The City of Poznań – Photogrammetry – from cadastre to digital twin

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Key words: photogrammetry, cadastre, digital twin, GIS, open data, CityGML, smart city

SUMMARY

The City of Poznań, located in central Poland with the city population of over 500,000 citizens, is also a strong industrial and new technologies' center.

The Geodesy and Urban Cadastre Management Board GEOPOZ (ZGiKM GEOPOZ) in Poznań is one of the local government organizational units in charge of the cadastre and the Geographical Information System in Poznań. For almost 30 years now it has been gathering and applying spatial data in support of Poznań and its citizens.

The spatial data, obtained mainly through the photogrammetry, facilitate managing the urban fabric of Poznań. For that purpose, modern photogrammetric stations in the process of stereodigitalization of aerial photographs provide standardized data to supply the city cadastre, the geographical information system and the 3D model – a 'digital twin' of the City of Poznań.

The 3D model of Poznań, as a part of Poznań Geographical Information System, employs data collected from ALS (Airborne Laser Scanning), DTM (Digital Terrain Model), DSM (Digital Sufrace Model), true ortho and TLS (Terrestrial Laser Scanning) data obtained by ZGiKM GEOPOZ. The digital twin bult on the basis of these data, is fundamental to make urban space decisions and to present their results to citizens. These data, published through the GIS portal are available to download to any interested party, in the open data form. Open data published as a part of Poznań Geographical Information System , fit the smart city idea and promote data application by administration, institutions and citizens.

The forthcoming climate change and the need to prepare the city to meet its new challenges as well as a concern to secure the sustainable growth, require collecting the new data sorts and conducting analysis in the area of a broader natural environment. Among the data, those related to urban greenery and its environment are of special importance. In this respect remote –sensing analysis based on the photogrammetric information provide an excellent solution, making photogrammetry an integral part of a modern and smart city.

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1. The City of Poznań – smart city concept – digital twin

Poznań is a city located in central Poland and is the capital of Wielkopolskie Voivodeship (Greater Poland Voivodeship). Its history dates back to the 10th century, and it was granted town rights in 1253. From the very beginning of the Polish state it has been an important centre of education, culture and political life. These days it is a thriving centre of science, industry and new technologies, with a population of over 500,000.

The history of Poznań has developed in its citizens a strong sense of self–governance and related thriftiness. The Geodesy and Urban Cadastre Management Board GEOPOZ (ZGiKM GEOPOZ) is a local government budgetary unit reporting directly to the Mayor of Poznań. Since more than 30 years, it has been performing tasks associated with land management and geodetic service in a comprehensive manner, and since 2003 it has been carrying out activities in the field of Spatial Information System. In 2018, ZGiKM GEOPOZ launched e–services in the form of web portals. They serve a wide range of clients including real estate professionals such as surveyors, appraisers, bailiffs or designers, as well as representatives of institutions responsible for managing the city's technical infrastructure, which was especially significant during the COVID–19 pandemic. It is a unit that integrates the tasks of real estate management, geodetic resource management and SIP (Spatial Information System) within the smart city concept.

The outcome of these tasks is a digital twin of the city of Poznań, functioning as part of a Spatial Information System. In 2018, an innovative 3D model was developed that enables interested city services and citizens to visualise, view and carry out analysis via a web browser. In addition, it is feasible to download data functioning within the "digital twin" using "open data" in many popular data formats, including but not limited to CityGML. An important aspect that was given special attention during the project is the feasibility of updating the model, which is crucial in a fast–paced metropolis. This tool represents a milestone in the functioning of a modern city like Poznań.

2. Photogrammetry – history and present

An important aspect of any information system is to hold up–to–date data. This is especially relevant for spatial data. For a city the size of Poznań, gathering information about the dynamically changing space through direct geodetic surveys is time–consuming and economically unviable. The solution to these demands is photogrammetry. Data gathered by photogrammetric techniques and Airborne Laser Scanning (ALS) are consistent and objective for the entire area. They enable detailed spatial analyses to be carried out and, in addition, the time taken to collect the data is relatively short. In Poznań, the merits of the use

of photogrammetry were identified already in the 90s of the 20th century, when in ZGiKM GEOPOZ in the Department of Photogrammetry, works on the creation of the City Map of Poznań were initiated. It was launched in 1997 in vector form and was updated in biennial cycles through the use of photogrammetric techniques. The oldest aerial photographs in the possession of ZGiKM GEOPOZ were taken in 1989 in analogue form. The first fully digital aerial photographs for the entire city area were acquired in 2010, while in 2011 data was obtained by using a thermal camera. In 2021, photogrammetric works were carried out for the entire metropolitan area of Poznań. As a result of the photogrammetric flight, vertical and oblique images were taken and Airborne Laser Scanning (ALS) was realized. This data will be used to develop, among other things, a detailed mesh model and a true orthophoto. They constitute an invaluable source of information not only for the city of Poznań but also for the surrounding towns.

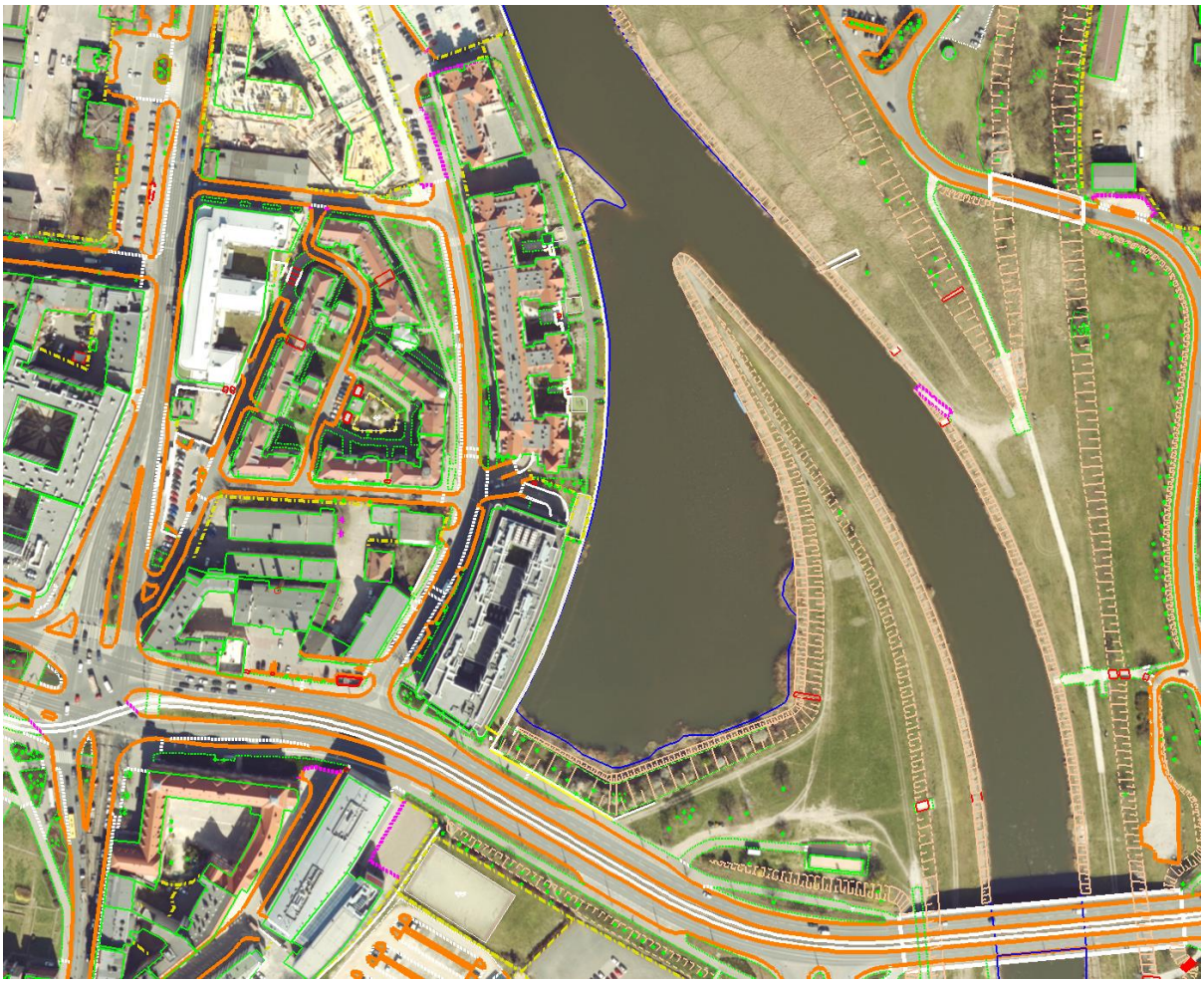

Fig. 1. Vector data acquired by stereodigitization of aerial photographs.

Aerial data are the most important source of data on the functioning of urban space. Geospatial analyses use photogrammetric products such as orthophoto, true orthophoto, Digital Terrain Model (DTM), Digital Sufrace Model (DSM)and Airborne Laser Scanning (ALS). On their

basis, a 3D model of the city is created and kept up to date, and the data contained in the state geodetic resource is verified. As part of the work, modern photogrammetric stations are used, where vector data on urban space and land use are acquired through stereodigitization. They are used to supply the geodetic resource, which makes it possible to verify the accuracy of data stored in the databases and update vector layers. In addition, information on the location of trees is recorded as part of the operation of the Urban Greenery Database. This enables a tree inventory to be carried out and analyses to be made concerning the condition of urban greenery. Roof planes acquired using photogrammetric stations, together with ALS data, allow the creation of detailed LoD2 models of buildings, necessary for the analysis of the solar potential for the installation of photovoltaic panels. The comprehensive use of photogrammetric data is part of the development strategy of the City of Poznań. In the following part of the article, the details of the solutions outlined will be presented.

3. National Geodetic and Cartographic Resource in Poland

3.1 Databases of the geodetic and cartographic resource of the city of Poznań

The responsibilities of the Geodesy and Urban Cadastre Management Board GEOPOZ are, among others, to create, maintain and make available the databases specified in the provisions of the Geodesy and Cartographic Law for the area of the city of Poznań. They have a major role in many areas of life, which is why it is so vital to keep them as up–to–date as possible. Key elements of the geodetic resource include:

3.1.1 Register of Land and Buildings (Cadastre)

The Land and Building Register is one of the most important public registers containing data on land, buildings and premises with their location, purpose and data on their owners. It is entirely maintained in vector format.

3.1.2 Topographic Objects Database with a level of detail sufficient to produce standard cartographic reports at scales 1:500 – 1:5000 (BDOT500)

The BDOT500 database collect information on land use and development. BDOT500 for the city of Poznań is maintained in a hybrid form using raster and vector data at a scale of 1:500. The raster content is successively replaced with vector data as part of the ongoing updating of the resource with data from survey reports resulting from works submitted by geodetic contractors.

3.1.3 Databases of Spatial Registration of Utility Infrastructure (GESUT)

Databases of spatial registration of utility infrastructure (GESUT) covers information on existing and planned land utility networks, their location, purpose and basic technical parameters, as well as on entities that have authority over these networks. At the end of 2021, the process of vectorisation of the land development network was completed and the initial GESUT database for the City of Poznań was created.

3.2 WEGA – unified system for geodetic resource management.

The tasks related to management of the state geodetic and cartographic resource for the city of Poznań are provided by the WEGA system.

WEGA is a comprehensive system that enables the collection, maintenance and updating of databases for the county area and making materials, datasets and documents available to natural and legal persons, within the scope of all maintained databases:

- Register of Land and Buildings – Cadastre (EGiB)
- Real Estate Prices and Values Register Database (RCiWN)
- Topographic Objects Database (BDOT500)
- Spatial Registration of Utility Infrastructure (GESUT)
- Detailed Geodetic Controls Database (BDSOG)
- Register of Towns, Streets and Addresses Database (EMUiA)

In addition, the system provides support for project documentation coordination in terms of project controls and issuing opinions.

3.3 Use of photogrammetric data – verification of records, BDOT500 update

Updating the databases of the geodetic resource on the basis of the surveying work completed does not ensure consistent updates throughout Poznań. There are many places that are not covered by investment development so surveying work in these areas is reported very rarely or has not been reported at all for many years. These areas have mostly raster or vector data based on resource materials from more than 20 years ago. In order to accelerate the transformation of raster data into up–to–date vector data, ZGiKM GEOPOZ has developed a procedure to update the database of topographic objects with a level of detail that ensures the creation of standard cartographic studies at scales of 1:500 – 1:5000 (BDOT500), with data acquired as a result of survey work related to the measurements of situational and altimetric measurements using stereodigitization of aerial photographs and processing the results of these measurements. Such an action allows for gradual, but relatively fast replacement of raster data with vector data, but what is most important, up–to–date information is entered into the database, consistent with the actual state on the day of performing a photogrammetric flight.

In the process of updating, data collected in the course of photogrammetric works are verified against the databases of the geodetic and cartographic resource, with particular attention paid to the source of data collection and their validity in relation to the actual state. In case of the existence of current data from land surveying in the area of interest, data provided by geodetic contractors are left in the BDOT 500 database.

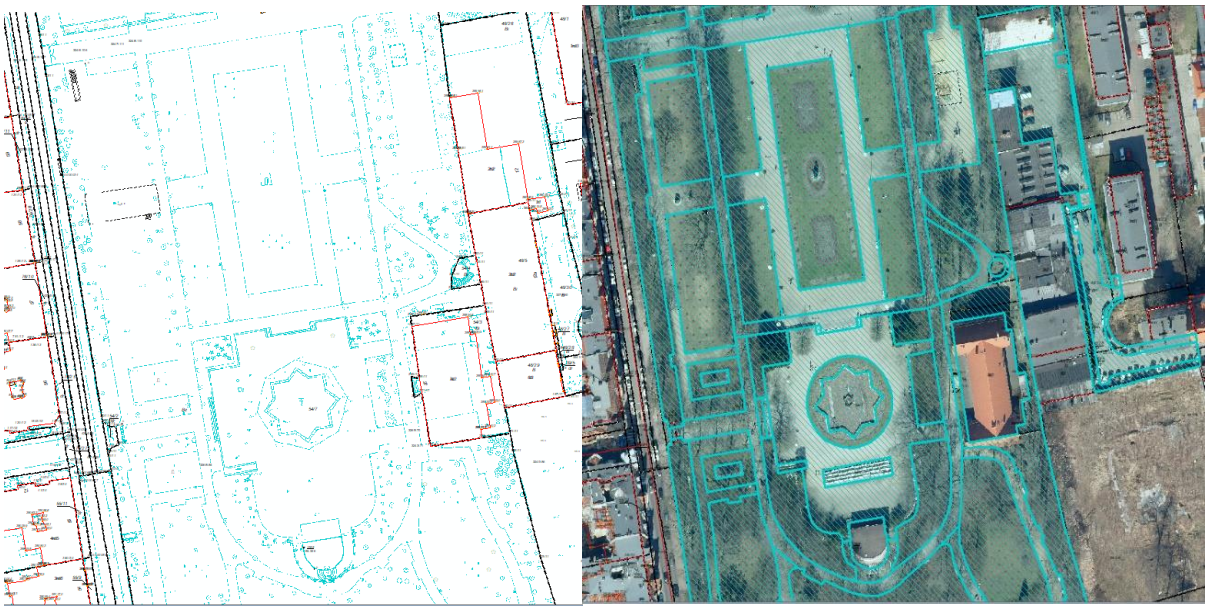

Fig. 2. Updating the BDOT500 database using photogrammetric data.

These works will help to provide up–to–date data on topographic object data in a timely manner. The entire work is performed by ZGiKM GEOPOZ employees, in particular by the Spatial Information System (SIP) unit and the Municipal Surveying and Cartographic Documentation Centre (MODGiK).

4. Spatial Information System and 3D model

4.1 The Spatial Information System of the City of Poznań – main assumptions and functioning

The Spatial Information System (SIP) of the city of Poznań has been functioning without interruption since August 2003. It is addressed to municipal entities, institutions, companies and individuals who are interested in using spatial data in their activities. The main objective of the SIP is to collect and integrate data from various sources in one place in order to facilitate the decision–making process in the city, as well as to give its citizens easy access to information on the functioning, changes and processes occurring within its borders. The SIP in Poznań is functioning on two levels. In the urban structure, users have access to extended legally protected information. The web–based version contains data that the city is permitted to provide without any legal restrictions to its citizens. The system includes around 500 thematic layers. The basic SIP layers include:

- registered plots and buildings sourced from the Land and Building Register Database maintained by the Municipal Surveying and Cartographic Documentation Centre ZGiKM GEOPOZ,
- photogrammetric layers created from stereodigitized aerial photographs,
- address system layers.

On the background of these objects, other thematic layers are presented to the users (local spatial development plans, Study of Conditions and Directions of Spatial Development, images created as a result of aerial photographs, etc.).

4.2 The Urban Greenery Database – Terrestrial Laser Scanning – remote sensing – satellite data

In view of climate change, which has a negative impact on the functioning of the city and the greenery within it, ZGiKM GEOPOZ, together with the municipal units, has initiated the creation of a database of urban greenery. The data collected on tree location, species, health status, etc. will facilitate better management of the city's environmental policy and a faster response to changes in the green structure. The database is created on the basis of digitalization of analogue materials (inventory projects), photogrammetric observations, point cloud obtained from air flights and 3D laser scanner (Topcon GLS–2000).

In order to standardise the work of all departments, ZGiKM GEOPOZ employees have created a plug–in that contains forms to facilitate data entry and the corresponding layers for editing. The works are carried out in open source software – QGIS. The database comprises inventoried and uninventoried trees. The wide range of data allows to automate the process of issuing them to orders and post–importation. Parks and squares constitute a priority in the creation of the Urban Greenery Database in addition to commissioned work. A detailed inventory of these important areas of the city is being carried out using Terrestrial Laser Scanning (TLS). The collected data is processed in the TerraSolid software, where the detection of individual trees, the calculation of crown volume and their height is performed. An additional product is a detailed point cloud, which is presented in the 3D portal of the city of Poznań. The Urban Greenery Database also provides a basis for creating a tree model in the CityGML standard. Using FME (ETL) tools, the process of updating the 3D database is closely linked to the expansion of greenery data in Poznań. Once the above information is acquired, remote sensing health indicators such as NDVI, ARVI and VARI are calculated from satellite and aerial data. Analysis of the values of the ratios and their changes over time, taking into account species composition, taxonomic characteristics and the time of the growing season, provides information on condition and health status. These data are passed on to the services responsible for monitoring vegetation in the city.

4.3 3D model – digital twin

All the solutions presented above constitute the grounds for the construction of a faithfully reflecting reality digital twin of the city, which is the essence of the implementation of the smart city concept. The 3D model is a tool for integrating spatial data in the Poznań area and is an integral part of the Spatial Information System. This project was carried out from October 2017 to August 2018. and is constantly being developed and updated. It includes a digital city model in the CityGML standard and the tools to publish and update it. It was created by integrating cadastral data and photogrammetric data, offering the possibility to switch from 2D

to 3D by adding an appropriate height and shape to the roofs of individual buildings. The city model is based on LoD1 and LoD2 buildings, the update of which is dependent on the availability of current data. The process of generating LoD1 buildings runs automatically using the capabilities of the FME software. It is refreshed in weekly cycles triggered by the volatility of the urban cadastre.

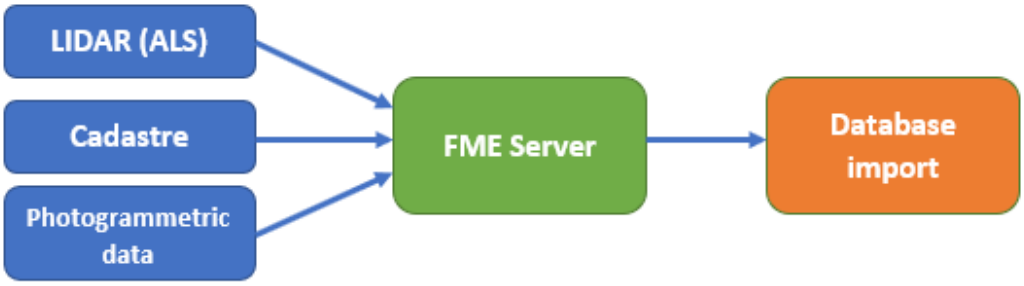

Fig. 3. Simplified LoD1 generation scheme.

As illustrated in the diagram (Fig. 3), the main sources of height for building masses are Airborne Laser Scanning data (ALS) and photogrammetric measurements based on vertical aerial photographs. They represent a great addition to the information on new development. The generation of 3D buildings in LoD2 standard is more complicated and there is no possibility to execute them fully automatically compared to LoD1 objects. Trained ZGiKM GEOPOZ employees are involved in this procedure, who also in this case use photogrammetric, cadastral and LIDAR data. The building is generated semi–automatically or manually depending on the complexity of the block. The specific steps are illustrated by the diagram below (Fig.4).

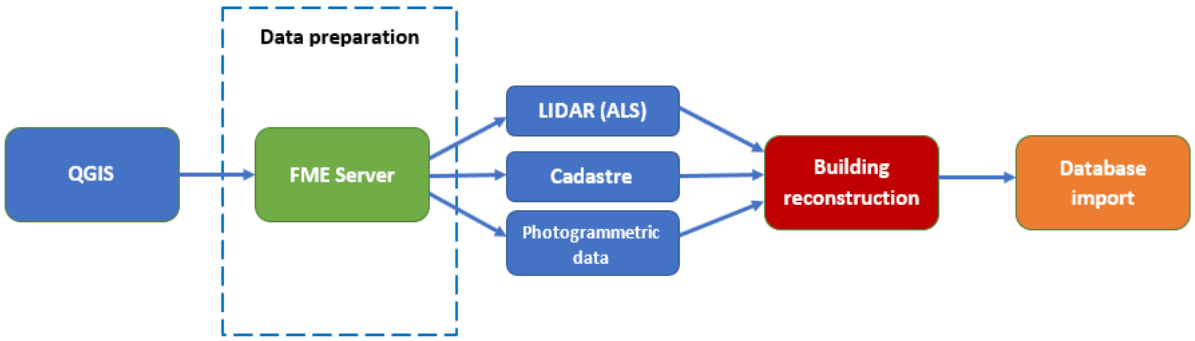

Fig. 4. Simplified LoD2 generation scheme.

To improve the operator's work, the time taken to acquire the relevant data was reduced using a combination of FME scripts and the open source software QGIS. Written in python, the plug-in enables to select an area and send the appropriate parameters to a script to prepare

the data for further work. Each generated building (LoD1 or LoD2) is saved in the CityGML standard and then imported into a database (3DcityDB). This enables objects to remain consistent, updated and easily managed. The model is systematically upgraded with new elements included in the CityGML standard (terrain model, small architecture, vegetation). All additional objects are also stored in the database.

4.4 Smart city – open data – citizens

The development of the 3D model and the Spatial Information System aims to support the city in implementing the Smart City concept. Buildings and other elements of the CityGML standard provide an ideal background for planning data. This combination leads to a better understanding of how the city is changing, its investment opportunities. The digital twin also offers the opportunity to present development concepts for new areas created by urban planning studios. Interaction with such a model facilitates the citizen–city debate.

Fig. 5. Spatial planning – 3D model

The 3D model is not only an opportunity to view objects on the portal, but also an extensive open data resource. Through the possibility of downloading objects from the 3D portal in various formats (skp, obj, dxf, 3ds, etc.) the city opens up to citizens – active users of both urban and virtual space. The data downloaded is not only used for commercial architectural projects, but also for various urban space analyses. The 3D model is of great interest to students, serving as very good training material. Open data is not only 3D data, but also a range of services issued in the OGC standard. Numerous WMS, WMTS and WFS layers provide a cross–section of how the city is functioning. Very popular services refer to photogrammetry, in particular collected orthophotos. They represent a kind of link between the cadastre and other data. They allow citizens to better orientate themselves in space and understand certain relationships in the urban network.

5. Conclusion

The city of Poznań, implementing the concept of smart city in practice, uses photogrammetry on many levels. The acquisition of data for the needs of the National Geodetic and Cartographic Resource, verification and updating of existing databases, creation of a 3D Model, the Urban Greenery Database, as well as the use of information for the operation of the Spatial Information System, results in better management of the city and more accurate decision–making. This has a direct economic and ecological impact by reducing the city's operating costs.
The Geodesy and Urban Cadastre Management Board GEOPOZ, as a self–government administration institution responsible for maintaining the geodetic resource and SIP, coordinates the city's activities in the field of spatial data, making it available to citizens and investors. Thus it gives the opportunity to interact with the digital twin and triggers interest in the subject of analysis of the functioning of space, which allows to get familiar with the urban structure and understand the processes occurring within it. This provides an opportunity to deepen the relationship between the citizen and the city. Constant pursuit of the development of photogrammetric and geodetic technologies and observation of global trends enables to be among the leaders of Polish cities using spatial data in practice. The 3D model development and open data offered by the city make it stand out from its European counterparts.

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BIOGRAPHICAL NOTES

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