Study of the dependence of city development indicators from urban form

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Abstract. Urban form is an important object of the decision-making process in urban planning. Indicators of spatial characteristics appear in the regulatory acts of the Russian Federation. In today's fast-paced world, the infrastructure that used to be acceptable becomes inappropriate over time, and adaptation by trial and error often leads to negative consequences. This study is part of a major effort to understand how the urban form affects the development of the city. The study of five significant spatial indicators and four important development indicators on the data of the fourteen largest cities in Russia did not reveal an essential correlation among the analyzed indicators. Nevertheless, the demonstrated direction in understanding the laws of the spatial development of the city can help in making decisions on the transformation of the urban environment and will give a new impetus to creating comfortable living conditions.

1. Introduction
Today, cities are the main economic centers of the world in which most people live and this number will increase. Two types of processes can be distinguished in the world: reconstruction and optimization of the existing urban development, and extensive development of new territories that determine an urban form. Urban form is the physical characteristics of its elements, which make up and give shape to urban development - these are streets, quarters, land and buildings [1]. The urban form can be calculated and there are many metrics that are used in urban planning: road network density, Dubelier coefficient, building density, accessibility to various objects. All these elements also appear in Russian legislation, for example, in the standards of urban development regulation and the rules of land use and development. At the moment, the influence of these parameters on the development of the city and the quality of life of residents has not been studied enough. In this regard, it is not possible to evaluate a particular urban development decision in terms of its contribution to the change in urban morphology [2]. At the same time, it is not completely clear what properties of the urban form can adversely affect the development of the city. Until now, there are no unequivocal answers to the questions of what city building density is better and how the density of the road network affects safety and environmental friendliness.

The purpose of this paper is to study the correlations of some spatial indicators and indicators of city development. It is supposed to be possible to find patterns that will be used in the preparation of urban planning documentation, which will reduce the number of erroneous urban planning decisions and ultimately make life in the city more comfortable and safe. And in this regard, the characteristics of the street-road network are considered in the first place, because the streets form the general shape
of the city and are the most sustainable element of the urban form that can last for hundreds of years [1].

2. Study of the influence of urban form on urban environment quality improvement

Urban morphology, as a science of urban form, generates knowledge to explain spatial trends in cities and creates the prerequisites for the development of new requirements and standards for urban planning [3]. Over time, humanity has been trying to comprehend and harmonize the relationship between man and an environment, which for more than 50% of people is a city. Berleant highlights two components of urban planning [4]:

- Development and better understanding spatial organization aspects associated with the social dimension of urban order.
- The nature of the professional relationship between the process of creating urban spaces and the participation of urban environment users with this process, in order to understand the importance of achieving a better balance between professional solutions and how the community uses these solutions.

At the moment, the urban form of Russian cities is most dependent on three documents: urban planning standards, master plan and land use and development rules. Urban planning standards establish certain minimum parameters for accessibility to social infrastructure and provision of utilities, including requirements for a street-road network [5]. The government of the Russian Federation regions or local authority in conjunction with designers to justify their decisions use the “SP. Urban planning”, which are the current version of the 1989 standard.

Books of the quality standard of the urban environment DOM.RF were published in 2019. They must completely update the old standards and adapt to modern requirements for the urban environment. At the moment, these standards are advisory, and their use is not regulated in any way by Russian legislation, and so far this document is at the same level as any scientific and educational literature. “SP. Urban planning”, although it is partially mandatory, is already out of date. Arguments for the use of various indicators of urban forms for the design of an urban environment of better quality are referred to the successful experience of urban development [6].

The study of the effects of urban form on the indicators of area development is carried out by many scientists in different directions. Recommendations on the use of the ratio of open spaces index in the legal zoning, which is determined by the ratio of the area of open spaces to the area of the built-up area to reduce PM10 emissions, were developed based on these studies [7]. There are studies that the density of the road network correlates with benefits in pedestrian and car movements, and also affect traffic congestion, but almost do not affect the preference in choosing a method of movement [8].

3. City development indicators

In the world there are many economic indicators, various indices and criteria that are used to assess both the quality of urban environment and the quality of life in general. Thus, it can be concluded that although many experts have not come to a common methodology for determining the quality of life, everyone agrees that it is determined by a certain system of indicators. Some of them are used at the state level, as the urban environment quality index from DOM.RF, and some are simply taken into account by some designers at will [9].

Various indices and indicators that are relevant for today's problems of the urban environment, fixed for the sustainable development of the UN, or often appearing on the agenda of congresses of organizations such as ISOCARP were analyzed when choosing indicators of the urban environment quality. Therefore, indicators of the development of the city associated with current problems of the urban environment, which could correlate with indicators of the road network or the general form of the city and the structure of built-up areas, were chosen.

Cities of Russia with a population of about one million people were chosen to ensure uniformity of the analyzed data. Table 1 shows the values of city development indicators for the cities selected in the
study. The information base for the analysis of city development indicators is formed from state statistical and analytical reviews [10-13].

### Table 1. City development indicators.

| N  | City               | Vehicles per 1000 people | Street infrastructure | Accident per 1000 people | Physical accessibility of public transport |
|----|--------------------|--------------------------|-----------------------|--------------------------|--------------------------------------------|
| 1  | Yekaterinburg       | 315                      | 35                    | 1160                     | 16.1                                       |
| 2  | Volgograd           | 263                      | 24                    | 1111                     | 16.7                                       |
| 3  | Novosibirsk        | 278                      | 21                    | 983                      | 17.0                                       |
| 4  | Nizhny Novgorod     | 290                      | 24                    | 2286                     | 16.8                                       |
| 5  | Kazan               | 305                      | 28                    | 1897                     | 16.3                                       |
| 6  | Chelyabinsk         | 276                      | 23                    | 1789                     | 13.2                                       |
| 7  | Omsk                | 283                      | 14                    | 2169                     | 13.7                                       |
| 8  | Samara              | 344                      | 30                    | 1338                     | 16.1                                       |
| 9  | Rostov-on-Don       | 234                      | 26                    | 723                      | 14.4                                       |
| 10 | Ufa                 | 288                      | 27                    | 1903                     | 13.3                                       |
| 11 | Krasnoyarsk         | 296                      | 29                    | 1478                     | 14.3                                       |
| 12 | Voronezh            | 315                      | 20                    | 1339                     | 13.7                                       |
| 13 | Perm                | 242                      | 32                    | 1213                     | 12.9                                       |
| 14 | Krasnodar           | 343                      | 38                    | 1217                     | 14.4                                       |

4. **Calculation of spatial development indicators of cities**

Remote sensing materials in the form of raster images (see figure 1) from the Global Human Settlements Layer (GHSL) with a resolution of 30 m and 250 m [14], as well as a road graph and information on the administrative boundaries of cities from OpenStreetMap (OSM) [15] were used to analyze spatial development of studied cities.

GHSL images with a resolution of 30 m were used to determine the growth of the built-up area within the administrative boundaries of each city from 1990 to 2014, due to the availability of data for this period. The pixel value is equal to the period at which time the building appeared on the area. The value of the built-up area growth is calculated as the ratio of the built-up area in 2014 to the built-up area in 1990. This indicator reflects how extensive the growth of the built-up area was.

The built-up area within the administrative boundaries of each city was calculated from GHSL raster images with a resolution of 250 m [16]. The built-up area was taken as the sum of the areas of pixels whose value would not be 0, which means the absence of any buildings or structures within the pixel boundaries. Using images of this resolution allows to determine the array of built-up area, which would not be possible using images with a resolution of 30 m, which divides the area into separate pieces with buildings, not taking into account open spaces in the city [17].

The compactness factor of the built-up area was determined by the formula of the compactness coefficient calculates as the ratio of the perimeter of the built-up urban area according to GHSL to the root of the area of this territory multiplied by 4 [18].

The density of the street network was calculated by the formula for the ratio of the length of the street network to the area of the built-up area [6], which was determined by GHSL raster images. OSM data was used to calculate the density of the street network and was selected by the identifier “highway” with the following values: “motorway”, “motorway_link”, “trunk”, “trunk_link”, “primary”, “primary_link”, “secondary”, “secondary_link”, “tertiary”, “tertiary_link”, “unclassified”, “residential”, “living_street”. These tags correspond to the objects of the street network that divide city blocks among themselves, as well as federal and regional roads passing through cities or bypassing them.
The length of the street-road network, which includes not only the street network, but also the internal courtyard roads and driveways, was used for a more detailed assessment of the safety of the urban environment.

Figure 1. GHSL image of Chelyabinsk: black – the area on which there is no development; from dark gray to white – built-up area.

The length and density of the road network is determined by the sum of the lengths of all objects with the tag “highway” from the OSM road graph, including all the tags for calculating the density of the street network with the addition of the “service” and “track” values, which correspond to the courtyard driveways and unpaved roads [19].

The calculation of spatial indicators was carried out using previously developed software tools [20], as well as QGIS 3.10 software [21]. The calculation results are shown in table 2.

5. Dependence assessment of studied indicators
Estimates of the ratio of spatial development indicators to cities development indicators were obtained by calculating the correlation coefficient, which are presented in table 3. It should be noted that no correlations were found between the density of the street-road network and the accident statistics [22], to which some sources refer [6, 23], as well as the influence of the shape factor of the urban area with the number of vehicles, which may indicate that non-compact city with too large area or with the presence of such an effect as leapfrog affects the level of motorization of the population, which in turn indirectly affects the statistics of accidents. There is also a slight dependence that the smaller the increase in the built-up area, the greater the physical accessibility, which also applies to a compact city, and is possible due to the difficulty of providing convenient public transport to large areas.

The street infrastructure indicator has the largest average modulus correlation coefficient with spatial indicators. This indicator is associated with a number of indicators, and it will also determine the amount of subsidies from the federal budget [24].

6. Conclusion
Some spatial indicators of the development of million-plus cities were calculated in this study. And at the moment, it was not possible to detect any dependencies between the studied indicators. This work is the first stage in the study of the relationship of urban form with urban development. Nevertheless, it is already possible to draw some conclusions, for example, the results obtained show that the widespread opinion about the direct effect of the density of the street-road network on the frequency of accidents is greatly exaggerated.
Table 2. Spatial development indicators.

| N  | City             | Street network length (km) | Street network density (km/sq.km) | Road network length (km) | Road network density (km/sq.km) | Compactness factor | Increased built-up area from 1990 to 2014 (%) |
|----|------------------|----------------------------|-----------------------------------|--------------------------|----------------------------------|--------------------|---------------------------------------------|
| 1  | Yekaterinburg    | 2335.30                    | 5.00                              | 6418.01                  | 13.75                            | 12.05              | 33.97                                       |
| 2  | Volgograd        | 2424.10                    | 6.39                              | 5861.54                  | 15.46                            | 10.47              | 10.09                                       |
| 3  | Novosibirsk      | 2065.08                    | 5.29                              | 6604.71                  | 16.93                            | 7.90               | 12.82                                       |
| 4  | Nizhny Novgorod  | 1468.05                    | 4.97                              | 4541.88                  | 15.37                            | 8.07               | 12.82                                       |
| 5  | Kazan            | 2038.05                    | 6.08                              | 4812.35                  | 14.36                            | 8.35               | 29.65                                       |
| 6  | Chelyabinsk      | 1639.34                    | 4.97                              | 4758.93                  | 14.43                            | 5.43               | 15.60                                       |
| 7  | Omsk             | 2265.37                    | 5.71                              | 7231.02                  | 18.24                            | 7.81               | 22.22                                       |
| 8  | Samara           | 1663.66                    | 5.74                              | 3651.84                  | 12.60                            | 9.70               | 6.01                                        |
| 9  | Rostov-on-Don    | 1749.05                    | 7.88                              | 3206.32                  | 14.44                            | 5.53               | 18.28                                       |
| 10 | Ufa              | 1984.94                    | 7.01                              | 3841.78                  | 13.56                            | 11.77              | 61.02                                       |
| 11 | Krasnoyarsk      | 1213.99                    | 4.89                              | 3574.89                  | 14.40                            | 6.98               | 9.06                                        |
| 12 | Voronezh         | 1933.96                    | 6.89                              | 5002.16                  | 17.82                            | 9.91               | 12.46                                       |
| 13 | Perm             | 1873.02                    | 5.55                              | 4057.39                  | 12.03                            | 10.12              | 32.10                                       |
| 14 | Krasnodar        | 3360.29                    | 10.20                             | 5622.53                  | 17.06                            | 11.37              | 43.72                                       |

Table 3. Calculation of correlation coefficients.

| Indicator                                      | Vehicles per 1000 people | Street infrastructure | Accident per 1000 people | Physical accessibility of public transport |
|-----------------------------------------------|--------------------------|-----------------------|--------------------------|------------------------------------------|
| Street network density (km/sq.km)             | 0.21                     | 0.34                  | −0.09                    | −0.22                                    |
| Road network length (km)                      | 0.15                     | −0.31                 | −0.09                    | 0.28                                     |
| Road network density (km/sq.km)               | 0.17                     | −0.55                 | 0.16                     | 0.05                                     |
| Compactness factor                            | 0.45                     | 0.48                  | −0.02                    | 0.09                                     |
| Increased built-up area from 1990 to 2014 (%) | 0.08                     | 0.42                  | 0.20                     | −0.38                                    |

The direction of further research is related to the study of the effect of urban sprawl. This is important because it has a detrimental effect on the economy, introducing cities to high infrastructure maintenance costs, as well as the many negative effects of lengthy daily correspondence [25]. Also, in the future it is important to evaluate how individual morphotypes, urban form and their combinations affect urban development. The results can be used to develop master plans, land use rules and development of Russian cities, which already at the level of law affect the decision-making process in urban planning.

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