Vladivostok City Morphology: Space Matrix as a Tool for the Urban form Analysis

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Abstract. This paper presents the study of building types in Vladivostok according to the Space Matrix methods. Type design practice and clustering of urban areas is an important task for urban development, management and regulation purposes. The hypothetical condition is checked, according to which the form of urban material fabric can be fully and adequately determined by the ground and floor space index. As a result of the study according to methodology described above, the main building morphotypes in Vladivostok were identified, a comparative analysis of the building type and usage rate was carried out, urban areas, for which an increase in urban density is the most appropriate process for the best effect, were identified.

1. Introduction
Determining the parameters of the urban material fabric, which are essential for modeling, designing and managing the spatial area development, is a relevant objective of modern urban science [1, 2]. Currently, the development of land use planning documentation is carried out on the basis of the principles of functional zoning, which imply the differentiation of areas on the grounds of a particular land use regime [3, article 19]. Issues of the building form, ground and floor space index and their relationship with socio-economic processes get undeservedly little attention, while the identification of building morphotypes by density parameters is necessary for the development of building mass regulations and urban spatial development strategies [4, 5, 6]. Type design practice makes it possible to determine the general principles and patterns for a particular building type, to identify the potential and development reserves for intermediate type areas. Another relevant objective is to study the spatial characteristics of post-socialist cities in a developing market economy [7].

Actual methods for studying building forms progress in machine learning [8, 9], as well as in upgrading algorithmic tools, including the Spacematrix spatial density matrix methods [10, 11, 12]. These methods have been refined and tested on the example of Vladivostok.

2. Methods
The Spacematrix methods determine the density of urban material fabric as a phenomenon with several variables and reveal the morphological dependencies of building area. Floor space index (FSI)
alone is not enough to determine the urban fabric morphology, since neighborhoods with the same density can have different building types and storey factor (Fig. 1).

Figure 1 shows how different areas may look with the same FSI. In all cases, the Floor space index is the same, but the Ground space index in the left case is relatively high, in the right case the GSI is low, and the average example is in an intermediate position, which is reflected in the Spacematrix diagram. The presented site development types have the same FSI, but their position on the Spacematrix diagram is different due to differences in GSI, OSR and L. More accurate description of the site development typology could be achieved, while using Spacematrix methods to determine the characteristics of these areas.

The Spacematrix variables used for this study are defined and calculated as follows:

**Floor Space Index (FSI):**

\[ FSI = \frac{F}{A} \]  

where F is gross floor area of all buildings located on the site (m²), and A is the area of the urban fabric (m²).

**Ground Space Index (GSI):**

\[ GSI = \frac{G}{A} \]  

where G is the built up surface or building footprint (m²), and A is the land plot area (m²).

The average number of floors (L) and the open space ratio (OSR) are derived from the basic indicators FSI and GSI and can be calculated as follows:

\[ L = \frac{FSI}{GSI} \]  

\[ OSR = \frac{(1-GSI)}{FSI} \]

The physical meaning of the average number of floors (L) is expressed as the ratio of gross floor area of all buildings to the building footprint:

\[ L=\frac{F}{G} \]

The open space ratio is the ratio of undeveloped area to the land plot area:

\[ OSR=\frac{(S-G)}{F} \]

Distributions of GSI and FSI indicators for Vladivostok areas, made on the basis of OpenStreetMap open data, are shown in Figure 2. It is counterproductive to consider the average values of indicators due to their dependence on the scope of the review, therefore modal values were found, having the highest distribution frequency: 18% for GSI and 7.5 thousand sq. m / ha for FSI. Complex review of the GSI and FSI indicators using the Spacematrix tool reveals certain building types, characterized by one or another ratio of building volumes and open space.
3. Results
The GSI and FSI parameters determine the position of each area on the coordinate plane (Fig. 3), which allows us to evaluate the ratio of these parameters. In the studies, carried out according to these methods for Stockholm, clustering of area groups was carried out empirically by the principle of point proximity using M. Pont matrix (2014) [13]. Building types are mathematically determined by the average number of storeys and 0.25 and 0.125 GSI to be able to conduct a comparative analysis with a similar study conducted for four cities in the Netherlands Ye, Y., & Van Nes, A. (2014) [14].
As a clustering result, 8 building types were identified, divided into groups depending on the average number of storeys (mid-rise - from 3 to 6, low-rise - up to 3, high-rise - from 6 to 12):

1) mid-rise block type has the high GSI (25-58%) and FSI starting from 8.0 thousand square meters / ha. Mainly consists of quarters of the historic city center. This building type amounts to 1.9%, (146 ha.);
2) mid-rise strip type has the average GSI and FSI. It is a site development type, which makes up the bulk of the building mass in Vladivostok; The total area is 20.7% (1595 ha);
3) mid-rise point type has the low GSI and FSI. Mainly consists of low-density buildings on the slopes of hills with a dangerous slope. The total area is 2.3% (176 ha);
4) low-rise block type has the high GSI with (up to 3 floors) and low FSI. Includes some quarters of the historical center, but mainly commercial, industrial and commercial-warehouse areas, as well as port territories. The total area is 9.7% (258 ha);
5) low-rise strip type has the average GSI and low FSI. Areas predominantly consist of blocked individual housing or garage cooperatives and also sparse commercial and industrial territories. The total area is 19.9% (1530 ha);
6) low-rise point type includes sparse single-storey buildings, mainly coastal and port areas. The total area is 40.9% (3143 ha) of Vladivostok built up land areas;
7) high-rise strip type has the average GSI (more than 6 floors) and high FSI (more than 9.0 thousand square meters per ha). Consists of compact multi-storey areas. The total area is 1.3% (97 ha);
8) high-rise point type has the low GSI. Consists of detached multi-storey buildings with large open spaces, microdistrict development. The total area is 1.2% (88 ha).
4. Discussion
Since the city development form is the basis for life processes, such parameters as GSI and FSI, number of storeys and the proportion of open spaces illustrate the internal logic of the city development, being in correlation with the land use intensity. The Spacematix methods, based on the FSI and GSI, show the construction volume distribution across the city. There is a significant correlation between these indicators and building morphotypes, but, nevertheless, the city development form cannot be fully reduced to them. Thus, for example, areas with individual residential buildings and with storage facilities were classified by the same type (type 5, type 6). Spacematix methodology can be improved by increasing the number of geometric parameters taken into account, for example, the perimeter and overall dimensions, the number of angles, etc. It is advisable to evaluate the results of the city development type study in relation to the role of the areas in the urban spatial structure.
Figure 4 shows the nodes of Vladivostok, centrality areas, which are ranked depending on their level of urban organization according to a study performed previously by Potapenko A., the author of this article [15]. A comparison of the spacing of local city centers and the city development types described in the current paper allows us to draw the following conclusions:

1) Centrality areas are mainly characterized by types with the high FSI and GSI above the average (I, II).
2) The high FSI with a large number of open spaces (i.e., the low GSI) is not favorable for the development of local centers.
3) Reserves for increasing the building density for centrality areas should be considered for area types with the high GSI and low FSI, where an increase in the number of storeys is possible; and for area types with the average GSI, where new construction is possible on existing open spaces.

5. Conclusions
As a result of this study, eight types of building density were identified. A comparative analysis of the land use intensity, determined according to the unevenly-zoned development model of Vladivostok, and the spacing of density types showed the dependence of the area density and multifunctionality, which make it possible to predict, regulate and control the change in building density.

The practical relevance of the research concerns the identification of reserves for increasing the urban density for socio-economic development while protecting adjacent natural territories and maintaining the density of urbanized areas.

Area clustering by building morphotypes is an effective tool for identifying area types for land use planning and strategic development.

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