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GEOMETRICAL STRUCTURE OF PUBLIC SPACES IN VIRTUAL CITY MODELS. EXPLORING URBAN MORPHOLOGY BY HIERARCHY OF OPEN SPACES

GEOMETRYCZNA STRUKTURA PRZESTRZENI PUBLICZNYCH W WIRTUALNYCH MODELACH MIAST. BADANIE MORFOLOGII MIASTA POPRZEZ STRUKTURĘ PRZESTRZENI OTWARTYCH

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ABSTRACT

Urban development is now becoming an increasingly complex challenge in global and local terms. The urban form is both, the element of the city's sense and the spatial framework of urban transformations. The morphology of the city is changing constantly with urban development. What can be continuously observed is, that "cities and their complexes grow spatially, forming large areas and absorbing new territories." [2]. Urban morphology consists of built-up tissue and voids in-between, so the urban development is directly related to the volume and geometrical structure of open areas and public spaces. If the public life occurs in the space in-between, exploring tools of advanced urban analyses focused on morphology of open spaces seems to be important and actual. Spatial disposition and relation between public spaces define unique features of towns and contribute to the general perception of the sense of cities. However the problem is not as obvious as it may seem in practical terms. While the analysis of the built-up tissue of cities is relatively achievable, a measurable analysis of the space in-between is a considerable challenge due to the lack of defined geometry. This geometrical aspect of open spaces in cities is addressed in this article. The promising and powerful data environment enabling the development of such analytic tools are 3D virtual city models. The already introduced by the author analytic method called 3D-Negative (N3D) allows quantification and measurable analyses of the "invisible" geometry. The method is closely related to GIS and cityGML environments. The purpose of the article is to analyze regularities, spatial distribution and structure of public spaces in selected cities in area and linear means.

Key words: 3D-Negative (N3D), cityGML, public spaces, urban morphology, virtual city models.

1. INTRODUCTION

Experiences based on observations of spatial development show the essence and necessity of an attentive attitude to urban landscape. The cityscape has been studied for years mainly in terms of structure and parameters of buildings, silhouettes of cities or behaviour of users in space. Similarly to the appropriateness of morphological studies of built-up structure, it is necessary to examine the structure of open spaces. This has been invoked in literature many times, but because of difficulty in measuring its volume and the difficulty of direct mapping it remains to a large extent as a postulate of paying attention to the essence of the genetic code of city recorded in geometry of space between buildings [3],[9]. Generating a geometric structure of open spaces within a virtual city model opens many possibilities for exploring the city's morphology by analysing the distribution and hierarchy of open spaces. Current capabilities of computer tools are evolving towards and enable the automation of many analytical processes. This tendency is addressed by the analysis of the morphology of open urban space using the N3D method. The worth emphasizing is the fact, that the developed procedure allows to perform the process of generating 3D-Negative geometries in an automatic manner, identical for different areas within a virtual model of standardized accuracy

2. BACKGROUND OF THE METHODOLOGY

After a period of very strong development of computer tools enabling digital reconstruction of the urban landscape and visualization of spatial data, the time has come when the use of these data for analytical purposes becomes widespread and highly appreciated in the planning and management of urban space. Accuracy of mapping reality using digital data, in particular 3D virtual models is very high. The qualitative gap divides the early models of cities from the turn of the 20th and 21st century and current virtual models. They are also shared by the current general availability and multiplicity of applications.

Spatial data in the form of 3D virtual city models are still very attractive for planning visualizations, building a virtual game world or public geographic portals presenting various locations in the world and cultural heritage. The real value, however, lies in the application possibilities for observations and advanced urban analyses.

Virtual city models have been developing in a diversified manner in terms of their design, accuracy, structure and method of obtaining source data. Depending on these parameters, the models have specific capabilities and limitations related to the application of computer tools and analytical methods when using them. Benefits resulting from different types of data were presented in different publications (Zwoliński, 2014). A challenge in the process of developing diverse 3D models of cities turned out to be the unification of data and accuracy - only with this assumption the city space can be treated as an objective set of spatial data.

In a generalized approach, within the development of the environment of virtual city models, we can distinguish the thread of the emergence and development of models embedded in the CAD environment and those that arise using the source data from aerial scanning[1].

In the first case, there has been a huge progress in the field of computer tools, that enable the construction and attractive visualization of even very accurate CAD models – however, they are still done basically in a manual manner from a human using the appropriate software. In the field of CAD models, however, used mainly for design and planning purposes, the problem of data standardization also appeared and constitutes a separate

[1] LiDAR – Light Detection and Ranging

field of developing computer techniques[2]. Obviously, the CAD environment also allows the use of virtual models for urban analyses, however, the assumption of the mapping of space based on manual measurements is burdened with the lack of full objectivity of spatial data.

The original assumption of the use of LiDAR techniques to search for archaeological sites and historical remnants turned into a very wide field of applications – in fact, to a complete scan of the space in which we exist. Airborne scanning allowed to register and save spatial data concerning both, natural and urban landscapes. Thanks to the implementation of the ISOK program[3], Poland has become a leader in the coverage and accuracy of the scanning data (Rubinowicz, 2017).

The LIDAR data has huge application potential. According to information materials prepared by GUGiK[4], the list of basic areas of application of scanning data covers at least a dozen or so items. These include: inventory applications, field measurements, generation of orthophotomaps, creation of coverage maps and land use, threat modeling, 3D building models, volumetric 3D analysis, energy potential analysis, 3D urban space modeling etc. [10]. For presented in the article on considerations in the field of advanced urban analyzes, 3D modeling of urban space based on LIDAR data is of key importance for further explanations. Particular significance and potential is related to the following in the framework of the ISOK project: the BDOT10k spatial database, the Digital Surface Model (DSM) and the Digital Terrain Model (DTM) – see Figure 1 (below). BDOT10k is a valuable resource because it combines numeric and statistical data with spatial data. The data is spatially very accurate and embedded in the geodetic coordinate system (Rubinowicz, 2017).

To underline the potential of analytical applications of the virtual cities' models environment, it is worth mentioning the recent achievements of CCU, ZUT in Szczecin. Namely, methods related to the analysis of the urban landscape in the field of the location of tall buildings (VIS)[5], in the field of landscape protection and city panoramas (VPS)[6] and in the scope of parametric analyses of the structure of open spaces in cities (N3D)[7]. The above methods have been developed based on the BDOK10k, DTM and DSM data combination.

The 3D-Negative (N3D) method developed by the author (Zwoliński, Rubinowicz, 2016) to enable a parametric analysis of the open space layout in cities is indicated in the article as a potential for exploration morphology of cityscapes by the means of its open spaces distribution.

3. 3D-NEGATIVE (N3D)

The 3D-Negative (N3D) method has been developed especially for the environment of virtual city models. Initially it has been developed for simple CAD models, later the tool was embedded in the citGML standard, finally the presented state of the method bases directly on LiDAR-based data – DSM, DTM models combined with vector map. However, for the purposes of the method, the virtual city model generated for further application

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[2] It is primarily about the so-called BIMs - Building Information Modelling, a technology developed for the uniform recording of technical and spatial parameters of planned buildings and investments.

[3] ISOK – (Informatyczny System Ochrony Kraju) Polish IT system of country protection against extraordinary threads is a part of implementation of EU INSPIRE directive implementing the unified spatial information system

[4] GUGiK – Główny Urząd Geodezji i Kartografii, [eng: The Main Office of Geodesy and Cartography)

[5] VIS – Visual Impact Size, a method devoted to analysis of cityscape in terms of potential conditions and locations of tall buildings in the city, author: K. Czyńska, P. Rubinowicz, CCU, WPUT

[6] VPS – Visual Protection Surface, a method focused on protection of cityscape and visual heritage of the cityscape, author: P. Rubinowicz, K. Czyńska, CCU, WPUT

[7] N3D – 3D-Negative, a method developed for parametric analysis of geometric structure of open spaces in cities, author: A. Zwoliński, CCU, WPUT

of the N3D method has been limited to the accuracy of LOD1 according to the cityGML standard. The theoretical construction of the method and construction within the virtual city model is presented on the Figure 1. The N3D has a triangulated spatial form stretched between the terrain and buildings in the city space, where the upper surface results directly from the height of the buildings. The geometry of the space between the buildings is detected and generated using the Delaunay triangulation. The strength of the method is the validity of the data and the accuracy of the virtual city model allowing for precise generation of the geometry of open spaces. The premise for creating the presented computer tool was to support planning of buildings or protection of the open space of cities based on unique spatial parameters and the arrangement and distribution of space between buildings - largely understood as a public space.

The 3D-Negative can depict open spaces of the city in terms of area, volume and in the context of spatial distribution. An additional element enabling the exploration of the city's morphology are spectral views that allow the analysis of public spaces in a linear and radial system. Due to the DTM data, the generated N3D model takes into account the relief of terrain.

The essence and accuracy of the N3D geometry is clearly visible in relation to the 3D model embedded in the popular Google Maps application (Fig. 2). Detection details of individual geometry vertices and interpolation of specific points are described in previous publications. In the N3D model, the logic of city urban composition is clearly visible – in the context of space between buildings. The N3D also illustrates areas resulting from strategic documents of the spatial planning process (green corridors, rings etc. delimited in local development plans).

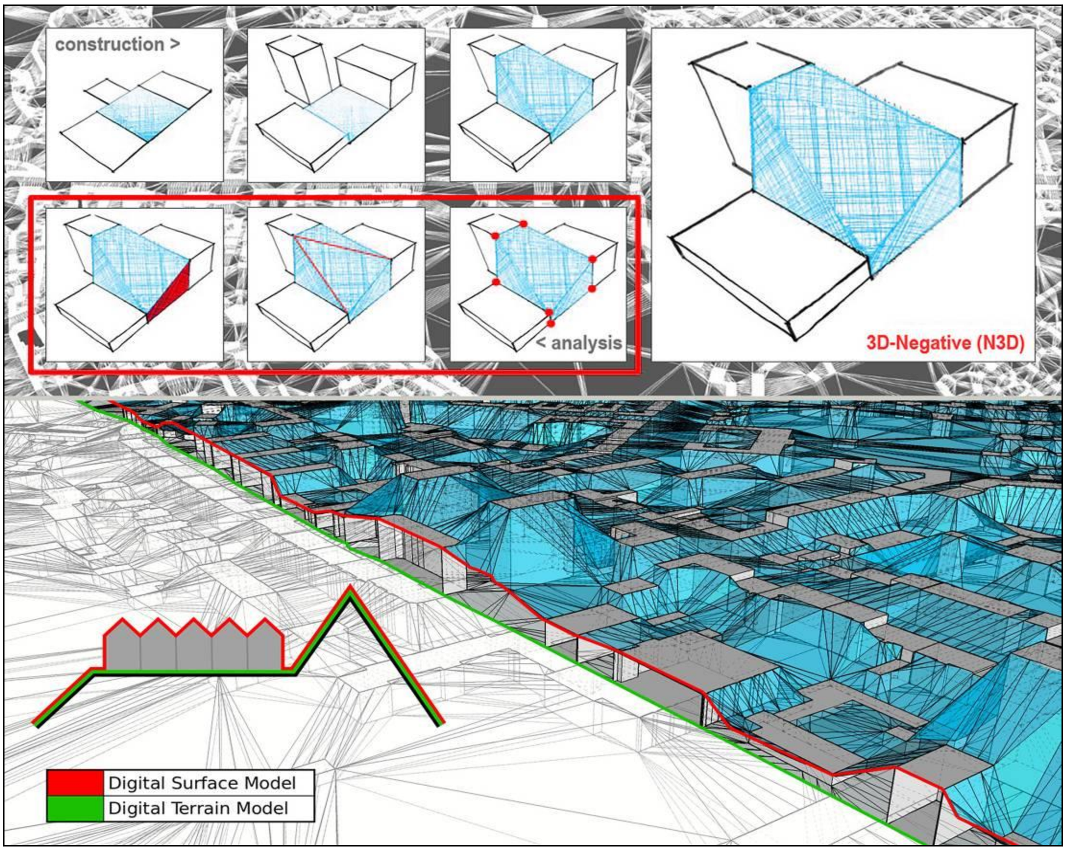

Fig. 1. Theoretical construction of the N3D method – volumetric representation of space between buildings in virtual city model (above). Construction of the 3D-Negative geometry with reference to source data from DTM / DSM models (below). Source: author

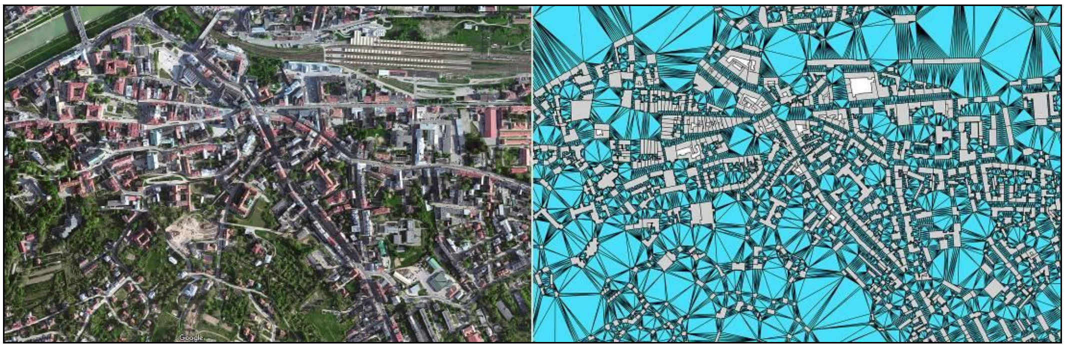

Fig. 2. Comparison of the same part of the city of Przemyśl (PL) represented by virtual city model embedded in popular open-access application Google Maps and by the N3D model of open spaces generated within LOD1 virtual city model. Source: Google Maps / author

The current verified capability of the computer tool is detection of the 3D-Negative for entire city area of one of polish small towns, for the area of around 85 km^2. Computer operations for the maximum tested area took around 2-3 hours. It is worth mentioning, that the N3D detection and generation process for the presented in the article area lasted less than 30 minutes.

4. EXPLORING MORPHOLOGIES BY OPEN SPACES

Summing up the presented methodology, the 3D-Negative (N3D) provides a kind of urban microscope that allows a different, new look at the city's morphology through the structure of open spaces. Thanks to the automated computer process of generating an additional three-dimensional model representing the space between buildings within a virtual city model, we get information about the structure of open spaces, which can be measured and analyzed using various parameters. Due to the use of data from aerial scanning (LiDAR), we are dealing with data of high accuracy and high availability in the European Union (thanks to the implementation of the INSPIRE Directive)[8]. Open-access standards for virtual city models do not offer tools for direct analysis of the "invisible" geometry of open spaces. The N3D is the complement to in-situ analytical work in the city space and publicly available, general city models (e.g. Google Maps / Earth). The details of detection and triangulation were presented in previous articles [15, p. 162-169].

To present the exploration of urban morphology in the scale of the city and its specific fragments, the N3D model was generated for the area of 15 km^2 of Koszalin - one of the cities located in western Poland. The selected area covers major part of the city. The selected city is an interesting example due to the existence of areas with clearly different types of open spaces. The city center is a compact urban structure, in the areas around the center there are buildings of loose diversified structure, in addition, the city is crossed by open areas connected with both, the public greenery and the city's linear infrastructure (railway etc.).

[8] Thanks to this, Poland has become a leader in the accuracy and accessibility of this kind of spatial data.

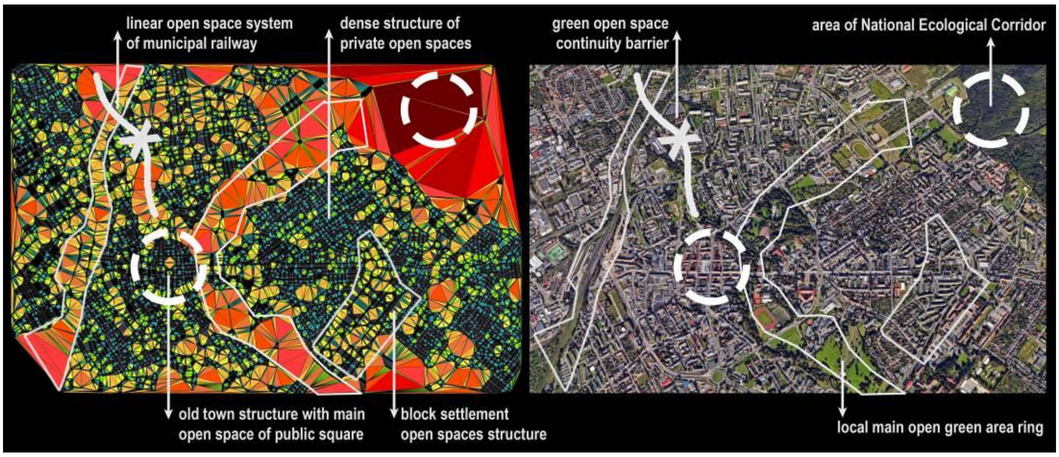

Fig. 3. Mapping of open space morphology using the surface parameter within the N3D geometry (on the left) vs. the real picture of the city structure – the city of Koszalin, PL. Selected components of open spaces structure marked on the figure. Source: author / Google Maps

The presented above (Fig. 3.) set of the open space (on the left) morphology mapping and the general city image (right) presented above shows how the elements of the hierarchy and distribution of these spaces are explained by mapping using the N3D method. The triangular geometry N3D is given with colors in shades from red (the largest open areas detected between the buildings) to the blue colors (smallest spaces). The most intense red elements of the N3D model are the largest open spaces in the hierarchy constituting large areas of high greenery - part of the nationwide ecological corridor. The other readable elements in the hierarchy of open spaces are linear systems that are: the main local area of public greenery (arched band connecting with the mentioned ecological corridor) and a sequence of open spaces designated by the course of the railway line (north-south on the west side of the city). The green belt of public green is a clear element of the city structure separating the part of the center from the areas invested in the later period. The N3D reveals not only the regularity of urban morphology, but also irregularities in the structure of the city's open spaces. In the western part, there is a cross marked with the disruption of the continuity of the system of green open spaces, which can be clearly seen in the geometric layout of the N3D model.

The second analytical potential of 3D-Negative method, regardless of the analysis and imaging of the overall morphology of open spaces in the scale of the whole city, is the ability to compare the hierarchy and distribution of open spaces in different types of buildings occurring in one or different cities. For the analysis, two areas were selected: A - a clearly defined city center, B - a fragment of the post-war city structure. Both areas represent a significantly different hierarchy of open spaces.

Hierarchy and the layout of the open spaces of area A is based on the open space of the main public square located in the geometric center of the dominant center and the system of surrounding spaces having a similar and homogeneous shape. Area B represents a more balanced in terms of size hierarchy, however, a less regular arrangement of individual open spaces. The size of single N3D components of the space between buildings is (except one exception) in the range up to 5000 m^2 (0.5 ha). In the case of terrain A, the size uniformity of individual spaces is very high - apart from a few isolated cases, the area of the remaining triangles defining the space between the buildings remains in the range of 200-500 m^2 (marked in light blue).

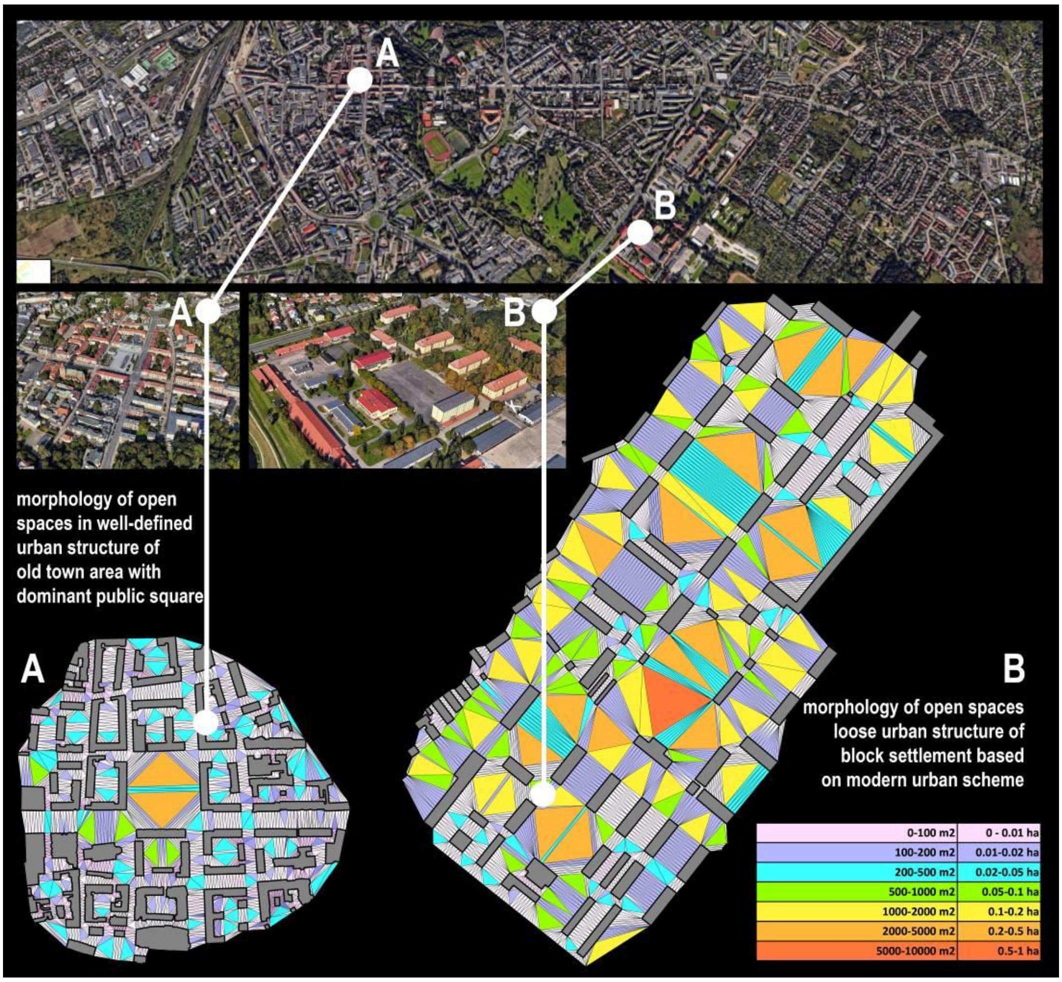

Fig. 4. Analysis of two different morphologically areas in Koszalin by the 3D-Negative within virtual city model. A – morphology of open spaces in well-defined urban structure of old town area with hierarchy of public spaces based on the dominant main public square; B – morphology of open spaces in loose urban structure of area with residential blocks planned in modern urban scheme (without clear hierarchy of public spaces). Source: author / Google Maps

3D-Negative has the ability to graphically illustrate the structure of open spaces, however, the parameters describing the N3D geometry can of course be presented by numerical means in the form of different types of graphs of parameter values. On the above charts presenting the size distribution of individual areas of open areas A and B (Fig. 5.), there are significant differences in the scope of this parameter. In the case of area A, the amount of space defined by N3D triangles with an area of over 200m^2 is a small percentage of the whole (less than 1%), while in area B, spaces with an area of less than 1000 m^2 (yellow and blue color) are distributed much more regularly and their share is much larger. Chart A presents a typical situation of space, for example in the Old Town systems, where the dominant space was developed and the surroundings are repeatable systems with small open spaces. The bending of results on the B-area graph informs about the area where the system is less defined and the hierarchy of open spaces is more like "equal rights" than the dictates of the dominant most important open space in the city. The number of geometric N3D elements of area A, meaning small spaces (up to 50 m^2) is more than 3 times bigger than the most numerous group of elements (50-200 m^2) for terrain B.

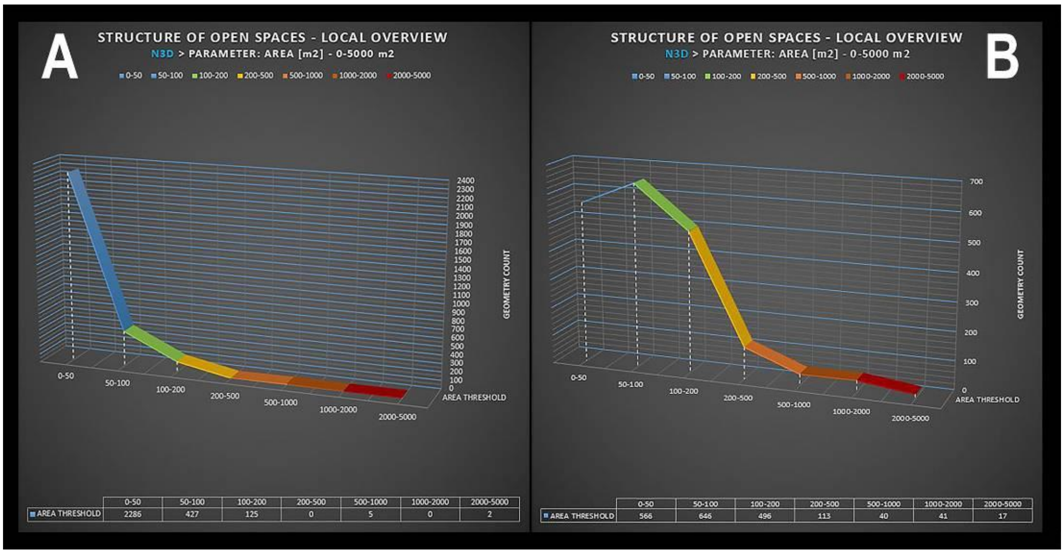

Fig. 5. Comparison of parameters representing distribution of open spaces by geometry count in estimated ranges of measured area of each geometrical components within area A and B. The seven parameter ranges of the area parameter are assumed between 0 – 5000 m^2 (0.5 ha). Source: author

The use of so-called spectral views is a separate way of exploring the morphology of open city spaces within the N3D geometry. The idea of this method of imaging is to show the structure of open spaces in the form of "X-rays" of the city. In practice, this method is based on showing sequences (linear or radial) of cross-sections through 3D-Negative geometry. In the presented case, for the area A (city center), a sequence of 10 sections spaced every 100 m was assumed (Fig. 6).

The presented spectrum of 10 cross-sections of N3D geometry for area A includes "x-ray waves" of length 1800m. The upper part of the illustration shows the arrangement of sequences of X-rays, below are marked two characteristic elements of the structure of the open space in separate spectral images of N3D. On the middle sequence, the area of open spaces in the area of the city's strict center was marked. In the bottom part of the illustration on the sequence, the image of the urban greenery system visible within the spectrum generated on the basis of 3D-Negative geometry is shown. The length of "waves" in the spectral view indicates the continuity of the city's open spaces.

5. CONCLUSION

The examples of exploration of urban morphology presented in the article using the city open space hierarchy aim, on the one hand, to indicate the potential of computer tools and the environment of virtual city models as an analytical environment, on the other hand to introduce a new method of parametric description and dimensioning of urban open spaces using the method of 3D-Negative. The N3D allows you to visualize the parametric invisible space between buildings. Comparative analysis of morphologically different areas allows to determine individual features of the city area in terms of shaping and protecting open spaces in cities. In the extension of the presented geometric approach, there are also volumetric analyzes of the "amount of air" in the city, issues of airing urban structures or urban composition of new investment areas of cities. Urban development of new urban areas is supported by 3D-Negative in the context of conscious organization of the structure and maintaining continuity of the open spaces of the city.

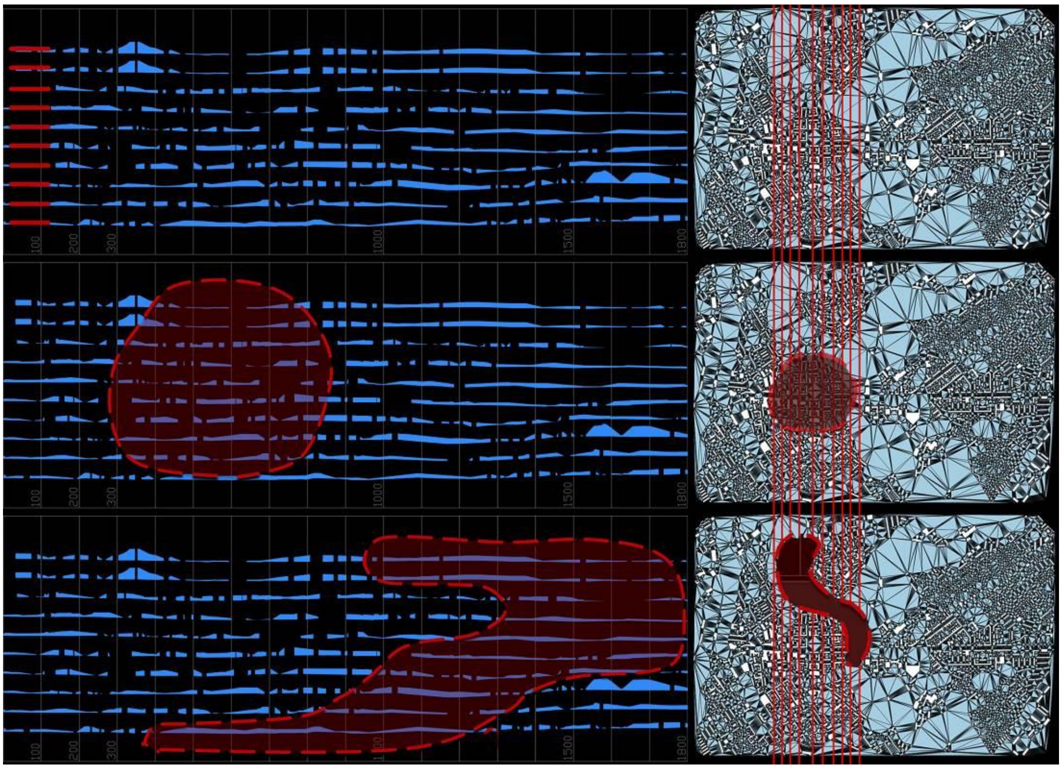

Fig. 6. The use of 3D-Negative in generating spectral views (linear or radial) of morphology of open spaces structure. The spectral views are generated for 10 sections (each 100 meters). The key components of open space structure – old town area and main public greenery area – marked on the middle and bottom spectral views. Source: author

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