

A method for the aggregation of spatial data in the study of urban structure on the example of trends in the localisation of tall buildings in Wrocław

Piotr Kryczka

piotr.kryczka@pwr.edu.pl |  <https://orcid.org/0000-0001-6735-2658>

Robert Masztalski

robert.masztalski@pwr.edu.pl |  <https://orcid.org/0000-0003-3408-4807>

Department of Urban Planning and Settlement Processes, Faculty of Architecture, Wrocław University of Science and Technology

Scientific Editor: Mateusz Gyurkovich,
Cracow University of Technology

Technical Editor: Małgorzata Sikora, Cracow
University of Technology Press

Language Editor: Tim Churcher, Big Picture

Typesetting: Anna Basista, Cracow
University of Technology Press

Received: February 10, 2020

Accepted: October 9, 2020

Copyright: © 2020 Kryczka, Masztalski.

This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Funding: License No. DIO.7211.180.2019 EN_N of 08.04.2019.

Competing interests: The authors have declared that no competing interests exist.

Citation: Kryczka, P., Masztalski, R. (2020). A method for the aggregation of spatial data in the study of urban structure on the example of trends in the localisation of tall buildings in Wrocław. *Technical Transactions: e2020033*. <https://doi.org/10.37705/TechTrans/e2020033>

Abstract

The dynamic development of technology benefits from an access to information about space, and thus this development has a significant impact on the urban form of cities. This applies not only to spatial behaviour of users but also to the principles of spatial policy. The purpose of this study is to systematise knowledge in the field of shaping the development of tall buildings in Poland in the light of available spatial data and their impact on the urban structure of cities. The method of aggregation of spatial data in the form of a point cloud from LiDAR laser scanning was validated; geospatial analysis and map studies in the GIS environment were conducted taking into account trends in building height distribution. The conclusions highlight the primary aim of the latest research methods that can be implemented in the context of urban analysis. The case study of Wrocław shows that the method for the aggregation of spatial data from laser scanning is a universal research tool in the search for trends occurring in the urban form of the city, in particular with relation to building height.

Keywords: LiDAR technology, urban planning, urban design, geospatial analysis, spatial policy, elevation point

1. Introduction

There are many factors that shape the spatial form of a city, which in fact should be correlated with complex functional subsystems. The spatial form is comprised not only of the physical elements of the urban structure, public spaces and surrounding buildings but also people whose perception directly and indirectly affects this form and, as a consequence, also its functions (Jopek, 2018: 81–89). One of the elements of the spatial form of modern cities is the presence of tall buildings. Although their positioning is not a rule. The fact of locating tall buildings is not sufficient. The landscape impact of tall buildings on the urbanized areas is significant, so it is important to think about the appropriate creation of space, so-called placemaking (Al-Kodmany, 2017). In Poland there has been a debate about their localisation for many years. This is particularly important in European cities, the cultural heritage of which is subject to conservation and is an extraordinary development attractor. At the same time, there is a strong need in cities to take into account the modernised image of space. These aspects give rise to a wide discourse on the potential locations of tall buildings, which constitute an attractive extension of the city landscape (Czyńska, Rubinowicz, Zwoliński, 2017: 319–341). Spatial policy regarding the location of tall buildings is an extremely important aspect of space creation. In this way, the vision of the development of building height in the city is established and the spatial framework of its implementation is defined. In addition to spatial policy, there are also other symbolic or technological dimensions related to the development of tall buildings. Often in history, it was their influence that determined the progressive interest in tall buildings, which sometimes arose in a chaotic manner in urban space. Nowadays, virtual (computer) analytical methods are available, which enable analysis of urban landscape changes as well as the study of the functional and spatial structure. Additional elements supporting the analysis are open-access data related to spatial resources enabling information about space to be downloaded free of charge, in various digitised formats, and then processed.

In connection with the above, the purpose of this study is to systematise knowledge relating to shaping the development of tall buildings in Poland in relation to the available spatial data and its impact on the urban form of cities. The formulated research method is based on data aggregation and takes into account the trend analysis of the existing spatial structure of the city, as illustrated by the example of Wrocław. The essence of the study is the possible standardisation of proceedings, which can be used in different cities. The general aim of the study should be understood as one of many voices in the discussion on the methods and tools in architecture and urban planning research, the gist of which is the analysis of general trends affecting the quality of the urban environment.

2. Materials and methods

The evolution of technology plays a crucial role in determining the developmental goals of a modern city. We now have increasing access to spatial data. In particular, this applies to data from laser scanning (LiDAR), which is conducive to the development of new horizons in the field of shaping smart cities. Thanks to these techniques, we can talk about more and more effective space management and the modelling of phenomena using geoinformatics (Dwivedi, Uniyal, Mohan, 2015: 40–50) It is important in this respect to skilfully process data from relatively different fields, e.g. remote sensing and spatial planning, which synergistically break down analytical barriers in the development of particular fields of science (Borsa, Zagajewski, Kulawik, 2017). The development of contemporary research methods is not only conducive to the increasingly accurate analysis of spatial phenomena but also to influencing

discourse on the twenty-first-century city paradigm, including influencing new research fields and innovative scientific disciplines, e.g. landscape urban planning (Kosiński, Zieliński, 2016: 7–52).

Data from a point cloud created by laser scanning opens wide possibilities for use in both urban engineering and urban design. Until now, the most popular methods of data imaging have been two-dimensional data on flat surfaces, but the large-scale laser scanning application has enabled the acquisition of extensive elevation information which has been digitally processed to create digital surface models (DSM) (Santos, Rodrigues, Tenedório, 2013: 71–75). Three-dimensional data and its subsequent conversion into an urban plan may refer to urban planning standards and indicators upon which the Polish spatial planning system is based. However, a particularly important role of scanning is the ability to process data into three-dimensional models of cities. This procedure is not simple and is an important subject of research for scientists (Deng, Zhang, Zhang, 2004: 580–583). The possibility of using airborne laser scanning data is very wide. An increasing amount of research is being conducted with regard to city landscape analysis, the localising of tall buildings and determining strategic views in the city, which should be subject to special protection. The usefulness of this data is very high and the detail of its processing varies depending upon analytical needs (Czyńska, 2015: 1359–1366; Rubinowicz, Czyńska, 2015: 1395–1402).

The processing of 3D laser scanning data makes it possible to capture the value of building height with a reasonable degree of accuracy, which clearly makes such data particularly desirable in the urban analysis of the spatial structure of the city. However, transforming LiDAR data is not a trivial process and requires long-term efforts to prepare a correct 3D model (Kulawiak, Lubniewski, 2020: 1–25). Many cities in Poland decide to conduct geospatial analyses aimed at the protection of the value of the landscape. In particular, it is worth mentioning the studies: “Possibilities of locating high-rise objects in the aspect of protecting the panorama of the city of Cracow, Poland – analysis” (Jaśkiewicz, 2009; Bieda et al., 2020: 15–33) and “Study of the location of tall buildings” for Gdańsk, Poland (Bach-Głowińska et al., 2009). The zoning of tall buildings in the context of the urban landscape was defined in these studies. Comparable studies were also conducted for Szczecin (Czyńska, Marzęcki, Rubinowicz, 2011), Warsaw (Jankowska, Oleński, Błażejowski, 2008), Łódź (Bednarek et al., 2012) and Lublin (Czyńska, Marzęcki, Rubinowicz, 2011). All of these, although they mainly concern the issue of landscape protection, refer to the latest computer research methods in urban planning and design.

This study is based on open spatial data shared at the level of the Wrocław municipality and at the national level against which analyses were carried out in the environment of geographical information systems (GIS). Initially, spatial resources were verified and then, using analytical tools of ArcMap and ArcScene software, analyses were carried out related to the possibilities of locating tall buildings in Wrocław. The basis for conducting the above analysis was a set of digital elevation models (DEM) in the form of a point cloud, which was then processed into elevation points illustrating data on the height of buildings and structures in Wrocław (see Fig. 1 for examples).

Part of the data was available at the level of the Spatial Information System of the City of Wrocław as a point database in vector format (shapefile), which indicates the maximum height of the building or structure in the central point of this facility. The key point of this transformation is the fact that the height of the object does not always have to correspond to the point determining the height of the building in accordance with § 6 of the Regulation of the Minister of Infrastructure of April 12, 2002 on the technical conditions of buildings and their location, where this height applies only to “the top surface of the highest ceiling, including the thickness of the thermal insulation and the covering layer, without taking into account the elevators and other technical rooms raised above this plane of the machine room, or to the highest point of the flat roof or structure covering the building located directly above the rooms intended for people” (Santos, Rodrigues, Tenedório, 2013: 71–75). Therefore, it should be

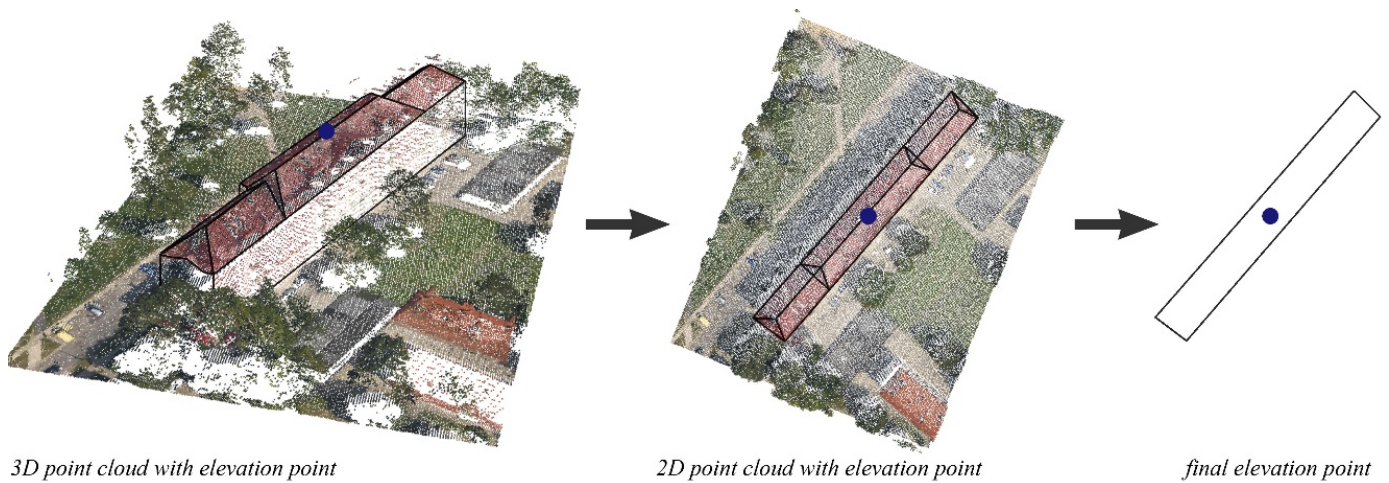


Fig. 1. A simplified diagram of processing data from a point cloud into elevation points with information about the height of the building – blue point (own study based on DTM data obtained from the resources of the Surveyor General of Poland)

understood that the data obtained may indicate heights higher than the above-mentioned points on the roof, for example, due to: additional technical elements, covers, etc., mounted on roofs, which can be verified using, for example, orthophotomaps. Nevertheless, the above data was considered crucial when analysing space because the fact is that the above infrastructure components installed on buildings also affect the perception of space by man and increase the physical height of the building.

3. Study area

The analyses were performed within the administrative boundaries of Wrocław. Wrocław is located in the south west of Poland, in the eastern part of the Dolnośląskie Province, on the Odra River (Fig. 2).

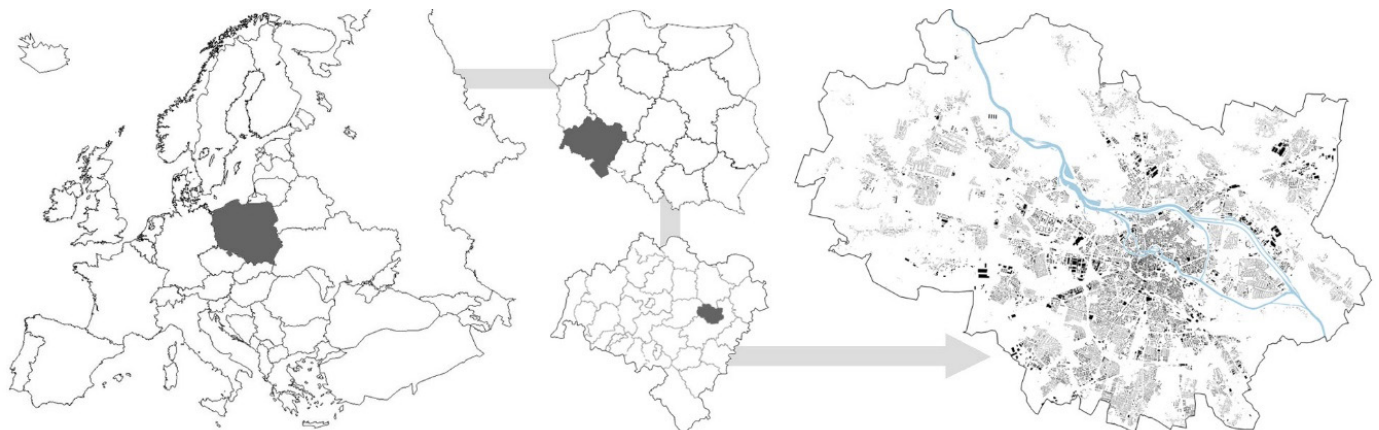


Fig. 2. Wrocław localisation (own study)

The study area was divided into different urban units. The urban units were used in accordance with the study on land use planning of Wrocław from 2018 (Fig. 3) (Uchwała Nr L/1177/18). The proposed division is favourable because of the indication of 101 units smaller than districts or complexes of districts, taking into account the diverse functional and spatial arrangement of Wrocław and the high sense of belonging of the local communities to the immediate area in which they live.

Urban units designate individual areas of the city centre and multi-family and single-family housing estates, as well as areas that are limited to service and industrial functions. In addition, according to the study (Uchwała Nr L/1177/18), the dominant greenery urban unit (Z) was introduced, which covers key areas for the protection of the natural values of Wrocław.

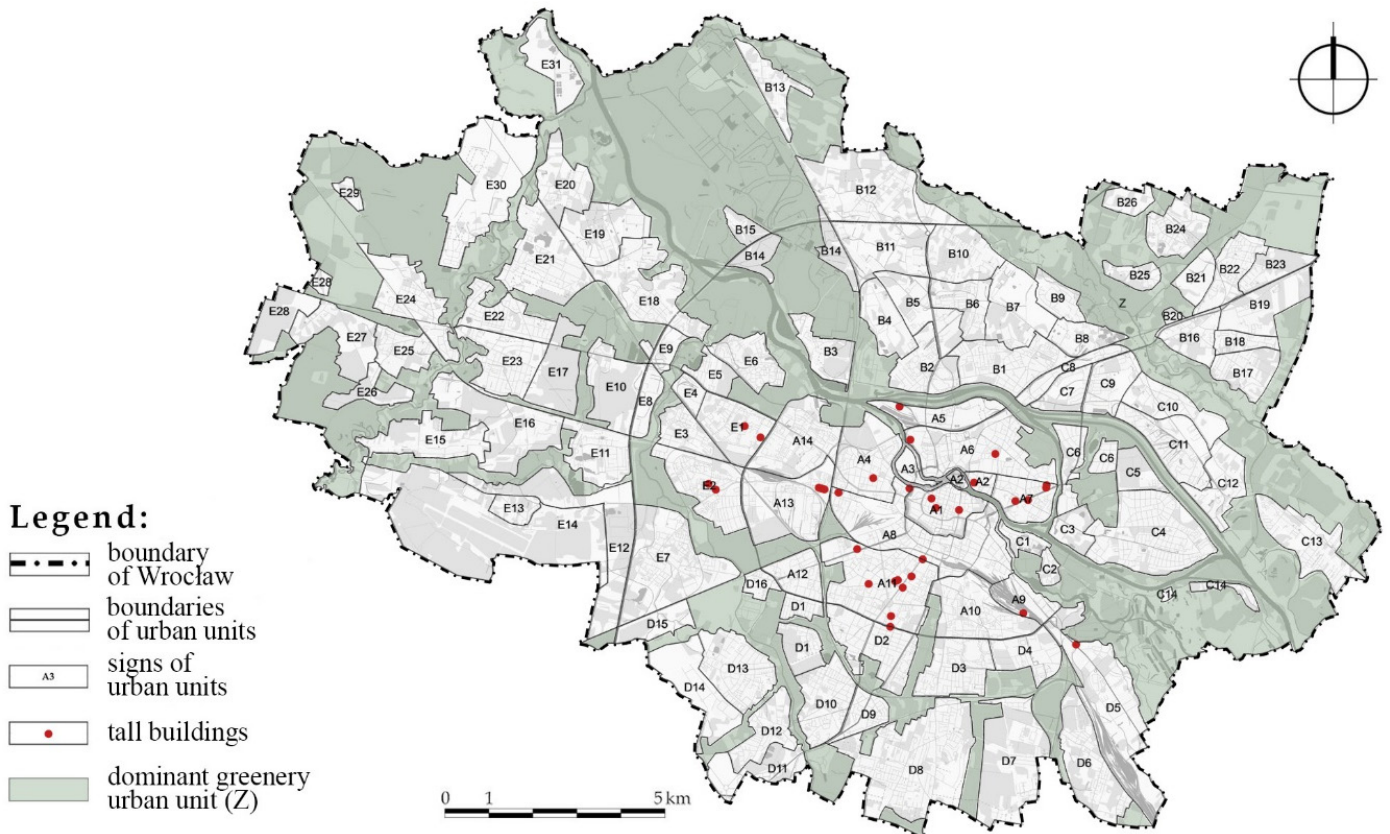


Fig. 3. Division of Wrocław into urban units (own study)

4. Results

The elevation points described above made it possible to conduct a sequence of analyses that related to the assignment of height to individual building objects on map sleepers, and then aggregation of data to urban units.

The first analysis was the height of the highest point of each building object, excluding street furniture. A vector layer containing building objects was acquired and the spatially located values of elevation points were subsequently assigned to the layer with building objects. As a result, it was possible to visualise the map with colour differentiation of the height of building objects throughout the city relative to divisions in accordance with the typology of building functions in Polish legislation (Fig. 4).

As part of the analysis, the locations of objects taller than 55 meters (together with technical elements located on the roofs) were marked on the map. Territorially, tall buildings are located in the centre of Wrocław rather than in the peripheral areas, which is where low buildings predominate. It is not possible to identify an unequivocal principle of locating tall buildings, which also results from the functional diversity of these objects. Some of tall buildings emphasise viewing axes or entire viewing areas (e.g. church towers), yet the overall structure of the city does not clearly indicate the compositional principles and strategies for situating housing and tall service buildings, particularly in the case of secular building. However, some of tall buildings emphasise local composition systems. The tallest building in the city is the Sky Tower skyscraper located in the Śródmieście Południowe urban unit (A11). It is significantly dominant in the city landscape; this is particularly due to the absence of equally tall buildings throughout Wrocław. Other tall facilities are the chimneys of the Wrocław CHP plant and the Cathedral of St. John the Baptist in Ostrów Tumski, which are barely half as tall as the Sky Tower.

The effect of the significant difference in the height of the Sky Tower with those of the next tallest buildings in Wrocław means that it can be viewed from many places



Fig. 4. Height to the highest point of the construction works (own study)

in the city. Czyńska and Rubiniowicz (2017: 87–98) determined the visual impact of Sky Tower in the city using the VIS (visual impact size) method. The skyscraper does not blend in strongly with the urban structure of the city that surrounds it; therefore, its internal exposure (from streets and squares located in city centre) is not significant. “It does not visually interfere with important historical views of the city. The low impact of the building is primarily associated with the compact urban composition of the Old Town and downtown, which ‘protects’ these areas from the visual impact of the building” (Czyńska, Rubiniowicz, 2017: 97). The highest range of visual impact of a tall building applies to both the areas adjacent to it and to “outside” views, i.e. views from outside of the urbanised area of city centre.

The elevation points obtained from laser scanning in Wrocław in June 2015 constitute a very accurate data set. Within the city, over 125,000 points with maximum heights of building objects were determined. In order to identify the spatial trends, the set of points was generalised and the elevation points were then aggregated to the borders of the urban units in which they occur. As a result of the above generalisation, the maximum building height in each of the urban units was determined. The Śródmieście Południowe urban unit (A11) had the highest maximum building height in the city due to it being the location of the tallest building in the city – the Sky Tower (Fig. 5).

Territorially, it can be seen that the units with the tallest buildings are those which are located in central Wrocław. Among the units with the tallest buildings are: Śródmieście Nadodrzańskie urban unit (A6), Ostrów Tumski urban unit (A2), the Old Town urban unit (A1), and Grunwaldzki Square urban unit (A7). In the regions of these units, both service (including sacred) and residential buildings as well as industrial and technical facilities dominate. In the peripheral areas, a limited range of building heights is predominant, and in some areas of urban units (Rędzin Port urban unit – B14, Węzeł Pawłowicki urban unit – B26 and Żar Przemysłowy urban unit – E38) the maximum height of buildings reaches the value of 0 m due to the complete absence of buildings on these areas and this therefore also resulted in a lack of altitude points.

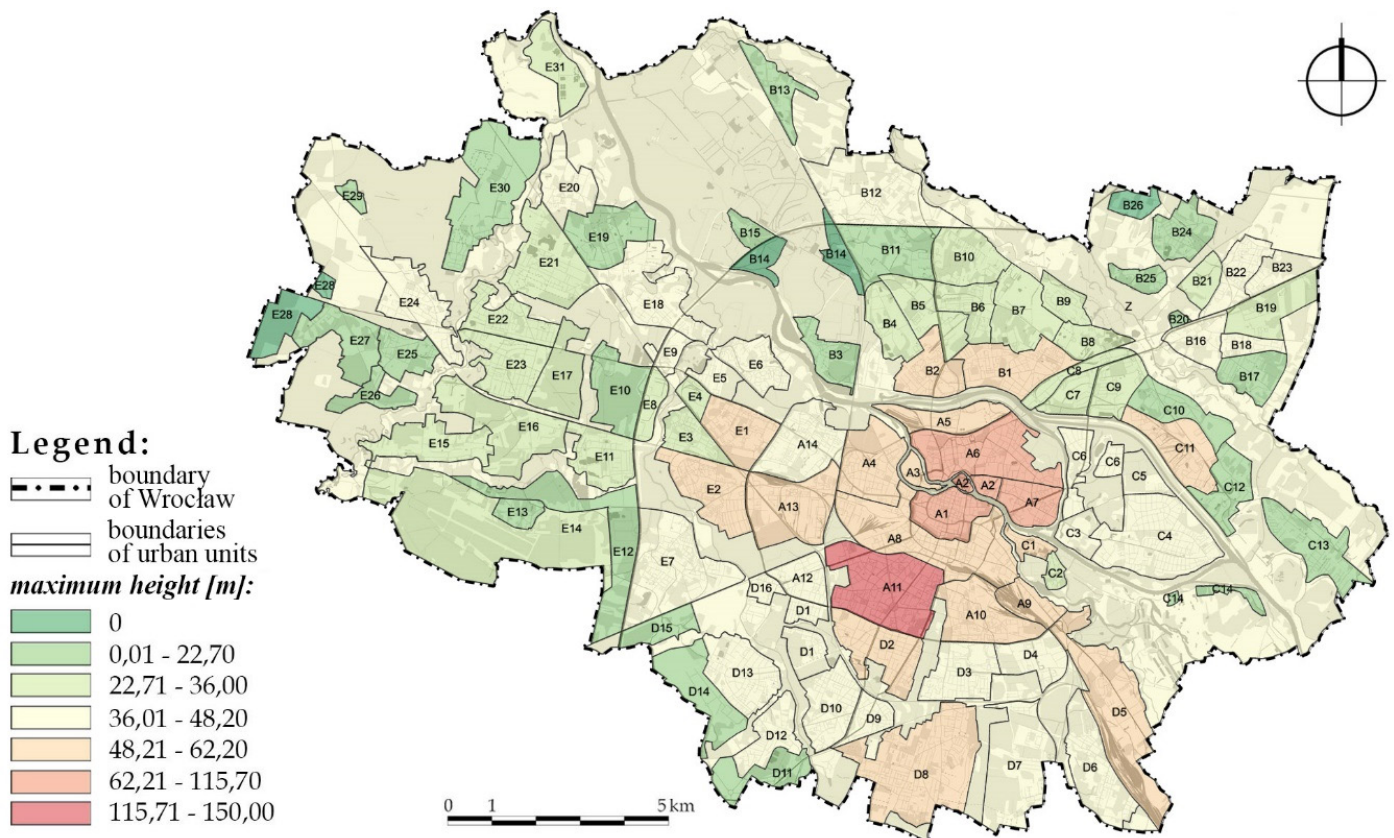


Fig. 5. Maximum building height in each urban unit (own study)

Using the model of elevation points assigned to the urban units, the average height of buildings within them is also indicated (Fig. 6). The purpose of the analysis is to verify the relation between the maximum and average building height in each urban unit.

In contrast to the analysis of the maximum building height, the value of the average building height in the area of the Śródmieście Południe urban unit is not the highest in the city. The areas with the most buildings with high elevation points (thus increasing the average height value) are urban units located in the city centre: Old Town urban unit (A1) and Śródmieście Nadodrzańskie urban unit (A6), as well as the Gądów urban unit (E1), which is located in the west. Similar to the analysis of the maximum building height, the city’s peripheral areas are characterised by the lowest average building height in Wrocław, particularly in urban units located in the west.

The situating of tall buildings may be related to moderating the scale of the current tall buildings, which is in contrast to the surrounding lower buildings. Therefore, using the elevation point data, it was proposed to analyse the maximum amplitude and average height of buildings in urban units (Fig. 7). As a result of the analysis visualisation, the areas with the strongest standard deviation in the examined units were determined.

Intuitively, the area with the greatest differentiation between the maximum and average height of buildings in urban units would appear to be the area of Śródmieście Południowe urban unit (A11) and this was indeed confirmed as a result of the above analysis. The analysis confirms the fact that the Sky Tower dominates over the surrounding buildings – the skyscraper is around fifteen times higher than the average height of the A11 unit. Even despite the fact that it is surrounded by buildings that are around 50–60 m high (so-called gallery buildings), the scale of the skyscraper is over 3.5 times larger than the buildings directly adjacent to it.

The exposure of the tall building depends on its maximum height but it is also affected by the height of the terrain above sea level, which creates the

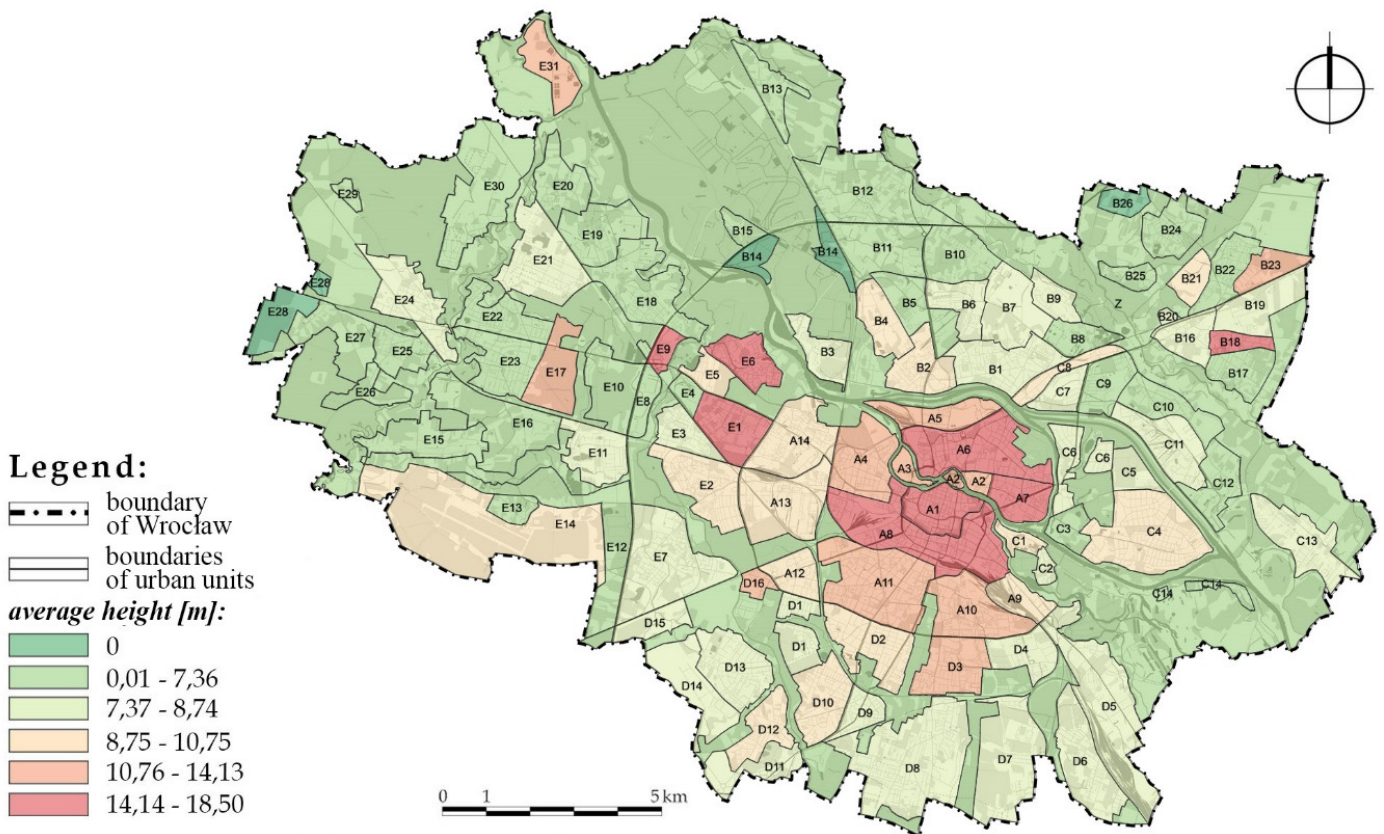


Fig. 6. Average building height in each urban unit (own study)

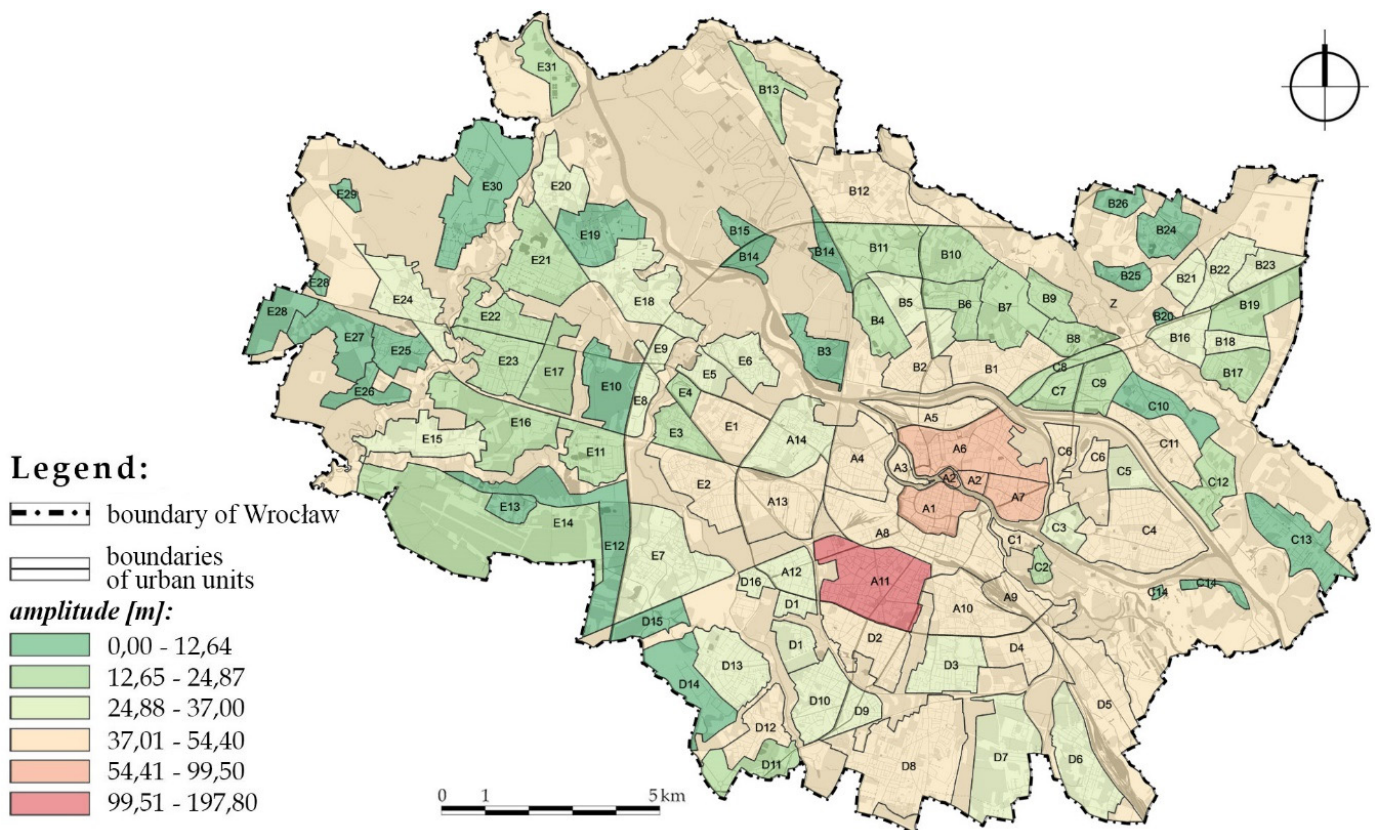


Fig. 7. Amplitude of the maximum and average building height in an urban unit (own study)

impression of an increase or decrease in the height of the object in different parts of the city. In order to identify areas with increased exposure, the altitude above sea level was analysed on the basis of the digital terrain model (DTM) data excluding buildings, structures and vegetation (Fig. 8).

As a result of the analysis, it should be stated that the area of Wrocław is relatively flat and not very diverse in terms of the height of terrain. The lowest region is the valley of the Odra River, while the actual range of the extreme height points above the riverbed is less than 36 m. The decreases in the city area are also small and it usually do not exceed more than 2%. The areas with the highest altitude above sea level within the administrative boundaries of the city are the areas to the south of the southern ring road (Śródmiejska Trasa Południowa), as well as the area to the west of the city, located behind Leśnica and Mokra. Therefore, despite slight differences in height within the city, the areas indicated above may be exposed rather than other regions of Wrocław.

Using the elevation points assigned to buildings and structures on the vector layer, it is easy to build a simplified 3D model of the city, which is a good basis for building a detailed model, taking into account the sculpted facade and providing indications of the actual roof slopes¹. The 3D model can also be used to conduct less accurate, schematic analyses of visibility as well as shading and sunlight analyses of objects in the city. The result would be a 3D model of the city which would represent selected building objects in the form of prism blocks (Fig. 9). An additional advantage of these types of 3D objects is compatibility with other types of virtual software that enable building three-dimensional models of cities.

The above analysis synthesis is the structure of buildings and their heights in urban units, these are presented in the form of charts, one for each urban

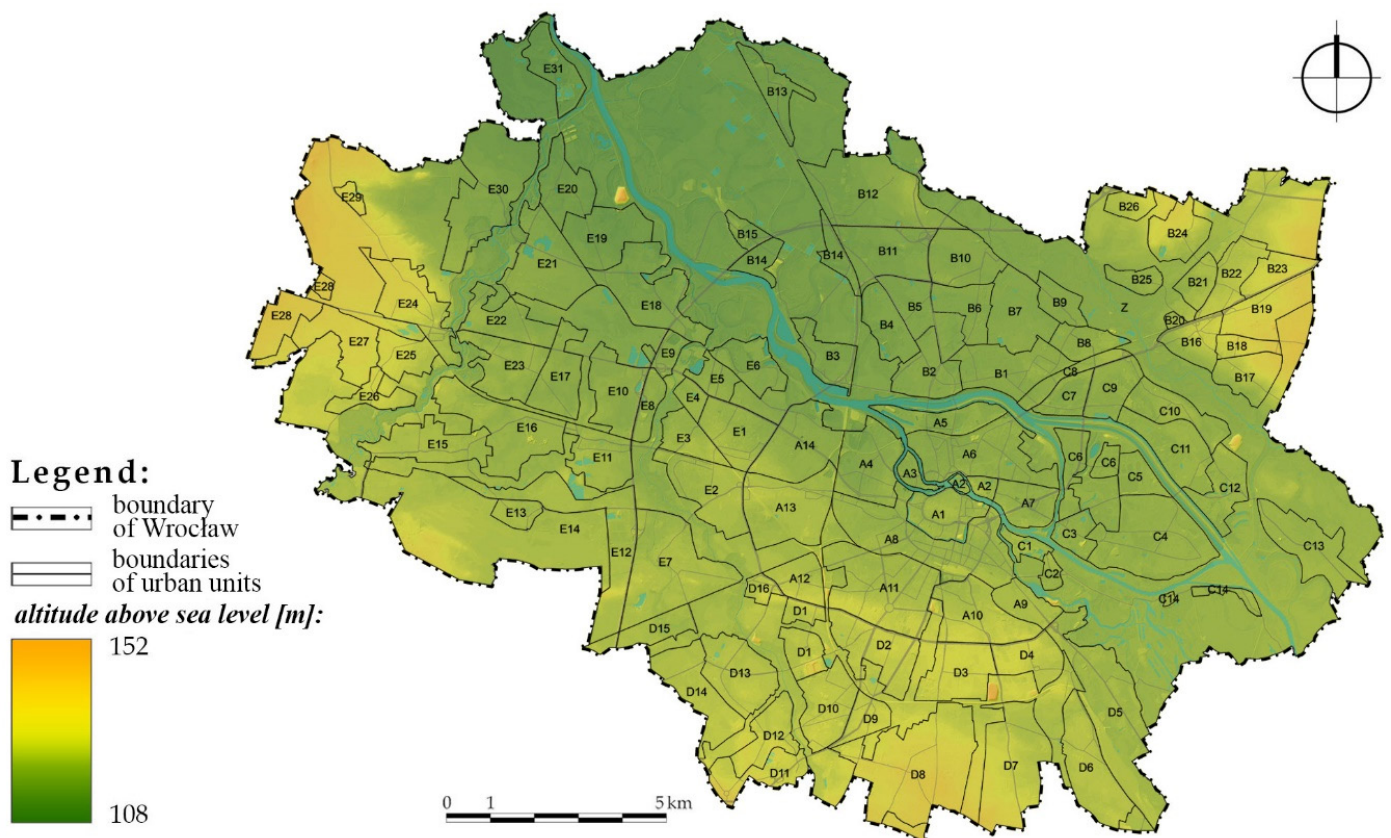


Fig. 8. Altitude above sea level (own study)

¹ The suggested proposal for building a city model is one of many available. Nowadays, the use of LIDAR data is becoming more common, which is then processed into city models.

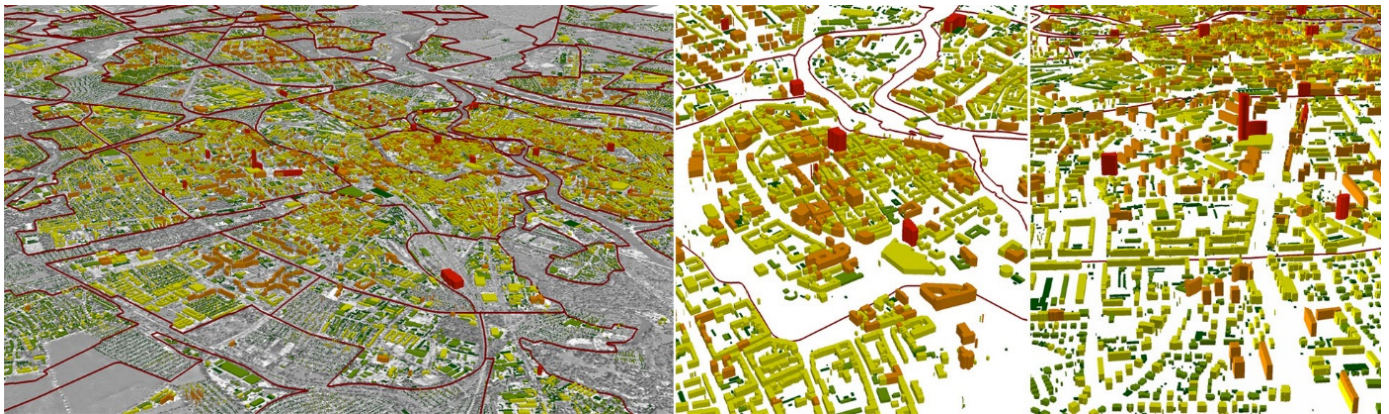


Fig. 9. Selected views of the simplified 3D city model (own study)

unit that has objects with registered altitude points. Elevation data in urban units were ranked from smallest to largest. For better visualisation, the graphs are symmetrical about the y-axis. Sample charts for selected urban units are presented below (Fig. 10).

Interpreting the charts for all urban units in the city, it should be noted that almost all units have dominants or accentuating height differentiation – this is evidenced by elevations located centrally in the charts, which are their maximum values and vary in height depending on the unit. It is also worth emphasising that the largest building heights and the most numerous groups of high objects are recorded in the central area of the city, particularly in units with codes beginning with the letter ‘A’. The shapes of the graphs also show how many objects in given height groups are within the area of a given unit and indicate which theoretical models of height distribution shape the structure of the studied units.

The presented graphs do not constitute a cross section of building height in urban units but only an increasing order of elevation points; they do, however, illustrate the distribution of buildings within the urban units while showing the large variation of building heights within the city. However, based on the transformation of the vector data into a raster structure and the TIN (triangulated irregular network) model, it is possible to create simplified cross sections, including buildings. An application has been implemented on the Wrocław geoportal website that enables the

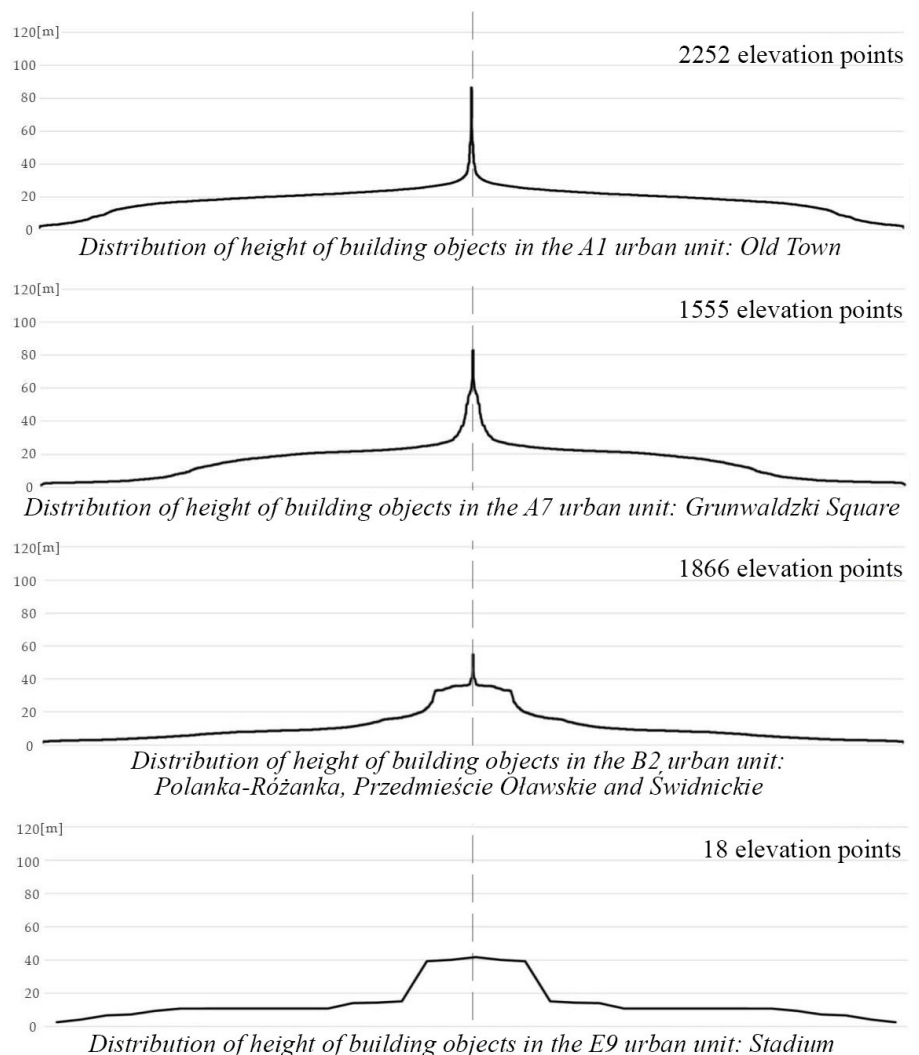


Fig. 10. The distribution of height of building objects in the chosen urban units (own study)

automated generation of a cross section by linearly indicating the place where it is to be made. The presented data allows verification of the heights of objects and terrain in relation to sea level.

5. Discussion

The analyses show spatial diversity in the distribution of building height in the city. The methods used for this are universal – their application is also possible in other cities for which laser scanning data is available. The aggregation of spatial data at the level of urban units makes it possible to identify trends in the height of buildings, and also allows attention to be paid to the problems of too high a diversity of building height, which can negatively affect the urban form of the city and, as a consequence, its perception. Certainly, the delimitation of urban units plays an important role in the analysis. In the case of different boundaries, the aggregation of data could produce different results.

It seems appropriate to question the need for the aggregation of spatial data. The primary aim of the adopted research procedure is to analyse spatial trends in the urban environment. Retaining data from the point cloud in its input form would not only be difficult for further data processing, it would also be very expensive. Data processing of a point cloud into elevation points can take place only once. The processed data then just needs to be updated with subsequent elevation points, for example, when the object is commissioned. In this situation, there is no need to create new data from laser scanning, and the database can be updated automatically while entering the object in the register of land and buildings. On the one hand, it reduces costs resulting from the lack of the need to constantly update LiDAR data, and on the other hand, the research task is facilitated by aggregating an enormous amount of data.

The aggregation of elevation data should be preceded by an analysis of the dispersion of tall buildings in the given city, also with regard to the function of these objects and the time of their creation. This approach indicates the form in which the further development of skyscrapers in the city could be conducted. On the other hand, the development of tall buildings does not have to be included in spatial policy of the city. Taking into account both the composition of individual objects and trends in the collective form can give a more complete picture of urbanised areas.

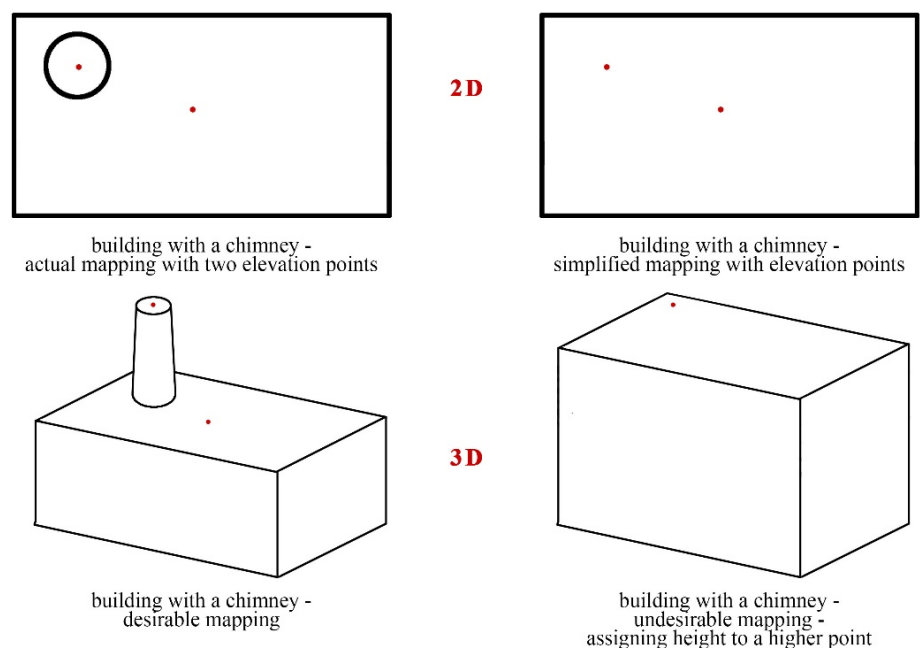


Fig. 11. Diagram of possible errors in a 3D model (own study)

In addition, difficulties in both 2D and 3D analysis result from the diversity of spatial data that comes from different sources. The process of data standardisation is lengthy and requires a number of actions based on the verification methods of various map backgrounds. As an example, the incorrect assigning of the maximum height to a given building can take the form of, for example, two height points representing two parts of one object that has different heights, as in Fig. 11.

The method for the aggregation of spatial data in the study of the urban structure on the example of the trends in the locating of tall buildings takes part in current research discussion regarding the usage of photogrammetry in urban planning and design. The conclusions from literature on the subject matter presented in the research material clearly indicate that thanks to analytical techniques combining urban planning and photogrammetry, one can speak of more and more effective space management. In addition, the crucial part of such a technique is to take into account the three-dimensional aspect of space, which is necessary (and often ignored) in Polish urban planning standards (Szumigata 2019). Investigating trends in the development of tall buildings in these times is particularly important. However, the major issues are to use the new horizons in planning smart cities, including LiDAR technology (Dwivedi, Uniyal, Mohan, 2015: 40–50) and set general principles for shaping the spatial policy of the cities. Consequently, it can be supplemented with detailed research relating to individual buildings (Czyńska, 2015: 1359–1366; Czyńska, Rubinowicz, 2017: 87–98).

6. Conclusion

The following conclusions can be drawn with regard to the analyses:

- ▶ Geospatial analysis is an important research element in the debate concerning the locating of tall buildings in cities. As a result of such analyses, it is possible to systematically capture the studied phenomenon and perform multi-faceted analyses related to tall buildings and their impact on the environment.
- ▶ Open-access spatial data in digitised formats greatly facilitate the implementation of geospatial analysis; however, different sources sharing this type of data use different methodology for their preparation and further processing and may therefore lead to partially incorrect or distorted study results.
- ▶ The multitude of data made available by the Municipal Office of Wrocław via the municipal geoportal website and the state geodetic resource enables the implementation of a number of analyses that are characterised by their relatively high levels of accuracy. The available elevation points form the basis for many analytical studies, which in a detailed or generalised manner enable the examination of building heights in the city.
- ▶ The objects on the border and above fifty-five metres in height are accidentally identified as being in the city of Wrocław, which means that uniform rules for shaping the spatial composition in terms of tall buildings in relation to the spatial composition of the entire city cannot be found. Some of these objects emphasise the local urban composition within individual building complexes.
- ▶ As a result of the performed analysis, it should be stated that Sky Tower is a significantly tall object in the city and the urban unit in which it is located. The skyscraper is over fifteen times taller than the average height of the building in the Śródmieście Południowe urban unit, and 3.5 times larger than the tallest buildings neighbouring it. As a result, spatial actions are necessary, which will moderate the scale of the currently varying heights.
- ▶ The visual impact of the Sky Tower building is not significant within the historic central areas of the city, which are protected by a dense

- urbanised structure. Nevertheless, outside the central area of intensive development, the skyscraper dominates the landscape.
- ▶ The average building height in the urban units is the highest in the centre of Wrocław and within units where large-block buildings dominate. Therefore, it is possible to supplement these areas with tall buildings not scaled to the surroundings.
 - ▶ The topography of Wrocław is not a significant indicator in the relation with locating tall buildings. The area with the strongest possible exposure resulting from the elevation of the terrain may be the area to the south of the southern ring road (Śródmiejska Trasa Południowa).
 - ▶ The building height for urban units in Wrocław leads to the unequivocal conclusion that there are differences in the development of city within individual units, which are local dominants or objects that have a significant impact on the landscape throughout the city or the wider environment. The key point of this conclusion is the fact that the spatial composition of Wrocław takes into account the need to create objects higher than the surroundings, however not as rescaled as the Sky Tower, which is the dominant feature of the entire region.
 - ▶ The method for the aggregation of spatial data obtained from laser scanning is a universal research tool in the search for trends occurring in the urban form of the city, particularly in relation to building height.

The authors would like to thank the Surveyor General of Poland for providing them with a set of measurement data regarding the digital terrain model.

References

- Al-Kodmany, K., (2017). *Understanding Tall Buildings. A theory of placemaking*. New York: Routledge Taylor & Francis Group.
- Bieda, A. et al. (2020). 3D Technologies as the Future of Spatial Planning: the Example of Krakow. *Geomatics and environmental engineering*, 14(1), 15–33. <https://doi.org/10.7494/geom.2020.14.1.15>
- Bach-Głowińska, J. et al. (2009). *Studium lokalizacji obiektów wysokościowych*. Gdańsk: Biuro Rozwoju Gdańska.
- Bednarek, K. et al. (2012). *Studium lokalizacji obiektów wysokościowych kształtujących sylwetę Łodzi*. Łódź: Miejska Pracownia Urbanistyczna.
- Borsa, M., Zagajewski, B., Kulawik, B. (2017). *Teledetekcja w planowaniu przestrzennym*. Warszawa: Ministerstwo Infrastruktury i Budownictwa.
- Czyńska, K. (2015). Application of Lidar Data and 3D-City Models in Visual Impact Simulations of Tall Buildings. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XL-7/W3, 1359–1366.
- Czyńska, K., Marzęcki, W., Rubinowicz, P. (2011). Studium wartości widokowych miasta Lublin. *Obserwatorium Polityki Miejskiej IRMiR RSS*. Retrieved from <http://obserwatorium.miasta.pl> (date of access: 2020/09/01).
- Czyńska, K., Rubinowicz, P. (2017). Sky Tower impact on the landscape of Wrocław – analysing based on the VIS method. *Architectus Pismo Wydziału Architektury Politechniki Wrocławskiej*, 2(50), 87–98. <https://doi.org/10.5277/arc170207>
- Czyńska, K., Rubinowicz, P., Zwoliński, A. (2017). Analiza Zabudowy wysokiej w krajobrazie miasta. *Teka Komisji Urbanistyki i Architektury PAN oddział w Krakowie*, XLV, 319–341.
- Deng, F., Zhang, Z., Zhang, J. (2004). Construction 3D Urban Model from LiDAR and Image Sequence. *ISPRS Archives*, XXXV, B3, 580–583.
- Dwivedi, M., Uniyal, A., Mohan, R. (2015). New Horizons in Planning Smart Cities using LiDAR Technology. *International Journal of Applied Remote Sensing and GIS*, 1(2), 40–50.

- Jankowska, M., Oleński, W., Błażejowski, M. (2008). *Analiza urbanistyczna lokalizacji budynków wysokościowych na obszarze śródmieścia Warszawy*. Warszawa: Miejska Pracownia Planowania Przestrzennego i Strategii Rozwoju.
- Jaśkiewicz, M. et. al. (2009). *Możliwości lokalizacji obiektów wysokościowych w aspekcie ochrony panoramy miasta Krakowa – analiza*. Kraków: Biuro Planowania Przestrzennego Urzędu Miasta Krakowa.
- Jopek, D. (2018). Czynniki kształtujące przestrzenną formę miasta. *Rozwój Regionalny i Polityka Regionalna*, 42, 81–89.
- Kosiński, W., Zieliński, M. (2016). Landscape urbanism and the urban landscape. Theory, practice, education. *space & FORM*, 25, 7–52.
- Kulawiak, M., Lubniewski, Z. (2020). Improving the Accuracy of Automatic Reconstruction of 3D Complex Buildings Models from Airborne Lidar Point Clouds. *Remote Sensing*. 12(10), 1643, 1–25. <https://doi.org/10.3390/rs12101643>
- Marzęcki, W., Czyńska, K., Rubinowicz, P. (2005). *Studium kompozycyjne Szczecina ze wskazaniem terenów dla zabudowy wysokiej*. *Biuletyn Informacji Publicznej Urzędu Miasta Szczecin RSS*. Retrieved from <http://bip.um.szczecin.pl> (date of access: 2020/09/01).
- Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. z 2019 r., poz. 1065).
- Rubinowicz, P., Czyńska, K. (2015). Study of City Landscape Heritage Using Lidar Data and 3d-City Models. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XL-7/W3, 1395–1402.
- Santos, T., Rodrigues, A.M., Tenedório, J.A. (2013). Characterizing urban volumetry using lidar data. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XL-4/W1, 71–75.
- Szumigata, P. (2019). *Diagnoza stanu ochrony historycznych struktur urbanistyczno-krajobrazowych powiatu poznańskiego na podstawie metody Historycznych Kodów Przestrzennych i zapisów miejscowych planów zagospodarowania przestrzennego*. Poznań: Wydawnictwo Uniwersytetu Przyrodniczego.
- Uchwała Nr L/1177/18 Rady Miejskiej Wrocławia z dnia 11 stycznia 2018 r. w sprawie uchwalenia studium uwarunkowań i kierunków zagospodarowania przestrzennego Wrocławia.

Metoda agregacji danych przestrzennych w badaniu formy urbanistycznej miasta na przykładzie tendencji lokalizacyjnych budynków wysokościowych we Wrocławiu

Streszczenie

Dynamiczny rozwój technologii sprzyja dostępowi do informacji o przestrzeni, a tym samym ma niebagatelny wpływ na formę urbanistyczną miast. Dotyczy on nie tylko zachowań przestrzennych użytkowników, ale także zasad prowadzenia polityki przestrzennej. Celem opracowania jest usystematyzowanie wiedzy z zakresu kształtowania rozwoju budownictwa wysokościowego w Polsce wobec dostępnych danych przestrzennych i ich wpływ na formę urbanistyczną miast. Poddano weryfikacji metodę agregacji danych przestrzennych w formie chmury punktów ze skaningu laserowego LiDAR, sporządzono analizy geoprzestrzenne i opracowania mapowe w środowisku GIS uwzględniające tendencje w zakresie rozkładu wysokości zabudowy. We wnioskach podkreślono istotę najnowszych metod badawczych możliwych do implementacji w kontekście analiz urbanistycznych. Studium przypadku dla Wrocławia pokazuje, że metoda agregacji danych przestrzennych ze skaningu laserowego jest uniwersalnym narzędziem badawczym w poszukiwaniu tendencji występujących w formie urbanistycznej miasta, w szczególności w odniesieniu do wysokości zabudowy.

Słowa kluczowe: technologia LiDAR, planowanie przestrzenne, urbanistyka, analizy geoprzestrzenne, polityka przestrzenna, punkt wysokościowy