



Original article

The use of LIDAR point clouds for spatial analysis of changes in building development in large housing estates. An example of the Widzew Wschód and Radogoszcz Wschód estates in Łódź

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ABSTRACT

Urban densification can have various consequences. To identify and interpret these, spatial analyses of changes in the built environment over a specific period are needed. This article investigates the use of LIDAR point cloud data to detect changes in development in two large pre-fabricated housing estates in Łódź, Poland. Developed during the socialist era, these estates have undergone spatial and functional transformations over the past decades. The study uses LIDAR data from 2012, 2017, and 2021, supplemented with orthophotos, Google Street View, and fieldwork conducted in 2023 to identify and verify changes in development. The analysis included classification of point-cloud data, conversion to raster and subtraction of rasters to detect new and demolished buildings. The results show a clear trend to increase the density of buildings in both estates, with more than 11,000 m² of new built-up area added in each case. New developments include residential, commercial and service and communication facilities, often replacing open spaces or previously undeveloped areas. The study confirms that the LIDAR point cloud is a valuable tool for detailed detection of changes in various urban objects. Analyses based on this type of data can serve as a monitoring function. It also highlights the need to integrate historical data to capture earlier stages of transformation and suggests including development analysis in future research.

KEY WORDS: urban densification, GIS, remote sensing data, Poland

ARTICLE HISTORY: received 3 September 2025; received in revised form 2 April 2026; accepted 15 April 2026

1. Introduction

The development of remote sensing in urban research initially focused on the analysis of aerial and satellite images. Many studies (DRZEWIECKI, 2008; GRZEGORCZYK, 2009; KIJOWSKI & BOGDAN, 2009; SOERGEL, 2010; PIECH & SZPOT, 2023) have pointed to the potential of remote sensing to map and monitor changes in the urban environment. The dynamic development of technology and the widespread

implementation of LIDAR laser scanning have significantly improved the accuracy and speed of spatial analysis. Data obtained using LIDAR technology have allowed detailed studies of changes in building structure and land cover, with particular emphasis on green areas (WĘŻYK ET AL., 2023; BIELECKI & BĘDKOWSKI, 2024).

One of the important elements of the spatial structure of many European cities, where changes in development are significant from the point of

view of spatial planning, are large, prefabricated housing estates built in the second half of the 20th century. They were built in many European countries, but developed on the largest scale in Central and Eastern Europe (CEE) countries, including Poland. Their spatial layout was planned in the spirit of modernism and the principles codified in the Athens Charter, exemplified by the slogan 'Sun, space and green' (MUMFORD, 1992). The housing estates were built under various economic, demographic, and political conditions. Their common feature was financing from public funds. In Poland, during the communist period, 1945-1990, in the absence of land rent and unrestricted access to urban land (or suburban, which was incorporated for this purpose), these housing estates were built quickly and carelessly to meet the housing shortage in the cities. In the largest housing estates located on the outskirts of the cities at that time, large undeveloped areas were left to be completed at a later stage, only after the residents had settled in (SZAFRAŃSKA, 2016). The political transformation of the early 1990s initiated spatial and functional changes in these housing estates. One of the most important changes was the intensification of its original development (MATLOVIČ & SEDLÁKOVÁ, 2007). The process of densification applies to both residential buildings and buildings serving other purposes.

The aim of this research was to use LIDAR point cloud data to detect changes in development in a selected area and to analyze and evaluate these changes. The study was carried out in large housing estates with block housing. Two housing estates built in the 1970s and 1980s, located in Łódź, the fourth largest city in Poland, were selected as the study area.

2. Literature review

The introduction of LIDAR point clouds into remote sensing resources has significantly expanded the possibilities for the spatial analysis of both the natural and socio-economic environments. The interdisciplinary nature of the use of these types of data is increasingly emphasised in the scientific literature, ranging from biology and forestry to computer science and geography to urban planning. Research on modelling urban development and structures using elevation data, which allows for a detailed analysis of space and its transformation over time, has gained particular importance (BIELECKI & BĘDKOWSKI, 2024).

An important area of research is the reconstruction and modelling of urban areas using LIDAR data. Works such as LIDAR urban site modelling (ZHANG ET AL., 2012; ZHOU & NEUMANN, 2012) and generating compact meshes under planar constraints (VERDIÉ ET AL., 2011) emphasise the role of automated data processing in obtaining accurate 3D models of buildings. In the first of these articles, the authors presented a method for converting LIDAR data into detailed models of urban structures, which is important for the analysis of urban change. The second article focusses on creating compact, optimised building meshes based on aerial data, which supports both urban planning and spatial planning. The modelling of residential areas is the subject of further advanced research. The article "Modelling Residential Urban Areas from Dense Aerial LiDAR Point Clouds" (ZHOU & NEUMANN, 2008) presents an approach to reconstructing densely constructed residential areas based on point clouds. The authors developed a method for effective classification and segmentation of buildings that has a direct application in the analysis of land use intensification.

The issue of detecting changes in building structure using LIDAR data has been explored in more detail in the publications "Integrated change detection and classification in urban areas (airborne laser scanning point clouds (MATIKAINEN ET AL., 2010) and "LIDAR-based change detection of buildings" (VOSSELMAN ET AL., 2005). Both works show that comparative analysis of data from different years enables precise detection of demolitions, superstructures, or newly constructed buildings, which is particularly useful in the analyses of changes in dense urban areas. In the context of building change research, the article "Complete reconstruction of residential urban areas from dense aerial LIDAR point clouds" (ZHOU & NEUMANN, 2013) is also important, in which the authors present a complete residential area reconstruction process based on LIDAR data, taking into account not only the building structures but also their spatial relationships. This work shows how spatial data can be used for urban analysis at the neighbourhood level.

Empirical studies on changes in the development of large housing estates show various aspects of this phenomenon. Some focus on recording the spatial and morphological changes that occur in housing estates and their impact on the urban composition of this type of development (VASILEVSKA ET AL., 2020; SZCZEREK, 2021; STARCZEWSKI ET AL., 2024). Others show the broader context of this phenomenon, such

as functional changes and changes in the availability of services through their commercialisation (ŠUŠKA & STASÍKOVÁ, 2013; SZAFRAŃSKA, 2015; OUŘEDNÍČEK & KOPECKÁ, 2023) and through the development of other non-commercial functions, e.g. sacralisation of space (JAŹDŹEWSKA, 2010). There are also studies showing the social and economic aspects of spatial changes in large housing estates, including space privatisation (GÓRCZYŃSKA, 2013), gentrification, and social segregation through the emergence of gated communities (SZAFRAŃSKA, 2014, 2016; GORCZYCA, 2016; TREIJA ET AL., 2018; GRUNDSTRÖM & LELÉVRIER, 2023). In individual estates, observed changes differ significantly in pace and scale; however, most of them experience the process of increasing the built area, often referred to in the literature as densification (TREIJA ET AL., 2018; SZCZEREK, 2021;). This process is discussed in the scientific literature from various perspectives. On the one hand, it is assumed that planned densification of buildings and the pursuit of urban compactness protect against excessive suburbanisation and uncontrolled urban sprawl, and thus fits in with the principles of sustainable urban development and the idea of a compact city (SALINGAROS, 2006) or a 15-minute city (ALLAM ET AL., 2021). Conversely, however, it may lead to overinvestment in urban space, especially if it results from the primacy of developers' interests over those of residents and is carried out at the expense of public spaces or areas of natural value (FORTUNA-ANTOSZKIEWICZ & ŁUKASZKIEWICZ, 2021).

In summary, the literature provides numerous examples of the effective use of LIDAR data for urban space analysis, building modelling, and change detection. The growing availability of data in Poland, initiated, among others, by the ISOK (IT System for National Protection) project in the first decade of the 21st century, is conducive to the development of this type of analysis also in the local context, as exemplified by the study presented in this article on changes within the residential areas of Widzew Wschód and Radogoszcz Wschód in Łódź.

Given the interdisciplinary nature of this type of research, it should be noted that the methods used to study changes in block housing estates and the sources of data may vary, ranging from less advanced ones, such as the analysis of city plans and topographic maps, through aerial and satellite photographs, to the increasingly used LIDAR point-cloud data. This research is an example of the use of the latter type of data and an attempt to contribute to a new approach to the analysis of changes in various forms

of development as a diversification of traditional research on this topic.

3. Study area

The study area is located in Łódź, one of the largest cities in Poland, with a population of 645.7 thousand as of the end of 2024 (Statistical Office in Łódź, lodz.stat.gov.pl). Until recently, the city was the second largest in the country, but is currently undergoing severe depopulation and advanced (fastest in Poland) ageing processes (JANISZEWSKA & DMOCHOWSKA-DUDEK, 2017). At the same time, over the last decade, the city has experienced a Russian annexation of Crimea and has intensified each year since then (SZAFRAŃSKA & BAUDOUX, 2025). This phenomenon has an impact on the local housing market, including construction activity, which also covers residential areas dating back to the communist era. Investments in these residential areas are attractive to developers due to the existing infrastructure and extensive service programs that do not require additional development. They are also attractive locations for commercial services due to their extensive infrastructure and proximity to potential customers. These areas are also well connected by public transport. Two housing estates were selected for analysis: the Widzew Wschód estate, the one of largest estate in Łódź with approximately 34,000 residents (Public Information Bulletin, City of Łódź Office, uml.lodz.pl), and the smaller and newer Radogoszcz Wschód estate with approximately 16,000 residents (PLESIŃSKI, 2025) (Fig. 1). The selected housing estates represent the same type of development characteristic of the socialist period of urban growth. They were constructed during the second phase of this development in Polish cities, following the 1974 revision of housing standards, which introduced lower building density, greater spacing between buildings, and more extensive open spaces. Nevertheless, they differ in spatial layout. The newer one (Radogoszcz Wschód) was planned and built more carefully. Therefore, even though they represent the same type of development, their spatial transformations may have proceed in different ways. The selection of these estates was motivated by the aim of examining the spatial transformations occurring within such developments and identifying the differences between them.

The Widzew Wschód housing estate covers an area of 2,48 km² and is currently the second largest prefabricated estate in Łódź. It is located in the

eastern part of the city, in areas spatially separated from the historic urban fabric, but relatively close and well connected. To the north, it directly adjoins the railway line connecting Łódź with Warsaw and other cities in the Łódź agglomeration. Several hundred metres from its northern border is the Łódź Widzew railway station. A big road running through the estate (Rokicińska Street) is the main transport axis of the city, which runs from west (through the city centre) to east (part of road 713 connects the city with the A1 motorway). The second-longest street, Pushkin Street, runs north to south and cuts the estate almost in half. The intersection of these streets is one of the largest in the city. The estate was built in the late 1970s and 1980s and consists of several smaller estates. The buildings are quite loosely arranged. It is characterised by a large amount of open space, which was left during its construction for commercial and service functions and recreational areas. The buildings are of a mixed type, with elements of all the layouts used in housing estates (comb, linear, cluster and block). In 2014, there were 300 multifamily residential buildings on the estate (SZAFRAŃSKA 2016). Most of them were built using panel technology, which at that time dominated almost all residential construction in large Polish cities. Most of the housing estate consists of low-rise buildings with five floors, but about 1/5 are high-rise buildings (12 floors).

The Radogoszcz Wschód estate has an area of 1.27 km² and is located in the northern part of Łódź (Fig. 1), east of one of the main exit roads from the city towards Zgierz and Gdańsk and the intersection of the A1 and A2 motorways (road number 91). The streets intersect in the south-west corner of the estate and create one of the largest intersections in the city. To the east of the estate, there is a railway line and a stop for the Łódź agglomeration railway. Residential buildings were built in the years 1982-1992. Although the estate was built using large-panel technology, its appearance and layout differ from those built in Łódź and Poland during the socialist period. The buildings create semi-open internal courtyards, where there are playgrounds, rest areas, and estate greenery. The spatial layout of the estate refers to traditional urban solutions. Its central part is occupied by the green, representative big square (Słoneczny Square), around which there are residential buildings with built-in service and commercial functions on the ground floors. The heights of the buildings and their architectural form are varied, which gives the Radogoszcz-Wschód estate an original physiognomy. In 2014, its development included 199 multifamily residential buildings (SZAFRAŃSKA 2016). Four-story buildings dominate. The main communication axis of the estate is Nastrojowa Street, which runs meridionally and intersects the estate, and Świtezianki and Pstragowa streets that branch from it.

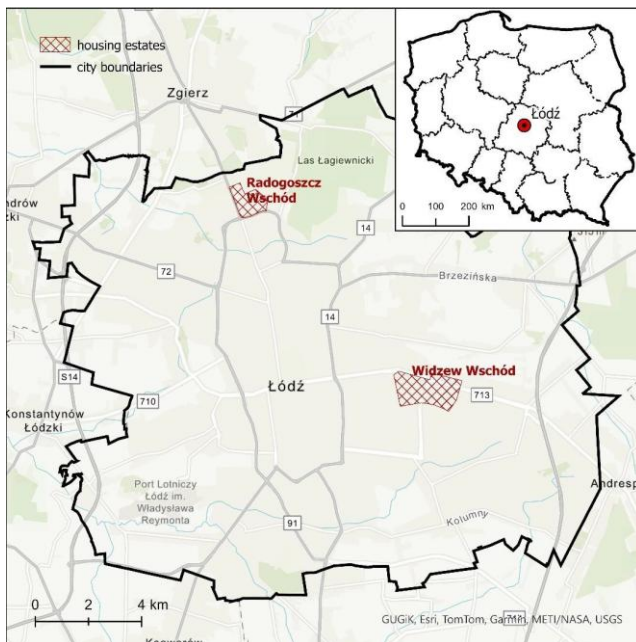


Fig. 1. Location of the research area within the administrative borders of Łódź (Source: own study)

4. Materials and methods

The data source for the analysis of changes in the development of Widzew Wschód and Radogoszcz Wschód housing estates in Łódź were LIDAR point clouds from three research periods: 2012, 2017 and 2021. These data were provided by the Łódź Geodesy Centre (ŁOG) for the purposes of research conducted at the Faculty of Geography of the University of Łódź. On this basis, it was possible to analyse changes in the spatial structure of buildings and identify any transformations of the area during the analysed period.

Point-cloud analyses were supplemented by an orthophotomap obtained from the resources of the Main Office of Geodesy and Cartography (GUGiK), made available through the Geoportal website (National geoportal website - www.geoportal.gov.pl). An orthophotomap is a high-resolution image of the ground surface obtained from aerial photographs. It was used to verify the types of buildings and

their changes during the analysed period, which could not be clearly identified on the basis of LIDAR data.

In addition, Google Street View (Google Maps - www.google.com/maps) was used to perform a qualitative assessment of the condition of the buildings and to verify changes to individual buildings and the spaces between them. This service allowed for a virtual walk through the analysed housing estates and provided a view from street level. It was particularly useful for interpreting the nature of the buildings (eg, distinguishing between residential and commercial buildings) and assessing the technical condition of the structures.

To correctly identify the results of changes in development and recognise the functions of new buildings, a group of geoinformation students from the University of Łódź checked the changes and functions directly in the field in January 2023. This ensured that the reported changes in development had actually occurred and that the functions of the new buildings in 2023 were identified.

Methodology:

- Acquisition of LIDAR data and its characterisation;
- Division of the study area into 15-18 smaller sub-areas;
- Classification of 'building' and 'ground' points and their extraction from the point cloud;
- Conversion of data to rasters;
- Detection of changes;
- Field research;
- Interpretation;
- Conclusions.

LIDAR point clouds are characterised by very high measurement accuracy, reaching a density of 12 (2012, 2017) to 24 (2021) points per 1 m² in the study area. The data comes from the ISOK/GUGiK resource and has a declared horizontal accuracy of ±0.20 m and vertical accuracy of ±0.10 m. The classification of points was performed by GUGiK in accordance with the ASPRS Positional Accuracy Standards, and its accuracy is consistent with the ISOK specification (classification accuracy above 90%). Such high resolution ensures detailed mapping of the terrain and buildings, which allows for precise analysis of changes in the spatial structure of housing estates (BUCIOR ET AL., 2006; GRIGILLO & KANJIR, 2012). However, due to the large volume of data, these files were divided into smaller packages covering individual sectors of the study area. The division into data packages was adopted based on

data sharing via Geoportal in the form of packages corresponding to a topographic map sheet. After matching the Widzew Wschód and Radogoszcz Wschód housing estates with the available data packages, 15-18 packages were selected for each of the periods analysed.

All data packages were saved in separate folders corresponding to the three study periods (2012, 2017, and 2021). LiDAR data processing and analysis were carried out using LASTools v2.0.3, which enables point cloud processing, height normalisation, and vector extraction based on point classifications.

LASTools v2.0.3 software was used for data analysis and processing, which allows point classification and conversion of point clouds into raster images. This process included the following:

- Classification of points - to separate points belonging to buildings (class 6) and areas without vegetation (class 2).
- Height normalisation - by converting point heights relative to sea level.
- Conversion of points to raster images - enabling further spatial analysis and comparison of changes in building density.

For this purpose, the following script was used, developed, and tested in classes with geoinformation students at the University of Łódź:

- `dir /b *.laz > lista_LAZ.txt`
- `lasheight -lof lista_LAZ.txt -ground MB05.dtm -replace_z -odix_norm`
- `dtm2ascii -i MB05.dtm -o MB05.asc`
- `lasboundary -i *_norm.laz -merged -o budynki.shp -keep_class 6 -concavity 2`

Script description:

- `dir /b *.laz > lista_LAZ.txt` - creates a list of all .laz files in the working directory.
- `lasheight` - normalises point heights relative to the Digital Terrain Model (DTM), producing height-above-ground values.
- `dtm2ascii` - converts the DTM raster to ASCII GRID format for use in GIS software.
- `lasboundary` - extracts vector building footprints from height-normalised point clouds using points classified as buildings (class 6)

The final output of this research process are raster images with a pixel size of 0.5 m (Fig. 2) showing the layout and height of buildings in the Widzew Wschód and Radogoszcz Wschód estates in the three analysed periods (2012, 2017, 2021). This approach allowed for a comparison of changes in development (number and area of buildings).

Further stages of the analysis involved subtracting rasters to detect changes. This operation consisted of subtracting the pixel values with the same coordinates from two raster layers, which allowed

us to obtain a different image showing changes in the density and height of buildings over the years under study.

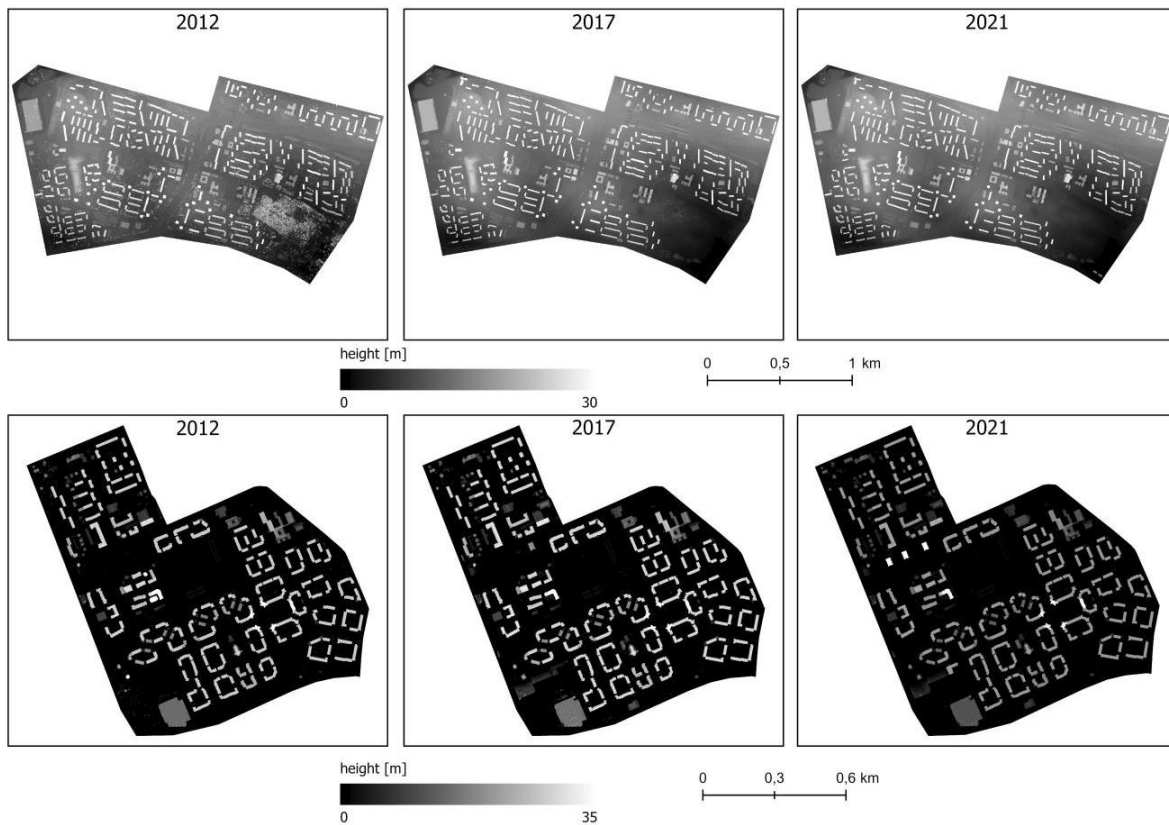


Fig. 2. Raster images of buildings in the Widzew Wschód and Radogoszcz Wschód housing estates in individual years based on LIDAR point clouds (Source: own study)

5. Results

In the years 2012-2021, the Widzew Wschód and Radogoszcz Wschód estates in Łódź saw an increase in development, with greater dynamics of change observed in the years 2012-2017 (Fig. 3). The spatial

representation of the changes in the built-up area in the studied housing estates is presented in Figs 4 and 8. The absolute number of new and demolished buildings and their area in the studied estates between 2012 and 2021 is presented in Table 1.

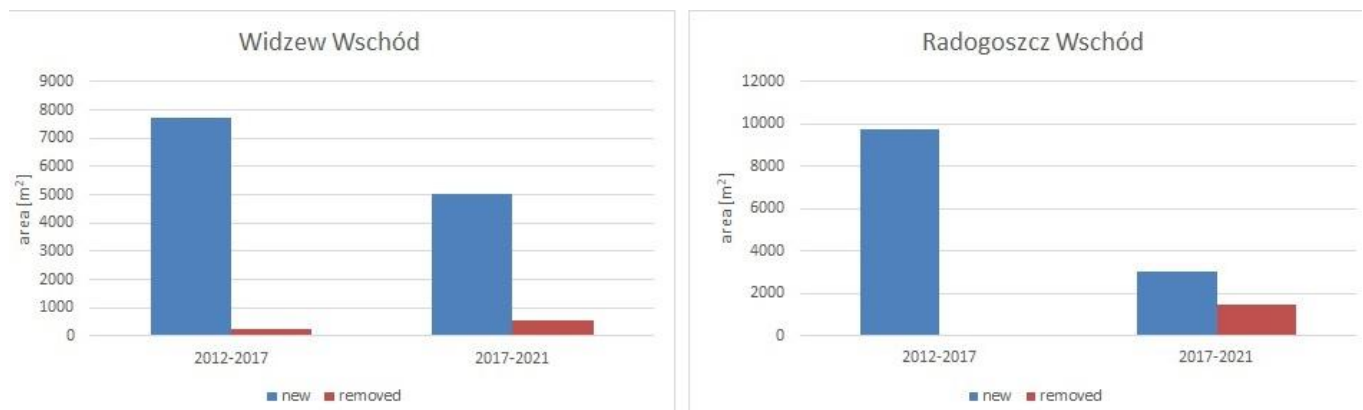


Fig. 3. Graphs of the dynamics of development changes in the studied housing estates according to the time periods 2012-2017 and 2017-2021 (Source: own study)

Table 1. New and demolished buildings in Widzew Wschód and Radogoszcz Wschód housing estates in Łódź in 2012–2021

Name of the housing estate	New buildings				Buildings demolished		
	Function of the building	Number of buildings	Building area [m ²]	Percentage of changes in building area compared to the current development	Number of buildings	Building area [m ²]	Percentage of changes in building area compared to the current development
Widzew Wschód	Communication	14	2963,90	0,93	6	809,35	0,25
	Commercial and Service	8	4010,78	1,25			
	Residential	7	5796,28	1,82			
	Total	29	12770,96	4,00			
Radogoszcz Wschód	Communication	1	96,96	0,06	9	1530,74	0,94
	Commercial and service	5	9546,15	5,87			
	Residential	5	3139,92	1,93			
	Total	11	12783,03	7,86			

Based on raster subtraction we observed an increase in the number of buildings and built-up area in the Widzew Wschód housing estate by 11,961.6 m² over one decade (2012–2021), representing nearly 4% of the estate's current built-up area (Table 1). This result indicates an intensified development in this housing estate.

In the Widzew Wschód housing estate, changes in the spatial layout of new buildings over the years under study are visible in its northern part and on its outskirts. Only a few small buildings were removed during this period (Table 1, Fig. 4).

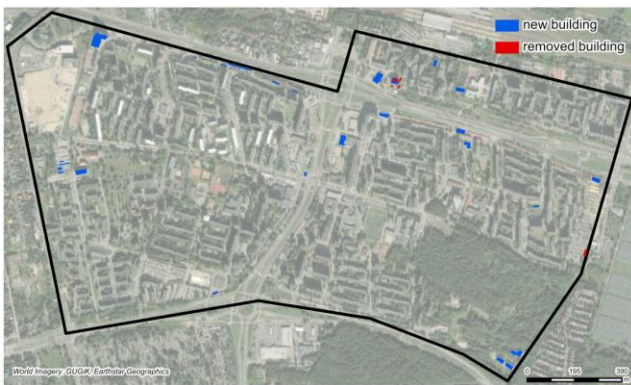


Fig. 4. Changes in the buildings in the Widzew Wschód housing estate in Łódź between 2012 and 2021 (Source: own study)

Residential buildings constituted the largest area, followed by commercial and service buildings (Table 1). It is clear that new developments have appeared close to Rokicińska Street, which cuts through the estate in the north. To the north of Rokicińska Street, near the large intersection with Aleksandra Puzzkina Street, a NETTO supermarket (Fig. 5) and a residential building called 'Apartamenty Adamięckiego' (Adamięckiego Apartments) appeared

after 2017 on the site of the demolished small buildings (Fig. 5). Further north, at the same time, a new residential building was 'squeezed' between the existing buildings near the Widzew railway Station – the so-called Four Corners Station. South of Rokicińska Street, also in a good location on the second major thoroughfare of this housing estate, Puzzkina Street, another multi-sector supermarket (Fig. 6) was built before 2017, followed by another one further east. These were built next to other existing small supermarkets. Detection of changes revealed that a new structure had been erected next to the school building between 2012 and 2017. During the inventory, it turned out that it was a semicircular structure made of sheet metal, used by young people for sports activities (Fig. 7).

Some of the new investments in the Widzew Wschód housing estate served transport purposes. This was the largest group of buildings, despite having the smallest total area (Table 1). The detection of changes revealed: a roof or enlargement of carports along Rokicińska Street, as well as the construction of a viaduct on this street.

In the Radogoszcz Wschód housing estate, changes in the spatial layout of new buildings over the years under study are visible in its western part. Several buildings were demolished during this period (Table 1, Fig. 8), and no new buildings were constructed. The increase in the built area by 11 252,29 m² in the study period is comparable to that of the Widzew Wschód housing estate. However, this is a smaller estate - the increase in building area accounts for nearly 7% of the estate's current building area. These results suggest that the built-up area of Radogoszcz Wschód is growing faster than that of Widzew Wschód.



Fig. 5. Example of field verification of change detection in the Widzew Wschód housing estate in Łódź – (a) orthophotomap from 2017, (b) orthophotomap from 2021, (c) (d) photographs from 2023.



Fig. 6. Example of field verification of change detection in the Widzew Wschód housing estate in Łódź – (a) orthophotomap from 2017, (b) orthophotomap from 2021, (c) (d) photographs from 2023

The increase in development could be related to new residential and commercial investments, the expansion of existing buildings, or other investments. The results of field research made it possible to determine the function of the new buildings in the Radogoszcz Wschód housing estate. Among the changes noted, similar to those in the Widzew Wschód

housing estate, new buildings were identified that serve the following functions: residential, services (supermarkets) and recreation/sports. The research methodology was identical and the results were very similar; therefore, only examples of changes in the development of this housing estate will be presented and the differences noted will be indicated.



Fig. 7. Example of field verification of change detection in the Widzew Wschód housing estate in Łódź – (a) orthophotomap from 2017, (b) orthophotomap from 2021, (c) (d) photographs from 2023

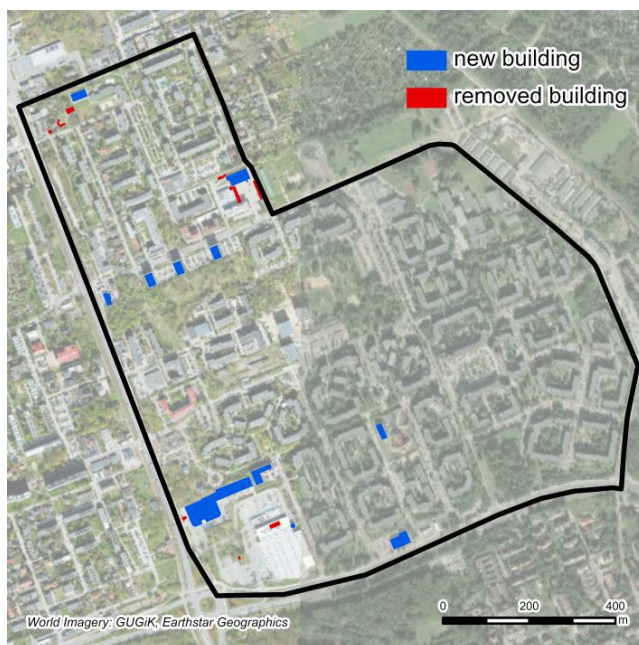


Fig. 8. Changes in the buildings of the Radogoszcz Wschód housing estate in Łódź between 2012 and 2021 (Source: own study)

The first group of new buildings were residential buildings, which, unlike those in Widzew Wschód, were built on vacant plots away from the oldest buildings serving this purpose. The largest group in terms of the area of new buildings were commercial and service buildings (Table 1, Fig. 8), which were located in wasteland - similar to the Widzew Wschód

housing estate – near major streets and other large commercial facilities. Examples include a NETTO supermarket, a Biedronka store, and a shopping centre with several shops (Rossmann, Lidl, Pepco, a pharmacy, a pizzeria, and a fitness club). Similarly to Widzew Wschód, a semicircular building was noticed near the school, which also served as a sports facility.

In both analyzed housing estates, new developments are located mainly on private land and, to a lesser extent, on plots owned by the City of Łódź. In the case of new residential development, these plots previously belonged to housing cooperatives and were sold to developers.

6. Discussion and conclusions

In summary, analysis of changes in building development using LIDAR data on the example of the Widzew Wschód and Radogoszcz Wschód housing estates in Łódź allowed for precise tracking of changes in the spatial structure of these urban units. The results confirm that aerial laser scanning data constitute an effective tool for research on the transformation of built-up areas, enabling microscale analysis – both at the level of individual street quarters and entire housing estates. Regular updates of LIDAR data within the National Spatial

Information System in Poland will enable the continuation of this type of analysis in the future.

The conclusions of this study are consistent with the observations of other authors who have used LIDAR data to analyse urban development (VOSSelman ET AL., 2003; TRAN ET AL., 2018). In urban studies, it is also important to consider other components of the urban environment, such as greenery and recreational spaces, whose changes can also be effectively monitored using remote sensing data (BIELECKI & BĘDKOWSKI, 2024). They can be included in the analysis of changes in development to determine where new buildings have appeared or to plan new investments in the city.

Changes in development are associated not only with an increase in built-up areas analysed in the horizontal layout, but also in the vertical layout. Therefore, as was done by VU ET AL. (2009) for Tokyo, LIDAR should also be used to assess the height of new buildings. In the case of the study in Łódź, the number of floors of buildings was determined during the outdoor research, verifying the LIDAR analysis results and identifying the building functions. The height of buildings determined using LIDAR data would certainly enable easier and faster analysis, e.g. in planning, landscape or forecasting and estimating the number of inhabitants, which is particularly useful in the event of the need to evacuate people due to natural, epidemic or war threats, which is a topic that has been discussed more and more frequently recently.

One of the limitations of analyses conducted using LIDAR data is the lack of archival data from before 2010. In Polish conditions, this is particularly important because the process of intensification of development in the discussed housing estates began as early as the 1990s. To cover a longer period of time, it is necessary to use additional data sources, in particular, aerial photographs, satellite imagery, and geodetic resources, and integrate them into a common analytical model. The combination of data from different sources is one of the many benefits offered by Geographic Information Systems and has been used by many researchers for dynamic studies or to verify results with existing databases (VU ET AL., 2009) or multispectral imagery (AWRANGJEB ET AL., 2010). In the future, the authors intend to use the latest advances in 3D change detection methods (KHARROUBI ET AL., 2022) and discuss changes in the physiognomy of buildings.

The combination of spatial data analysis and field observations enabled not only a quantitative

assessment of densification processes, but also a discussion of their functional consequences for the settlements studied. The results obtained provide a basis for further research on the transformation of residential space in cities and the development of methods that support sustainable spatial planning. The authors did not consider the digital terrain model presented by SHIROWZHAN & SEPASGOZAR, (2019), as it had previously been verified that there were no hills or other geomorphological characteristics in the study area. They recommend checking the geomorphology of the area before analysing the buildings, especially their height.

It should be emphasized that the method based on LiDAR data has its limitations – it does not allow for the identification of changes occurring inside buildings or changes in the functions of objects if they do not involve modifications to their outline or external geometry.

When placed in the broader context of spatial transformations in large housing estates in Central and Eastern European (CEE) countries, the results of this study correspond closely with changes identified in estates in Bratislava, Prague, Riga (ŠUŠKA & STASÍKOVÁ, 2013; TREJJA ET AL., 2018; OUŘEDNÍČEK & KOPECKÁ, 2023) and other comparable cases (see SZAFRAŃSKA, 2016). However, the findings related to the dynamics of development in the analysed housing estates are not directly comparable with those reported in the cited studies due to methodological differences. Despite this, all studies address the same process of densification in large housing estates and consistently confirm the ongoing trend towards increasing building density within these areas. Nevertheless, the observed changes can have a negative impact on living conditions by reducing green areas and recreational space. Moreover, the appropriation of space, which is a consequence of the construction of gated communities, has a negative impact on public space in housing estates. However, in specific cases, changes in housing estate development may contribute to the creation of new attractive public spaces, which has not been present in these housing estates so far, and the creation of multifunctional commercial, service, and transport routes. Given the importance of the quality of life of urban residents and their sustainable development, phenomena such as progressive changes in urban development should be continuously monitored using various methods and across different spatial scales.

Acknowledgements

We thank the Łódź Geodesy Centre for providing the data. We would like to thank the third-year geoinformation students (2023/2024) for the field inventory and help in processing the data. Michał Czajkowski, Klaudia Dudek, Zuzanna Kulisz, Anna Kwiatkowska, Aleksandra Nisztuk, Joanna Nowacka, Aleksandra Pelska, Rafał Spała, Klaudia Wojtunik, Rafał Zakrzewski, Daria Zdulska, Adam Zwierzchowski, Daria Adamczyk, Wiktoria Augustyniak, Paulina Gancarczyk, Jan Karolak, Kamil Kowalski, Grzegorz Kraszkiewicz, Damian Rokicki, Jakub Słysz, Sebastian Stupski, Arteusz Trojanowski, Piotr Trzmielak, Szymon Wierzbicki.

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