Basic principles of online service development for functional zoning and definition of urban space development scenarios

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Abstract. The management of municipalities is becoming more and more difficult every year: the complexity of urban infrastructure is increasing, road traffic is growing, and new communications are emerging. In the context of the development of modern Russian cities, the task of transforming inefficiently used public areas comes to the fore. The most promising approach - participatory design - sets the vector for the development of a comfortable urban environment in the Russian Federation. The actual material accumulated at its use allows revealing regularities of occurrence of these or those scenarios of use of public spaces. In the article the example of creation of information system for a choice of suitable scenarios of development of public urban space on the basis of use of a principle of co-projecting is considered. The basic methods of raster maps processing, principles of work with the spatial data for automation of process of city planning on the basis of the forecast of city development are stated. The complex of mathematical models built on the basis of neural networks and analysis of large data sets, which allows with a given probability to forecast the development of urban space on the basis of the data of geoinformation systems and the wishes of users, is described.

1. Introduction

Working out of the concept of complex reorganization of city territories and planning of scenarios of their use assumes studying of their structure, and not only by means of cartographic services. It is necessary to involve in the process of designing the citizens themselves. Only in this case, it is possible to form a quality specification for the transformation of public space. The use of participatory design methodology is an effective tool for developing an information system for urbanists, design bureaus and municipalities. It is necessary to collect the project documentation, to carry out the analysis of the data, registers of public spaces, geoinformation systems (GIS), to define the basic methods of work with raster images, maps and vector layers, to carry out research of estimations for aggregation and visualization of the city information, creation of a design part of analytical service and forecasting of use of city spaces. The data processing of which will be made in developed information system, include the statistical data, the situational plan, the register of objects and small architectural forms, the transport and pedestrian scheme, functional zoning.

To build the scenario, the general principles of improvement set forth by the Government of the Russian Federation in the Priority National Programs "Formation of comfortable urban environment"
"Housing and urban environment", "Smart city" of the Program "Digital economy of the Russian Federation" are used.

2. Methodology for participatory planning
The technique of co-designing was developed in the early 2000s. After 2010, this direction of urbanism gradually became a leader in Russia. Participatory design is the process of forming the environment with the involvement of residents, representatives of administrative structures, businesses, investors and other interested parties in the project to identify the true problems and values [1, 2]. The process is organized in such a way as to provide an opportunity for different categories of interested citizens and organizations to participate in decision-making. Communication takes the form of moderated dialogue [3].

In public spaces, the social aspects described in a set of scenarios are important. For example, the "Roller-skating, skateboarding and cycling" scenario involves flat tiles, shoe benches, bicycle racks, route design and navigation, etc. Scenario planning methods attract attention with their high efficiency in times of uncertainty and complexity. Scenario planning encourages strategic thinking and helps to overcome constraints by developing several options for future urban activities. Each scenario designed should be unique in its context and actors, and the methodological approach may be similar [4, 5]. As a result, there is a need to develop some standards for urban improvement projects. The standard allows to improve the quality of the works and at the same time reduce their cost. It describes general approaches without limiting the artistic and architectural component and regulates not so much the appearance as the technical characteristics of the place. Competently compiled standard leaves room for unique architectural solutions and artistic objects.

Further development of the co-projecting technique implies:
- study of existing scenarios for the use of territories;
- classification and identification of typical scenarios;
- analysis of cartographic data for functional-spatial zoning;
- search for regularities in the formation of scenarios of certain types;
- development of a standard for forecasting optimal scenarios for the use of public spaces.

Scenarios for the use of public spaces are influenced by the type of zoning of the area. On the territory of the municipality contour functional zones are formed: residential, industrial, recreational. As a rule, in the center of any city there are authorities and administrations, cultural institutions, the largest trade enterprises, which allows to allocate it to a special social and business zone [6]. Spatial organization of functional zones united by transport links is the planning structure of the city. The transport system in combination with the engineering systems of life support form the urban framework of the territory, which serves as the basis for the development of the functional zoning scheme [7]. The strategy of involvement and new mechanisms of project decision making with the participation of citizens, business community, city authorities and other stakeholders imply the development of social design tools and the formation of active urban communities, which, in turn, will participate in the life of the city, creating a sustainable social environment, moving from local to large-scale and global [8]. Using participatory design techniques, the decision making process will involve citizens, design bureaus, government and developers [9]. The developed information system should solve the problem of designing in a short time and with the best result. Urbanists should get a whole range of different scenarios of territory development based on the analysis of the current state and the list of desired transformations. Such an approach, together with the principles of participatory design, will allow the introduction of "Smart City" technologies in residential areas.

3. Solution design

3.1. Using GIS to define the city development strategy
Cities are complex and dynamic systems [10]. Comprehensive consideration of all factors, formation of development strategies, elaboration of specific activities and plans for urban development are
impossible without the use of modern information technologies [11, 12]. Geoinformation systems (GIS) play an important role in urban management. The combination of GIS capabilities with the toolkit of participatory design will enable the integration of concepts of public authorities, scientific developments in the field of urbanism and public participation.

The basis of urban planning is a scenario, on the basis of which the analysis of possible development of the territory is built, a variety of possible situations is studied [13]. Planning support systems were first proposed by the American Scientist B. Harris [14]. They consist of various technologies and provide detection, analysis, assessment of urban problems and decision making, providing integration of scenario planning and geoinformation technologies.

City data are often mixed in nature, so the task of filtering and structuring them is relevant. The key role in decision making is played by robust assessments [15]. The task of city data is most often considered as a nonparametric or semi-parametric model with a finite number of parameters. Estimation of parameters by the maximum likelihood method (MMP) is effective when the existing experimental data coincide with the a priori ones. The papers [16] prove the loss of efficiency of MMP estimations in case of deviations of real data from the a priori assumptions, as well as the complexity of building multiparameter models. The use of statistical methods of estimation of distribution parameters allows us to determine the homogeneity of data and structure them, reducing the impact of interference.

Multi-criteria evaluation (MCE-GIS) is widely used in scenario planning, providing for multi-purpose decision-making [17]. Multicriteria evaluation solves practical problems with the use of evaluation matrix, but the use of raster and vector images leads to different solutions, there is uncertainty in the standardization and aggregation of criteria. In particular, considering the criteria as an expression of belonging to fuzzy sets, we can see that the process of aggregation of a set of weighted linear criteria, common for raster systems, lies between a rigid intersection and unification. It is connected with the Boolean superposition in vector systems:

\[
\text{compliance} = \sum w_i X_i \cdot \prod c_j ,
\]

where \( w_i \) - weight assigned to factor \( i \), \( X_i \) - factor \( i \) evaluation criterion, \( c_j \) - limitation \( j \).

The construction of matrix elements requires the reflection of the characteristics of the decision-making process, which is described by a number of criteria. MCE-GIS identifies the assessment factors that influence urban development. These factors are then assessed on the basis of the various assessment criteria and weights are assigned according to a set of actions. A comprehensive assessment of the results can be made by compiling an assessment matrix integrated with the assessment coefficients for different classes and weights, respectively. The criteria are aggregated by means of a weighted average of the scores on the criterion.

Suppose all criteria have been standardized before weighing to a total numerical range using a linear scaling method between the minimum and maximum values of this criterion. The linear scaling is within the agreed range (0-255) as follows:

\[
X_i = (x_i - \text{min}_i) / (\text{max}_i - \text{min}_i)
\]

where \( X_i \) - factor \( i \) evaluation criterion, \( x_i \) - initial value of the factor, \( \text{max}_i, \text{min}_i \) - maximum and minimum factor value.

MCE-GIS is a practical application of scenario planning ideas based on GIS technology. Thanks to this method, it is possible to form alternative scenarios and identify strategies with the highest efficiency, taking into account the current state of the system and depending on the desired result.

3.2. Determination of the functional zone from geo-tagged images

Functional zoning of the environment is of great importance for the optimization and planning of the urban structure. Open spatial data such as geo-tagged photos from social networks and OpenStreetMap
data can be used to classify urban functional zones. Combining high-level features of geo-tagged photos with road network data or location of significant objects, it is possible to obtain a functional zoning map of the territory.

For visual tasks of a high level of low-level representation of images is not enough. The high-level representation is described by a collection of objects, where the image is presented in the form of a scale invariant map for a large number of pre-trained objects of a particular task [18]. The collection describes each image with available objects, encodes semantic and spatial information. The representation of the object collection contains extensive semantic information; on which you can base the classification of images [19].

Depending on the size of the functional zones, 6-10 object classes can be defined. In the city it can be ponds, shops and cafes, educational institutions, residential complexes, public spaces. A photo can belong to one or several classes. With the help of statistical methods, it is possible to determine the overall purpose of the zone. Each photo is associated with an XML file that contains geospatial, temporal, and contextual information. As a training set, 75% of the photos are selected, the rest are used as a test set. Due to the differences in the coordinates of the road network and images, it is necessary to unify the coordinate system. This will help ensure that the images are in the correct location. At the object extraction stage, the source image is filtered to map the results. Coding maps responses is carried out using a three-level (L0, L1, L2) policies of the Union of the pyramids. To match the image properties of the input data, the training and test samples are scaled to a specific range. Then cross-validation is performed.

Each image can be considered as a separate point with geotags [20]. Then they are compared with urban functional areas. Then the number of images and their categories in each functional area are estimated for each scale. For each zone, its function type is defined as follows:

$$P = \frac{\max(c_i)}{2\sum_{i=1}^{n} c_i}$$

where $n$ is the number of types of photos taken in the functional area, $c_i$ is the number of photos of the same type taken in this area. When $P \geq 1$, the type of this zone is the same as $\max(c_i)$, otherwise it is a mixed-functionality zone. Such methods can be used to collect data from target groups of residents and to determine popular scenarios for the use of the territory.

### 3.3. Aggregation and storage of spatial data

Application of BIGDATA technologies brings a number of advantages to urban projects. A typical problem when working with large data - the huge number, high speed of formation and their variety. Studies often use personal user data, terrain data, information about city objects, infrastructure and dynamic data. Such information needs to be presented in different ways, so it is necessary to use selection criteria and source quality analysis.

The main attention is paid to the search for patterns in data sets to provide an overview of the current state of urban objects [21]. For urban analysis, methods of visualization based on statistical estimates are often used. Before the introduction of technologies using big data, it is necessary to assess the readiness of the city system. For this purpose, three groups of indicators are studied: competences, sources of information and infrastructure. Each indicator within the group is assessed on a scale from 1 to 5, then by averaging the final assessment of the group and determined by the value of the complex indicator of readiness of the urban system.

Competencies characterize the presence and level of development of centers and information systems in the city, used for the collection, processing, analysis of data, educational programs aimed at creating and expanding professional knowledge in the field of data analysis. Sources of information characterize the presence of actually used and potential data sources, on the basis of which the city can
make managerial decisions. Infrastructure characterizes the availability, accessibility and quality of various methods of data transmission such as broadband Internet, city Wi-Fi network, mobile packet communication.

4. Features of technical and software implementation

The structure of the online service has been chosen for the project implementation, as its mandatory elements are the delimitation of access rights, dynamically changing data, constant support of actual cartographic data. At the heart of the online service are the data of OpenStreetMap (OSM), on the basis of which all spatial data processing is carried out. OSM are open non-commercial online maps of the world, created together by users. Data from personal GPS-trackers, aerial photographs, video recordings, satellite images and street panoramas provided by some companies and organizations participating in the project are used to create maps. The map render must be performed on the client’s side with upload of actual data via API, and there must be a spatial (PostGIS) and user (PostgreSQL) database, which determines the architecture of the respective client-server application (Figure 1).

In the service being developed, the information is collected by users and management structures independently, the Program analyzes them and makes a forecast based on usage scenarios. The user can manually change individual parameters to clarify the forecast. At this stage, the service of functional-spatial zoning of the territory is being developed. The service contains division of users by roles for differentiation of functions of the city architect (the author of the project) and ordinary users to whom have the right of access to system and possibility to choose scenarios of use of territories.

Several approaches to data processing are envisaged:

- Data visualization without additional processing.
- Monitoring of the states of urban spaces, creation of a workflow for improvement.
- Collection of complete statistics on urban spaces, use of built-in algorithms for urban planning.
• Development of a development scenario based on GIS data.
• Obtaining complete data from maps of the current state of the territory.

The service assumes the use of neural networks for data analysis, as well as for classification of the developed scenario. As a result, it is guaranteed that the opinion of citizens will be taken into account automatically, pedestrian traffic, transport accessibility and other factors will be analyzed. To work in the system, the territory is indicated by marking the boundaries of the project on online maps. Specific key indicators are defined (pedestrian traffic, current usage scenarios, site lighting, underground utilities, landscaping, small architectural forms). Input data set is defined in the system. For the user's convenience, instructions are provided for step-by-step uploading and verification of the data. In case of incomplete data loading, the forecast is not performed. In the interactive mode the user will be able to determine the desired parameters (presence of certain objects, small architectural forms, types of activity, partial zoning task). According to the results, a map is created, which includes zoning according to usage scenarios, a pedestrian transport scheme, and recommendations for creating a barrier-free environment. The presence of all objects on the map is regulated by the user and their location can be fine-tuned.

The main development languages are Java and Python. Figure 2 shows the class diagram for the functional and spatial zoning of the territory, taking into account the data from the local database. When implementing zoning, the main role is played by the correspondence of the scenarios of territory use to the purpose of the territory. For this system, it is also important to monitor changes in the project and the frequency of use of tools, this is implemented through logging logs.

![Image of class diagram]

Figure 2. Class diagram.

5. Conclusion
The process of urban space planning is a complex optimization problem, which can be solved by means of multivariate analysis, classification problems and robust statistical methods. The basis for the development of public territory is its zoning. For functional zoning it is possible to use the photofixation tool. One can define the map of functional areas using the hautegaronne photos with classification. Also, neural networks serve as a means for spatial zoning of the territory.
Scenario planning based on geographic information systems data is an effective method. This technique allows not only to solve the problems of planning in the face of uncertainty, and taking into account the views of different social groups. In the context of participatory design methodology, software design should take into account the differentiation of access rights for urban architects and residents. The developed system uses neural networks as an intelligent core. This tool is used not only to create a scenario of territory use, but also to process the input data. This gives an advantage in forecasting for any urban space and a significant scalability of the service.

The developed information system for determining the scenarios of urban space development implies scalability, extensibility and cross-platform. This is because the desktop application will allow you to use more analysis and visualization tools. The use of processing a large amount of data will stimulate the use of parallel programming technologies and distributed systems, data confidentiality will be implemented with the help of electronic digital signature [22].

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