanned aerial vehicles (UAVs), to provide valuable base-maps. Within the works author promotes usage of UAV as an alternative land tenure recording approaches to create a sustainable land administration system (Casiano et al. 2020). Additionally the adaptation capacity of unmanned aerial vehicle (UAV) technology in Rwandese and Kenyan land administration systems, was the subject of Tan teams work (Tan et al. 2021). The literature also extensively describes the issues related to functioning drone platforms, UAV components, type of sensors, sensor types, airspace regulations, data acquisition, data processing and data analysis, as well as advantages, limitations and challenges of UAV technique (Gomez and Purdie 2016; Antoine et al. 2020; Svenström et al. 2021; Vujičić and Tijana 2017). Special attention should be given to the Giordans' team whose as a members of IAEG C35 Commission workgroup "Monitoring methods and approaches in engineering geology applications" within the work evaluated and described a general overview of unmanned aerial vehicles (UAVs) and their potentiality in several engineering geology applications (Giordan et al. 2018, 2020).

The use of small drones in larger commercial applications is growing (Bartsch et al. 2016) with their deployment in remote work, leading to significant cost reductions and capability enhancements their applicability in many industries (e.g. engineering, transport sector, mining, networks in management contexts, agricultural usage - scanning) (Bushell and Merkert 2020). The ability of UAV to view from altitude a large sites and areas at a low cost significantly extends the range of applications, including a new image acquisition capabilities and new data acquisition ability (obtaining or updating data).

In the case of the Upper Silesian Coal Basin under analysis, currently there is no up-to-date, systematised and publicised database of post-industrial sites despite the fact that the base was so established several years ago. The dispersion of information and the dynamics of change within brownfields and their immediate surroundings are serious barriers to the construction of the database and especially its subsequent updating, which caused problems in the functioning of the previous database. The amount of these areas is also a problem. The development of an information system that collects spatial data, including highly variable data, poses a huge challenge in terms of ensuring that the system is up to date, and only such a system can support the process of restoring sites to economic use. It was decided to use several types of data to build a database of post-industrial sites for the Silesia Voivodeship.

The article describes the methodology and scope of work related to the acquisition of data that can be collected using drones covering surface infrastructure and land use of brownfields, allowing for the identification of negative phenomena on their site as well as monitoring of naturally occurring processes. The article presents the benefits of traditional using drones, the limitations and advantages over other data sources for the inventory of brownfields and their potential to monitoring changes in these spaces. The article is based on an inventory of 600 brownfield sites in Upper Silesia. What's worth highlighting, in terms of the number of sites analyzed using UAV, none of the works cited above deal with the drone use on such a large scale in relation to post-mining and post-industrial sites.

2 Scope and scale of conducted works

2.1 Study area

2.1.1 Upper Silesia Region

The study area covers the whole of the Silesian Voivodeship, which has been strongly influenced by heavy industries, notably coal mining and metallurgy industries. It is still one of the most industrialized regions in Europe. For several years there has been an intensive period of very significant changes in the economic field of each of the cities in the Silesian Voivodeship. Concentration of industry in such a small area has contributed to the destruction of the natural environment, resulting in the creation of brownfields, such as waste dumps, pits and sites left after disused plants. Post-industrial areas, which were used directly for industrial activities in the past and have not been given new functions, cover about 1% of the voivodeship's area. What is particularly important, the share does not include degraded areas, which are much larger. According to the literature, the total amount of areas degraded by industry occupy almost 7 thousand ha in the Silesian Voivodship, which (< 5.5% of the region's area. Their share is the largest in the Western subregion (1686 ha – 12.5% of the total) and Central subregion (4116 ha – 7.3% of the total). It should be noted that, a significant part of these areas is located in places attractive for business (Zagórska 2008). Practically every city has within its borders sites directly or indirectly related to industrial activity which require a process of revitalisation and reconversion towards new economic activities or the provision of ecosystem services. At the same time, there is a great demand for investment areas both for services, logistics and housing. The dynamics of socio-economic transformations directly affect the space of post-industrial cities. The areas of post-industrial sites, as well as whole districts of cities, are transforming and acquiring new functions. This poses specific challenges in terms of monitoring these changes and the management of areas in a state of transition. The answer to this challenge is to build a brownfield management system with a particular focus on post-mining sites. The basis of the IT management system is a database on brownfield sites. A simplified flowchart of the work conducted using drone technology to update obtain reliable spatial data for the purpose of database development is presented below (Fig. 1).

The database is developed under the OPI TPP project (Extension of the system for management of post-mining areas in the Silesian province), co-financed by the European Regional Development Fund under the Regional Operational Programme of the Silesian Voivodeship for

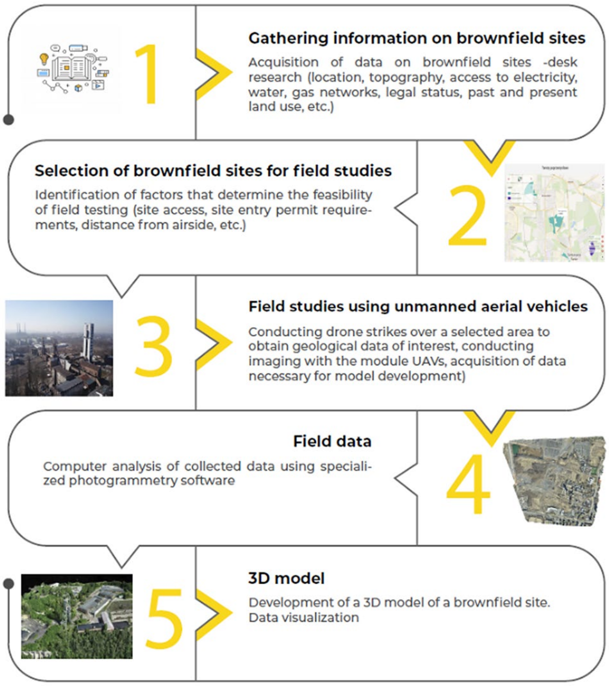

Fig. 1 The stages of a brownfields inventory using the UAV technique

2014–2020, Measure 2.1 Support for the development of digital public services.

2.1.2 Brownfield sites

The database of post-industrial sites in the Silesia Voivodeship covers a total of 600 sites with a total area of 9882 ha.

The sites are divided into two main groups: post-mining areas with an area of 5882 ha and other industrial activities with an area of 3966 ha. Areas with mixed genesis have been classified into one of the groups on the basis of the size of the impact of the type of economic activity. Further internal division of post-mining areas is related to their specificity and different management method. A significant proportion of the post-industrial sites described in the database are managed by municipalities or state institutions established to manage post-mining assets. Some of these sites belong to private owners. Access to data on brownfield sites is highly limited. The first attempts at an inventory began in 2007, and the first database was created in 2013. Initially, the work focused primarily on data on the environmental hazards present on brownfield sites, and to a lesser extent on the potential of these sites to provide new economic or social functions. The developing brownfields database contains information on brownfields, including location, land use, morphology, infrastructure provision, accessibility as well as information on hazards resulting from previous industrial activity. The database also collects statistical data from statistical offices - this part of the database is beyond the scope of this article. Much of the data collected is information on phenomena with limited dynamics of change. However, the transformation process means that a significant part of the land is being transformed, causing rapid change. Moreover, limiting the role of the mining industry in the economy causes a significant increase in the number of brownfields.

2.2 Experimental tools and methods

Data are collected directly from landowners and managers, existing mapping studies and GIS databases, field observations and data acquired by UAVs, which are the focus of this article. All acquired data are collected in a spatial database and can be used as a basis for further analyses using GIS tool.

2.2.1 Research equipment and accessories

DJI's Phanthom 4 RTK (real time kinetic) drone is used to collect the data. The most important parameters of the devices that affect data quality and the data collection process – according to the producer's specifications are described below.

(1) Mapping accuracy meets the requirements of the ASPRS Accuracy Standards for Digital Orthophotos Class III.

(2) (H/36.5) cm/pixel, H means the aircraft altitude relative to shooting scene (unit: m).

(3) Max operating area of approx. 1 km² for a single flight (at an altitude of 182 m, i.e., GSD is approx. 5 cm/pixel, meeting the requirements of the ASPRS Accuracy Standards for Digital Orthophotos Class III.

(4) Positioning Accuracy: Vertical 1.5 cm + 1 ppm Horizontal 1 cm + 1 ppm. 1 ppm means the error has a 1 mm increase for every 1 km of movement from the aircraft.

(5) Operating Environment: surface with diffuse reflection material, and reflectivity > 8%(such as wall ,trees, humans, etc.).

(6) Max Transmission Distance FCC: 4.3 mi (7 km); SRRC / CE / MIC / KCC: 3.1 mi (5 km).

DJI Terra software is used for mission planning and raw data processing. The software generates high-resolution orthomosaics for detailed and accurate measurements. DJI Terra allows you to make a 3D model as well as perform a preliminary ground cover classification. The software enables direct analysis and the generation of data into formats that can be used in GIS software for specialised analysis.

Table 1 Main data sources for the brownfield database

Type of data	Source	Comments
Location / address	GIS*	Terrain delineation - UAV
Area	UAV	-
Land use	UAV	Classification according to Corine Land Cover
Ownership and management structure	GIS / City Hall	
Zoning in planning documents	GIS / City Hall	
Underground infrastructure	Infrastructure managers	
Condition and volume of buildings	UAV	
Internal traffic system	UAV	
Waste deposited on the site	UAV	A site visit is often necessary to determine the composition
Flood risk zones	GIS	
Slope identification	UAV	
Preliminary greenery inventory	UAV	A site visit is often necessary to determine the composition and condition
Soil contamination	Existing documentation / field studies	
Access points to the site	UAV	
Thermally active sites (ignited heaps)	Thermal camera	
Neighbourhood development	UAV	
Administrative decisions issued	City Hall	
Socio-economic statistics	Statistical Office	

**GIS - publicly available geographical information systems.*

2.2.2 Type and sources of collected data

Table 1 shows the scope of the data collected in the database and their primary source. The table indicates the type of data and how or where it was obtained. Some of the specific data concerning brownfields were borrowed from the existing publicly available databases (e.g. municipal spatial information systems), as well as through consultations with representatives of municipal authorities. There are dozens of attributes for each site in the database. UAVs are the source of half of the data collected. The assumed time of performing the flights for an area of 100 km^2 (the area of all the post-industrial sites in the Silesian Voivodeship) is about 50 h - not including the process of data preparation and processing as well as access to the site in order to conduct an inventory.

3 Results and discussion

3.1 Database - quantitative characteristics

The database of post-industrial sites includes the characteristics of over 600 post-industrial sites located within the Silesian Voivodeship. There are several dozen brownfields in cities such as Ruda Śląska, Bytom, Zabrze, Siemianowice Śląskie and Rybnik. As an example, the location of brownfields areas within the administrative borders of the city of Ruda Śląska is presented below (Fig. 2). The lack of tools for continuous monitoring of changes taking place in these areas makes it very difficult to manage these spaces. The use of UAVs also makes it possible to update data on an ongoing basis, especially in cities with such a high percentage of brownfields.

The surface area for which drone strikes were conducted exceeded 1 ha, and for the majority of areas was several times larger. In terms of the workspace, which within the project was subjected to dorn inspection, it is worth to highlighting that the scale adopted for the division of brownfield sites is consistent with literature data which indicates that the average area for which UAVs technique were commonly used was below 1 km^2. For example, most rural areas (76% cases) for which the UAV technology were used were <1 km^2. The authors explained this fact by the nature of demonstrative studies, a small areal coverage is likely sufficient for demonstrating the scientific basis of a drone-based remote sensing application. Also worth noting is the fact, that small aerial drones (weight <25 kg) have expanded the remote sensing toolkit for disaster management activities. (Kucharczyk and Hugenholtz 2021; Cracknell et al. 2017). Data obtained within the work were introduced into the database (system), developed within the OPI-TPP 2.0 project. As mentioned above, the sites are divided into two main groups: post-mining areas and areas affected by other industrial activities. Additionally, in the database, in order to catalog the entered sites and to standardize the provided information, the sites were further classified within 3 categories: settling ponds, heaps and post-industrial areas (with the presence or absence of technical infrastructure elements). The classification was based on information regarding the past (or present) land use form.

3.2 Database - qualitative characteristics of brownfields

The acquisition of data on brownfields was conducted in two ways: (1) on the basis of a field inspection supported by drone strikes and (2) on the basis of in-depth desk research. Generally, for each of the brownfield entered into the database, the information concerning the location, past and

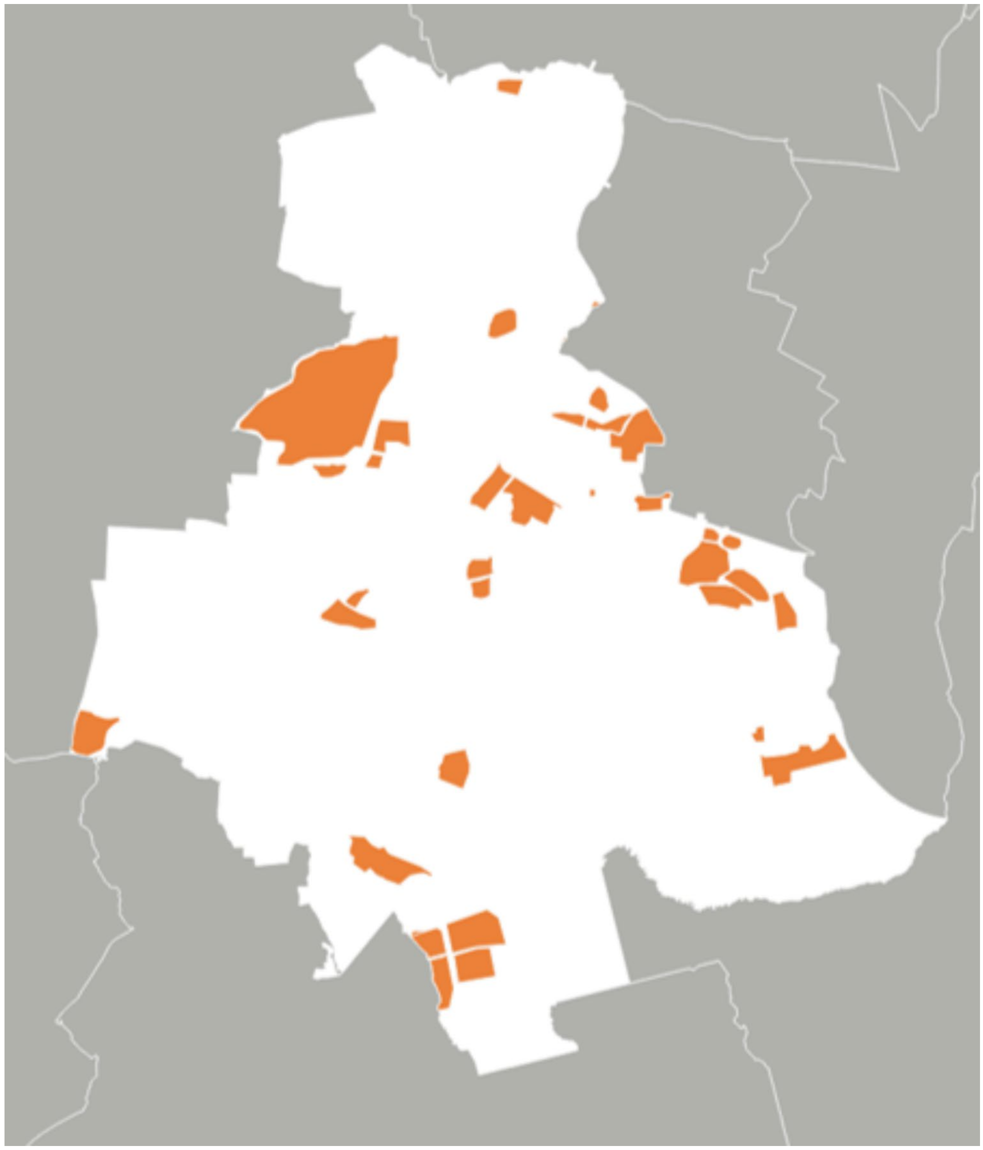

Fig. 2 An example of the location of brownfields within the city of Ruda Śląska, Poland

present site development form as well as factors determine the investment potential of the area were collected. Within the project (OPI-TPP 2.0) for more than 600 brownfield sites, the following detailed information was collected: location data (district, city/town, street, facility no., etc.); geographic coordinates, site genesis (past and present land use), land cover (degree of greening, type of vegetation cover), legal status, shape of the area, level of access to public roads, presence of internal roads/trails, distance from industrial areas, city centers, transport infrastructure (airports, transfer centers, distribution centers, railroad stations, etc.), distance from residential zones, cultural objects, naturally valuable objects and areas, objects and areas under conservation supervision, presence of infrastructure elements (with assessment of its condition and potential threat), occurrence of wild dumps, presence of invasive plants, site access to power, water and sewage, gas, heating, telecommunication networks, etc. Ultimately, the site-specific data obtained for each post-industrial area will be used to assess the investment potential and the site capacity to provide ecosystem services. The aforementioned data, before being entered into the database, was collected using an web form. The development of the online form was intended to unified data and improve fieldwork. An example of a form used to collect brownfields data, run through a web application is shown below (Fig. 3).

The data obtained from the drone flights after computer processing were used, among others, to develop a 3D model of the area, and were also individually entered into the database.

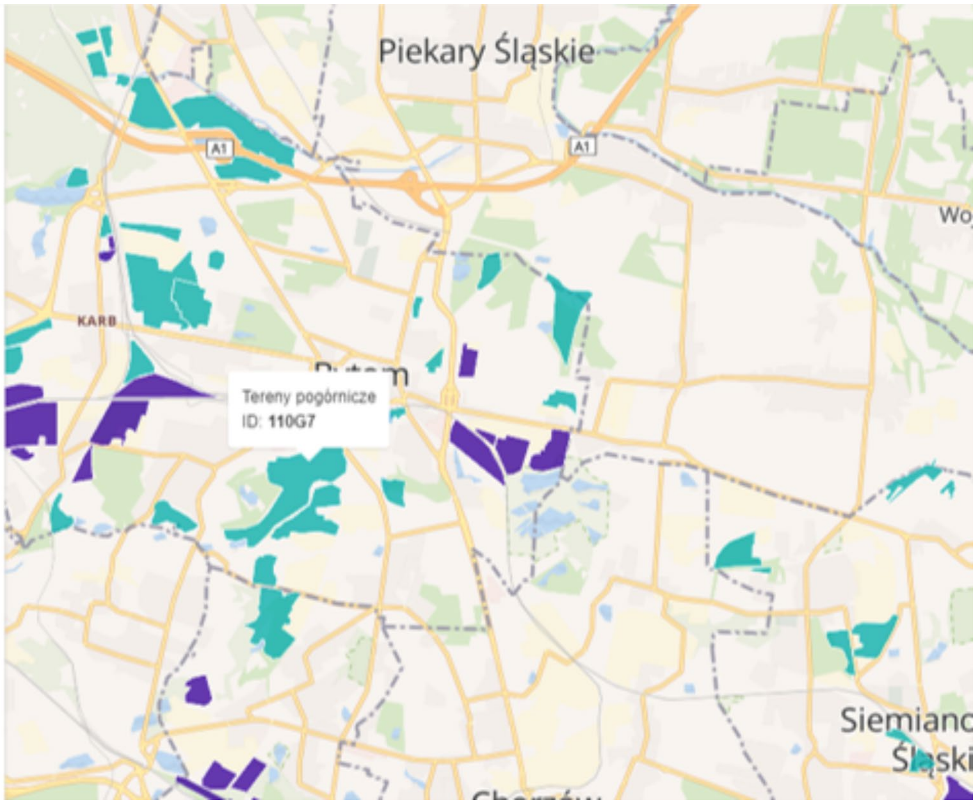

Fig. 3 Example of web form page used in the data collection process

3.3 Drone analysis *vs.* field inspection

In developing a database of brownfield sites, the effectiveness of collecting data directly in the field as well as from UAV data was compared. Maximum reduction in data processing time and ease of interpretation was achieved by analysing UAV data after the researcher had visited the site. Basing only on field surveys and public mapping materials limits the effectiveness of detection of such elements as land use, determination of building volume or contaminated surfaces. A reliable description of the relief or mapping of transport systems without geodetic work is impossible. Analysis of accessibility to land and development of neighbouring areas is difficult, and reliance on publicly available GIS systems and cartographic materials may result in a lack of access to up-to-date data - which is particularly important in areas in transition, where changes are very intensive. Difficulties in data identification increase with the size of the site area, the complexity of the land use and the variety of relief - where the researcher is unable to visually cover the whole site at one time. At least 25% of the sites identified in the database had significant site access restrictions. In part the barriers were due to existing fences and restrictions put in place by owners. A significant proportion of these sites are located in floodplains, heavily contaminated areas, with significant slopes or bounded by spatial features such as railway lines or rivers. None of these elements is a significant obstacle to data collection using UAVs. One of the biggest advantages of using a UAV is the ability to repeat the survey periodically and obtain comparable data. This makes the update process more efficient and less subjective. The use of UAVs has limitations, including the need for qualified personnel to operate the aircraft. The flights are also dependent on weather conditions and time of day. It should be noted, that the conditions apply to most of the field work even without the use of specialized equipment. Some areas are also excluded or strongly restricted for UAV traffic. This concern, among others, zones around airports and strategic objects. In the case of collecting data for the brownfields database, these situations were very rare. In the case of data collected from the field, the limitations primarily relate to the identification of objects under dense tree canopy such as obscured infrastructure or waste piles. It is also problematic to collect data in the area of tall objects such as chimneys or shaft towers.

The assessment of plant species composition or identification of invasive plants is possible, however, it requires taking additional photos with a suitable approximation (Fig. 4).

3.4 Comparision: googlemaps *vs.* GIG data

Photography is another special form of data acquisition. While drone inspection is commonly used by industry or

Fig. 4 Examples of technical infrastructure objects occurring on brownfield sites (Siemianowice Śląskie, Poland)

policy-makers for monitoring environmental condition (smog, emissions, locating illegal dumps, monitoring transport routes), acquire data (pictures, videos) might also be successfully convert into information to support decision making process for selection a possible form of land development. The ability to visualize the drone inspection results is particularly important in terms of assessing the state and scale of actual changes that have occurred in the field over past few years. In relation to the mentioned problem, the lack of available up-to-date data and imagery relates especially to cities and areas where transformation activities are most intensive. Currently, a dozen or so sites of large industrial plants are in the process of liquidation and transformation, which results in several dozen post-industrial sites undergoing changes in the way of development. The use of UAVs enables virtually cost-free monitoring of these processes. The role of the field inspection that should be carried out for each site is emphasized by the fact that often the information contained in open access geoportals does not reflect the real conditions that prevail in the field. As an example, an orthophoto image obtained from a commercial spatial information portal is shown below in comparison with an image obtained during a drone flight. According to the data from geoportal on the site the technical infrastructure elements are present, which in fact are no longer there (Fig. 5).

3.5 3D terrain model

Drone Photogrammetry allows the imagery captured by a drone to be used to generate detailed 3D models and measurements of physical structures and property. Based on developed model, we were able to identify identify all types of terrain irregularities, including: cliffs, sinkholes, excavations, hills, etc.; measure topography (low-lying areas, peaks); and as well as assess the presence in the field of technical infrastructure and other elements important in terms of future land development. It should be emphasized that the development of a 3D model of the sites, that can be presented to a potential investor is an undeniable advantage of the UAV technology. An example of a terrain 3D model developed on the basis of data gathered by drone is presented in Fig. 6.

Fig. 5 Examples of images obtained for brownfield sites during the data analysis. a imagines obtained from available geolocation portal (googlemaps.pl); b image obtained by UAV usage (Boże Dary Mine, Katowice, Poland, 2021)

Fig. 6 An example of a 3D model of a brownfield site, based on data collected by UAV (Heap in City of Radlin, Poland, 2021)

4 Conclusions

The database of post-industrial sites in the Silesian Voivodeship is the first database of its type, which uses such a significant extent data collected by UAVs. Other cases of such direct use of drone data for spatial planning and economic development of the whole region have also not been identified.

(1) An assessment of the problem caused by brownfields in the Silesian Voivodship proved that post-industrial sites disturb the functional and spatial continuity of the region, and due to the significant land devastation and degradation and the presence of various types of waste they pose a huge environmental and socio-economic problem. On the other hand, well-connected location near city centers, makes these sites extremely valuable in terms of potential investment areas. All those facts prove the need to develop new, official and investor-friendly tools for brownfield management that support the decision-making system. The works conducted under OPI-TPP 2.0 project proves that an important tool to support the process of brownfield management is an information system (database) containing data about all brownfields in the region along with their full characteristics. Nevertheless, due to dynamic changes in the area of land use, it is crucial to develop the system in a way which allows for quick, cheap and easy update of the data included in it. Such a possibility is given by the UAV technique that allows for quick identification of scale and scope of changes which occurred in the area since the last site inventory.

(2) The paper has illustrated applicability of UAV technology for acquiring data on brownfields (analyses of over 600 cases within the project). Conducted research showed that with lower capital costs and wild range of capabilities, drones can capture existing data in new ways, or capture uncollected data for new analysis. Drone usage enables the target database managers (e.g. officials, entrepreneurs) taking advantage of the new opportunities being offered by the technology to do gather data in new ways, for the same or better outcome.

(3) UAV technology may have an important role to play, both at the stage of brownfield identification and inventory, as well as during the monitoring phase of works related to their further development (e.g. drones allow for monitoring of impacts and progress of land remediation, recultivation, demolition, or individual stages of construction works from a unique vantage point that provides a valuable supplement to the more typical ground-level view.

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Declarations

Declaration of competing interest The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

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