An Example of Multitemporal Photogrammetric Documentation and Spatial Analysis in Process Revitalisation and Urban Planning

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Abstract: Urban space is undergoing permanent and dynamic transformations resulting from economic and social changes, technological development and migrations of people from rural areas to cities. It strongly affects the evolution of the landscape and city structures. Current photogrammetric techniques allow for the acquisition of data for large areas within a relatively short time, and thus, allow for fast updating and verification of existing data files. The authors of this paper have focused their research on the possibility to use multi-variant spatial analysis in the process of revitalisation of degraded areas in cities. The industrial district of Warsaw was selected for this study, where problems concerning the development of formally industrial areas located in the attractive part of the city (close to the city centre) are extremely visible. As a result of urban development, degraded areas are included within administrative boundaries of the city and have created urban wastelands.

1 INTRODUCTION

Spatial planning and processes of revitalisation are not sufficiently supported by geo-information technologies and therefore are still time consuming processes. The basic advantage in the use of photogrammetric data in combination with their processing in GIS systems for the needs of spatial planning is the possibility to easily present spatial phenomena and to visualise changes and trends which take place within a given area. Graphical presentation of the existing conditions, as well as proposed transformation, simplifies and supports the decisions made for those purposes (Ogryzek and Rząsa, 2017).

Recently, interest in the revitalisation of degraded areas has grown. It is foreseen that this trend will continue due to the development of legal means which simplify such activities. The act of October 9, 2015 on revitalisation was enacted and its provisions are the implementation of one of the basic components of the Polish National Revitalisation Plan, which is currently being developed. The introduction of general frames of formal implementation of revitalisation processes include many changes which aim at the creation of the system of incentives for revitalisation. This document stresses the mutual relations of the effects of revitalisation and changes in the system of local spatial planning, which lead to limitations of uncontrolled suburbanisation and direction of investments to degraded areas in cities.

According to Art. 2.1. of the act of October 9, 2015, revitalisation *"is the process which leads degraded areas out from crisis conditions; this process is performed in a complex way, through integrated actions for the benefits of the local society, space and economy, and is territorially focused and performed by stakeholders of revitalisation, based on the municipal programme of revitalisation"* (Dz. U. of 2017, item 1023, 1529, 1566).

On the one hand, the needs for the use of attractive locations of degraded areas and, on the other hand, the lack of the methodology of the revitalisation process considering specific features of those areas, generate the demands for development of revitalisation procedures, integrated with the needs of the local society, specified in strategies of development of territorial units.

The objective of the experiments carried out in this study was to generate multitemporal photo-

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grammetric products to develop the methodology of visualisation and the use of spatial analysis for the spatial planning and revitalisation of the selected degraded areas. Unfortunately, in the case of archival photographs, several problems with processing this kind of data exist. From the photogrammetric perspective, archival datasets are hardly ever provided together with information that is needed to perform a standard approach to scanned, analogue photograph processing using professional photogrammetric software (such as camera specification and approximate values of exterior orientation parameters) (Gonçalves, 2016).

2 THE POSSIBILITES OF THE USE OF PHOTOGRAMMETRIC PRODUCTS IN SPATIAL PLANNING

Nowadays, actual image processing algorithms allow us to regenerate photogrammetric documentation to create new opportunities to carry out historical urban analysis. It might be noticed that they store unique information about the past that often is useful for many disciplines such as topographic mapping, geology, geography, architecture, archelogy, etc. (Nocerino et al., 2012; CMAP, 2017). Based on archival photographs, it is possible to generate 3D models characterized by different levels of detail (Nocerino et al., 2012), orthoimages (Redecker, 2008) and digital terrain models (Redecker, 2008; Zawieska et al., 2017). Modern photogrammetric algorithms, which depend on the image-based approach together with the photo interpretation and 3D reconstruction techniques, allow not only the generation of 3D documentation, but also information about the period in question to be added. A spatio-temporal or 4D modelling approach allows researchers to identify, describe, and subsequently analyse changes in individual scenes and buildings as well as across landscapes. Such data about change through time assist researchers as they work to reconstruct changes in buildings and try to understand landscape transformations (Nocerino et al., 2012). Multi-temporal image analysis is used for many different purposes such as the investigation of land cover dynamics (Ratcliffe and Henebry, 2004), detection of change in historic city centres (Patias et al., 2011), creation of 4D interactive presentations of heritage sites (El -Hakim et al., 2008), modelling of architectural changes (Stefani et al., 2011), 4D city modelling (Schindler, 2010) and urban analysis (Vizzari, 2011).

Nowadays, the photogrammetric approach for historical image processing is based on the structure-from-motion (SfM) and multiview-stereo (MVS) approach, which is a combination of photogrammetric and computer vision methods. It is a fully automated 3D reconstruction technique, which refers to the simultaneous estimation of camera orientation, self-calibration and dense point cloud generation (Moussa, 2014; Zawieska et al., 2017). However, (in many cases) the processing of historical images is generally done with semi-manual procedures, such as finding corresponding tie points, measuring ground control points, image bundle adjustment and segmentation/classification steps (Nocerino et al., 2012). During the analysis of historical aerial photos, there can be several sources of error (Redecker, 2008; Nocerino et al., 2012):

a) inaccuracy or total lack of meta -information about inner orientation (focal length and coordinates of fiducial marks) and additional (i.e., distortion) parameters;
b) missing specifications about the flight mission (especially flying height);
c) poor radiometric image quality (e.g. haze, image darkness, non-uniform luminosity, etc.);
d) distortions caused by roll and pitch due to sudden movements of the plane;
e) improper transport or storage procedures of the film (e.g. humidity, temperature, etc.) and
f) inaccurate processing of original films or hardcopies in field laboratories.

2.1 Location of Experiments

Analyses were performed for a selected part of the Wola district in Warsaw, which covers an area of 1292 ha. This area is characterised by its location close the City Centre (Śródmieście) district. It is an attractive area in relation to location and investment opportunities; however, due to the high level of degradation and the presence of neglected post-industrial and railway areas, it remains incompletely arranged. This area also requires the presence of activities which would contribute to its revitalisation.

2.1.1 The Coverage of Local Spatial Development Plans

The study of the conditions and directions of the spatial management and local plans of spatial development are the most important planning documents in Poland at the local level of planning. The local plan of spatial development is the local law right and consists of provisions concerning the area destination and distribution of public investments and specifies the ways and conditions of development. In the Wola district, 15 local development plans exist covering the total area of approximately 1,162 hectares, and local plans covering the total area of approximately 156 hectares are under development. An area of 126 hectares is not covered by the local plans (Fig. 1).

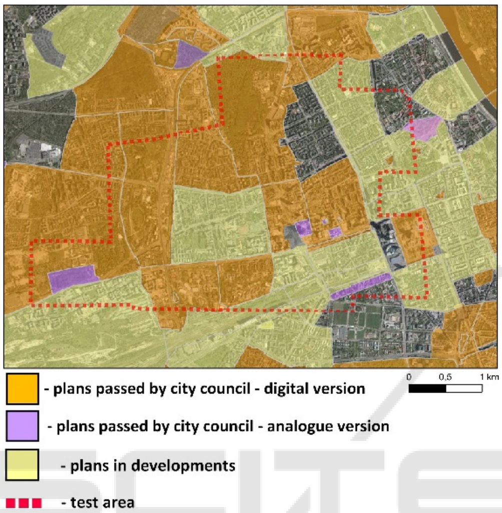

Figure 1: A map presenting the coverage of existing spatial management plans in the Wola district.

2.2 Materials and Methods of Research

Multi-source, multitemporal data were used in this study (between 1976 and 2013). The following datasets were used for experiments:

a) archival data:
- 8 photographs from 1976, scale 1:18500;
- 10 photographs from 1982, scale 1:20000;
- 7 photographs from 1987, scale 1:20000;
- 6 photographs from 1990 scale 1:20000.

b) current data:
- orthophotomap RGB from 2013, GSD 10 cm;
- classified point cloud from aerial laser scanning (2013).

Salach (2017) suggests an alternative method to processing archival photographs. In this method, in the first step, scanned photographs are pre-processed using the open source SAPC application (Fig. 2a). Pre-processing consists of transforming scanned archival photographs to a form with specificity similar to digital images, i.e. the same principal point position in each photograph and the same resolution achieved through cutting out the black photographic frame (Fig. 2b). Next, aerial triangulation of pre-processed photographs is performed using Structure from Motion software. This approach may be very useful and effective, essentially in cases with a lack of required information about the camera and exterior orientation parameters.

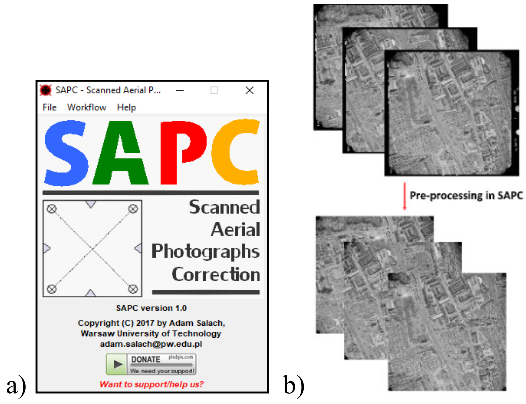

Figure 2: a) Main window of SAPC application; b) Example of pre-processing of archival photographs in the SAPC application.

Using the above methodology, archival photographs of the test area were pre-processed using the SAPC application. Aerial triangulation was then performed using Agisoft PhotoScan software. Ground control points used to orientate archival photographs were acquired from current orthophotomaps (Fig. 3). Z-coordinates were assigned to those points basing on the LiDAR point cloud.

Figure 3: Example of GCPs used to align archival photographs.

In the next step, archival orthophotomaps/true-orthophotomaps and point clouds from dense image matching were generated and processed into digital surface models (DSM). The figure below presents a fragment of the test site on the archival point cloud (1990) (Fig. 4a) and on the LiDAR point cloud (Fig. 4b):

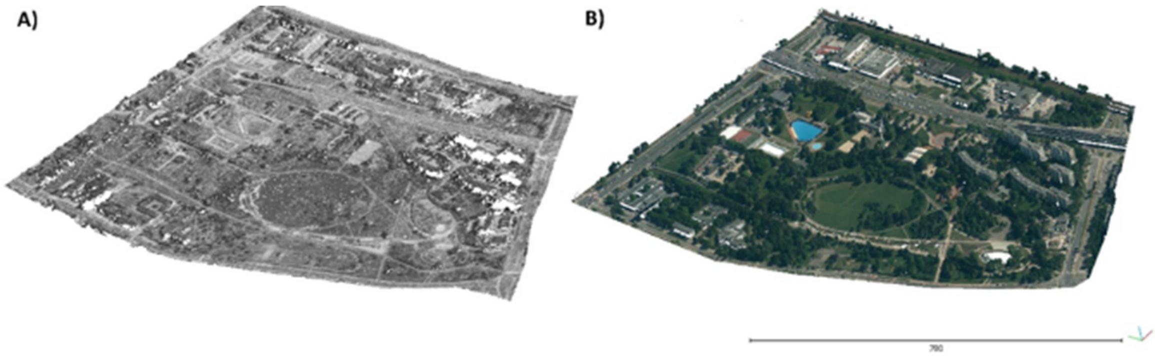

Figure 4: a) The test site on the archival point cloud (1990); b) The test site on the LiDAR point cloud.

Additionally, the DTM and DSM were generated based on the point cloud from laser scanning.

2.3 Performed Analyses

2.3.1 Analysis of Terrain Surface Changes – Buildings, Development and Vegetation Cover

Using the classified LiDAR point cloud it is possible to determine the percentage of green areas (as for 2013) divided into low, medium and high vegetation, as well as buildings located within the test site. In the first step, the LiDAR cloud was processed to the raster which represented the dominating class in the GRID of 1m resolution. Then raster was then processed into a polygon layer (Fig. 5).

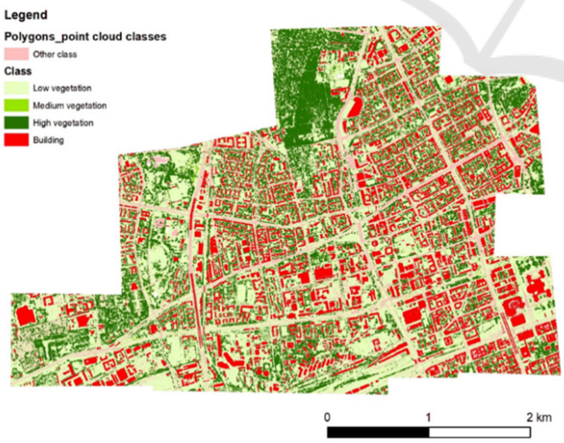

Figure 5: The test site divided into land cover classes.

After summing up the areas of polygons assigned to particular classes, it was simple to calculate the percentage of analysed classes in the test site: low vegetation – 42.54 %, medium vegetation –1.30 %, high vegetation –23.97 %, buildings –19.85 %. This data allows us to evaluate the intensity of building development, as well as to determine the percentage of biologically active sites. The data indicated an increase in development over the analysed period can be observed.

The analysis of multitemporal data allows us to investigate land cover changes. This influences the determination of the current trends of development of the analysed area and, as a result, allows us to plan changes and eliminate negative trends. For this purpose, the differential DSM was generated by subtracting the archival $DSM_{archival}$ from the current DSM_{LiDAR} (2013).

Figure 6: Raster showing constructed and highly modernised buildings within the test site in the period 1976-2013. The orthophotomap of 1982 is shown in the background.

After reclassification of the resulting differential DSM, it was possible to locate buildings which have been recently constructed within the test site (Fig. 6). Furthermore, using the differential DSM, it is possible to perform detailed analysis of changes in the development of an area. The example below (Fig. 7) shows a fragment of the test site in which several skyscrapers (with heights of 200 m) were constructed.

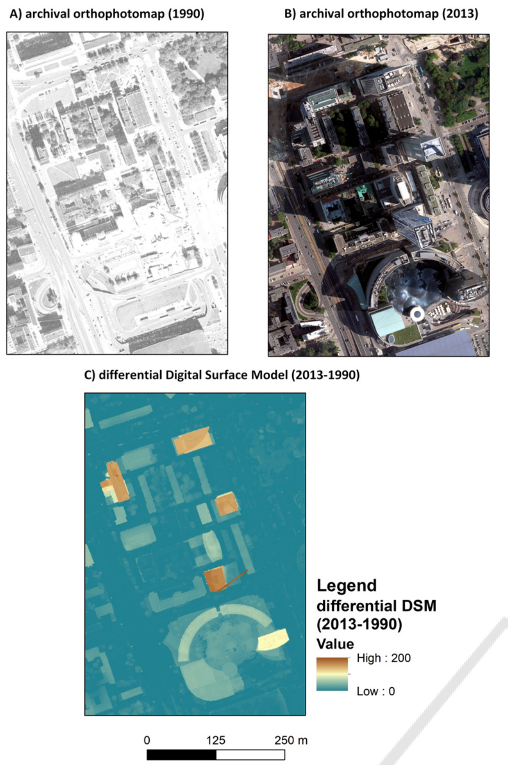

Figure 7: Fragment of the test site in which several skyscrapers were constructed.

It could be observed that within the period of 37 years, the percentage of industrial areas decreased and the percentage of housing areas or degraded (not arranged) areas increased. The differential DSMs allow us to perform specialised analyses of the city development structure and to define possible areas where chemical pollutions of subsoils may occur (Fig. 8).

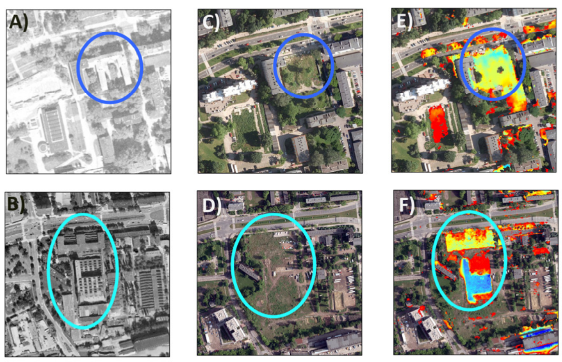

Figure 8: An example of changes in post-industrial areas towards housing development - a), b) example of an archival orthophotomap with an industrial site, c), d) current orthophotomap showing where industrial sites existed in the past, and e), f) differential DSM overlapping the current orthophotomap.

In order to analyse the vegetation growth, differential DSMs since 1990 were used (Fig. 9). The polygons below contain forest areas from the National Database of Topographic Objects BDOT10k).

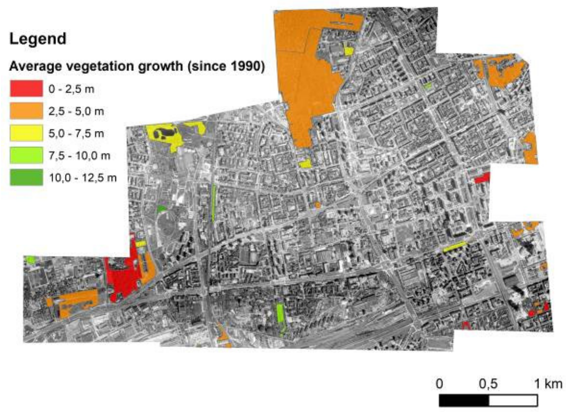

Figure 9: Visualisation of average vegetation growth (since 1990).

The analyses indicate the growth of vegetation, especially in the north and south-west side of the analysed area. New plantings can also be observed. Such analyses can assist planners in determining the area's biologically active surface.

2.3.2 Analysis of Changes of the Road Network

As a result of the performed analyses of the road network changes, the changes in the types of roadways, road beds and geometry were noticed within the analysed period. The location of the second subway line influenced the improvements of the transportation accessibility of the analysed area.

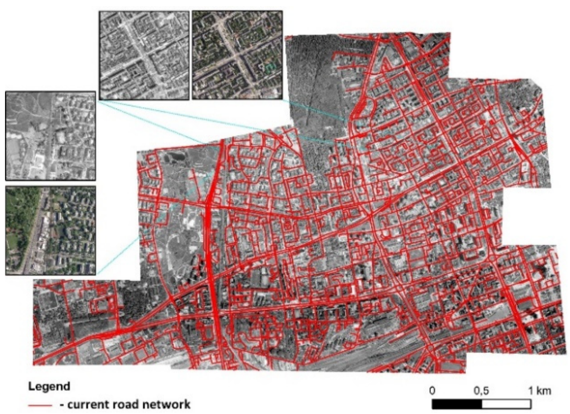

Figure 10: Roads from the land and buildings register on the background of an archival orthophotomap.

The road network has not been dramatically changed. New roads were constructed only at the edges of the area, with the majority of the remaining changes concerning the development of traffic lanes and changes to pavements. Closer to the city centre, the road network has not been changed, as illustrated in Fig. 9.

2.3.3 Analysis of the Possibility to Locate New Buildings - Visibility Analysis

In the case of areas located close to the city centre, it is particularly important to perform visibility analysis. This type of analysis can identify the locations of new buildings in such a way that new objects are sufficiently illuminated and not obscured by other buildings. According to the ordnance of the Minister of Infrastructure of April 12, 2002 regarding technical conditions which should be met by buildings and their locations, "the distance between a building with rooms dedicated for the permanent stay of people and another object should allow for natural illumination of those rooms" (Art.13.1.). This condition is met if between the arms of the angle of 60 degrees, any obscuring part of the same building or another obscuring object is located within a distance not shorter than the height of obscuring - for obscuring objects of a height up to 35 m and 35 m for obscuring objects higher than 35 m.

In the first stage, places where buildings were demolished in specified areas may be detected using multisource data. These indicated areas can be the locations of new investments. The raster in Fig. 11a indicates areas in which a building was demolished during the time period 1990-2013. It was created by reclassifying differential DSM. With regard to the accuracy of the generated archival model, it was assumed that only values > 5m of differential DSM correspond to real land cover changes.

In the next step, visibility analysis may be performed for places in which new buildings are to be constructed based on DSM created from LiDAR point cloud (Fig 11b).

2.3.4 Analysis of Types and Conditions of Development

The conditions of the existing development were analysed for the selected test site. Using multisource data, i.e. true-orthophotomaps/orthophotomaps and aerial laser scanning, the heights of buildings and standards of development may be differentiated.

The analysis indicates that degraded, post-industrial objects exist in fragments of the test site and modern, exclusive housing districts have arisen beside them (Fig. 12).

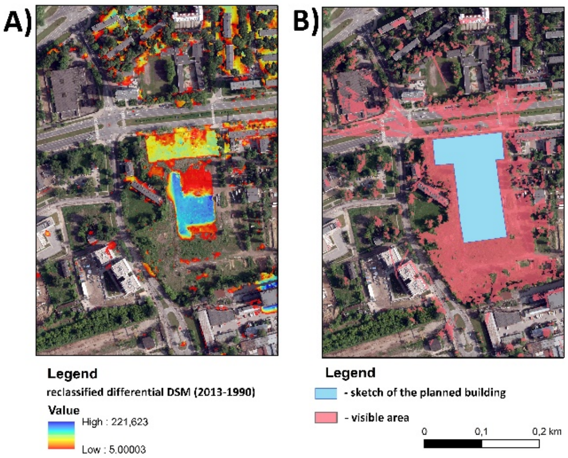

Figure 11: a) Reclassified differential DSM (2013-1990) and b) Visibility map for the planned building.

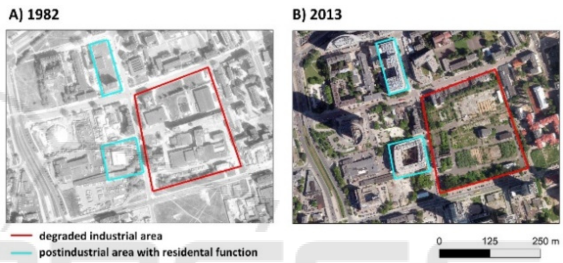

Figure 12: An example of degraded, post-industrial areas and newly constructed apartment houses. The degraded industrial area is marked in red while the post-industrial area with residential functions is marked in blue.

2.3.5 Identification of Soil Pollution

Polish legislation has undergone considerable modifications due to the necessity of adapting it to EU requirements. Among other things, these modifications have concerned issues related to the pollution of post-industrial areas. An important step in this field was the publication of the Ordnance of the Minister of the Environment of September 1, 2016 on the register of historical pollution of the Earth's surface (Dz.U. 2016 item 1397), which, among other things, obligates that maps of historically polluted areas are produced.

Based on the geo-chemical atlas of Warsaw, places of increased intensity of harmful substances in soils were identified (the surface layer of soils, 0.0 – 0.3 m) (Fig. 13).

Soils with alkaline pH dominate within the area. In the south-western part of the district, in previous railway areas, close to the concentration of objects of industrial functions, the increased concentration of arsenic, barium, chromium, copper and mineral oils, and in the central part of the district, the concentration of polycyclic aromatic hydrocarbons (PAH), zinc and mercury was identified.

Due to the lack of commonly accessible information concerning locations of post-industrial areas and possible, developers sometimes locate housing or trade-and-service investments in attractive areas where industrial plants existed in the past. Such areas are not always analysed with respect to the intensity of concentration of harmful substances and, as a result, they are not the subject of re-cultivation. Inhabitants, afraid of their health, and willing to act against such conditions, create maps of pollutions of their own. Such a map was created in the Wola district when problems concerning several investments occurred (among others, in Skierniewicka Street and Obozowa Street). Inhabitants of this district developed a map of locations of where industrial plants were located in the past. Despite the lack of professional aid in the cartographic development of that map, as well as serious methodological failures, that map should be considered as a valuable example of social activity in the field of ecological knowledge and the analysis of hazards for human health, which are important in the process of revitalisation.

The analysis of the changes in development performed based on multitemporal data in the context of the location of industrial plants may support the development of such maps, in particular, in the field of identification of lands polluted in the past (Fig. 14).

3 DISCUSSION AND CONCLUSIONS

In many cases, archival photographs may be the best source of historical information about urban areas.

A block of scanned aerial photographs can be easily processed into geo-referenced products such as orthomosaics, point clouds or digital surface models.

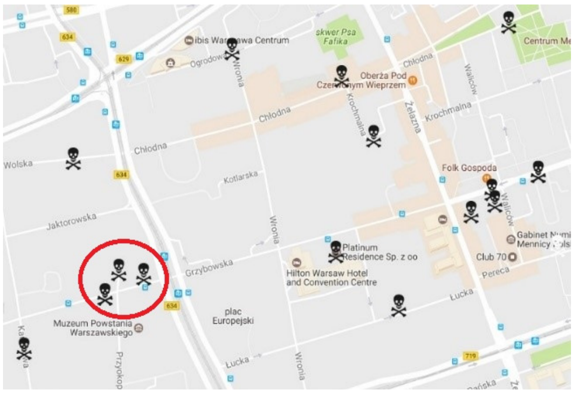

Figure 13: Map of possible areas of historical pollution of soils. The indicated area is analysed in the next figure.

These archival products are valuable resources for planning activities including landscape and land use analysis or assessment of environmental impacts.

An important advantage of using photogrammetric data in combination with GIS processing for spatial planning purposes is the possibility of achieving readable visualizations of spatial phenomena and changes which occur in specified areas. DSM indicates the height of individual projects that can be directly used for height analysis. Multitemporal photogrammetric documentation allows us to comprehensively evaluate the tested area in terms of future development and corrections of existing spatial development plans.

The accuracy of 3D reconstruction from archival photogrammetric data is limited by the quality of the scanned photographs available. Using Structure from Motion software to processing this kind of data is connected to the high unpredictability of the obtained results. Therefore, the results of spatial analysis with the use of archival geo-referenced DSM models or ortophotomaps should be always verified by a spatial planner.

Figure 14: An example of fragments of archival (A, B) and current (C) orthophotomaps in which industrial objects were located and where the analysis of the increased intensity of harmful substances may be performed.

This paper presents the possibilities of the integration of photogrammetric data for the needs of spatial management, in particular for the needs of supporting revitalisation processes. Applying the appropriate data orientation and its recording in the database makes is possible to visualise and to perform spatial analysis with consideration of the third dimension. The use of high resolution photogrammetric data and the functionality of Geographic Information Systems (GIS) may simplify the effective management of urban spaces. The spatial analyses performed, based on, among others, photogrammetric data, are undoubtedly useful tool for forecasting and optimisation.

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