Model of formation plans for the urban areas development

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Abstract. We consider the problem of optimal (at a cost) development of the area, taking into account the restrictions on the required area of residential premises, and on the area of the land plot allocated for the construction of residential buildings. The problem of optimal development of the area was considered for the case of a linear dependence of the construction cost on the number of houses of each type. The results are summarized for the case of concave dependencies of the construction cost on the number of houses of each type. We consider such special cases when the amount of living space for all houses is equal or the area required for building a house is also equal for all houses.

1. Introduction
The construction complex of the Russian Federation is represented by 235351 enterprises, of which 227452 are enterprises of small business (including micro-enterprises) or 96.6% of their total number, while micro-enterprises make up 179947 subjects of economic activity whose share is 76.5%. The volume of work performed by the type of economic activity "Construction" in 2015 amounted to 6148.4 billion rubles.

The main production volume is concentrated in the field of housing construction, so in 2016 residential buildings with a total area of 103.4 million square meters were introduced, while for the same period non-residential buildings were introduced with a total area of 32.4 million square meters, which is about 3.2 times less. Consequently, the bulk of work in construction is concentrated in the field of residential construction, which is explained by several factors: first of all, the presence of a sufficiently large number of dilapidated and emergency housing, especially in the regions. It is enough to remember that the series of houses 1-464 was the most common in the USSR series of panel 5-storey houses of the first period of industrial housing. In the period from 1958 to 1964, the construction of houses of the 1-464 series was carried out by about two hundred (!) DSK (house-building factories) throughout the country. The standard term of their service was determined at 25 years, of course, it had long expired and there was a need to decide the future of these houses. Moscow has already made a decision about their demolition. However, there are also series where the number of floors is 8 and 9, as well as 5-storey floors with improved characteristics (including brick ones), the perspective of which is still unclear.

On the other hand, modern conditions dictate an increase in the quality of life of the country's population, one of whose indicators is housing security. Despite the fact that according to statistics, the average housing supply is more than 24 square meters per person, there are questions about the quality of this housing, which can vary greatly depending on the region. Thus, a situation arises quite often when the existing housing is no longer comfortable. There is a demand for new housing economy class, but modern planning. This demand stimulates supply in the construction market.
A somewhat unexpected aspect of the increase in the share of housing construction in the total volume by type of economic activity “Construction” is the investment function performed by real estate objects, which include housing. At that time, because of the current economic situation in the country, out of the real investment instruments aimed at preserving and increasing the funds available to potential investors, only real estate has remained so far, the interest of small investors in housing construction is understandable. It also contributes to the increase in housing construction. Moreover, it is housing, since non-residential real estate requires a one-time investment of funds that are very significant in volume.

Thus, construction organizations are faced with the task of creating residential real estate in the light of current trends in housing development. An integrated approach to this problem involves simultaneously with the construction of housing construction and infrastructure. This leads to the need to organize the design of neighborhoods according to uniform standards and requirements. And at the design stage it is necessary to coordinate the interests of all the participants in the construction: the municipality; construction organizations implementing a specific development project; future tenants; owners; investors.

This requires the use of modern methods that ensure the optimal combination of the interests of all counterparties and increase the efficiency of construction organizations. Moreover, the analysis showed: with the average annual number of people employed in construction in 2016 in the amount of 5,651.9 thousand people, which is 8.3% of the total number of labor resources in the country's economy; the share of construction in the gross domestic product of the country was 5.9%. This may indicate a rather low efficiency in the use of labor resources in the field of construction, since 8.3% of labor resources contribute only to 5.9% in the country’s GDP. The fact that the share of unprofitable organizations in the total number of organizations was 21% testifies to the relatively low efficiency of the country's construction enterprises.

Consequently, there arises the need to develop new approaches to the formation of an effective set of models that ensure optimal (at a cost) development of the area, taking into account restrictions on the required area of residential premises, on the area of land allocated for the construction of residential buildings and taking into account the risks of implementing the proposed projects.

2. Formulation of the problem
There are m-types (projects) of houses for building up an area. Each project is characterized by a cost value of $c_i(x_i)$, depending on the number of houses $x_i$ of this type included in the plan and the floor space $s_i$, it provides. If an $i$-th type project is included in the plan, then the number of houses $x_i$ must meet the conditions

$$x_i \leq b_i, \quad i = 1, m,$$

(1)

$b_i$ – the maximum possible number of houses for the project of the $i$-th type, chosen for reasons of architectural diversity.

Since there is a known dependence of the specific cost of the project on the number of houses [1-2] built under this project, we assume that $c_i(x_i)$ will be a concave function of $x_i$, and the logical condition $c_i(0) = 0, i = 1, m$. Savings are achieved through a more rational plan for the procurement of materials and components, the organization of combining work, reducing the time to prepare for the construction of a new facility, since the objects are of the same type. In this case, the following optimization problem arises: to find $x_i \geq 0, \quad i = 1, m$, such that they allow minimization of the total cost of the entire complex of works on the development of the neighborhood

$$C(x) = \sum_{i=1}^{m} c_i(x_i),$$

(2)

under restrictions (1) and (3)
where \( s_i \) – the size of the area of the house, built on the \( i \)-th project to be implemented; \( R \) – the minimum allowable amount of commercial space for all projects.

3. Dichotomic programming method

Consider the task in a continuous version. Then the following theorem will be true.

**Theorem 1.** There is an optimal solution in which out of the number of projects included in the plan for no more than one number of houses is less than the maximum allowable of \( b_i \).

Let project \( j \) be a project whose number of houses included in the plan is less than \( b_j \). If we exclude this project, then for the remaining projects we obtain a task with variables \( \{x_i\} \), which take the value of either 0, or \( b_i \). Solving this problem by the dichotomous programming method, we obtain the dependence of the minimal costs \( C_j(s_j) \), \( 0 \leq s_j \leq R \) on the area \( s_j \), which are provided by the projects included in the plan, with the exception of the project \( j \).

The optimal value of \( s_j \) (and therefore \( x_j \)) is determined from the equation

\[
C_j(R) = \min \left[ C_j(s_j) + c_j(R - s_j) \right].
\]  

(4)

Solving the problem for all \( j = 1, m \) and choosing the best option we get the optimal solution.

**Theorem 2.** Let be \( s_i = s, \; i = 1, m \). In this case, Theorem 1 is also valid for the integer solution.

To solve the problem, we describe the implementation of the branch and bound method [3-4].

As is known, for the successful application of this method it is necessary to determine the method of obtaining lower estimates. For this purpose, in this case, it is proposed to use the procedure of embossing [5] the cost functions directed to the execution of the intended production program. For this purpose, it will be necessary to construct a convex function \( \tilde{C}(x) \) as close as possible to the original function \( C(x) \) from below.

We will call it the evaluation function \( \tilde{C}(x) = \frac{c(b)}{b} \cdot x, \; 0 \leq x \leq b \). The evaluation problem in the continuous case is easily solved. The solution algorithm is represented by the flowchart in figure 1.

Accounting restrictions on the area of land leads to an additional restriction. Denote \( t_i \) - the area required for the construction of a house of the \( i \)-th type, \( N \) - the total area of land allocated for the construction of residential houses. We confine ourselves to the case of a linear dependence of the cost of construction on the number of houses of each type [6-7]. The challenge is to maximize the living space

\[
S(x) = \sum_i x_i \cdot s_i,
\]  

(5)

under restrictions

\[
T(x) = \sum_i t_i \cdot x_i \leq N,
\]  

(6)

We got the problem of integer linear programming with two constraints. Standard software can be used to solve it [8-9].

4. Conclusion

The analysis of the existing models and methods for optimizing the development plans of the area showed that the model support of the problem covers only the processes associated with the general planning methods of building and functional zoning. That is, the existing complex of methods and models do not ensure that, on the one hand, economic factors associated with the choice of parameters
for housing development are taken into account, and on the other hand, it does not allow for the interests of all parties to the analyzed process, in particular property owners.

A model of optimal development based on the cost minimization criterion based on the modification of the dichotomous programming method is proposed, characterized in that the optimal solution of the problem includes no more than one project in which the number of houses is less than the maximum allowed (Theorem 1), which reduces the initial problem to an analysis of a limited number of options whose number is determined by the number of projects used, and also to extend the results of Theorem 1 to the integer case (Theorem 2).

![Block diagram](image)

**Figure 1.** Block diagram of the solution of the evaluation problem in the continuous case.
A modification of the branch and bound method for solving the cost minimization problem has been developed. It differs by constructing lower construction cost estimates based on replacing the cost function with its convex approximation as close as possible to the original function from below, which makes it possible to formulate a criterion for obtaining an optimal solution by ordering the projects in descending order.

References
[1] Huang N, Li J and Ross A 2018 The impact of the cost of car ownership on house price gradient in Singapore Regional Science and Urban Economics 68 160-71
[2] Ford C 2017 Cost of Constructing a Home. National Association of Home Builders Special Studies http://www.nahbclassic.org/generic.aspx?genericContentID=260013/
[3] Ivanchev M, Mitev I G and Yanev N 1976 Realization of the branch and bound method for solving the general mixed integer programming problem USSR Computational Mathematics and Mathematical Physics 16(3) 241-6
[4] Qian X and Liu Y 2013 Branch and Bound Algorithm for Dependency Parsing with Non-local Features Transactions of the Association for Computational Linguistics 1 37–48
[5] Worgull M, Heckele M, Hetu J-F and Kabanemi K K 2006 Modeling and Optimization of the Hot Embossing Process for Micro and Nanocomponent Fabrication Microsystem Technologies 5(1)
[6] Carswell A T 2012 The Encyclopedia of Housing (SAGE)
[7] Hogan M 2014 The Real Costs of Building Housing The Urbanist 530
[8] Ozdemir Y, Basligil H and Sarsenov B 2012 A Large Scale Integer Linear Programming to the Daily Fleet Assignment Problem: A Case Study in Turkey Procedia - Social and Behavioral Sciences 62 849-53
[9] Atamtürk A and Savelsbergh M W P 2005 Integer-Programming Software Systems Annals of Operations Research 140(1) 67–124