Application of neural network algorithms to optimize the development of residential neighbourhoods

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Abstract. The paper presents proposals for the use of neural network algorithms to optimize the development of residential neighbourhoods: the corresponding model is shown, its features are discussed, the relevance and prospects for the development of the proposed approach in the planning of new residential neighbourhoods are substantiated. The proposed model allows to optimize the economic efficiency of residential neighbourhoods by varying the parameters of their design, construction, and operation, considering the characteristics of the life cycle of construction and investment projects.

1 Introduction

The development of the modern urban planning industry is a systemic task in which the issues of organizing a comfortable urban environment, convenient and practical places for social, medical, cultural and sports purposes, recreation, park and pedestrian zones, infrastructure of road networks, bike paths and much more are intertwined in a complex way. The attractiveness of new districts is greatly influenced by their size and location, sufficiency, diversity, and quality of services available to the population, transport connectivity with the rest of the city and nearby settlements, as well as the uniqueness of technologies, engineering, layout, and design solutions used in the design and construction [1-4].

However, the implementation of the most daring and advanced projects must necessarily be coordinated with their economic feasibility and efficiency. The development of new construction technologies opens new opportunities for engineers, designers, designers from the point of view of the technical achievability of the plans of these specialists, but the issues of the price of projects and their payback period, as a rule, are beyond the capabilities of new technologies and remain in the zone of external constraints of projects [5-7].

The most promising projects for urban development today are those that determine the appearance of entire neighbourhoods [8-10]. In fact, we are talking about the construction of residential areas with full social infrastructure in new territories. For such projects, considering the features of construction objects, their location and relationships can be performed within the framework of well-known approaches of the theory of system analysis

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[11], for example, a morphological approach describing the entire variety of system elements and their relationships (relationships). Even though the size of the morphological description of the system strongly depends on the number of objects contained in the system, because the number of relationships between them grows proportionally to the square of the number of these objects [12], for the scale of neighbourhoods, the morphological description turns out to be quite acceptable [13-15].

Of the large amount of data contained in the project documentation for individual construction projects and neighbourhoods, only a relatively small part of them will be required to calculate the economic efficiency of the project. Considering this information as input parameters of the neighbourhood model, it becomes possible to optimize its development to achieve maximum economic efficiency of construction and subsequent use of housing.

It is also important to note that any construction and investment projects have a certain stage of development [16-18], including the stages of project preparation (ideas, concepts), design (sketch, design, working documentation), preparation of the object (planning, general preparation, local preparation), construction (preparatory period of construction and installation works, the main period of construction and installation works), completion of the project (commissioning of the facility), operation (operation in the initial period, operation in the main period, operation in the pre-liquidation period), liquidation (preparation, demolition, reclamation). For this reason, for correct calculations of economic efficiency, the neighbourhood model must consider the features of its life cycle, include parameters that depend on the number of the project stage and the duration of this stage. The primary results of the calculations will also be linked to the stages, but the performance indicators will characterize the project, throughout all its stages from the idea and concept to demolition and reclamation, or throughout a given number of stages of the life cycle.

Among the well-known approaches of the theory of system analysis [11], it is recommended to use a genetic-prognostic approach to describe evolving systems, which complements the morphological description with a time-dependent state of system objects and their relationships [12].

Among the practical problems of constructing a model for evaluating the effectiveness of a neighbourhood, it should be noted that the initial formalization is weak for a some of parameters, for example, the attractiveness of a neighbourhood for potential residents, therefore, when constructing a model, it is proposed to use a fuzzy logic apparatus that provides the necessary capabilities for creating appropriate fuzzy models. The strengths of the fuzzy logic apparatus are [19] a convenient description of the conditions for solving the problem in natural language and the possibility of approximation of any mathematical system by a system based on fuzzy logic — the fuzzy approximation theorem [20]. The disadvantages of fuzzy approaches are associated with some freedom (expert subjectivism) in the formation of fuzzy rules and membership functions of input and output parameters of models. However, these disadvantages are well compensated by the construction of adaptive algorithms, the parameters of which change and adjust as they are applied [19]. Algorithms based on fuzzy logic are traditionally called neural networks. Intelligent systems, also called artificial intelligence systems, function based on such algorithms [21, 22].

The purpose of this work is to build a model of residential neighbourhoods based on neural network algorithms designed to optimize their economic efficiency by varying the parameters of their design, construction, and operation, considering the features of the life cycle of construction and investment projects.

2 Proposed model

Within the framework of the proposed model, the objects of the neighbourhood are divided into several types, $T = \{t_0, t_1, t_2, \ldots\}$: residential objects ($t_0$), medical, educational, sports facilities, shops, restaurants, recreational areas, parks, pet walking grounds, elements of transport infrastructure, etc. Each of the types of objects in general, it is divided into types (t_i: $K_i = \{k_i1, k_i2, \ldots\}$) depending on the features of functioning, scale, target population for which it is designed. For example, educational facilities can be divided into kindergartens, schools, universities.

Each object of the neighbourhood in the first approximation is also characterized by the coordinates of its location (x, y) on the map of the neighbourhood, the projection area (S_n) and the total area (S_t), as well as possibly some additional characteristics depending on the type and type of object. This representation of the neighbourhood is as simplified as possible; however, it allows you to form the necessary relationships and relationships between objects that determine the general characteristics of the neighbourhood in the future, including its economic efficiency. It is also important to note that the listed parameters of objects can be easily obtained from information models (for example, BIM), project documentation for individual construction projects and the neighbourhood.

Figure 1 shows a conditional image of a neighbourhood made within the framework of the proposed approach. The boundaries of the neighbourhood play the role of restrictions in changing the coordinates of objects.

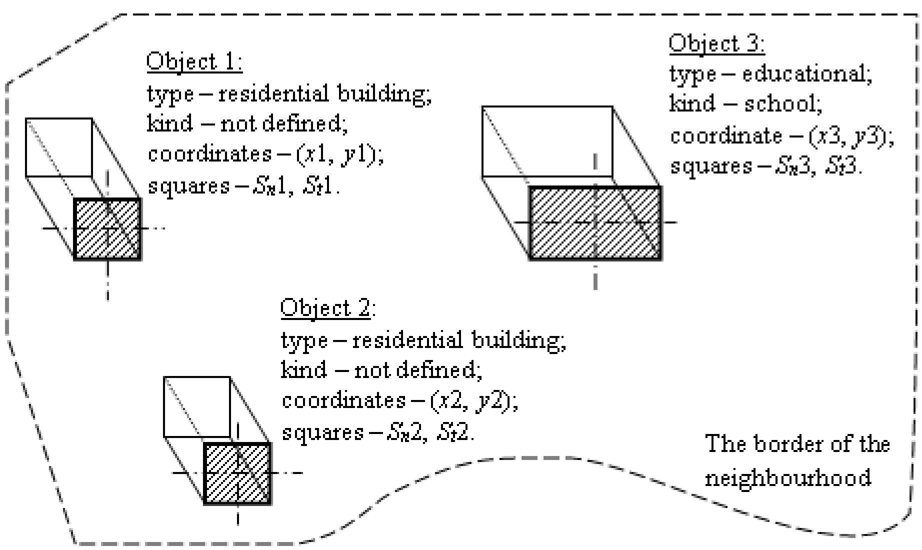


Fig. 1. A conditional image of the residential neighbourhoods.

Capital (one-time) costs for the construction of a neighbourhoods can be very precisely determined in advance if the total area, the technologies used, the features of the decoration of buildings, etc. are known. However, these costs turn out to be their own at each stage of the life cycle and make a certain contribution to the total cost of the project. To account for the share of costs at each stage, it is appropriate to introduce an appropriate weighting factor w_i such that the sum for all w_i equals 1, where i – denotes the stage of the project (see, for example, Table 1).

To obtain absolute values of costs in the first approximation, it is quite sufficient to consider only the total areas of objects and the corresponding calculation coefficients. These calculated coefficients can be reliably obtained from the data of state monitoring systems and statistical accounting of construction activities. So, to estimate the cost of 1 square meter of housing in the region, it is enough to attribute the total cost of the construction of known objects for the studied period to the volume of the area of the housing introduced for the same period. The remaining features of the erected buildings (classiness, features of engineering and design solutions, etc.) can be considered later, using their own correction coefficients for each feature.

Table 1. An example of the distribution of the weighting coefficient of capital expenditures by stages of a construction and investment project.

Weight factor	Construction and investment stage (number/name)						
	1	2	3	4	5	6	7
	Preparation of investment project	Designing	Approvals and access to the area	Construction	Initial exploitation	Exploitation	Liquidation
w_i	0.03	0.05	0.01	0.80	0.01	0	0.10

When implementing the proposed model within the framework of neural network algorithms, all weight and correction coefficients will be adjusted in the process of training these networks on real examples and cases implemented in the relevant development regions. Because the average statistical data are selected for the initial values of the coefficients of the model, the results of its calculations before training will also correspond to the average statistical data, which ensures the mathematical stability of the computing apparatus used, and subsequent training of the model will help reduce the calculation error by considering the specific features of the development of specific neighbourhoods.

Regular costs for the construction and maintenance of the neighbourhood will primarily depend on the duration of a particular stage of the construction and investment project. For such regular costs, it is no longer possible to introduce normalized weighting coefficients, as in the case of capital expenditures. Nevertheless, within the framework of neural network calculation, it is possible to introduce binary coefficients b_i, where i – denotes the stage of the project, which can consider (turn on/off) certain cost mechanisms at different stages of the project. As an example, Table 2 shows the value of such a binary coefficient for the regular costs associated with the land tax allocated to the neighbourhood.

Table 2. An example of the behaviour of the binary coefficient of regular costs associated with the land tax, according to the stages of the construction and investment project.

Binary coefficient	Construction and investment stage (number/name/duration)						
	1	2	3	4	5	6	7
	Preparation of investment project	Designing	Approvals and access to the area	Construction	Initial exploitation	Exploitation	Liquidation
	1 month	6 month	3 month	18 month	2 years	48 years	6 month
b_i	0	0	1	1	1	1	1

Binary coefficients can also be adjusted when setting up the model. The calculated parameters of regular costs, as well as in the case of capital (one-time) costs, can be determined from statistical data, or for example from regulatory documents and rules. Considering the features of specific objects that affect the amount of regular costs can also be performed through correction coefficients selected in the process of training a neural network on real objects. Regular expenses play a particularly significant role at the stage of operation of neighbourhoods, primarily due to the special duration of this stage.

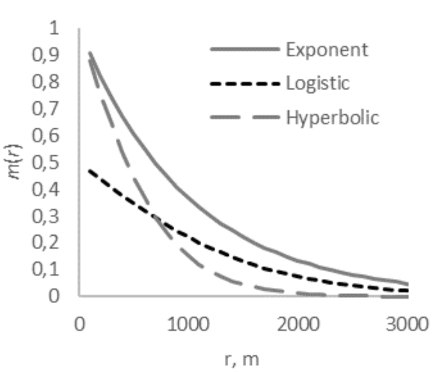
In addition to the costs, the construction and operation of any residential area should bring profit to investors, buyers of residential and non-residential premises (when they are sold or leased), tenants of non-residential premises and the state (at the expense of taxes and deductions). The assessment of profit, as well as expenses, can be carried out through appropriate weighting and binary coefficients linked to the types and types of objects of the neighbourhood and their areas. All primary calculation coefficients, like the one described above for expenses, can be reliably obtained from the data of state monitoring systems and statistical accounting of economic and economic activity. All other features of the functioning of objects, depending on their type or additional parameters, should be considered later, using correction coefficients adjusted on real examples specific to the region under consideration.

When calculating the correction coefficients in the proposed model, special attention is paid to the attractiveness of the neighbourhood, which depends in the first approximation on the number of objects of various types and their relative location. Considering the opinion of residents regarding attractiveness is carried out based on their conclusions, built within the framework of fuzzy logic (for example, "*the more, the better*", "*the closer, the better*", "*the closer, the better, but not closer than a quarter*", etc.). Thus, depending on the location of a residential building and other objects of the neighbourhood creates a pair relationship, formalized by the m_{ij} function between i and j objects, reflecting the degree to which the current configuration of the neighbourhood corresponds to the ideal expectations of residents. The value of the m_{ij} function changes from 0 – complete non-compliance with expectations, to 1 – full compliance.

For example, the ideal situation for residents is the proximity of the park to their apartment building. This situation is described by a linguistic expression: "*the closer the park is to the house, the better*." The formalization of the expression is performed by introducing the function $m(r)$, the argument of which is the distance r from the house with coordinates (x_0, y_0) to the park with coordinates $(x1, y1)$. thus, by varying the position of the park relative to the house, you can increase the attractiveness of the neighbourhood.

The explicit form of the function $m(r)$ is largely arbitrary [19] and can be represented by various analytical expressions (see Table 3).

Table 3. Possible variants of the explicit expression of the characteristic function $m(r)$, where r_0 are the parameters of the model.

Function name	**Explicit form of the function**	**Graphical display of the function**
Exponential with saturation (Exponent)	$m(r) = \exp(-r/r_0)$	
Logistic (Logistic)	$m(r) = \exp(-r/r_0) / [1 + \exp(-r/r_0)]$	
Hyperbolic tangent (Hyperbolic)	$m(r) = -2\exp(-r/r_0)] / [\exp(r/r_0) + \exp(-r/r_0)]$	

Different functions may arise between different objects of a neighbourhood, for example, the proximity of a park to a house may increase attractiveness more than the proximity of a school. To obtain a general attractiveness characteristic for each residential object, based on all paired functions m_{ij} between this object and the others, an integral attractiveness function M_i for the i-object of the neighbourhood can be introduced. In fact, the integral function is obtained by performing a fuzzy inference from the general set of m_{ij} functions, considering the corresponding coefficients of significance of individual m_{ij} functions. For some models, negative significance coefficients can be applied, which are used for factors that reduce the attractiveness of the neighbourhood.

Among the methods of constructing fuzzy conclusions, fuzzy conclusions can be applied using the algorithms of Mamdani, Tsukamoto, Sugeno, Larsen, etc. [19]. There is some freedom in choosing the fuzzy inference algorithm, as well as in choosing the explicit type of characteristic functions, which, however, has a relatively weak effect on the results of calculations of the proposed model.

The approaches embedded in the proposed model are fully suitable for implementation within the framework of neural network algorithms, which makes it possible to form an intelligent system for evaluating the effectiveness of a neighbourhood project and optimizing its development at the early stages of design and ensures its integration with existing information models of buildings and the neighbourhood.

In the future, the proposed model can be supplemented with auxiliary capabilities, including considering the distribution of the age composition of residents and the formation of the characteristic functions of m_{ij} and, accordingly, the implementation of fuzzy conclusions for each age group separately for each residential object. This, in turn, will open the possibility of project orientation of neighbourhood to specific target groups of consumers, which will undoubtedly further increase the efficiency of such construction and investment projects.

3 Demonstration of the proposed model

Below is a demonstration of the proposed model implemented using spreadsheet technology. The model is maximally simplified, considers only capital expenditures, contains only two objects, one of which is a residential building located at the origin of coordinates, and the second is a conditional social object with coordinates (x, y), the proximity of which to a residential building increases the attractiveness of a residential object.

The parameters of the model objects used for the calculation are shown in Tables 4 and 5. The author draws attention to the fact that all the values entered in Table 4 are hypothetical, and the calculation itself in its current form was created only to demonstrate the principles of calculations according to the proposed model.

Table 4. Model parameters.

Model Parameters	**Parameter value**
Construction cost, rub/sq.m	90 000
Cost of implementation, rub/sq.m	120 000
Object 1 – residential building: • coordinates • area, sq.m	(0, 0) 4 800
Object 2 – social object: • coordinates	(x, y) – vary

The attractiveness assessment is performed according to the formula $m(r) = \exp(-r/r_0)$, where $r_0 = 1500$ m (model parameter). Attractiveness within this model increases the cost of implementation by (1 + m) times.

Table 5. Weight coefficients of the model.

Weight coefficients	Construction and investment stage (number/name)						
	1	2	3	4	5	6	7
	Preparation of investment project	Designing	Approvals and access to the area	Construction	Initial exploitation	Exploitation	Liquidation
Cost weighting factor (costs)	0.03	0.05	0.01	0.80	0.01	0	0.10
Weighting factor of sales (income)	0	0	0	0.4	0.58	0.02	0

The result of the calculation is the value of the difference between income and expenses, given for the different location of a social object relative to a residential building. The calculation results are presented in Table 6.

Table 6. Results of calculation of the demo model, million rubles.

Coordinates of object 2	Construction and investment stage (number/name)							Total
	1	2	3	4	5	6	7	
	Preparation of investment project	Designing	Approvals and access to the area	Construction	Initial exploitation	Exploitation	Liquidation	
(500, 500)	-24	-38	-43	62	538	19	-58	**455**
(300, 500)	-24	-38	-43	75	556	19	-58	**486**
(200, 200)	-24	-38	-43	109	606	21	-58	**573**

Table 6 shows a clear dependence of the increase in the efficiency of a conditional micro-district depending on the relative location of its two objects and allows us to evaluate these indicators both in integral values and by stages of a construction and investment project.

In the presented demonstration of the model, the neural network algorithm was not trained. In practice, such training is performed in standard ways, including, for example, back propagation algorithms.

4 Conclusions

The paper presents the application of neural network algorithms for optimizing the development of residential neighbourhoods, proposes an appropriate model, discusses its features, shows the relevance and prospects for the development of the proposed approach when planning new neighbourhoods.

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