Method for justification options for housing stock reconstruction

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Abstract. The main contradictions in the theory and practice of housing stock objects reconstruction are revealed. The technical condition of housing stock reconstruction facilities is analysed and a study of the organization and planning of housing stock reconstruction in the North-western federal district is performed. A method of substantiating options for reconstruction of housing stock in the North-Western federal district has been developed. Its practical significance lies in its application to justify the reconstruction option for technical re-equipment and modernization of housing facilities in Federal and municipal authorities implementing state policy in the field of providing the population with comfortable living conditions, as well as in regional departments of contractors, which perform housing facilities repair work, at the stage of design estimates development for the reconstruction of facilities. Thus, the purpose of the study (to improve the efficiency of planning the housing facilities reconstruction in the North-western federal district on the basis of the developed scientific and methodological apparatus) has been achieved.

1. Introduction
At the present stage, a significant number of buildings and structures in the North-western federal district of Russia have increased indicators of building structures physical wear, since most of them were built and put into operation before 1990 [1, 2].

Figure 1 shows information about the technical condition of buildings and structures in the North-western federal district by year of construction as of 2019. At the same time, in the article the technical condition of the object is understood as a set of building properties that characterize data on its serviceability and operability. 72.5 % of the buildings (mostly the objects, which were built in the period 1941-1990) were buildings of the second and third categories of technical condition [3, 4].
The analysis of capital investments for housing reconstruction in the North-western federal district (table 1; figures 2 and 3) shows that a significant number of objects require repair work for the reconstruction and buildings and structures overhaul and increase the capacity indicators of existing urban infrastructure due to the reduced level of performance and the need for buildings technical and re-equipment [5, 6, 7].

**Table 1.** Capital investments implementation under the program part of the Federal targeted investment program (FTIP) in order to improve the technical condition of the North-western federal district housing stock from 2016 to 2018.

| Number | Years | Allocated funds amount, thousand rubles | Realized funds volume, thousand rubles | Realization level, % |
|--------|-------|----------------------------------------|----------------------------------------|---------------------|
| 1      | 2016  | 5 844 020,0                            | 5 115 258,0                            | 87,0                |
| 2      | 2017  | 3 037 600,0                            | 2 656 328,6                            | 87,4                |
| 3      | 2018  | 2 911 539,6                            | 2 568 650,9                            | 88,2                |
| Summary|       | 11 793 159,6                           | 10 340 237,5                           | 87,7                |

**Figure 1.** Characteristics of buildings and structures in the North-western federal district by year of construction (as of 2019).

**Figure 2.** Analysis of FTIP capital investments for the construction of the North-western federal district housing stock from 2014 to 2018 (million rubles).
Figure 3. Analysis of capital investments for the reconstruction of the North-western federal district housing stock from 2014 to 2019, million rubles.

An analysis of the housing stock reconstruction and management in the North-western federal district showed that restoration and reconstruction predominate over some other forms of construction production. The capital investments volume in reconstruction in this direction exceeds the same indicators for current repairs in the last five years, which indicates a great demand for this method of improving the housing stock technical condition. At the same time, it is known that the specifics of the reconstruction object, the degree of work complexity, restrictions and features directly affect the capital investments volume and affect management decisions on the reconstruction project justification [8, 9, 10].

The capital investments analysis for infrastructure reconstruction in the North-western federal district also shows that this region has a large volume of reconstruction of existing buildings and structures, and there is a need to increase the buildings and structures capacity indicators. Funding for buildings and structures capital repairs in the North-western federal district amounted to 391.43 million rubles in 2017; 254.5 million rubles were allocated in 2018. Thus, in terms of allocated funds reducing, there is a growing role of housing stock reconstruction and organizational-technological solutions optimizing. Besides, improving the efficiency of investment is most urgent and requires scientific and methodological justification [11, 12, 13, 14 and 15].

In modern conditions the decision making task of the housing stock reconstruction is characterized by the presence of contradictions:
- lack of a well-founded approach to the organization and planning of housing stock reconstruction, and as a result, non-compliance with the characteristics required for comfortable living of the population after the completion of buildings reconstruction;
- increased physical and moral wear and tear, lack of reliable data on the buildings and structures technical condition, which leads to overstating the necessary financial resources for the objects reconstruction;
- elimination of negative decisions consequences at the design stages, that increase capital investment during the buildings and structures operation and reduce the effectiveness of providing the population with comfortable living conditions;
- insufficient theoretical developments in domestic technical science, lack of methodological documents on the need to optimize the reconstruction of facilities due to limited capital investment;
- there is no scientifically based classification of housing stock objects according to the priority of reconstruction planning, which results in haphazard and inefficient capital investments spending [14].

2. Materials and methods
The authors’ scientific task of the study was a methodology development for justifying the option and planning of housing stock reconstruction in the North-western federal district based on the generalized criterion method.
The purpose of the study was to improve the efficiency of planning the North-western federal district housing stock reconstruction based on the developed scientific and methodological apparatus.

The authors of the article performed the following tasks during the research: the technical condition of housing stock was analyzed and a study of the organization and planning of housing stock reconstruction in the North-western federal district was performed; a method of substantiating options for reconstruction of the North-western federal district housing stock has been developed; an assessment of the economic efficiency of the developed scientific and methodological apparatus is made.

The validity and reliability of the obtained scientific results is achieved by selecting real economic and statistical input data and using proven mathematical and methodological tools, which is confirmed by the economic efficiency of the customer organizations in making decisions on the facilities reconstruction in the North-Western Federal district. A computational experiment was performed to confirm the rationality of the developed method.

The research theoretical significance is determined by: conceptual approaches substantiation and contradictions' identification in the theory and practice of planning the reconstruction of housing facilities; indicators system justification for evaluating options for housing stock object reconstruction; using the generalized criteria method and modernization of previously developed methods based on analysis, the theory of the effectiveness of object management during technical re-equipment and reconstruction, which is a significant contribution to the development of the scientific basis for the organization and planning of restoration of the buildings and structures technical condition, investment evaluation during reconstruction, housing stock restoration, as well as improving the theory and methods of feasibility studies and time costs.

The practical significance of the study is: the justification of making reasoned decisions on capital investments for the housing facilities reconstruction was made; scientific and methodological apparatus was realized in organizations and enterprises that plan and perform housing facilities reconstruction; the prospects for the developed methodology practical use in universities and research organizations of federal executive authorities was determined.

3. Results

A study of the organization and planning of housing facilities reconstruction has been conducted, which showed that housing facilities have different levels of reliability of structural elements and terms of their failure-free operation, due to different design schemes and construction periods. It is revealed that there are four approaches to solve the problem of organizational and technological systems functioning reliability, what is based on the conducted research (table 2). The criteria for evaluating options for objects reconstruction are justified.

**Table 2.** Forms of matching functions for performance indicators in various approaches to the organizational and technological systems reliability problem.

| Number | Desired result | Function | Performance indicator |
|--------|----------------|----------|-----------------------|
| 1      | Random event A | $p = \begin{cases} 1, & \text{by } A \text{ is occurred} \\ 0, & \text{by } A \text{ is not occurred} \end{cases}$ | $P_u(A)$ |
| 2      | Set by the parameter $y^{tp}$ | | |
|        | Fuzzy variable $y^{tp}$ with the membership function $\mu$ | | |
| 3      | $y^{tp}$ - random variable $\gamma^{tb}$ with the distribution $\hat{\gamma}^{tb}$ | | |
| 4      | $p = \begin{cases} 1, & \text{by } y(u) \geq y^{tp} \\ 0, & \text{by } \hat{\gamma}^{tb} \leq y^{tp} \end{cases}$ | $P(\gamma(u) \geq y^{tp}) = 1 - F(y^{tp})$ |
|        | $P(\gamma(u) \geq \hat{\gamma}^{tb}) = \int_{\hat{\gamma}^{tb}}^{y(u)} dF(y)$ | | |
The method is applicable to substantiate the option of housing stock object reconstruction during technical re-equipment and modernization of objects in organizations and enterprises that perform repair work, as well as in Federal and municipal authorities that plan and organize the restoration of the housing stock technical condition.

It is necessary to define a number of key parameters within implementing the method. There is a housing facility in need of reconstruction, which can be characterized by the number of parameters $M$.

It is necessary to take into account a number of external factors that can influence decisions within evaluating the reconstruction option for object $L$. It is necessary to make a decision on the justification of the reconstruction option. Variants of reconstruction of the object $n$ are defined. A number of General criteria is defined for these variants, that affect decision-making and by which it is possible to fully characterize each variant $p_n$.

For these options, a number of general criteria $n$ have been identified that influence decision-making and by which it is possible to fully characterize each option $p_n$. The criteria should meet the general condition:

$$p_n \rightarrow \max.$$  \hspace{2cm} (1)

Comparison of reconstruction options of a building or structure is based on comparison of their vector estimates by preference. The vector estimation of a variant is calculated using the formula:

$$P(p/v) = v_1 \times \bar{p}_1 + \ldots + v_n \times \bar{p}_n.$$  \hspace{2cm} (2)

where $P(p/v)$ – vector estimation of the housing stock reconstruction option; $v_1$, ..., $v_n$ – the coefficients of criteria importance $n$; $\bar{p}_1$, ..., $\bar{p}_n$ – normalized values of the $n$ criteria, that affect the decision to justify the reconstruction option for the object.

Define the normalized values of the criteria $\bar{p}_n$ and assign a significance factor $v_n$ to each criterion (table 3).

The weight coefficients are determined by the formula:

$$v_j = \frac{x_j}{\sum_{j=1}^{n} x_j}.$$  \hspace{2cm} (3)

where $x_j$ – the sum of expert ratings $m$ based on one of the criteria $n$; $\sum_{j=1}^{n} x_j$ – total amount of values $x_j$.

**Table 3.** Determining weight coefficients using the ranking method.

| Experts | Criteria |
|---------|----------|
|         | $y_1$    | $y_2$    | $y_3$    | $y_4$    | ...     | $y_n$    |
| 1       | $x_{11}$ | $x_{12}$ | $x_{13}$ | $x_{14}$ | ...     | $x_{1n}$ |
| 2       | $x_{21}$ | $x_{22}$ | $x_{23}$ | $x_{24}$ | ...     | $x_{2n}$ |
| ...     | ...      | ...      | ...      | ...      | ...     | ...      |
Thus, the coefficients \( v_n \) for the criteria \( n \) that affect the decision on the reconstruction of the object are obtained, which in total are equal to one.

Since the evaluation criteria are heterogeneous and have different scales due to their nature, it is necessary to bring the initial criteria to a comparable form - normalize them. The normalized criteria \( \hat{p}_n \) are dimensionless and their values range from 0 to 1. Values \( \hat{p}_n \) calculate using the formula:

\[
\hat{p}_n = \frac{p_{n}^{\text{fac}}}{p_{n}^{\text{pr}}},
\]

where: \( p_{n}^{\text{fac}} \) – the actual values of the criteria \( n \); \( p_{n}^{\text{pr}} \) – limit values of criteria \( n \) (which are determined and based on the maximum values of the object’s characteristics).

For the most complete representation of the methodology for housing stock reconstruction evaluating options, an algorithm is formed (figure 4).

**Figure 4.** Algorithm for substantiating the option of reconstruction of the housing stock object.
According to the algorithm for justifying the housing stock reconstruction option, the calculation of significance coefficients, the determination of normalized values, and the determination of option vector estimates are performed. A comparison of vector estimates of each option for reconstruction of a housing facility shows which option is the most optimal.

In order to increase the automation of the process and reduce the time spent, the method is implemented using the received patent for the invention "Decision support system for building restoration" (figure 5). The technical result is automation and support of management decision-making in the conditions of several criteria, based on which reconstruction planning is carried out. The system use increases the efficiency of planning repairs in federal and municipal authorities that implement state policy in the field of providing the population with comfortable living conditions. Thus, the method forms a comprehensive approach, confirmed by the patent for the invention of the Russian Federation no. 2716351 "Decision support system for building restoration" [14].

**Figure 5.** Decision support system for building restoration: 1 - module for monitoring the buildings; technical condition; 2 - sensors; 3 - autonomous data collection units; 4 - control station; 5 - block for entering parameters; 6 - information analysis module; 7 - block for determining the building reconstruction cost; 8 - block for determining the building operation cost; 9 - information processing module; 10 - reference indicators block; 11 - ranking criteria and calculation block; 12 - memory block; 13 - displaying information block

Within developing the presented methodology the application’ effectiveness was evaluated while analyzing options for restoring the residential building technical condition in Saint Petersburg.

The authors of the article expressed the comparative cost of reconstruction of objects by the ratio:

\[
\frac{KV_{rec,i}}{T_{rec}} \leq \frac{KV_{new}}{T_{new}}
\]

The characteristics of residential house reconstruction options are shown in table 5. The calculation performed by the authors allows us to conclude that option C of reconstruction of the housing stock is the best option for restoring the technical condition of the object. The economic effect of the implementation of option C of the reconstruction will be:

\[
E_p = E_n \times KV_{rec,i} \times (T_1 - T_2) = 0,15 \times 155(1,8 - 1,6) = 4,65 \text{ million rubbles.}
\]
Table 4. Options for design solutions for reconstruction.

| Indicators                                      | Measure unit | Reconstruction options |
|-------------------------------------------------|--------------|------------------------|
| The facility capacity W                         | m²           | A: 2000 B: 2050 C: 1950|
| One-time costs for new construction of a similar facility KV<sub>new</sub> | million rubles | A: 500 B: 500 C: 500 |
| One-time expenses for reconstruction of the object KV<sub>new</sub> | million rubles | A: 150 B: 160 C: 155 |
| Annual operating expenses C<sub>cep</sub>         | thousand rubles/m² | A: 75 B: 78 C: 79.5 |
| Duration of construction of a new similar facility t<sub>new</sub> | year         | A: 2 B: 2 C: 2        |
| The duration of the reconstruction t<sub>rec</sub> | year         | A: 1.7 B: 1.8 C: 1.6  |
| Object service time after reconstruction T<sub>rec</sub> | year         | A: 30 B: 30 C: 30     |
| New object’ service time T<sub>new</sub>         | year         | A: 50 B: 50 C: 50     |

The economic efficiency of the selected option is:

$$E = \frac{e_p}{KV_{rec,i}} \times 100\% = \frac{4.65}{155} \times 100\% = 3\%,$$ (7)

this shows the expediency of using the developed scientific and methodological apparatus in planning the reconstruction of a housing facility.

4. Discussion

As a result of the research, the scientific task of developing a methodology for justifying the option and planning of reconstruction of housing facilities in the North-Western federal district based on the generalized criterion method, which is essential for the effective planning of housing facilities reconstruction in the North-Western Federal district, was solved.

The effectiveness of the research results was evaluated with the justification of using the method of options comparative analysis for project proposals for reconstruction, which showed that the use of the developed methodology, as well as practical recommendations for planning the reconstruction of housing facilities, allows you to get an economic effect of 10 to 15% of the reconstruction cost.

5. Summary

The scientific significance of the method lies in the fact that unlike the other, it enables the comparative assessment of the housing stock reconstruction variants on the basis of the generalized criterion taking into account weight coefficients and their normalized values to identify the most optimal variant. The method allows to justify organizational and economic decisions within reconstructing a housing facility.

The theoretical significance of the developed method is to justify the efficiency of capital investment distribution in the optimal case of object reconstruction based on the generalized criterion method.

Its practical significance lies in its application to justify the reconstruction option for technical re-equipment and modernization of housing facilities in Federal and municipal authorities implementing.
state policy in the field of providing the population with comfortable living conditions, as well as in regional departments of contractors, which perform housing facilities repair work, at the stage of design estimates development for the reconstruction of facilities.

Thus, the purpose of the study (to improve the efficiency of planning the housing facilities reconstruction in the North-western federal district on the basis of the developed scientific and methodological apparatus) has been achieved.

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