Quality assessment of urban areas based on neural network modeling and GIS

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Abstract. In this article the authors carry out the research of the urban development areas structure and propose the system of its characteristics on the basis of sector affiliation of the municipal economy. The authors have developed an algorithm for quality assessment of urban development areas. The results of the research are presented on the example of several central quarters of Arkhangelsk city. The city's residential development was formed in the periods from 1900-1950, 1950-1980 and from 2002 to date. It is currently presented by low-rise wooden, homestead type residential houses and barracks-type houses; mid-rise and high-rise brick and panel buildings of typical development, buildings of large-panel housing construction. Structural SOM-analysis compiled separate quarters of Arkhangelsk into 5 groups with a high level of characteristic similarity: "Commercial", "Prospective complex development", "Sustainable development", "Perspective renovation of residential development", "Investment-unattractive". Typical development strategies for each group of quarters are determined. Most developed areas characterized by upward height. The development strategies for depressed areas is in a high-rise building, which show the economic, social and environmental benefits of upward growth of the city. Using GIS allows to visually reflect the state and assess the quality of the urban development area by the aggregate of all parameters, and also to assess the quality of the quarters for each sector.

1 Introduction

Issues of complex reproduction, reconstruction and renovation of urban development areas are considered in a great number of scientific researches [1,2,3,4,5]. However, at this moment, the planning of reproduction is fragmentary and does not have system-structural relationships. One of the most significant factors limiting the efficiency of real estate reproduction management is the lack of its monitoring support. At the same time, the information-analytical systems forming experience enables us to resolve a contradiction between the need for optimization of monitoring systems and insufficient development of theoretical and technological mechanism ensuring the fulfillment of this management task.

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Most of the existing similar methods for assessing the quality of the territory are aimed at calculating the final integral quality index with a complex internal structure of components, high degree of subjective assessment and also with a lack of optimal index value and understandable levers to change it.

This research is aimed at solving the problem of the neural network modeling and geoinformation technologies adaptation for building an intelligent monitoring system, dispatching and effective organizational and technical management of the urban development area.

2 Materials and methods

Within the framework of the research, the authors solve the problem of designing an intelligent operational management system and urban development monitoring on the basis of structural analysis and data visualization.

2.1 Structural analysis of the urban development areas quality

The area of urbanized development is a complex system and has a set of characteristics of its constituent objects. In aggregate the sectors of the municipal economy have a common task – to serve the need of city's population. That is why the development level of municipal economy sectors depends on population, its resettlement and reflects the quality of urban development areas. This research covers the analysis of urban development characteristics on the basis of sector affiliation of the municipal economy, which includes housing and utilities sector, transport sector, consumer market, construction sector, social sector, services providing public safety, management, communications, information systems and other organizations serving the needs of the city.

Each sector of the municipal economy cannot be characterized by one particular parameter. It is represented as a complex hierarchical system of parameters (characteristics) and can be described with varying degrees of detailing. The city's areas have different qualitative and quantitative indexes for each characteristic. In this research a quarter is taken for the territorial unit of urban development. An aggregate assessment of all characteristic indexes generates an overall assessment of the unit's quality (quarter).

Structural analysis of urban development multidimensional characteristics is performed by clustering the objects under study (quarters) in comparable groups with a high level of similarity of characteristics inside each group. The clustering mechanism is based on the use of neural networks of T. Kohonen's self-organizing maps (Self-Organizing Map - SOM). Self-organizing map (SOM) is an effective neural network modeling software tool for synthesizing multidimensional data [6,7].

The proposed method of mathematical modeling enables one to structure information based on material and intangible development parameters and to obtain integrated quality indexes of areas. The obtained data is used to plan the complex reproduction of urban development by forming typical management programs for objects referred to a particular group [8].

2.2 Visualization of the areas quality structural analysis

The application of geoinformation systems (GIS) involves the structuring and visual representation of data by information layers of hierarchical structure of urban development characteristics.

3 Experiment

Research results are represented on the example of separate central microdistricts of the Arkhangelsk city.

The methodology of the research included following stages:

1. Forming the databases of area characteristics for each sector of municipal economy. The list of chosen characteristics describing each sector is presented in the table 1. It should be noted that such method makes it possible to change freely both the list of studied sectors and the detailing degree of characteristics in their description, i.e. to vary the amount of characteristics describing the system in accordance with the objectives of a particular research.

Table 1. Characteristics of municipal economy sectors

Municipal economy sector		Characteristics
Housing and utilities sector	Residential development	Stage 1 - structural analysis of housing stock: - overall indexes of MDU: capital group, capacity, area of apartments, number of floors, operational lifetime, general rate of wear, replacement cost; - indexes of structural elements. In total, during the clustering of a representative sample of 316 objects 33 indexes participated in the analysis [8]. Stage 2 - Determination of the average type of residential development for the quarter according to the clustering
	Utilities	Types and length of networks in the quarter (security), network material, network wear and operational lifetime.
Transport sector		Structural analysis of the quarter's transport infrastructure quality - transport accessibility of the quarter (7 indexes for clustering 90 quarters) including quarter area, quarter form, road traffic, technical condition of roads, etc. [9]
Consumer market		Structural analysis of quarters for the supply of trade units (6 indexes for clustering 90 quarters) including distance from the quarter center to the nearest shopping mall of the city scale, number of small stores of industrial, household and grocery goods, number of public catering, etc.
Construction sector		Index for the municipality. Characterized by the number of building owners (local and/or from other regions), presence of construction sector enterprises. Used to assess the quality while comparing different municipalities within the region, country.
Social sector		Structural analysis of quarters for the supply of social infrastructure facilities (8 indexes for clustering 90 quarters) including provision of residents of the quarter with medical help, children's preschool and school institutions, the proximity and accessibility of the recreation zone, etc.
Services providing public safety		Index for the municipality. Used to assess the quality while comparing different municipalities within the region, country.
Management, communications, information systems		Index for the municipality. Used to assess the quality while comparing different municipalities within the region, country.

2. Structural analysis of urban development areas (quarters) for each sector of municipal economy. The results of the structural analysis are presented in the table 2.

The analysis was carried out by clustering objects (of housing stock [8] and separate quarters of the Arkhangelsk city) using of SOM in comparable groups with a high level of similarity of characteristics inside each group [10].

Description of the general characteristics for each group. At this stage, it is possible to define typical reproduction strategies for the objects of each residential property group, typical development strategies for each group of quarters for a particular sector.

Table 2. Clusters characteristics of municipal economy sectors in Arkhangelsk

Municipal economy sector	Results of clustering
Residential development	16 clusters, which are combined into 4 types of residential development [8]: Group 1 - New housing stock; Group 2 - Housing stock in good condition; Group 3 - Aging housing stock; Group 4 - Ramshackle and emergency housing stock.
Transport sector	4 clusters with different levels of transport infrastructure [9]: Group 1 - Good - maximum traffic and good road conditions around quarters with a shape close to square and with a large area; Groups 2, 3, 4 - Satisfactory - average traffic and satisfactory condition of roads around quarters, respectively, of rectangular shape and with a small area, a square shape and with an average area, a rectangular, strongly elongated shape and a large area; Group 5 - Poor - minimal traffic and unsatisfactory condition of roads around quarters with a form close to a square and with an average area.
Consumer market	3 clusters with different levels of consumer market development: Group 1 - Quarters, which are centers of shopping and entertainment activities of the city; Group 2 - Predominantly quarters around quarters of group 1 - public and business center of the city Group 3 - Sleeping areas of the city with a low level of consumer market development
Social sector	4 clusters with different levels of social sector development: Group 1 - insignificant removal from recreational zones and the average level of provision with social facilities; Group 2 – quarters located next to recreational zones, best provided with schools, not provided with kindergartens; Group 3 - quarters remoted from recreation zones, medium provided with schools, not provided with kindergartens Group 4 – quarters located next to recreational zones, not provided with schools and kindergartens. Selected quarters provides the same and higher level of medical and polyclinic care availability in comparison with other parts of the city.

3. The final structural analysis of urban development areas (quarters) based on the results of quality assessment of particular sectors. Structural analysis was carried out by clustering objects (particular quarters in Arkhangelsk) using SOM [10] in comparable groups with a high level of similarity of characteristics inside each group.

At this stage, an overall assessment of areas quality was performed by the totality of all parameters.

The description of the general characteristics for each group makes it possible to determine the common vector of development for them - general typical development strategies for each group of quarters (table 3). Most developed and depressed areas of the city are revealed, as well as the most investment-attractive areas for development.

The efficiency of the clusterization is shown in Fig. 1 and 2. To illustrate the dissimilarity of the city's areas the authors constructed graphs of all quarter index indices (normalized characteristics of objects) included in the representative sample (Fig. 1) [5]

Table 3. Characteristics of quarters' clusters in Arkhangelsk

| Group of quarters	Housing stock	Transport infrastructure	Consumer market	Social infrastructure	Description
"Commer-cial"	Absence or a small proportion in the total development	Good - maximum traffic and good road conditions around quarters with a shape close to the square and with an average area	Concentra-tion of the main shopping and entertain-ment facilities of municipal importance	Close to recreational zones, Not provided with schools and kindergartens	Quarters, built-up with public and business facilities with a lack of or a small proportion of residential property in the central part of the city. Do not require development.
"Prospecti-ve complex develop-ment"	Large number of ramshackle and emergency housing units with a dot-building new residential development	Good - maximum traffic and good road conditions around quarters with a shape close to a square and with a large area	Average - public and business center of the city	Close to recreational zones, Not provided with schools and kindergartens	Investment-attractive for the complex construction of highly liquid real estate for residential and commercial purposes due to renovation of existing buildings
"Sustain-able develop-ment"	In good condition, partially aging, point-new	Satisfactory - average traffic and satisfactory condition of roads around quarters	Average - public and business center of the city	Average and above-average provision of social facilities	Quarters of historically sustainable development in the central part of the city with a developed social infrastructure and social and business areas. They require comprehensive rehabilitation measures: current and major repairs, spot development.
"Perspecti-ve renovation of residential develop-ment"	In good condition and aging, point-ramshackle	Bad - minimal traffic and unsatisfactory condition of roads around quarters	Low level of consumer market develop-ment	Minor distance from recreational zones and the average level of provision with social facilities	Historically developed social infrastructure. Investment-attractive for complex and point-based residential development, not attractive for commercial development on condition of the transport infrastructure development.
"Invest-ment-unattracti-ve"	In good condition and aging, lack of free areas for development	Bad - minimal traffic and unsatisfactory condition of roads around quarters	Low level of consumer market develop-ment	Close to recreational zones, Not provided with schools and kindergartens	Investment-unattractive because of the lack of free or renewable area for development. Possibility of point development. The existing and prospective development has reduced liquidity due to lack of infrastructure. Development through budget financing of infrastructure development.
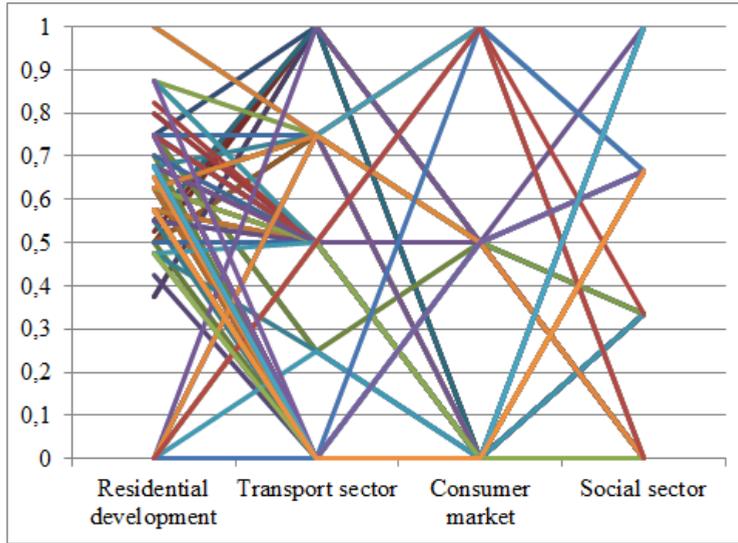
Fig. 1. Map of the normalized characteristics of all sample objects

The different situation can be seen on the graphs illustration of objects' normalized characteristics. Figure 2 shows the graphs of indices of clusters within the 1 and 3 of 5 clusters, which are described in table. 2.
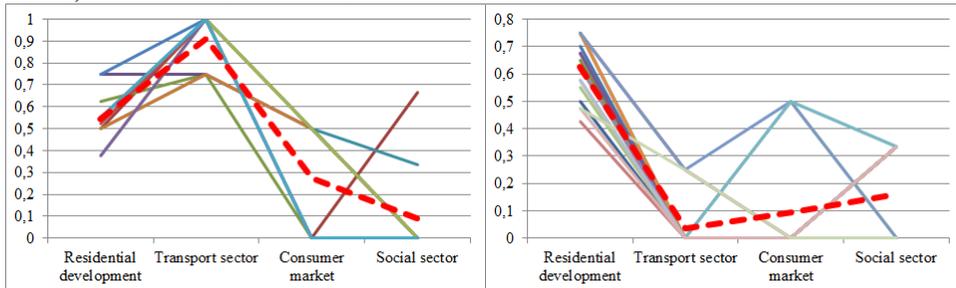

Fig. 2. Map of normalized characteristics of objects 2 of 5 clusters

4. Visualization of the obtained cluster analysis using geoinformation technologies (GIS). Using GIS enables us to visually assess the state of the urban development area, reflect both the overall areas quality assessment by the aggregate of all parameters, and the quality of the quarters for each sector. An example of visualization of the general clustering of quarters in the central part of Arkhangelsk is shown in Fig. 3.

5. The urban development state monitoring is carried out through periodic (every 1, 3 or 5 years) areas surveys and identifying the values involved in the assessment of characteristics for each sector. Periodicity of the survey is chosen on the basis of the current dynamics of changes in the state of each sector. For example, for a housing stock, it is advisable to carry out a repeated clustering every 3rd years, which corresponds to the periodicity of planning the work of capital repairs and the average time for new construction. Therefore, the state of objects during this period may change. For transport infrastructure, the periodicity of the survey should be annual, which is determined by the dynamics of road's surface deterioration and the annual repair plans.
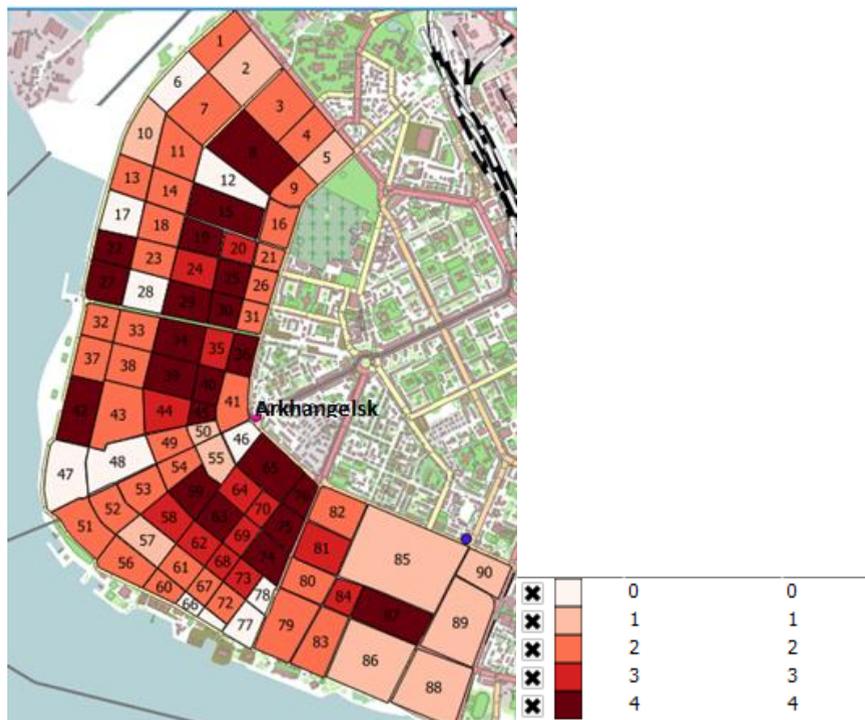
Fig. 3. Map of the general clustering of quarters in the central part of Arkhangelsk

Thus, if the overall assessment of the area quality within all parameters changes, then a quarter can get from one cluster (group) into another. At the same time the transition to a better one demonstrates the effectiveness of ongoing activities while transition to a worse quality cluster shows the lack of activities or their inefficiency and the need to take measures to improve the quality of the area (quarter).

4 Results

This article provides an algorithm for quality assessment of urban development areas. The results of the research are presented on the example of several central quarters of Arkhangelsk city. On the basis of more than 50 urban development characteristics the authors have obtained 5 groups of quarters with a high level of characteristics similarity within each group.

Thus, new computational and analytical methods for monitoring the characteristics of the hierarchical components of urban development areas were suggested. The novelty of the study is to justification for advantages of applying structural analysis for qualitative ranking of areas. The advantage of the proposed methodology is that it gives the opportunity to assess the quality of areas: to identify the most investment-attractive (unattractive) quarters for further development; to determine the strategy for its development with a list of specific activities.

It should be especially noted that the proposed method is universal, according to the authors' view. Its universality is as follows:

- the possibility of varying the list and a set of characteristics;

- the possibility of applying the method for monitoring and assessment of different areas, regardless of their geolocation and scale.

- the possibility of adapting the methodology for monitoring other processes occurring in urban areas (changes in the research topic).

The universality of such system and its "fast" processing allows one to assess the state of any urban massifs with the entire set of its capital construction objects. Systematic monitoring enables us to track the direction and development dynamics of areas. It makes it possible to respond quickly to the changes that occur.

Conclusion

The main objective of the research is to improve the efficiency of the organizational and technical management of urban development areas as complex systems of hierarchical components due to the implementation of the developed methods of monitoring and analyzing data. Application of the proposed methods will enable one:

- to form a long-term town-building strategy for the urban development area taking into account the complex comparative assessment of the individual quarters' quality

- to implement budget planning of reproduction within their investment and social efficiency.

- to accelerate the planning process and make adjustments to urban development programs in real time, to reduce the time and resources spent on monitoring and analyzing data.

Gratitude

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