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INDICATORS OF THE COMPACT CITY CONCEPT – NECESSARY DATA AND THE POSSIBILITY OF APPLICATION

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Abstract
The main objective of the study is to analyze the availability of statistical and spatial data necessary to define a set of indicators of a modern compact city model, as well as, to propose a multi-criteria method to determine the importance of individual indicators. An accessible and relatively easy to use set of compact city indicators is a necessary tool, both at the stage of evaluating a unit for a selected concept, as well as, during the implementation of its main postulates. The modern compact city model is now the key direction of the Polish urban policy and has been implemented in many cities around the world for years in connection with the principle of sustainable development. The paper presents the previous interpretations of the selected urban concept, its main assumptions, as well as, the author's set of measurable indicators with sample weights, which were analyzed in the framework of the case study. To determine the weights, multi-criteria decision-making method (AHP – Analytic Hierarchy Process) was used, while GIS technologies were used at the stage of presentation of the values of selected indicators.

Keywords: **AHP method; Compact city; GIS technology; Indicator; Land use policy; Multi-criteria analysis.**

1. INTRODUCTION

The key role of cities in modern space is undeniable, they are places of concentration of population, economy, and infrastructure. At the same time, cities are most affected by contemporary social problems (e.g. depopulation, and population aging), ecological problems (e.g. increasing environmental pollution), as well as spatial problems (an e.g. growing problem of spontaneous suburbanization) [1, 2]. The response to the growing problems of urbanization is the dissemination and implementation of various concepts and models of sustainable urban development.

Due to the implementation of selected concepts into urban policies, an important element of contemporary research is the work related to the creation of measurable indicators, enabling both the assessment of individual cities in the light of a given concept and the comparative analysis of many cities in the form of multi-criteria rankings. So far, indicators enabling evaluation of cities have been proposed, among others in the context of the smart city concept [3, 4, 5] and green city [6]. It is also worth mentioning the principle of sustainable development and proposals for a set of measurable indicators relating to sustainable urban development [7].

This paper focuses on the concept of a compact city and indicators to assess cities against the basic principles of this concept. The compact city model plays an increasing role in contemporary urban planning and is inseparably connected with the principle of sustainable development [8]. What is important, the idea of a compact city has also been taken into account in the Polish urban policy. In 2015, it was officially declared that one of the objectives of the urban policy in Poland is to shape compact and sustainable cities [9].

The priority objective of this work is to develop a set of compact city indicators based on the analysis of available statistical and spatial data. The first part of the paper is devoted to the literature studies in the field of the compact city. The next part concerns the compact city indicators, and attention is paid primarily to the practical feasibility of their implementation and the availability of necessary data. Then, using the AHP method, an exemplary set of weights is estimated. The last part of the paper presents the main conclusions of the conducted analyses, as well as future potential directions of research. This paper complements (in the context of the main assumptions of compact city) and develops selected topics (in the scope of indicator weighting) presented in the PhD thesis, in which first of all the full assessment of 4 Polish cities from the point of view of the compact city concept was made [10].

2. DEFINITION AND THE MAIN ASSUMPTIONS OF THE COMPACT CITY CONCEPT

The compact city concept is very often combined with the work of Dantizng and Saaty [11], who sought a rational model of city development in the context of growing urbanization problems in the United States. The proposed model assumed the development of the city in the form of concentric zones: core, core edge, inner residential area, mid-plaza, outer residential area. Apart from the master plan, attention was also drawn to the plan of the transport system or technical infrastructure [11]. It should be emphasized that the model presented above has not been implemented, and the contemporary model of a compact city is not precisely defined and has been subject to many interpretations [12].

Table 1 gives an overview of the definitions of compact city concepts developed over the last 20 years. Importantly, the table updates and complements (among others, the subject of the research and the main assumptions of the concept) the author's reviews carried out in 2015 [13] and 2017 [10].

Table 1.
Overview of definitions and main assumptions of the compact city concept (based on selected studies from 1996–2018)

Author (year)	Title/the main subject of research	The definition of the compact city concept	The main attributes of the compact city (based on the definition)
P. Nijkamp, S.A. Rienstra (1996)	Sustainable transport in a compact city.	"This concept is embodied in the «compact city», where housing is provided in a relatively high-density form, and where jobs are concentrated in the central city and in a limited number of sub-centers" [14].	– relatively high density, – the concentration of jobs in the city center, – a limited number of sub-centers.
R. Burgess (2000)	The global perspective of the compact city concept.	"It is possible to offer a tentative and composite definition of contemporary compact city approaches as: «to increase built area and residential population densities, to intensify urban economic, social and cultural activities and to manipulate urban size, form, structure and settlement systems to pursuit of the environmental, social and global sustainability benefits, derived from the concentration of urban functions»" [15].	– increase built area and residential population densities, – intensify urban economic, social and cultural activities, – the concentration of urban functions.
E. Burton (2002)	Measuring urban compactness (on the example of UK cities).	"(…) the compact city is usually described as one or other or all of three types of city, two that are related to «product»: (1) the high-density city, (2) the mixed-use city, and one that is related to «process»: (3) the intensified city" [16].	– high density, – mixed land use, – intensification.
J. Arbury (2005)	Analysis of urban growth management on the example of the selected city.	"This model differs greatly from conventional urban development (or sprawl) by focusing on urban intensification, creating limits to urban growth, encouraging mixed-use development and placing a greater focus on the role of public transportation and quality urban design" [17].	– urban intensification, – limits to urban growth, – mixed land use, – an important role of the public transport system, – high-quality urban design.

A. Polit (2010)	Advantages and disadvantages of the compact city concept.	"For many years, the remedy for all diseases of contemporary urban planning caused by the phenomenon of sprawl was seen in the concept of a compact city. The idea was to design buildings with relatively high intensity, to mix the functions of urban areas and to base their functioning on efficient public transport. Clear urban boundaries, revitalizing city centers, encouraging cycling or walking, and improving the quality of public spaces are important guidelines of the Compact City concept" [18].	– relatively high density, – mix land use, – the effective public transport system, – clear cities boundaries, – revitalization of city centers, – pedestrian and bicycle communication, – high quality of public space.
K. Solarek (2011)	The review of contemporary concepts of city development.	"The concept (...) is connected (...) with the structuring of space and with the main assumptions heading towards the shaping of Compact Cities, developing inwards, intensively - but according to their scale and character – built-up, with a mixed function of the area, pedestrian-friendly, and accessible by communication" [19].	– urban development within existing boundaries, – mixed land use, – well-development communication system.
OECD (2012)	A comparative assessment of the compact city policies in OECD countries.	"Spatial urban form characterized by «compactness». By understanding various definitions of a compact city, this report defines its key characteristics as i) dense and proximate development patterns; ii) urban areas linked by public transport systems; and iii) accessibility to local services and jobs" [12].	– dense and proximate development patterns, – urban areas linked by public transport systems, – accessibility to local services and jobs.
E. Węcławowicz -Bilska (2012)	The review of the selected urban development concepts	"The compact city of short distance is an urban concept that promotes a relatively high density of built-up areas with a diverse, mixed-use of land. An efficient public transport system will encourage the abandonment of car transport and a compact urban layout will encourage walking and cycling" [20].	– relatively high density, – mixed land use, – the effective public transport system, – pedestrian-oriented habitation.
P. Chhetri et al. (2013)	The analysis of the realization compact city model in Melbourne.	"The land-use policy changes built around the concept of the compact city include the following: Intensification, consolidation or densification, particularly around inner suburbs. In-fill development and redevelopment of brownfield land. More intensive use of urban land. Sub-divisions and conversions of existing development. Re-zoning and greater mixing of land use. Greater dwelling density and re-urbanization. Higher degrees of accessibility" [21].	– intensification, – in-fill development and redevelopment of brownfield land, – mixed land use, – re-urbanization, – higher degrees of accessibility.
M. Stangel (2013)	Contemporary urban design in the context of sustainable development.	"The paradigm of a city of compact or sustainable urban planning in a broader sense calls for a dense, multifunctional building structure that is comfortable to walk and transport, with access to local services, jobs and green spaces" [22].	– dense and multifunctional urban form, – effective public transport system, – accessibility to local services, jobs, green spaces.
R. Kotharkar, P. Bahadure, N. Serda (2014)	Measuring urban compactness (on the example of Indian city).	"Essentially the compact city model defined as «…a high density, mixed-use development, within a restrictive geographical area with enhanced public transport and infrastructure facilities»" [23].	– high density, – mixed land use, – clear boundaries of urban development, – effective public transport system and infrastructure.
B. Komar (2014)	The analysis of space quality of the selected housing estates in the context of sustainable development.	"A compact city is a city that has the following characteristics: a revitalized center, a high density of buildings, mixed functions of urban areas and numerous services. The Compact city also supports walking and cycling, reducing distances between work and housing, as well as building multifunctional facilities" [24].	– the revitalized city center, – high density, – mixed land use, – promotion of cycle and pedestrian communication, – reduction distance between the place of work and housing.

Z. Paszkowski (Report of Living Space of Poles) (2014)	The selected trends of development of cities in Poland.	"A city model with an intensive, multifunctional and well-structured urban form, which also includes well-equipped recreational greenery and good accessibility to all necessary public services" [25].	– dense and multifunctional urban form, – accessibility to public services and green spaces.
National Urban Policy 2023 (2015)	Definition activities of government administration in terms of urban policy in Poland.	"In planning development, local governments should act in accordance with the idea of a compact city, which - implementing the principles of sustainable development - promotes a polycentric structure, taking the form of dense and multifunctional buildings, served by pedestrian, bicycle and public transport, while reducing the need to use individual car transport" [9].	– polycentric structure, – dense and multifunctional urban form, – effective public transport system with bicycle and pedestrian communication.
S. Gzell (2015)	The selected problems of contemporary urban planning.	"(...) the idea of a compact city may be served by increasing the intensity of housing development, the development of urban set-aside, poorly used traffic areas or post-production areas" [26].	– intensification, – revitalization of industrial or fallow areas.
K. Gasidło (2017)	Analysis of the methods to achieve compactness in existing dispersed urban form.	"Compact city is generally defined as a compactly developed city, as the term compactness evokes closeness, focus, continuity, concentration. Buildings and components of technical and social infrastructure should be close to each other, concentrate around public space, which reduces the distance and facilitates access to all functions of the city" [27].	– well-connected buildings with technical and social infrastructure; – accessibility to city functions.
S. Tapper, T. Klöti, M. Drilling (2018)	Urban green spaces in the compact city (on the example of Swiss cities).	"The compact city approach is marked by high density, mixed land use, pedestrian-oriented habitation, the utilization of development reserves for construction projects and the structural transformation of former industrial areas or fallow land into service or residential areas of high quality (…)" [28].	– high density, – mixed land use, – pedestrian-oriented habitation, – revitalization of industrial or fallow areas.

Source: author's own work based on literature in the table.

To sum up the literature review, it can be considered that the above-mentioned definitions of the idea of a compact city have a common denominator. Almost everywhere there is a postulate to shape a relatively dense and multifunctional urban fabric. In addition, the emphasis is on efficient public transport and urban planning to encourage the development of pedestrian and bicycle transport. It is worth noting that in recent years additional assumptions have been put forward in relation to revitalization, which is an effect of the postulate of "inward development of cities". The concept of a compact city based on sustainable development assumes revitalization of degraded urban areas, which have lost their original value as a result of both the passage of time and structural changes. However, the development of inward is to be accompanied by the protection of open spaces and public spaces, which are a key element of any urban structure. To sum up the literature review in this part of the paper, it can be stated that the compact city policy is one that postulates the relative shaping of a dense and multifunctional urban structure, connected with an efficient transport system, also assumes the successive development of brownfield areas, while protecting open spaces and public spaces [10].

On the basis of the review of definitions, it can be noted that the compact city concept is not one-dimensional, apart from spatial aspects, it also refers to the social or environmental dimensions, which are inherent in the paradigm of sustainable development. However, finding the answer to the question whether the selected city can be both compact and sustainable need closer studies. Primarily a set of measurable compact city indicators is necessary, which should be compared with well-established sets of sustainable development indicators. In the next part of the paper, taking into account the above assumptions as well as the results of research conducted by other authors, a set of measurable indicators for a compact city has been proposed.

3. INDICATORS OF THE COMPACT CITY CONCEPT

3.1. The literature review

One of the best-known attempts to measure the compactness of cities is the study by E. Burton [16]. As E. Burton pointed out years ago that the research on the compact city concept is difficult due to, among

other things, the lack of clearly formulated indicators enabling the measurement of cities in terms of the selected concept. The author proposed 41 indicators, which she then tested on 25 English cities. The indicators were divided into three basic groups: density indicators, mix-of-use indicators, and intensification indicators. The density indicators group included 14 indicators in total, which were divided into additional subgroups: density of population, the density of built form, the density of sub-centers and density of housing. In turn, in the mix-of-use indicators group, 11 indicators were proposed concerning the provision of facilities (balance of residential and nonresidential land uses), a horizontal mix of uses (geographical spread of key facilities) and vertical mix of uses. However, in the largest group of intensification indicators, a total of 16 indicators were taken into account. These indicators were additionally divided into 4 subgroups: increase in population (re-urbanization), increase in development, increase in density of new development and increase in density of subcenters. Additionally, composite compactness indicators were proposed, taking into account 6 dimensions: "compact" (average of all compactness indicators), "dens" (average of all density indicators), "mixuse" (all mix-of-uses indicators), "intens" (all intensification indicators), "intpop" (all population-intensification indicators) and "intblt" (all built-form-intensification indicators) [16]. Summing up the set of indicators developed by Burton, it can be concluded that they constitute a very large group (41 indicators have been proposed in total) and in most cases, they refer to the compactness of urban structures. The proposed set of indicators is a valuable contribution to the research on compact city indicators, however, their implementation requires the knowledge of many precise data, often going beyond the framework of generally available statistics.

A set of indicators to measure cities against the compact city concept was also developed in the report "Compact City Policies. A Comparative Assessment" by OECD [12]. Importantly, the report was the finalization of a three-year project entirely devoted to the concept of a compact city. The OECD proposed a total of 18 indicators for monitoring and evaluating compact city performance, while case studies were developed for 5 selected metropolitan areas (Melbourne, Vancouver, Paris, Toyama, and Portland). The indicators were divided into two main categories, i.e. indicators related to compactness and indicators reflecting the impact of policies promoting a compact city on the environmental, social and economic spheres. For the first category, indicators were proposed related to [12] :

- density and neighborhood: population and urban land growth; population density on urban land; retrofitting existing urban land; intensive use of buildings; housing form (more specifically: share of multi-family houses in total housing units); trip distance (more specifically: average trip distance for commuting/all trips) and urban land cover;
- public transport system: trips using public transport and proximity to public transport (more specifically: share of the population (and/or employment) within walking distance (e.g. 500 meters) of public transport stations in total population);
- accessibility to local services and jobs: matching jobs and homes; matching local services and homes; proximity to local services; and trips on foot and by bicycle.

In the second category, however, a total of five indicators illustrating the impact of compact city policy on selected issues have been proposed:

- environmental: public space and green areas; transport energy use and residential energy use;
- social: affordability (that is a share of household expenditure on housing and transport in total household expenditure);
- economic: public services (that is expenditure on maintaining urban infrastructure (roads, water facilities, etc.) per capita).

Importantly, as indicated in the report, the above list is preliminary it is the result of a literature review, and some indicators need additional research and improvements. Due to the availability of data, only selected indicators have been included in the case studies [12].

Kotharkar et al. [23] also measured the compact urban form, and the case study concerned the Indian city of Nagpur (the largest urban center in central India). At that time, the following six groups concerning the urban form were proposed, for which indicators were determined:

- density: gross population density; average (built-up area) density; land use spilled up; average land consumption per person;
- density distribution/dispersion: density profile (presents the dispersion across metropolitan area and agglomeration of people around centrum); density gradient (presents degree of urban sprawl); population by distance to the center of gravity or CBD;
- transportation network: mode share; average trip length; road network density; congestion index;

walkability index;
- accessibility: service accessibility; public transport accessibility;
- shape: dispersion index;
- mixed-use land composition: land use split up; a ratio of residential to non-residential use; a ratio of built to open area.

Summarizing the next set of indicators, it can be noted that despite the different classification of key urban form characteristics, the indicators refer to similar aspects, i.e. density, transportation network and mixed land use [23].

Liaqat et al. [29], on the other hand, conducted research on the measurement of sustainable urban development in the light of the compact city concept. For this purpose, they also proposed a set of measurable indicators and a case study was developed for the Pakistani city of Lahore. Based, among others, on the aforementioned studies by Kotharker et al. [23], as well as on the results of interviews with experts, Liaqat et al. [29] developed a comprehensive set of indicators to assess sustainable urban development in the light of the compact city concept. The paper distinguishes three characteristic features, to which the following indicators have been assigned:
- density: gross population density; average town density; density profile;
- transportation and accessibility: average trip length; road network density; public transport accessibility;
- mixed-use land consumption: land use split up; average land consumption per person; a ratio of residential to non-residential use; a ratio of built up to open area.

To sum up, the above list proposes a total of 10 indicators, characterized by a relatively easy calculation algorithm and a reference to three key assumptions: density, transportation and accessibility, and mixed land use.

3.2. The main assumption of a set of compact city indicators

The following guidelines have been followed during the work on the compact city index set (compare: Coombes, Wong [30]):

I. Indicators should be as quantitative as possible, even if they relate to qualitative aspects, in order to facilitate both the assessment of a single center and the establishment of rankings.

II. The indicators should reflect the key assumptions and specifications of the chosen concept.

III. Indicators should be developed taking into account the availability and reliability of the necessary data to facilitate their practical implementation and exit from the theoretical framework.

IV. Indicators should be separable, each indicator should relate to a different issue.

V. The indicators should enable measurement on the scale of the whole city or even the metropolitan area.

Based on the existing definitions and assumptions of the compact city concept (Table 1), as well as the sets of indicators developed by other researchers, five pillars of the contemporary compact city concept were proposed as a synthesis: city compactness, accessibility, public transport system with cycle and pedestrian communication, urban regeneration with the development of brownfield land and public spaces [10].

3.3. Set of the compact city indicators – the source of data

In this subchapter, tables from 2 to 6 present proposals for compact city indicators, taking into account the availability of the necessary data and the division into 5 thematic groups: city compactness, accessibility, public transport system with cycle and pedestrian communication, urban regeneration with development brownfield land and public spaces.

In almost every definition of the compact city, there is a concept of density. In research, both population density and building density appear. In addition, it is not uncommon to distinguish between net and gross population density/buildings. It should be stressed, however, that in the light of sustainable development and the contemporary compact city concept, relative density, adapted to the character and function of a given center, plays a key role. Available statistical data (both at the international and national level) enables the measurement of both population density within the administrative boundaries of the city and within built-up areas (after their determination). Also important is the trend in the development of these indicators. Table 2 presents proposals of indicators from this group. Importantly, intermediate analysis (e.g. developed areas) can be describe with superficial measures, however, the final indicators are numerical, usually expressed as a percentage.

As it is pointed out by Gasidło [27] a compact city should be analyzed not only from the point of view of

Table 2.
Indicators of city compactness

No.	Indicator	Unit	Formula	Justification	The basic source of data
I1	The population density within the administrative boundary	The number of inhabitants per 1 km^2	$\frac{number\ of\ inhabitants}{total\ area\ of\ the\ city}$	The basic indicator of the city, commonly included in public statistics.	National Statistical Office
I2	Change of the population density within the administrative boundary	%	$\frac{a-b}{a}$ *100%	The indicator presents urbanization trends.	National Statistical Office
I3	Share of developed areas in a total area	%	$\frac{developed\ areas}{total\ area}$ *100%	The indicator presents the level of development areas in a city.	Regional Surveying and Cartographic Documentation Centre
I4	The population density in developed areas	The number of inhabitants per 1 km^2 urban land	$\frac{number\ of\ inhabitants}{developed\ areas}$	The indicator presents the population density only in built-up areas in a city.	National Statistical Office; Regional Surveying and Cartographic Documentation Centre

a – the population density within administrative boundary at the beginning of the period
b – the population density within administrative boundary at the end of the period
Source: author's own work.

Table 3.
Indicators of accessibility

No.	Indicator	Unit	Formula	Justification	The basic source of data
I5	Accessibility to service facilities	%	$\sum \frac{residential\ area}{access\ zone}$ *100%	The indicator presents the share of residential areas within the access zone (e.g. 500 m) to service facilities (facilities where commercial and service activities are carried out, e.g. shopping centers) in the city.	Regional Surveying and Cartographic Documentation Centre
I6	Accessibility to education facilities	%	$\sum \frac{residential\ area}{access\ zone}$ *100%	The indicator presents the share of residential areas within the access zone (e.g. 500 m) to education facilities in the city.	Regional Surveying and Cartographic Documentation Centre
I7	Accessibility to health facilities	%	$\sum \frac{residential\ area}{access\ zone}$ *100%	The indicator presents the share of residential areas within the access zone (e.g. 500 m) to health facilities in the city.	Regional Surveying and Cartographic Documentation Centre
I8	Accessibility to green areas	%	$\sum \frac{residential\ area}{access\ zone}$ *100%	The indicator presents the share of residential areas within the access zone (e.g. 500 m) to green areas in the city.	Regional Surveying and Cartographic Documentation Centre
I9	Accessibility to public transport	%	$\sum \frac{residential\ area}{access\ zone}$ *100%	The indicator presents the share of residential areas within the access zone (e.g. 500 m) to public transport in the city.	Regional Surveying and Cartographic Documentation Centre

Source: author's own work.

its geometric shape but also the efficiency of land use and the quality of life of its inhabitants. Therefore, the intensity of use is insufficient. What is important, apart from density (as a characteristic feature of a compact city), there is also a postulate of mix land use. Currently, there is a return to the traditional design of multifunctional spatial structures, which facilitates access to the necessary functions and facilities (retail and service, educational, green areas, etc.). Therefore, accessibility (which is often referred to in the context of the compact city) is resultant mixed land use. The buffer analysis can be used to determine these indicators. At the beginning, the selected functions and facilities with access buffers (zones) should be determined (e.g. access buffer with a radius of 500 m). Then, it is necessary to estimate the share of residential area (one-family houses and/or multi-family houses) within the access buffers. At the final stage, the share of residential area in all designated access buffers should be summed up. Importantly, the proposed approach enables the analysis of the availability of the selected objects in

Table 4.
Indicators of the transport system

No.	Indicator	Unit	Formula	Justification	The basic source of data
I10	Number of passenger cars per 1000 population	pieces	$\frac{number\ of\ cars * 1000\ inhabitants}{total\ number\ of\ inhabitants}$	The indicator shows the popularity of using individual car transport	National Statistical Office
I11	Cost of a combined monthly ticket (all modes of public transport) for 5–10 km in the central zone	euro	–	The indicators show accessibility to public system in the economic aspect	Urban Audit
I12	Length of bicycle lanes per 1000 population	km	$\frac{length\ of\ lane * 1000\ inhabitants}{total\ number\ of\ inhabitants}$	The indicator shows the state of investment in cycle infrastructure	National Statistical Offices
I13	Length of bus lanes per 1000 population	km	$\frac{length\ of\ lanes * 1000\ inhabitants}{total\ number\ of\ inhabitants}$	The indicator shows the state of investment in bus infrastructure	National Statistical Offices

Source: author's own work.

Table 5.
Indicators of urban regeneration with development brownfield lands

No.	Indicator	Unit	Formula	Justification	The basic source of data
I14	The share of areas to be included in the urban regeneration in a total area	%	$\frac{areas\ for\ urban\ regeneration}{total\ area} * 100\%$	The indicator shows areas which need corrective actions	Local Action Plan for Urban Regeneration
I15	The share of the investment areas offered by the city in a total area	%	$\frac{investment\ areas}{total\ area} * 100\%$	The indicator shows investment areas, especially brownfield lands	Data provided by city offices

Source: author's own work.

Table 6.
Indicators of public spaces

No.	Indicator	Unit	Formula	Justification	The basic source of data
I16	The share of public open areas in a total area	%	$\frac{public\ open\ areas}{total\ area} * 100\%$	The indicator shows public open areas, e.g. forests and copses.	Regional Surveying and Cartographic Documentation Centre
I17	The share of public recreational and sports complexes in a total area	%	$\frac{public\ recreational\ and\ sports\ areas}{total\ area} * 100\%$	The indicator shows localization of recreational and sports complexes, e.g. parks, sports centers.	Regional Surveying and Cartographic Documentation Centre

Source: author's own work.

the spatial aspect.

Relatively compact and multifunctional urban structures should be linked by an efficient public transport system, which is a key aspect of the sustainable development of modern cities. According to the OECD report, "a compact city implies higher intra-urban mobility and less automobile dependency" [12]. It is worth noting that the topic of transport is increasingly included in public statistics (e.g. within the Urban Audit program) [31].

Another important postulate of the modern compact city model is to develop inwards within the existing borders. In this context, the key role is played by the successive development of brownfield sites and their comprehensive urban regeneration.

The last element of a compact city is public spaces, due to the availability of data, a percentage of public open spaces, as well as generally accessible recreation and sports areas, are taken into account in this paper.

Summarizing the proposed set of compact city indicators, it should be stated that the main sources of information on Polish cities are generally available

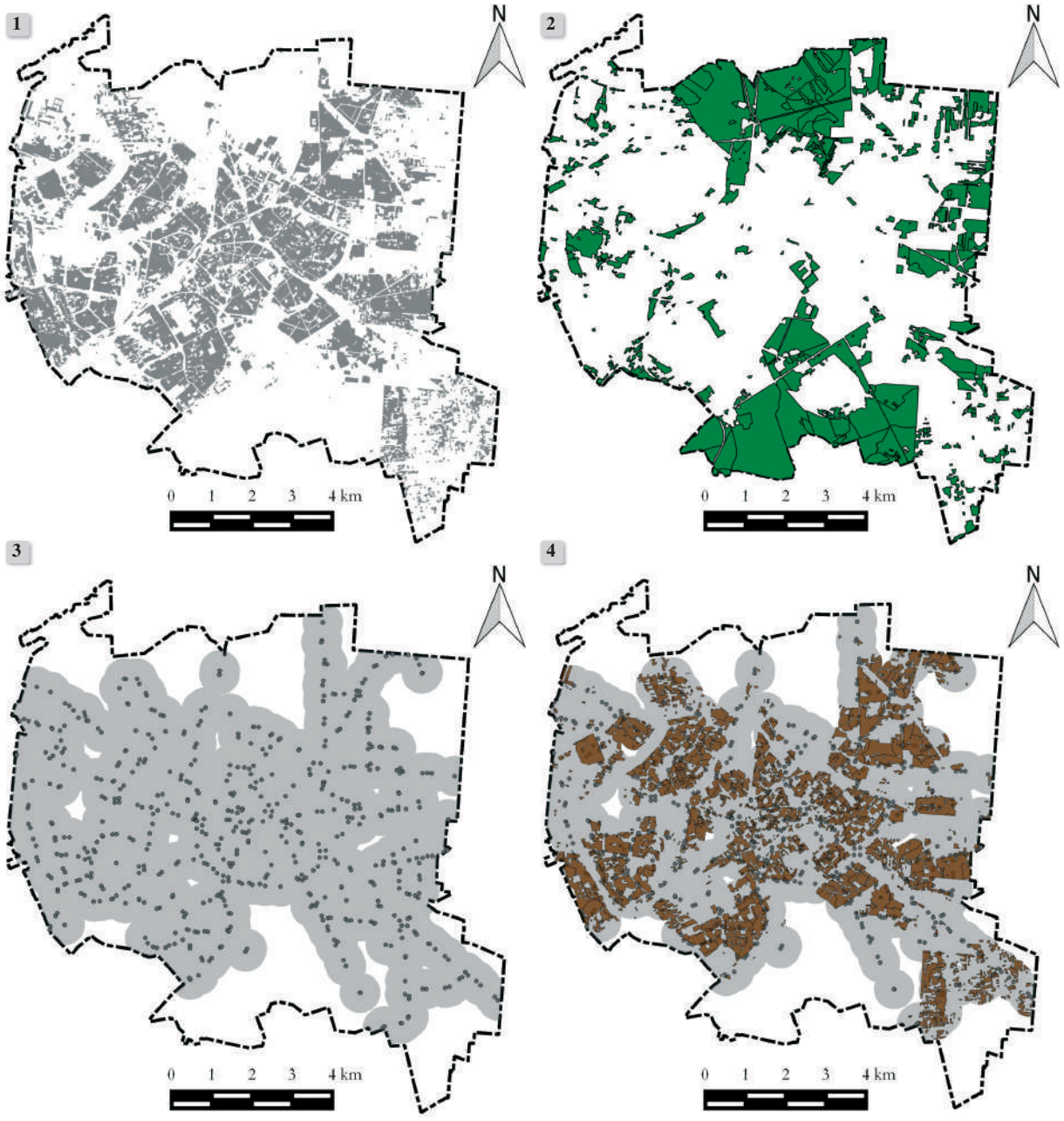

Figure 1. Built-up areas in Bialystok
Figure 2. Green spaces in Bialystok
Figure 3. Public transport stops with access zone (500 m) in Bialystok
Figure 4. Residential area in access zone of public transport stop in Bialystok

Source: author's own work based on Database of Topographical Objects from Regional Surveying and Cartographic Documentation Centre in Bialystok [32]

statistics: international, national and local, as well as information made available by geodetic and cartographic documentation centers. An important source of information is the Topographic Objects Database. Simple GIS analyses enable both delimitations of selected areas, e.g. built-up areas (Figure 1) or green spaces (Figure 2), as well as research on accessibility, e.g. of public transport systems (Figures 3 and 4).

4. DEFINITION OF WEIGHTS OF THE COMPACT CITY INDICATORS – A CASE STUDY

When ranking cities, as well as at the stage of individual urban analyses, it is important to determine the validity of the criteria used as a basis for the assessment. In this paper, one of the best-known

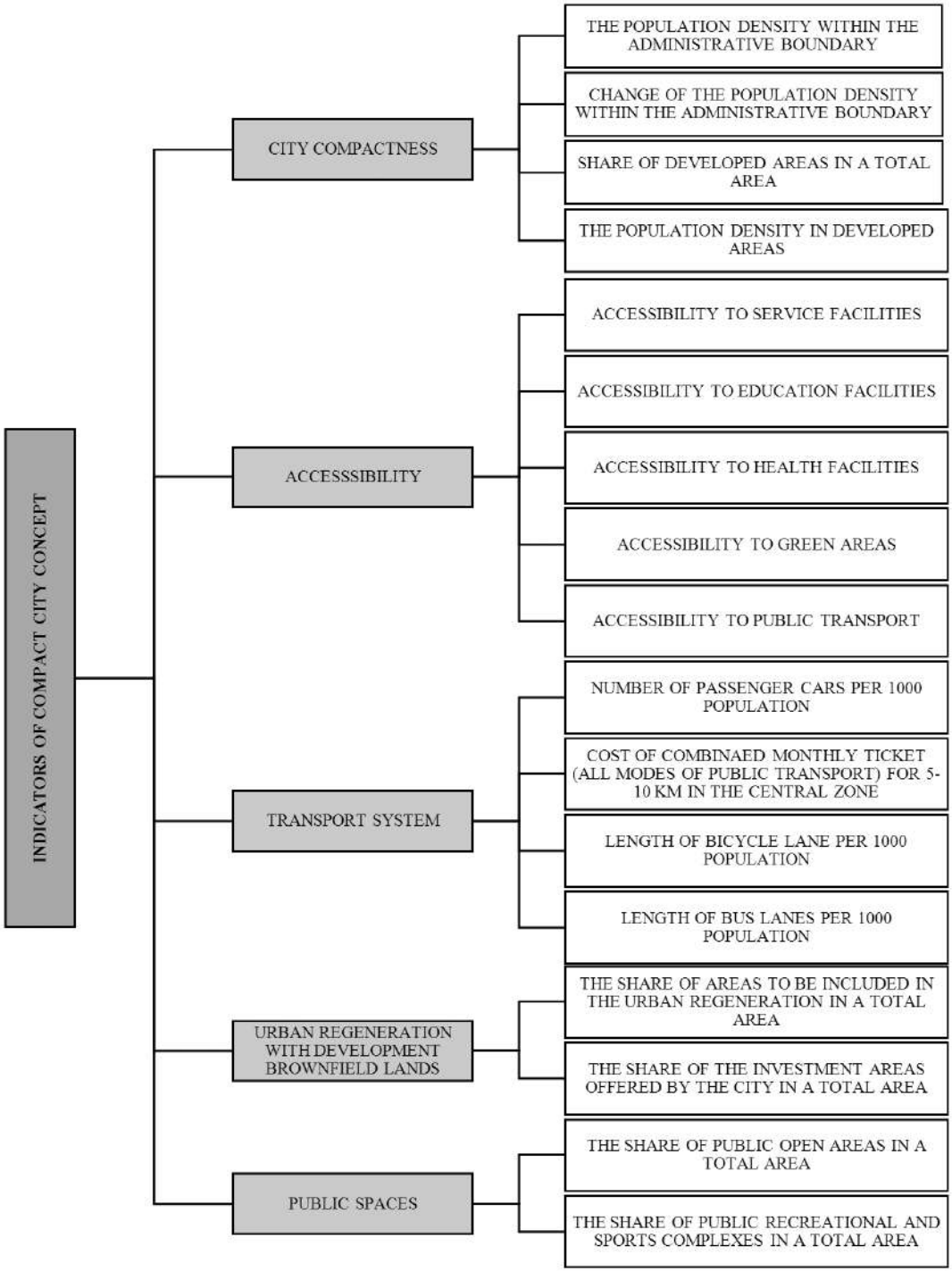

Figure 5.
Hierarchical structure of indicators of the compact city concept. Source: author's own work

methods of multi-criteria decision support, the AHP method developed by a well-known American mathematician T.L. Saaty, was proposed to determine the weights of the previously formulated compact city indicators. The case study developed a hierarchical structure of compact city indicators and proposed two sample weights sets: variant I, assuming equivalence of the main groups of indicators (Table 7) and variant II, assuming a slight preference for compactness and accessibility indicators (Table 8).

Due to the popularity of the AHP method, the main assumptions and calculation stages are presented below [33, 34, 35]:

I. Decomposition of the decision-making problem - the easiest graphic form of decomposition is the development of a hierarchical structure (Figure 5), including goal, criteria (main, sub-criteria, etc.), decision-making alternatives. The number of levels and elements of such a structure is strictly dependent on the nature of the considered decision problem.

II. The structure of the comparison matrix – at each defined level of the developed hierarchical structure, a series of comparisons is made in pairs of individual elements (groups of criteria, main criteria, sub-criteria, etc.). For pair comparisons the classical Saaty scale is used, where: 1 – means equal importance of considered elements, 3 – a moderate advantage of one element over another, 5 – strong advantage, 7 – very strong advantage, 9 – absolute advantage. In addition, even numbers and the inverse of the above values can be used. The result of a series of comparisons in pairs is an estimation of the weights of individual elements. In this paper 1 matrix with dimensions 5×5 was determined, corresponding to the group of indicators and 5 matrices taking into account the basic compact city indicators (respectively matrix with dimensions 4×4 – indicators of compactness, 1 matrix with dimensions 5×5 – indicators of accessibility, another matrix with dimensions 4×4 – indicators of transport system and 2 matrices with dimensions 2×2, taking into account indicators of urban regeneration and public spaces).

III. The evaluation of the consistency of comparisons in pairs – within the AHP procedure there is a possibility to evaluate the consequences of comparisons in pairs, which can be made with the index of inconsistencies and the coefficient of inconsistency.

IV. Preparation of the final ranking of decision variants – the last stage of the multi-criteria analysis constitutes a ranking of the considered decision variants due to their participation in the implementation of the defined superior objective. Due to the nature of the issues discussed in this paper, this stage has been omitted.

Table 7.
The weights of compact city indicators – option I

Indicator groups	Global weights	Indicators	Global weights	Local weights
City compactness	0.200	The population density within the administrative boundary	0.250	**0.050**
		Change of the population density within the administrative boundary	0.250	**0.050**
		Share of developed areas in a total area	0.250	**0.050**
		The population density in developed areas	0.250	**0.050**
Accessibility	0.200	Accessibility to service facilities	0.200	**0.040**
		Accessibility to education facilities	0.200	**0.040**
		Accessibility to health facilities	0.200	**0.040**
		Accessibility to green areas	0.200	**0.040**
		Accessibility to public transport	0.200	**0.040**
Transport system	0.200	Number of passenger cars per 1000 population	0.250	**0.050**
		Cost of a combined monthly ticket (all modes of public transport) for 5-10 km in the central zone	0.250	**0.050**
		Length of bicycle lane per 1000 population	0.250	**0.050**
		Length of bus lanes per 1000 population	0.250	**0.050**
Urban regeneration with development brownfield lands	0.200	The share of areas to be included in the urban regeneration in a total area	0.500	**0.100**
		The share of the investment areas offered by the city in a total area	0.500	**0.100**
Public spaces	0.200	The share of public open areas in a total area	0.500	**0.100**
		The share of public recreational and sports complexes in a total area	0.500	**0.100**

Source: author's own work.

Table 8.
The weights of compact city indicators – option II

Indicator groups	Global weights	Indicators	Global weights	Local weights
City compactness	0.333	The population density within the administrative boundary	0.250	**0.083**
		Change of the population density within the administrative boundary	0.250	**0.083**
		Share of developed areas in a total area	0.250	**0.083**
		The population density in developed areas	0.250	**0.083**
Accessibility	0.333	Accessibility to service facilities	0.200	**0.067**
		Accessibility to education facilities	0.200	**0.067**
		Accessibility to health facilities	0.200	**0.067**
		Accessibility to green areas	0.200	**0.067**
		Accessibility to public transport	0.200	**0.067**
Transport system	0.111	Number of passenger cars per 1000 population	0.250	**0.028**
		Cost of a combined monthly ticket (all modes of public transport) for 5-10 km in the central zone	0.250	**0.028**
		Length of bicycle lane per 1000 population	0.250	**0.028**
		Length of bus lanes per 1000 population	0.250	**0.028**
Urban regeneration with development brownfield lands	0.111	The share of areas to be included in the urban regeneration in a total area	0.500	**0.056**
		The share of the investment areas offered by the city in a total area	0.500	**0.056**
Public spaces	0.111	The share of public open areas in a total area	0.500	**0.056**
		The share of public recreational and sports complexes in a total area	0.500	**0.056**

Source: author's own work.

The calculations presented in the above tables have been made in a spreadsheet, but there is also software with a built-in AHP algorithm.

4. CONCLUSION

The following conclusions can be drawn from the literature studies on the compact city and the review of available statistical and spatial data:

- the compact city is one of the most popular development concepts which has been taken into account in many national urban policies and scientific works, however, most of them relate to its theoretical assumptions, the compact city indicators are an important research stream. The most important research indicators are the compact city indicators, which enable cities to be assessed in the light of the main assumptions of this concept;
- the set of indicators should be relatively simple and based on available data, the use of compact city indicators from the world literature to assess Polish cities is difficult due to the lack of complete data;
- the paper proposes a total of 17 compact city indicators, grouped according to the main pillars of the concept (compactness, accessibility, transport system, urban regeneration, and public space), constituting a systematization of the existing definitions of the compact city;
- the compact city indicator set has been supplemented with information sources and sample weights, which may facilitate their practical implementation;
- among the future directions of research one can indicate the extension of the tree of the hierarchical structure by the next level, i.e., ranges within individual indicators, as well as the assessment of Polish cities in the light of compact city with multicriteria analysis.

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