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Agnieszka Bieda[1], Jarosław Bydłosz[2], Piotr Parzych[3],
Katarína Pukanská[4], Ewelina Wójciak[5]

3D Technologies as the Future of Spatial Planning: the Example of Krakow[6]

Abstract: The main goal of the paper is to make a general assessment of the application of 3D technologies in spatial planning. It was performed with the city of Krakow as the case study. The paper describes the outline of the spatial planning system in Poland and the planning conditions of Krakow. The data obtained from laser scanning for Krakow are also briefly characterized. The possibility of using these data for locating high-rise buildings in terms of the protection of Krakow's panorama and within two programs "IT system of the Country's Protection Against Extreme Hazards" (ISOK) and "Integrated spatial data monitoring system for air quality improvement in Krakow" (MONIT-AIR) were analyzed in the paper. The main result of the research is the assessment of what studies or measurements may be used to meet particular spatial planning needs or requirements.

Keywords: spatial planning, urban planning, 3D modelling, Krakow, Airborne Laser Scanning (ALS), Light Detection and Ranging (LiDAR)

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[1] AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Geomatics, Krakow, Poland, email: agnieszka.bieda@agh.edu.pl
ORCID ID: https://orcid.org/0000-0002-9725-5960

[2] AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Geomatics, Krakow, Poland, email: jaroslaw.bydlosz@agh.edu.pl
ORCID ID: https://orcid.org/0000-0002-0350-8112

[3] AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Geomatics, Krakow, Poland, email: piotr.parzych@agh.edu.pl
ORCID ID: https://orcid.org/0000-0002-4182-1978

[4] Institute of Geodesy, Cartography and GIS, Faculty of Mining, Process Control and Geotechnologies, Technical University of Košice, Košice, Slovakia, email: katarina.pukanska@tuke.sk
ORCID ID: http://orcid.org/0000-0002-7332-7691

[5] ESW Wycena Nieruchomości, Krakow, Poland, email: biuro@esw24.pl

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1. Introduction

Spatial planning concerns how people shape and manage space [1]. It differs from urban planning and architectural design as its final effect are maps (local development plans) [2], the creation of which requires the consideration of social, economic and environmental issues.

Envisaging our future is a collective responsibility of communities, planners and decision-makers, therefore visualization techniques are increasingly becoming an important tool applied in spatial planning [3]. Planning analyses are more comprehensive if they can be done in three-dimensional space [4].

The paper [5] describes 29 different possibilities of using 3D modelling that include urban design. However, the spatial planning where areas with specific designation are arranged, instead of locating construction objects in space, is missing.

While the creation of 3D models of whole cities or their fragments is acceptable in urban design [6–19], the authors ask whether conducting analyses in three-dimensional space for the purpose of spatial planning is reasonable as well. According to the authors, conducting 3D analyses could facilitate the creation of planning studies in three-dimensional space. This view is consistent with the already published proposal to include spatial planning objects in the 3D cadastre [20].

As part of the research, an analysis of selected elements of the Polish spatial planning system was carried out. The study focused on the provisions related to the conditions taken into account when destined land for specific purposes and establishing the principles of its development and build-up. Attempts were made to link the 3D analyses carried out for the city of Krakow (Poland) which were possible to perform with them on the basis of data obtained from Airborne Laser Scanning (ALS).

2. Polish Spatial Planning System

As indicated in [21–28], planning procedures in European Union countries have significant similarities. Therefore, this paper focuses only on the Polish spatial planning system.

Spatial planning processes are hierarchical in Poland and are conducted within three levels of detail:

1) national,
2) regional,
3) local (municipal) [29, 30].

Appropriate planning documents are prepared at all levels. The characteristics of the most important ones are presented in Table 1.

Table 1. Characteristics of planning documents prepared in Poland

Level	Planning document	Description
Country	The concept of spatial development of the country	Approved by the Council of Ministers regulation. It defines the conditions, objectives and directions of country sustainable development and the actions necessary to achieve it
	Programs aimed at the realization of a public purpose development of national importance	Prepared by ministers and central government administration authorities, within the scope of their material competence. They take into account the same objectives and directions as the concept of spatial development of the country. Adopted by the Regulation of the Council of Ministers
Region	Spatial development plan of the region	Enacted by the regional council, taking into account the arrangements of the spatial development concept of the country
Municipality	Study of conditions and directions of spatial development	Resolution of the commune council, which is created in order to define the commune's spatial policy, including local spatial development principles. It is prepared for the area of the whole commune. It is not a document of local law. Its provisions are binding when creating a local spatial development plan
	Local spatial development plan	Resolution of the Commune Council drawn up in order to determine the designation of land, including the public purpose development, and to determine the methods of its development and build-up. It does not have to cover the whole commune. It is an act of local law. Administrative decisions are issued on its basis
	Decision on built-up conditions and spatial development	In the absence of a local development plan, a change in land use consisting in the construction of a building or the carrying out of other construction works, as well as a change in the use of the building or its part requires a decision on the terms and conditions of development. Such a decision is made by the head of the commune, mayor or president of the city at the request of the interested party. A public purpose development is located at the developer's request, basing on the decision on its location. Depending on the importance of the development, a public administration body at the commune or region level may be involved

Source: own study based on [31]

The creation of any such document must be preceded by detailed analyses. According to the Act [31], spatial planning and development in Poland in particular takes into account:

- requirements of spatial arrangement, including urban planning and architecture;
- architectural and landscape assets;

- environmental protection requirements, including water management and protection of agricultural and forest land;
- requirements for the protection of cultural heritage and monuments and contemporary cultural assets;
- requirements for the protection of health and safety of people and property, as well as the needs of the disabled;
- economic qualities of the space;
- the right of ownership;
- the needs of state defense and security;
- the need for public interest;
- needs for the development of technical infrastructure, in particular broadband networks;
- ensuring public participation in works on the study of conditions and directions of spatial development of the commune, the local spatial development plan and the regional spatial development plan, including through the use of electronic forms of communication;
- maintaining openness and transparency of planning procedures;
- the need to ensure adequate quantity and quality of water for the purposes of supplying the population.

3. Spatial Planning in Krakow

Krakow is located in southern Poland, in the central-western part of the Małopolskie Province, on the Vistula River (Fig. 1). The city is located in a valley, at the confluence of several geographical regions, in close proximity to the Tatra Mountains – the highest range in the Carpathian chain. It is the second largest city in Poland in terms of area (327 km^2) and population (769,498). The population density in Krakow is diversified and amounts to an average of 2,348 inhabitants per square kilometre [32].

Fig. 1. Krakow localisation

The extent of the city from south to north is 18 km, and from west to east – 31 km. The highest point in the city is Józef Piłsudski's Mound, 383 m above sea level. The lowest point in Krakow is the estuary of the Kościelnicki Creek (187 m above sea level).

Due to the fact that Krakow was the city for the coronation of Polish kings and became their necropolis, and also that there are many cultural institutions of national importance and the oldest university in Poland (the Jagiellonian University, founded in 1364), the city attracts crowds of students, tourists and investors. As a result, and to improve the quality of life of city inhabitants, the Krakow authorities are constantly working on new planning documents. The aim is to contribute to the continuous sustainable development of the city.

Among the 16 capitals of Polish regions, at the end of 2017, Krakow was ranked 6th in terms of the percentage of the area covered by the current local spatial development plans (Fig. 2).

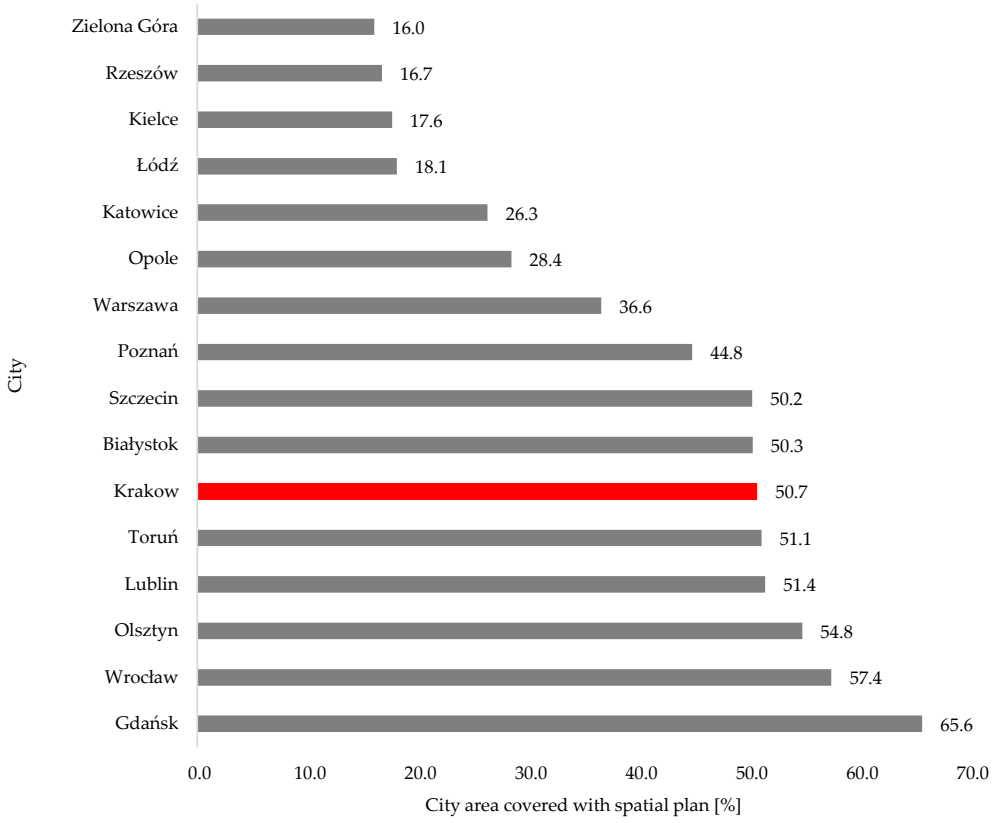

Fig. 2. Area of provincial capitals covered by local spatial development plans – as at 31.12.2017
Source: own study based on [33]

What is important, the area covered by local spatial development plans is constantly increasing (Fig. 3). Nevertheless, many development works in Krakow are still being carried out on the basis of administrative decisions on built-up conditions and spatial development.

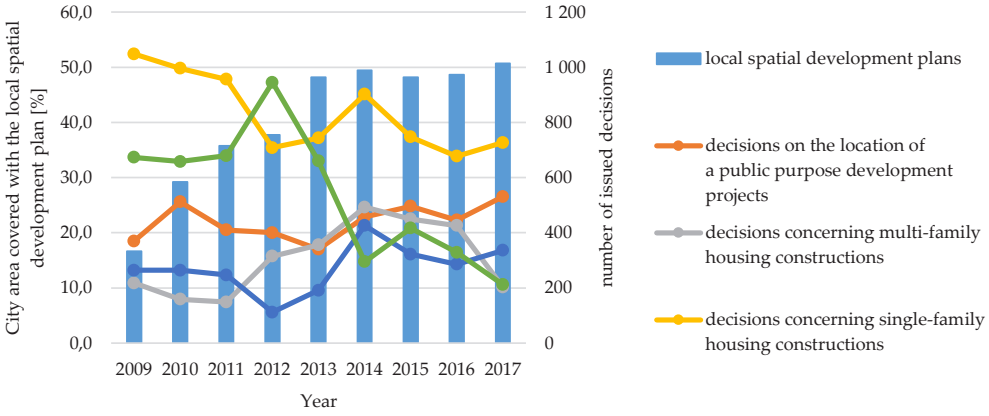

Fig. 3. Area of Krakow covered by local spatial development plans and number of issued decisions on built-up conditions and spatial development in the years 2009–2017

Source: own study based on [33]

As of 15 November 2018, 184 local spatial development plans in Krakow are in force, which cover slightly more than 60% of the city's area. The next 2 plans are awaiting their entry into force and 53 are in the process of preparation (Fig. 4).

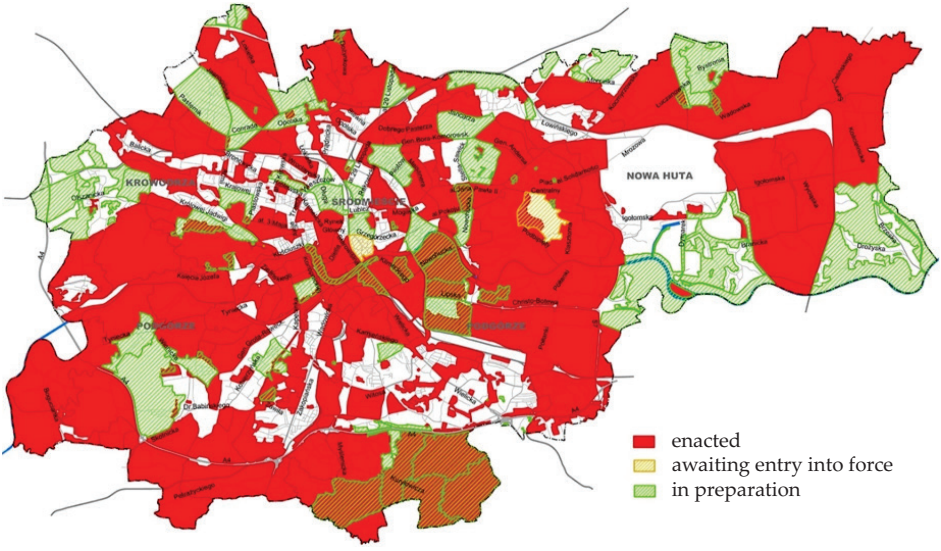

Fig. 4. Local spatial development plans in Krakow – as of 15.11.2018

Source: [34]

These documents are intended not only to create a new development, but primarily to organize the already existing ones with the simultaneous activation of development processes. The introduction of clear regulations coordinating and ordering the existing development is aimed at avoiding the kind of chaos that could lower the historical value of Krakow space [35].

4. Laser Scanning Data

The analyses described above were performed on the basis of data obtained through airborne laser scanning, which took place twice (Tab. 2).

Table 2. Airborne laser scanning of Krakow

Year	Flight altitude [m]	Point cloud density [point/m^2]	Measurement system
2006	350	min. 12*	FLI-MAP 400 (helicopter mounted)
2012	880	12	LMS-Q680i RIEGL laser scanner with GPS/INS: AeroControl and Hasselblad50 aerial camera (mounted on Cessna T206H aircraft)

* There are regions with a density of 16–20 points/m^2 in the study area.

Source: own study based on [36, 37]

The aerial measurements that took place in 2006 were ordered by the Krakow City Authority [36]. On the other hand, the measurements from 2012 were taken as part of a nationwide project aimed at creating an IT system for the Country's Protection Against Extreme Hazards (Polish acronym ISOK) [38].

On the basis of the measured points, it is possible to make a digital terrain model with a very realistic appearance, where even very small details can be easily observed (Fig. 5).

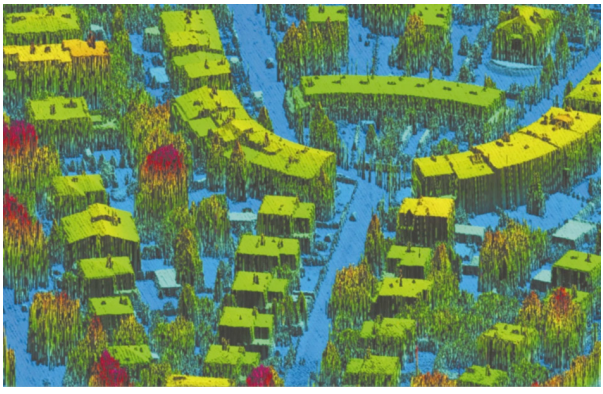

Fig. 5. A fragment of a numerical housing model of an urban complex represented by an irregular grid of triangles made on the basis of data from 2006

Source: [36]

On the basis of data obtained in 2006, the Spatial Planning Bureau of the City of Krakow performed an analysis in the year 2009 concerning the possibility of locating high-rise buildings in the aspect of city panorama protection [39].

The data obtained as a result of the aerial measurements from 2012 were used to prepare flood hazard maps and flood risk maps as part of the Information System for Protection against Exceptional Hazards (ISOK) [38], as well as to carry out analyses as part of the project "Integrated monitoring system of spatial data to improve air quality in Krakow" (MONIT-AIR), which started in 2014 [40].

5. Discussion

The result of the research on the source materials is a description of the analyses which were carried out in three-dimensional space, within the framework of the projects mentioned above. The authors believe that each of them could be used to a significant extent in the creation of planning documents at the local level.

Possibility of Locating High-Rise Buildings in Terms of the Protection of the Panorama of the City of Krakow

The aim of the analysis was to examine the possibility of locating high-rise buildings, i.e. buildings with a height of more than 55 m, in the area of Krakow. Its main assumption was to protect the panorama of the city (Fig. 6).

Fig. 6. Protected panorama of Krakow – view from Tadeusz Kościuszko Mound
Source: [39]

The protected area was defined by designating dominant objects which form the most characteristic fragment of the historical silhouette of the city (Fig. 7b). The visibility analysis was carried out from four main viewpoints (Fig. 7a). The selection

of specific viewpoints was determined by their cultural significance, frequency of attendance and the quality of exposure to the most valuable panoramas of Krakow (in particular to the Old Town, Wawel Royal Castle and Jewish Quarter Kazimierz, which were entered on the UNESCO World Heritage List).

a) b)

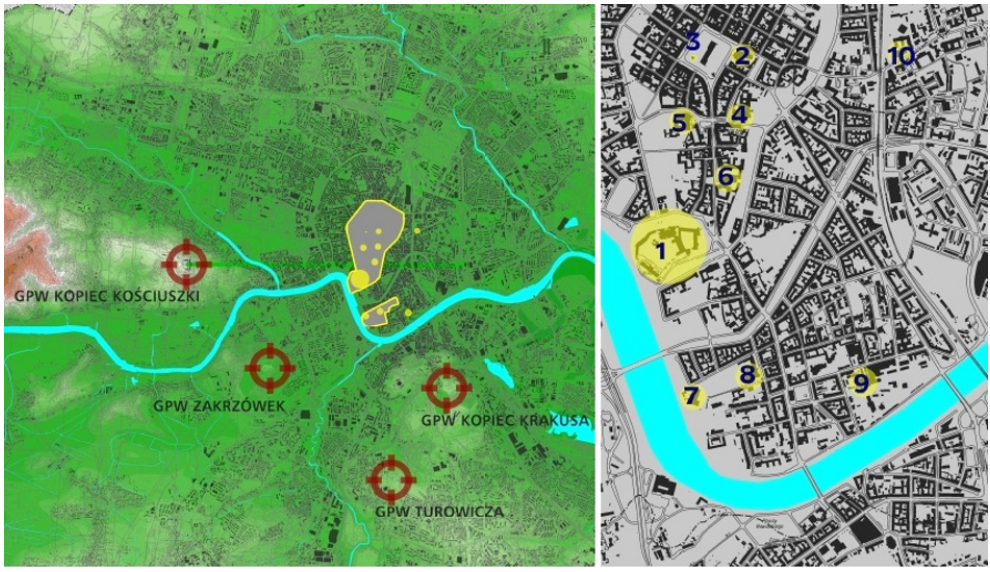

Fig. 7. Main viewpoints (a) and protected dominant features of Krakow silhouette (b): 1 – Wawel, 2 – St. Mary's Church, 3 – Town Hall Tower, 4 – Dominican Church, 5 – Franciscan Church, 6 – St. Peter's and Paul's Church, 7 – Church on the Rock, 8 – St. Catherine's Church, 9 – Corpus Christi Church, 10 – Jesuits Church

Source: [39]

The aim of the study required a method which, in an objective manner, within the boundaries of the whole city, would make it possible to define areas protected against high-rise build-up and those in which the locations of high buildings can be considered. The searches were carried out through subsequent analyses:

- the visibility fields from the main viewpoints (Fig. 8a),
- relative heights in the shadow zone of the protected silhouette (Fig. 8b),
- visibility of the foreground and background of the protected silhouette (Fig. 8c).

The last stage of the works was carried out in two-dimensional space. On the basis of the map of visibility of the foreground and the protected background, which was made using 3D analyses, after taking into account additional cultural and natural conditions, the areas where high objects can be created were determined (Fig. 8d). In order for this to happen, these areas should be designated for high-rise development in the relevant planning documents.

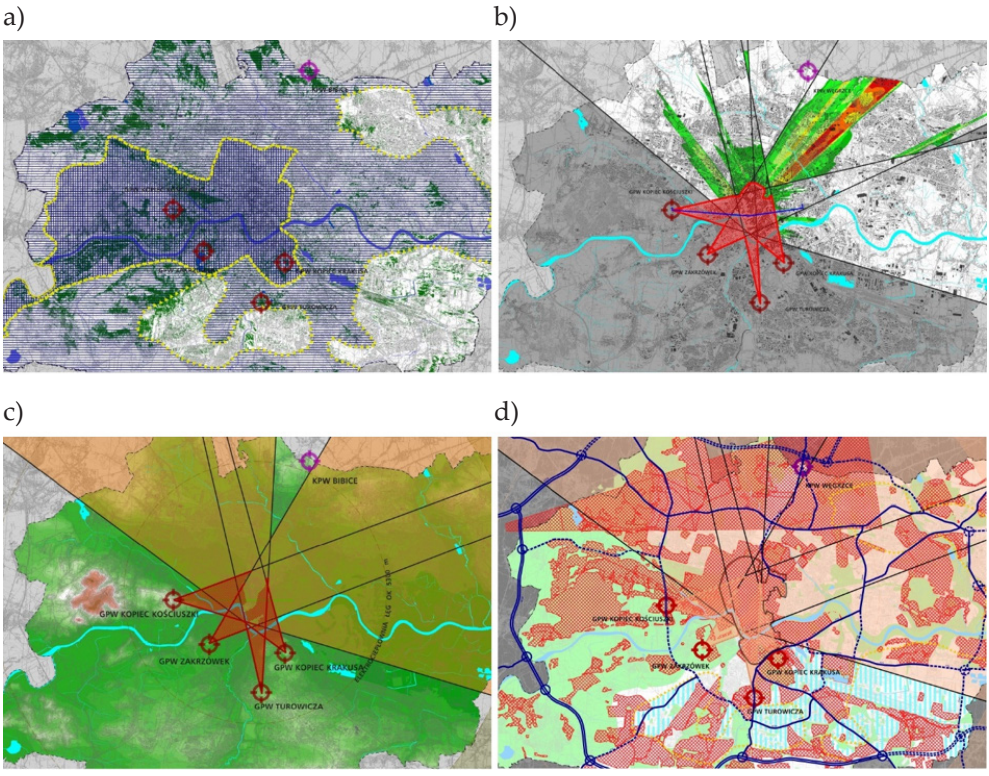

Fig. 8. Fragments of maps created to protect the Krakow silhouette: visibility of the area from the main viewpoints (a); areas visible from the main viewpoints where high objects will remain in the shadow of the protected panorama of the city (b); areas of visibility from the main viewpoints on the protected panorama of the city (c); areas where high objects can be created – marked with a light blue hatching (d)

Source: [39]

IT system of the Country's Protection against Extreme Harazds (ISOK)

As part of the research program, the Institute of Meteorology and Water Management of the Polish Research Institute, basing on a digital terrain model, created flood hazard maps and flood risk maps.

Flood hazard maps show areas with a certain probability of flooding, such as:

- areas where the probability of flooding is low – once per 500 years (*Q* 0.2%),
- areas where the probability of flooding is medium – once per 100 years (*Q* 1%),
- areas where the probability of flooding is high – once per 10 years (*Q* 10%),
- areas exposed to flooding in the event of damage or destruction of a dike (Fig. 9).

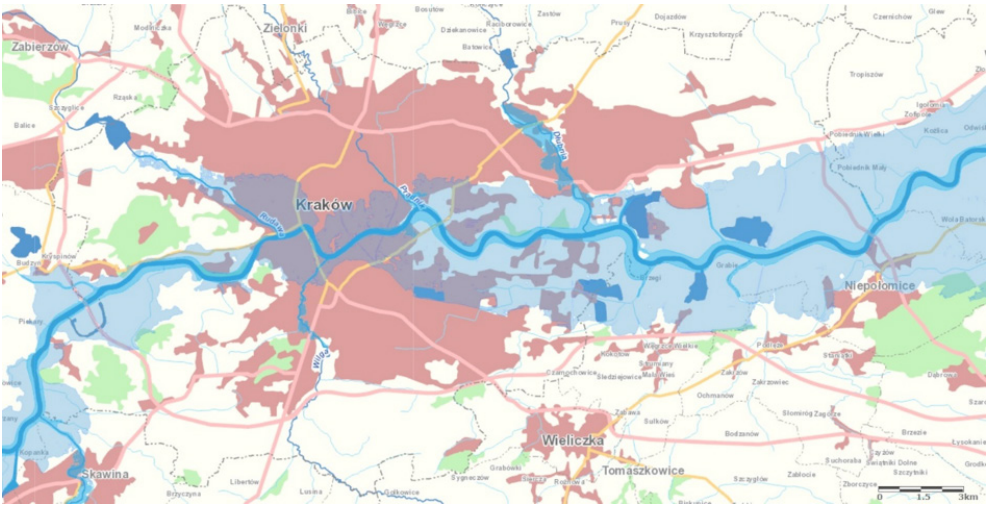

Fig. 9. The area of Krakow exposed to flooding in case of complete destruction of the dike

Source: [41]

Flood risk maps complement flood hazard maps. They no longer require 3D technology, which was necessary during the delimitation of floodplains.

These maps identify the values of potential flood losses and shall show the objects exposed to flooding with a certain probability of occurrence. They allow the assessment of flood risks to human health and life, the environment, cultural heritage and economic activity.

For this purpose, additional elements have been added to the areas presented in the flood risk maps:

- the estimated population living in the hazardous area;
- residential buildings and facilities of particular social importance (i.e. hospitals, schools, kindergartens, hotels, shopping centers and others) for which the floodwater depth is at least 2 meters;
- historic areas and objects;
- protected areas such as water intakes, water intake protection zones, bathing areas, nature protection areas;
- potential water pollution outbreaks in case of floods, such as industrial plants, sewage treatment plants, sewage pumping stations, landfills, cemeteries;
- the value of potential losses for individual land-use classes, such as residential areas, industrial areas, traffic areas, forests, recreational areas, agricultural land, water.

Examples of flood hazard maps and flood risk maps for the Krakow area, where the probability of flooding is once every 500 years, are presented in Figure 10.

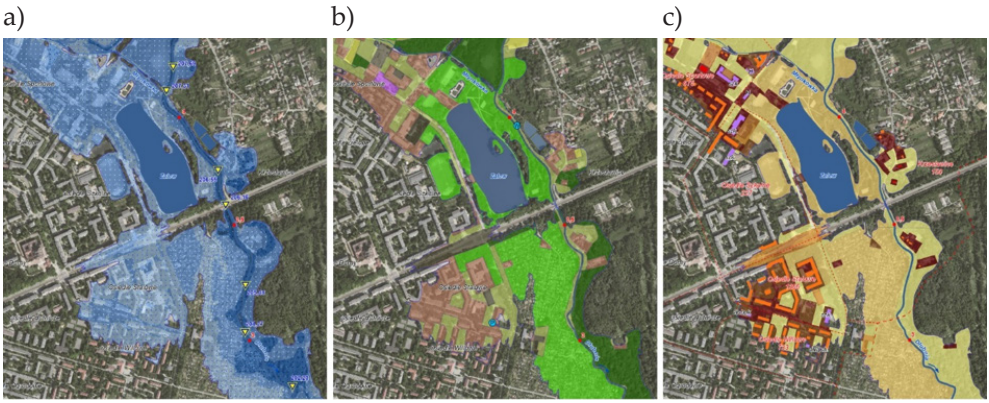

Fig. 10. Fragments of maps for the area where floods are likely to occur every 500 years: flood hazard map (a), flood risk map including negative consequences for the environment, cultural heritage and economic activity (b) and for the population including losses (c)
Source: [41]

As a result of the analyses carried out, areas were identified which, as a result of planning works, should be excluded from development, or where such development should be limited due to the danger to people and their property.

Integrated Spatial Data Monitoring System for Air Quality Improvement in Krakow (MONIT-AIR)

The MONIT-AIR project consists of 8 separate but interdependent and complementary activities. The first one concerns the assessment of ventilation conditions in Krakow with the use of an advanced modelling system [40]. The most important results of this activity include: results of wind field modelling, as well as a map of greenery and ventilation conditions in Krakow (Fig. 11a) and a map of land cover and area roughness (Fig. 11b).

Maps based on 3D analysis contain information about the average wind speed of 10 m above ground level, conditions for locating gardens and photovoltaic cells on roofs, and aerodynamic roughness of the terrain. The obtained results may be helpful in determining the areas excluded from development in order to create air corridors for city ventilation or to identify areas beneficial for locating wind or solar power installations.

Evaluation of the Possibility of Using the Existing 3D Analyses for Kraków in Spatial Planning

Table 3 lists the statutorily required conditions of spatial planning [31], which according to the authors, may be taken into account in the new planning documents on the basis of the existing 3D analyses for Krakow. The table includes only those conditions for which at least one described study can be used.

a) b)

Fig. 11. Fragments of maps made in the MONIT-AIR project: a map of greenery and ventilation conditions in Krakow (a) and a map of land cover and area roughness (b)
Source: [40]

Table 3. 3D analyses possible for application in spatial planning

Condition	Panorama protection	ISOK	MONIT-AIR
Architectural and landscape values	+		
Environmental protection requirements		+	+
Requirements for the cultural heritage protection	+	+	
Requirements for the health protection and persons and property safety		+	
Economic qualities of space	+	+	+
National defence and security needs			+
Public interest needs		+	

The analysis concerning the possibility of locating high-rise buildings in Krakow is of course closely connected with the protection of cultural heritage and architectural and landscape assets. Its main objective was to protect the characteristic silhouette of the historical part of the city against covering or introducing any unfavorable dominant feature into it (or in its background). It made it possible to identify areas in which high buildings cannot be allowed. Importantly, defining an area as intended for high-rise development may have a significant impact on its value [42].

Analyses within the framework of the program creating the National IT system of the Country's Protection Against Extreme Hazards (ISOK) have led to the identification of floodplains, which should be excluded from the possibility of development in order to protect life and health and the safety of people and property. Such provisions have a direct impact on the value of properties which are exposed to flooding [43]. Indirectly, these analyses also indicate conditions related to environmental (mainly protection of water intakes) and cultural heritage protection. On the basis of this analysis, the public interest needs resulting from the necessity to repair or expand facilities related to flood protection are also met.

Analyses made during the implementation of the project concerning the integrated spatial data monitoring system for improving air quality in Krakow (MONIT-AIR) take into account, first of all, the requirements of environmental protection. However, it is also possible to identify the best locations for renewable energy installations, based on wind or sun for example. Of course, their use is connected with the state's energy security [44]. It also has an impact on the economic assets of the space it concerns.

6. Conclusions

Although it is easier to imagine the use of 3D technology in urban planning and architectural design, it is clear that not all analyses prior to assigning land for specific purposes and establishing the principles of land use and development must be carried out in three-dimensional space (Tab. 3). However, it cannot be overlooked that 3D modelling makes it much easier to carry out studies and that 3D visualization can be useful to ensure public participation in the creation of planning documents. Also important is that the conditions of spatial planning with the use of 3D technology can be taken into account much more precisely. Nevertheless, such practices are still rarely used, and it is difficult to find references to them in the literature.

As early as 2009, the Spatial Planning Bureau of the City of Krakow made 3D analyses which were used to determine the location of areas for high-rise development. The areas for which restrictions on development should be introduced in order to protect the characteristic panorama of the city were also determined, there. These analyses can be considered as the first studies dedicated to spatial planning conducted for Krakow in three-dimensional space.

As it has been noted when analyzing the results of work under the projects related to the creation of the IT system of the Country's Protection Against Extreme Hazards (ISOK) and the Integrated Spatial Data Monitoring System for the Improvement of Air Quality in Krakow (MONIT-AIR), spatial planning may also use studies which will identify areas that should be excluded from development due to the fact that they are at risk of flooding and because they are included in the system of air

corridors for ventilation of the city. Similar analyses can be used to identify areas at risk of flooding during the location of hydroelectric power plants and flood protection dams, as well as to identify areas suitable for the location of wind farms.

In addition, three-dimensional analyses carried out for Krakow allowed to determine the buildings whose roofs can be used for the installation of photovoltaic installations on them. Similar maps made for non-urbanized areas, in turn, may allow sunlight to be included in the location of areas intended for agricultural production.

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Technologie 3D przyszłością planowania przestrzennego: przykład Krakowa

Streszczenie: Głównym celem artykułu jest ogólna ocena zastosowania technologii 3D w planowaniu przestrzennym. Została ona przeprowadzona na przykładzie miasta Krakowa. W artykule opisano zarys systemu planowania przestrzennego w Polsce oraz uwarunkowania planistyczne Krakowa. Krótko scharakteryzowano również dane uzyskane ze skaningu laserowego dla Krakowa. W pracy przeanalizowano możliwość wykorzystania tych danych do lokalizacji budynków wysokich w zakresie ochrony panoramy Krakowa oraz w ramach dwóch programów – „Informatyczny System Osłony Kraju przed nadzwyczajnymi zagrożeniami" (ISOK) i „Zintegrowany system monitorowania danych

przestrzennych dla poprawy jakości powietrza w Krakowie" (MONIT-AIR). W wyniku przeprowadzonych analiz określono, jakie badania lub pomiary mogą być wykorzystane do zaspokojenia konkretnych potrzeb lub wymagań planowania przestrzennego.

Słowa kluczowe: planowanie przestrzenne, planowanie urbanistyczne, modelowanie 3D, Kraków, lotniczy skaning laserowy (ALS), skaning laserowy 3D (LiDAR)