Analysis of Green Infrastructure in Lodz, Poland

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Abstract: The paper focuses on the analysis of biologically active areas of the city in terms applicable to the understanding of green infrastructure in their spatial and urban planning references. The paper is an expanded account of the writers' research on green infrastructure resources of the city of Lodz, concerning the spatial identification of green infrastructure and its diversity in spatial arrangement, extracting elements of its structure, as well as their functional diversity in relation to urban zones of the city. The research described in this paper also associated with an attempt to characterize elements of green infrastructure in chosen urban zones. The motivation to undertake the research reported in this paper was to look for ways to improve the analyzing and description of the green infrastructure of a city for the purpose of development planning. As a result of this paper, contributions to the analysis of urban green infrastructure were indicated. Reliable identification of morphological structure (diversity construction) of the current state of green infrastructure is crucial in the process of its modeling and determines the future direction of its development in the urban-industrial agglomerations. **DOI: 10.1061/(ASCE)UP.1943-5444.0000242.**

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Introduction

Justification of Chosen Topic

The concept of infrastructure comes from the Latin words (1) infra, in the bottom; and (2) structura, layout, array; it is associated with devices, facilities, public buildings and service institutions, or basic facilities and systems serving a country, city, or area (Free 2013). Commonly, however, the term is associated with roads, sewers, and transmission networks, which refer to technical infrastructure and other service facilities and social welfare (i.e., schools, hospitals, and nursing homes) which constitute social infrastructure. Currently in many publications this term is used as a key word in describing proper functioning of natural infrastructure, that is, green infrastructure (GI; Benedict and McMahon 2002; Bańko 2012).

The term green infrastructure has been used for a relatively short time. Green infrastructure is variously defined, identified, and assessed by experts from various scientific communities in the world (Smogorzewski 1974; Benedict and McMahon 2002; Szumański 2005; Kloss 2008; Amundsen et al. 2009; Schwartz 2009; Szulczewska 2009; Youngquist 2009; Kowalski 2011; Lucius 2011; Neuman 2011; Adamowski 2012; Gonzalez-Duque and Panagopoulos 2013; Kirnbauer and Baetz 2014). Nevertheless, it is not a new concept. The idea of green infrastructure was born over 160 years ago in the United States (Benedict and McMahon 2002; Kowalski 2011). This idea has evolved from associating parks with other green spaces and open areas serving the community as the area life support system, ensuring proper protection of natural values and biodiversity, which forms a spatial structure of a given area (Benedict and McMahon 2002; Szulczewska 2009). At present it is also identified with the multidimensional, integrated action whose "goal is to preserve the environmental reserves in the best possible condition, in accordance to the sustainable development idea: using today and maintaining for future generations the largest possible part of the planet's resources" (Kowalski 2011). In addition, the concept of green infrastructure is legally constituted (European 2013). According to European (2013), green infrastructure is a tool to ensure ecological and economic benefits to society, e.g., through the creation of local employment opportunities. In this paper, the writers adopted the definition of green infrastructure as a set of biologically active areas, along with a group of institutions and persons acting on behalf of those sites. The sites may be differently used and developed. Green infrastructure mainly consists of the following areas: (1) green spaces, (2) woodland areas, and (3) agricultural areas, as well as others. The morphological studies of spatial structure of urban green infrastructure and its components have a short history and are based largely on the analysis of maps, plans, satellite images of cities, as well as specialized studies, including planning (Liszewski 2012). In consequence, determination of spatial and functional features of green infrastructure allows researchers to improve the ecological standard of landscape of a city including the living conditions of the inhabitants.

Subject Matter, Scope, and Purpose of Paper

The subject of this paper is green infrastructure of the city of Lodz. The purpose of this paper is to determine the diversity of building green infrastructure in terms of spatial distribution and functional diversity.

General Characteristics of the Study Area

Lodz is the city located in the central part of Poland. In terms of area it occupies the fourth (29,325 ha), and in terms of population

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the third (737,000 inhabitants) position among Polish cities (CSO 2013a, b). This is an example of a city whose modern spatial layout is the result of dynamic development of textile industry from the second half of the nineteenth century and to the 1980s of the twentieth century (Markowski 2010). The area of Lodz can be subdivided into three urban zones by Janiak (2012), which can be determined by Chmielewski (2001), based on the dynamic of spatial development of the city, as follows: (1) downtown, (2) residential, and (3) suburban; the first two are internal and the third is outer.

The downtown zone is the oldest part of the city, based in its composition on the nineteenth century urban patterns. The dominating function here is services.

The residential zone surrounds the downtown zone and its urban composition is based on patterns of postmodernism. The dominating function is housing.

The suburban zone surrounds the residential zone and it has the nature of a rural complex. The dominating function is agroforestry.

Materials and Methods

Materials

Source material accounted for the following specialist studies: (1) ecophysiographic study (Miejska Pracownia Urbanistyczna w Łodzi 2007), (2) study on conditions and directions of spatial planning of the city of Lodz (Miejska 2010a, b), (3) map of green areas of the city of Lodz (Jakóbczyk-Gryszkiewcz 2009), (4) maps contained in the online land information system (Łódzki Ośrodek Geodezji 2012) of undeveloped areas of the city of Lodz, and (5) the Spatial Development Strategy of Lodz presented by Janiak (2012). Supplementary materials were as follows: (1) topographic map of the city of Lodz in scale 1:50 000 (Główny Urząd Geodezji i Kartografii 1992), (2) orthophotomap of the city of Lodz (Orthophotomap 2011), and (3) tourist city map of Lodz (Lodz 2010).

The research reported in this paper used the information contained in the text part of the paper on conditions and directions of spatial development of the city of Lodz (Lodz 2010), as well as statistical data of CSO (2013a, b, c). Such computer programs as *AutoCAD*, *Adobe Photoshop CS5*, and *Adobe Illustrator CS5* have been used for research tasks, and the Microsoft Excel 2007 program has been applied for preparing statistic summaries.

Methods

It can be stated that green infrastructure has no boundaries. However, for purposes of the research reported in this paper, it should be included in the administrative boundaries of cities (i.e., in this case, the city of Lodz), what results from the way the space is managed in Poland. The research method used involves the distinguishing of space/territories specific to different sets of elements of green infrastructure. Green spaces, woodland areas, and agricultural areas have been considered the main sets of green infrastructure elements. The surface of green infrastructure was calculated on the basis of the available materials and data using *AutoCAD*. In the comparative analysis of green infrastructure resources of the city of Lodz to similar cities, the cities of similar size and a similar number of residents were selected, taking the deviation of $\pm 15\%$ of the surface/number of residents in relation to the city of Lodz. The analysis of green infrastructure resources of Lodz refers to the urban zones of the city, not its administrative units. Due to the lack of data concerning the surfaces of these zones, their estimated area was calculated based on available materials using *AutoCAD* program. When calculating green infrastructure indicators (measured in square meters per inhabitant) the latest available surfaces of the green infrastructure and the population of the city at the end of 2012 were adopted (CSO 2013a, b, c). In calculating the number of inhabitants in the urban zones of the city, an estimated number of population in the administrative units making up the zone was adopted according to the latest data in the publication by Liszewski (2009). In this paper the recognition of the morphological structure of the sets of wooded streets and surface waters is preliminary and has only been mentioned.

The procedure of the research reported in this paper is as follows:

1. Preliminary identification of the green infrastructure of the city,
2. Analysis of the morphology of green infrastructure,
3. Analysis of the structure of the functional elements of green infrastructure,
4. Analysis of the spatial share of green infrastructure in conjunction with the urban zones,
5. Determination of parameters and indicators of green infrastructure,
6. Rating of diversity of the city green infrastructure resources,
7. Comparative analysis of the green infrastructure of the city of Lodz and selected Polish cities, and
8. Interpretation of results.

Results

Characteristics of Green Infrastructure Sets in the City of Lodz

Green infrastructure is functionally diverse. The functional structure refers to the main three sets, as follows: (1) green spaces, (2) woodland areas, and (3) agricultural areas.

Green Spaces

Green spaces represent the surface of 1,901.22 ha (6.21% in the city). The green spaces consist of areas of parks, areas of pocket parks, areas of allotment gardens, and areas of cemeteries. Parks occupy a total area of 696.42 ha (2.37% in the city). In the city there are 44 parks, 12 of which are historic parks of a total area of 337.3 ha. Parks abundance indicator is at the level of 9.44 m^2 of parks/inhabitant in Lodz. The largest one is Pilsudski Park (188.21 ha) and the smallest, Park at Brójecka Street (0.9 ha). Most of the parks are located in the downtown zone. Allotment gardens occupy a total area of 714 ha, which is 2.4% of the city of Lodz. The abundance indicator for allotment gardens is 9.69 m^2/inhabitant. In the area of the city there are 120 allotment gardens. Most of the allotment gardens are located in the residential zone. The largest allotment garden is Rodzinne Ogrody Działkowe (ROD) Obrońców Pokoju with the area of 39 ha, and the smallest one, not having its name, the area of 0.5 ha. Pocket parks cover the area of 276.4 ha, which is 0.94% of the area of the city. The abundance indicator for pocket parks in the city is 3.75 m^2/inhabitant. In the area of the city there are 18 pocket parks. Pocket parks are located mainly in the downtown zone. The largest pocket park is Skwer Dubaniewicza of area of 5 ha, and the smallest one is the Skwer Linkego with an area of 0.2 ha. Cemeteries cover the area of 214.4 ha, which is 0.7% of the city. The abundance indicator for cemeteries in the city is 2.91 m^2/inhabitant. Thirty cemeteries are located on the area of the city of Lodz. Cemeteries are primarily located in the suburban zone. The largest object is a Jewish cemetery with the area 40 ha, and the smallest one is the Evangelical Reformed cemetery with an area of 0.6 ha.

Woodland Areas

Woodland areas cover 2,820.6 ha (9.61% of the city). The abundance indicator for woodland areas in the city is 38.27 m^2/inhabitant. Woodland areas are located mainly in the suburban zone. The largest woodland area is Las Łagiewnicki with the area of 1,245 ha and the smallest one is Las Przy Olechówce of 2.5 ha.

Agricultural Areas

Agricultural areas cover 10,575 ha (36.1% of the city). Agricultural areas are dominated by arable lands (83%), which represent 30.01% of the area of the city. They occupy the surface of 8,803 ha. The agricultural areas also consist of meadows and pastures, which occupy the surface of 1,489 ha, what is 5.07% of the city area, as well as orchards occupying the surface of 283 ha, which is 0.96% of the city area. The abundance indicator for agricultural land is 143.48 m^2/inhabitant. The vast majority of agricultural areas are located in the suburban zone.

Other Areas

The set other elements of the green infrastructure of the city of Lodz include wooded streets and surface waters. The subsequent resource of these elements is outlined sketchily. The total length of wooded streets in the city of Lodz is 400.5 km, which represents 60.2% of the length of all the streets in the city. The downtown zone is characterized by the smallest share of wooded streets. Surface waters are mainly watercourses of the total length of 110 km and surface water reservoirs which take 15.5 ha. The total area of surface waters does not exceed 0.05% of the city area.

Green Infrastructure in Urban Zones of the City

Green Infrastructure in the Downtown Zone

The downtown zone is located centrally in the city and covers the area of 1,631.3 ha what equals 5.6% of the city of Lodz. The area is inhabited by 114,657 residents representing 15.56% of the total population of the city. The total surface area of green infrastructure in this area is 122.6 ha which represents 7.5% of the downtown zone. The estimated indicator of green infrastructure in the area is 10.71 m^2/inhabitant of the zone. It is dominated by green spaces, 122.6 ha (10.71 m^2/inhabitant of the zone). These are parks (96.05 ha, 8.37 m^2/inhabitant of the zone), cemeteries (15.45 ha, 1.37 m^2/inhabitant of the zone), and pocket parks (11.1 ha, 0.97 m^2/inhabitant of the zone). In the downtown zone there are no allotment gardens, agricultural areas, or woodlands. Moreover, in this zone there are 81.6 km of public roads, less than a quarter of which (22.7 km) are wooded streets. Sparingly represented surface waters occupy the total area of only 2 ha. The spatial arrangement of green infrastructure elements and functional diversity are shown (Fig. 1). The green areas are small and medium-surfaced objects (0.1–30 ha). They are arranged systematically and usually at long distances from one another.

Green Infrastructure in the Residential Zone

The residential zone has the area of 2,799.8 ha, which is 9.5% of the city of Lodz. The zone is inhabited by 149,957 residents representing 20.35% of the total population of the city. Green infrastructure elements together occupy the area of 427.4 ha, which is 15.3% of the residential zone. The estimated indicator of green infrastructure in the area is 28.5 m^2/inhabitant. The surface of green infrastructure of the zone is dominated by green spaces (329.6 ha, 21.98 m^2/inhabitant of the zone), parks (192.65 ha, 12.85 m^2/inhabitant of the zone), cemeteries (68.3 ha, 4.55 m^2/inhabitant of the zone), allotment gardens (62.35 ha, 4.16 m^2/inhabitant of the zone), and pocket parks (6.3 ha, 0.42 m^2/inhabitant of the zone). In this zone agricultural land has a smaller share of the surface (57 ha, 3.8 m^2/inhabitant of the zone) and woodland areas have the smallest share (40.8 ha, 2.72 m^2/inhabitant of the zone). Furthermore, the total length of wooded streets in the area is 58.1 km, which represents almost half (44.7%) of the total length of public roads in the area. The total area of the surface water is 3.3 ha. The spatial arrangement of elements and functional diversity of green infrastructure are shown (Fig. 1). In the residential area green spaces are medium and large objects (from 3 to 40 ha). They are evenly spaced and in close distances from one another. Agricultural lands and woodland areas are small objects located in the northern part of the zone.

Green Infrastructure in the Suburban Zone

The suburban zone has the largest surface area (24,893.9 ha) compared to the previously described zones. It constitutes

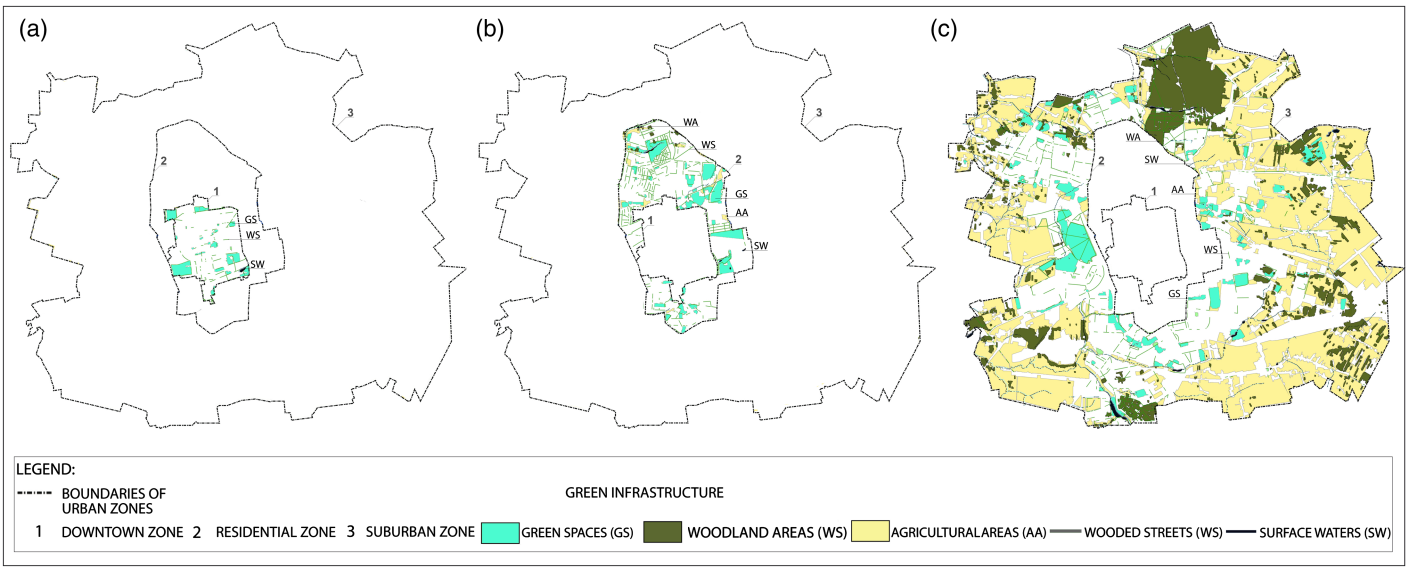

Fig. 1. Green infrastructure of Lodz city: (a) in the downtown zone; (b) in the residential zone; (c) in the suburban zone (data from Miejska Pracownia Urbanistyczna w Łodzi 2007; Jakóbczyk-Gryszkiewicz 2009; Lodz 2010b; Ortophotomap 2011; Łódzki Ośrodek Geodezji 2012; Janiak 2012)

Table 1. Elements of Green Infrastructure in Urban Zones of the City of Lodz

			City urban zones						City	
			Downtown zone		Residential zone		Suburban zone			
Serial number	Sets of green infrastructure	Elements of green infrastructure	Surface of green infrastructure element (ha)	Green infrastructure indicator for the element (m^2/inhabitant of the zone)	Surface of green infrastructure element (ha)	Green infrastructure indicator for the element (m^2/inhabitant of the zone)	Surface of green infrastructure element (ha)	Green infrastructure indicator for the element (m^2/inhabitant of the zone)	Surface of green infrastructure element (ha)	Green infrastructure indicator for the element (m^2/inhabitant)
1	Green spaces	Parks	96.05	8.37	192.65	12.85	407.72	8.63	696.42	9.44
		Pocket parks	11.1	0.97	6.3	0.42	259	5.48	276.4	3.75
		Allotment gardens	0	0	62.35	4.16	651.65	13.79	714	9.69
		Cemeteries	15.45	1.37	68.3	4.55	130.65	2.77	214.4	2.91
		Total	122.6	10.71	329.6	21.98	1,449.02	30.67	1,901.22	25.79
2	Woodland areas	Total	0	0	40.8	2.72	2,779.8	58,85	2,820.6	38.27
3	Agricultural areas	Arable lands	0	0	0	0	8,803	186.35	8,803	119.44
		Orchards	0	0	2.2	0.15	280.8	5.94	283	3.84
		Meadows and pastures	0	0	54.8	3.65	1,434.2	30.36	1,489	20.2
		Total	0	0	57	3.8	10,518	222.65	10,575	143.48
		Total, sum of areas	122.6	10.71	427.4	28.5	14,746.82	312.17	15,296.82	207.54

84.9% of the city of Lodz. The area is inhabited by 472,386 residents which represents 64.09% of the total population of the city. The zone has the largest area of green infrastructure, 14,746.82 ha, which represents more than half of the area of the zone (56.9%). The green infrastructure indicator is 312.17 m^2/inhabitant of the zone. The zone is dominated by agricultural areas, 10,518 ha (222.65 m^2/inhabitant of the zone). The remaining surface is occupied consecutively by 2,779.8 ha of woodland areas (58.85 m^2/inhabitant of the zone) and green spaces, 1,449.02 ha (30.67 m^2/inhabitant of the zone). Among the green spaces the largest area is occupied by allotment gardens (651.65 ha, 13.79 m^2/inhabitant of the zone) and parks (407.72 ha, 8.63 m^2/inhabitant of the zone). The remaining part of green spaces is occupied by pocket parks (259 ha, 5.48 m^2/inhabitant of the zone) and cemeteries (130.65 ha, 2.77 m^2/inhabitant of the zone). The total length of wooded streets in this area is 319.7 km, which comprises 70.5% of the total length of public roads of the suburban zone. The total area of surface water is 10.1 ha. The spatial arrangement of green infrastructure elements and their functional diversity are presented (Fig. 1). In the suburban zone, agricultural land has a mosaic arrangement traversed by woodlands and settlements, and the pattern of woodland areas is fragmented.

The total surface area of green infrastructure of the city of Lodz is 15,296.82 ha, which represents 52.16% of the area of the city of Lodz. The green infrastructure of Lodz is dominated by agricultural areas, 10,575 ha (69.1% of green infrastructure). Woodland areas, in turn, occupy 2,820.6 ha (18.5% of green infrastructure), and green spaces, 1,901.22 ha (12.4% of green infrastructure; Table 1).

The total green infrastructure indicator amounts to 207.54 m^2/inhabitant. Agricultural areas have the highest indicator (143.48 m^2/inhabitant). In the second place there are woodland areas, 38.27 m^2/inhabitant, and the lowest indicator is for green spaces, 25.79 m^2/inhabitant (Table 1). The average indicator of green infrastructure per inhabitant of the city of Lodz, being an arithmetic average of the foregoing indicators for different types of green infrastructure, is 69.18 m^2/inhabitant.

The comparison of green infrastructure resources indicator calculated for each urban zone depending on its surface area shows that with increasing surface of green infrastructure area the indicator per inhabitant grows (Fig. 2).

In relation to the three main elements of green infrastructure, the highest green infrastructure indicators are typical for the suburban area and they repeatedly exceed the indicators for the other two urban areas (Fig. 2).

Table 1 shows surface share as well as indicators for individual elements of green infrastructure in urban zones compared to indicators relevant to the area of the city of Lodz; see the "Discussion" section.

It appears that the lowest rate of green infrastructure resources per inhabitant is appropriate for the downtown zone. Twice the value of the indicator is achieved in the residential zone and the indicator in the suburban zone is about 29-fold higher.

Green Infrastructure in Lodz in Comparison with Selected Polish Cities

A more complete picture of green infrastructure resources of the city of Lodz can be obtained through a comparative analysis of these resources in similar cities. Szczecin, Wroclaw, and Krakow are considered to be similar cities. These cities are located in different geographical regions of Poland (Fig. 3).

A comparative analysis of green infrastructure resources proves that compared to the similar cities Lodz is on the third position in

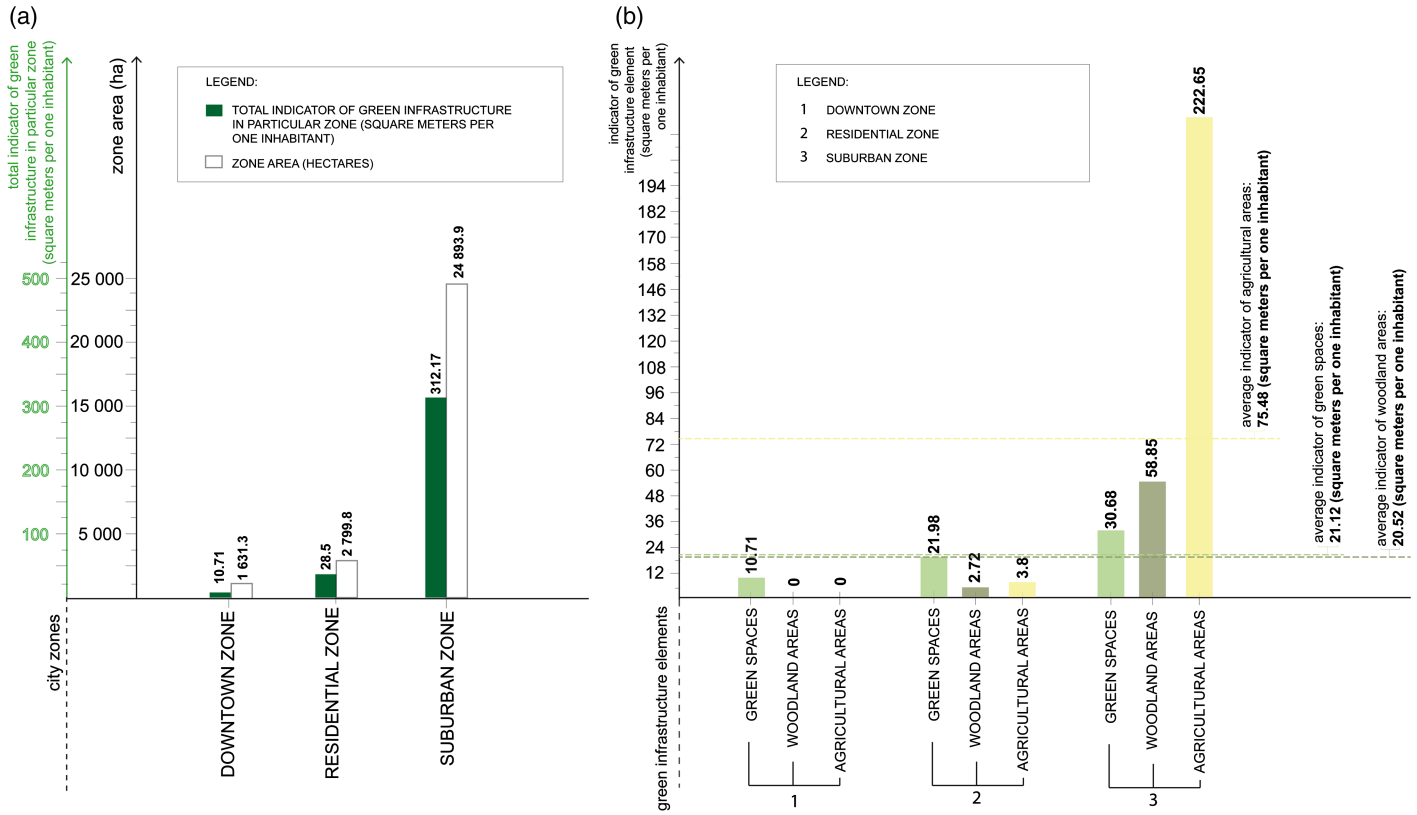

Fig. 2. (a) Presentation of total green infrastructure indicators for urban zones of the city of Lodz and the surfaces of these zones; (b) differentiation of green infrastructure indicators in urban areas of the city of Lodz (data from CSO 2013a, b, c)

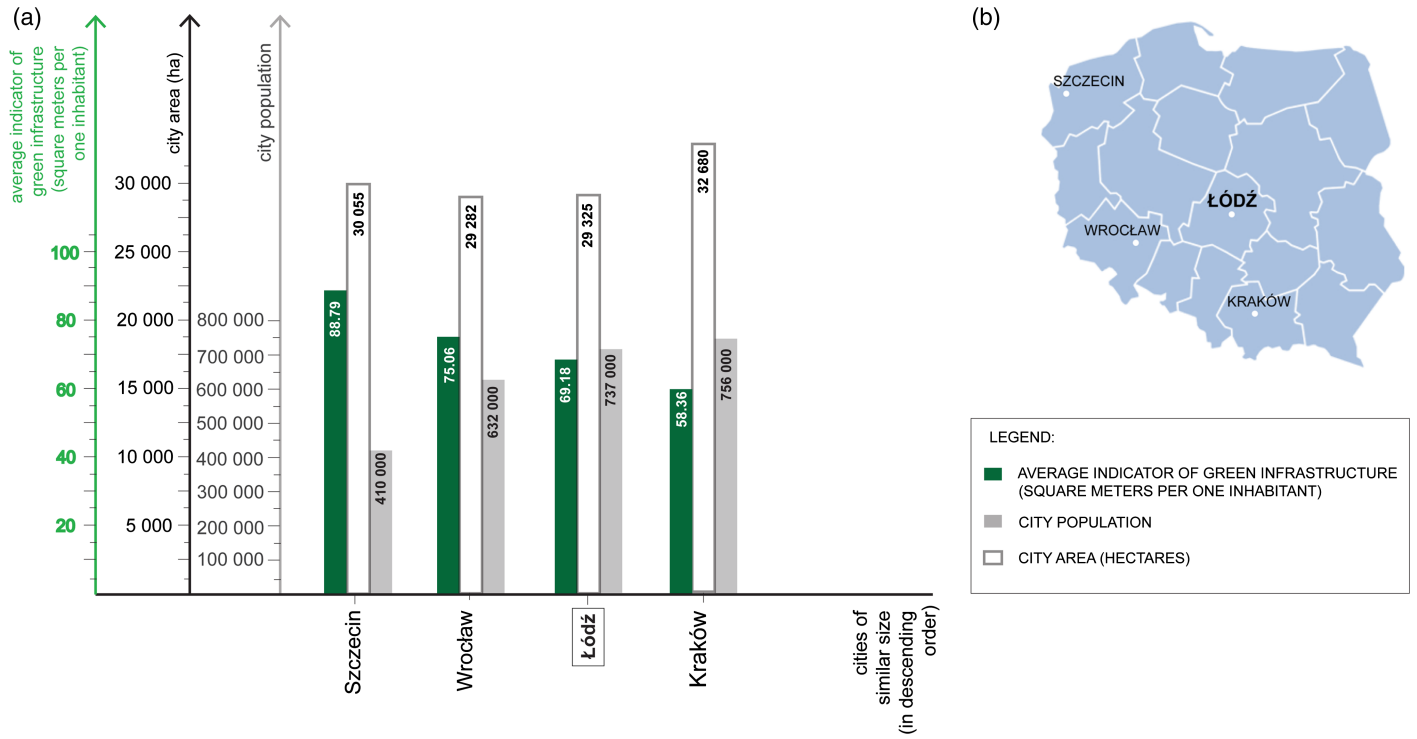

Fig. 3. (a) Comparison of the average green infrastructure indicator in cities similar to Lodz; (b) locations of cities similar to Lodz, selected for comparative analysis of green infrastructure resources (data from CSO 2013a, b, c)

the group. The results of the paper indicate that the average green infrastructure indicator of the city of Lodz is about 1.3× lower than the highest one, recorded in Szczecin (88.79 m^2/inhabitant), and the difference is 19.61 m^2/inhabitant (Fig. 3).

The comparative analysis confirms that the green infrastructure indicator is dependent on the relation between the city area and the number of its inhabitants. The larger the city area and the smaller the number of residents, the higher the green infrastructure indicator per inhabitant.

Discussion

The concept of green infrastructure in the analyzed publications is often defined by the forms of nature conservation, i.e., national parks, Natura 2,000 areas, reserves, and so on (Sundseth 2009; Gołąb-Korzeniowska 2011; Kowalski 2011). The forms of nature conservation are not elements of green infrastructure and as they result from the immediate need to protect natural resources, decisions tend to be of political nature, and may, in the long run, be invalidated. Legal protection of green infrastructure should be a subject of a separate study.

The theoretical and methodological rationales included in Szumański (2005) can be used in the studies of green infrastructure. The use of green spaces structuring in the study of morphology of green infrastructure allows for defining and determining its properties. This is crucial in the modeling process of green infrastructure. According to Szumański (2005), "it is impossible to transform any landscape situation into a more convenient one without the orientation of reality overview, without adequate diagnosis and evaluation." Identification of green infrastructure elements allows for recognition of its differentiation, which diagnosis, as a consequence, may serve to determine the future development of green infrastructure.

Referring to the analyzed literature, researchers can find a lot of research works related to the green infrastructure of the city of Lodz and the signification of some of its elements. These are, for example, the series of works by Koter (1974, 1979, 1988, 1994) and Liszewski (1977, 1978, 1994, 2012), and the previously mentioned specialized studies (Gramsz 2002; Marszał 2006; Miejska Pracownia Urbanistyczna w Łodzi 2007; Wycichowska 2008; Jakóbczyk-Gryszkiewicz 2009; Bomanowska and Podolska 2010; Miejska 2010a, b; Janiak 2012; Łódzki Ośrodek Geodezji 2012). These publications relate only to distinct components, examined individually. Among these works there are studies referring separately to green spaces, separately to woodland areas, separately to agricultural areas, separately to watercourses, and separately to water reservoirs. All of them were analyzed in terms of their share and role in the deployment area of the city, as well as their natural materials and landscape values (Mowszowicz 1962; Siciński 1989; Bonisławski 2002; Hereźniak 2002; Kurowski 2002; Kobojek and Kobojek 2005; Olaczek 2006a, b, 2008, 2010, 2012). However, there is a lack of studies referring to the spatial analysis of the morphology of Lodz green infrastructure which is treated as a whole and determined by the main components of green infrastructure, as follows: (1) green spaces, (2) woodland areas, and (3) agricultural areas.

After having analyzed specialist publications, the studies on the construction of green infrastructure showed a large discrepancy in share and generic structure of the elements of green infrastructure, which is differently characterized by various sources and authors (Smogorzewski 1974; Benedict and McMahon 2002; Szumański 2005; Amundsen et al. 2009; Jakóbczyk-Gryszkiewicz 2009; Schwartz 2009; Szulczewska 2009; Youngquist 2009; Miejska 2010a, b; Kowalski 2011; Lucius 2011; Neuman 2011; Adamowski 2012; CSO 2013a, b, c; Gonzalez-Duque and Panagopoulos 2013; Atecma 2007). This is due to different interpretations of the concepts of green infrastructure elements, which are often combined or appear in different groups or contexts (parks and pocket parks, urban greenery and green spaces, woodland areas as a part of urban parks, and so on) and they are often treated interchangeably or synonymously, which was also recognized by Szumański (2005).

Information about the area as well as other characteristics of green infrastructure elements is published in various sources and is recognized in different ways, sometimes divergent, and repeatedly there is a lack of any information, such as the surface of water reservoirs, the width of watercourses, the length of wooded streets, and so on.

The previously discussed situation can lead to many misunderstandings in the interpretation of information (data) on green infrastructure. Organizing and specifying the rationales for identifying elements of green infrastructure seem to be the urgent challenge of contemporary research studies in this field (Szumański 2005).

The concept of green infrastructure can be identified with the concept of open areas. Open areas are undeveloped areas within the city with dominant vegetation and in which buildings occupy less than 5% of the surface area (Wolski 2002; Smogorzewski 1974). They consist of the following: (1) agricultural areas (arable lands, meadows, pastures, and orchards), (2) woodland areas, (3) areas of watercourses and water reservoirs, (4) green spaces (parks, gardens, pocket parks, and cemeteries), and (5) other (e.g., pits, landfill sites, and military training grounds). These are elements of the nature system that also build the green infrastructure of the city.

The results presented in the paper indicate that the deployment of green infrastructure is varied in the city and its urban zones.

Analyzing the results (which have been collected in Table 1) it can be concluded that the strongest differentiation of green infrastructure areas was noted in the suburban zone. Second, most of the elements of green infrastructure in the suburban zone are of the most compact arrangement. In addition, this zone has the largest share of green infrastructure in the surface (56.9% of the area of the zone) and the highest indicator of green infrastructure (312.17 m^2/inhabitant of the zone), more than 10× higher than in the residential zone.

Residential zone is characterized by a smaller variation of green infrastructure elements and their share in the surface compared to the suburban zone. There are almost all the elements of green infrastructure in it (with the exception of arable lands). The spatial arrangement of these elements has a lower dispersion than in the downtown zone. The GI elements do not constitute a compact system but distances between them are smaller in comparison with the downtown zone.

The downtown zone is the least functionally diverse (Fig. 3). Green infrastructure elements of this zone are narrowed down to sets of green spaces. In this zone GI elements are dispersed and do not constitute a compact arrangement. The green infrastructure indicator in the downtown zone (equal to 10.71 m^2/inhabitant of the zone) is more than 2× lower than in the residential zone and 29× lower than in the suburban zone, which confirms the smallest share of green infrastructure in this zone compared to other urban zones of the city.

Considering the functional structure of GI elements presented in the study, differences in their common availability should be emphasized. While parks in the downtown zone are available to all inhabitants of the city, arable lands and orchards are restricted in their availability only to persons in possession of the land. This issue requires a separate study and the results can contribute

to a fuller picture of the possibility of using all elements of green infrastructure.

The green infrastructure indicator of the city of Lodz was compared to indicators for other Polish cities of similar size and population (Fig. 3). This analysis could be extended by the comparison of this indicator to indicators of other cities in Europe and in the world, similar in terms of population and area, or of similar origins of development (i.e., Birmingham, Manchester, and Detroit).

The research presented in this paper defines the diversity of building green infrastructure of the city of Lodz and functional-spatial relations of its elements in urban zones. However, the studies do not show all the relations of these elements, such as natural or ecological ones. Such analyzes are an equally important stage of work, allowing for more accurate recognition of the green infrastructure of the city of Lodz and its functioning, which requires, however, undertaking additional studies.

The study of green infrastructure in the city of Lodz could be extended to review recommendations and concepts for future development. In Lodz such concepts include, among others, the following: (1) the concept of the green ring of tradition and culture (Lodz 2014) implemented under the World Health Organization (WHO) Healthy City in Phase V-2009-2013 by K. Bald, and (2) a newer concept of the blue green network by the ecohydrology team from the University of Lodz in 2002 (Wagner and Zalewski 2013). However, the conditions for the development of green infrastructure, including a review of these concepts, are the subject of a separate article (A. Długoński, unpublished internal report, Warsaw University of Life Sciences, Warsaw, Poland, 2014). Currently it is difficult to speak of territorial development of green infrastructure. In the downtown zone it is impossible because of compact development. However, in suburban and residential zones plots are expensive, and the city government would rather allocate land for new housing and service investments. According to the writers, the possible direction of development of the city of Lodz is based on ecological activities together with indication of ecological and environmental models of green infrastructure. However, the precise outline of the future direction requires additional research on green infrastructure. These could involve assessing the degree of ecologization of green infrastructure, which is planned in the future.

Conclusions

The way of analyzing green infrastructure presented in the paper, in general, consists on the determining these natural resources of the city which are known as green infrastructure. The method in its results shows spatial diversity and functional diversity of elements of green infrastructure.

The existing practice of analyzing green infrastructure in Poland, due to the way of managing the existing green infrastructure, was in most cases narrowed to determining recreational resources (understood as green spaces) within the boundaries of the city or its neighborhoods (in terms of administration). The practiced method of analysis of green infrastructure, because of its obviousness, does not provide a complete picture of the whole green infrastructure in its spatial references. The rule seeking a full picture of the whole of green infrastructure (within the administrative boundaries of the city) is the principle of its determination in clear zones in the city landscape. The main zones should be recognized, as follows:

1. Downtown zone, defined as the central zone of the city, of leading service function;
2. Residential zone, a ring surrounding the downtown zone, of the leading residential function; and
3. Suburban zone, a ring surrounding the residential zone, of the dominant agricultural function and woodland areas with occasional occurrences of housing areas.

These zones should be canvas/matrix for the analysis of green infrastructure.

Another rule favoring a more complete picture of the whole green infrastructure resources should relate to its functional differentiation. Determinants of the functional structure of green infrastructure should be as follows:

1. Set of agricultural areas (including arable lands),
2. Set of woodland areas, and
3. Set of green spaces.

These sets are helpful in determining the morphology of the GI.

The methods for determining the morphology of green infrastructure and their spatial identification are different in various scientific centers/countries, which require further examination. The main feature of green infrastructure/biologically active open areas is the ability of these areas for water infiltration. This natural process is to be treated as a common and characteristic feature of all elements of the functional and spatial structure of green infrastructure.

The method of the analysis of green infrastructure determining its abundance and morphological structure, applied to the city of Lodz, pointed to the rule of differentiation of location of green infrastructure elements within the city, as well as the function of these elements. Abundance of the urban zones of the city, as measured by the total surface elements of green infrastructure in the zones, is the greater, the larger the surface area is, and the smaller, the share of developed areas in the zone is. Differentiation of the main roles of sets of green infrastructure elements in the zones is considered a rule. The social role dominates in the downtown zone. The economic role dominates in the suburban zone. The role of green infrastructure elements in the residential zone is mixed; some elements of green infrastructure in the zone play a social role and some play economic role. The natural role of green infrastructure elements is appropriate for each zone, regardless of the extent of the zone, as well as the extent of the elements of green infrastructure in the area.

The identified resource of green infrastructure on the example of the city of Lodz shows the complexity and many layers of its construction, including its diversity and potential of the service. The obtained results may provide a rationale for further studies on green infrastructure in cities, e.g., the following:

1. In relation to seeking the expanded picture of the green infrastructure of the city,
2. In relation to defining provision of ecological services of green infrastructure elements of the city, and
3. In relation to the parameterization of green infrastructure of the city.

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