Methodology for choosing the best design solution in construction

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Abstract. The article investigates a methodology for qualitative evaluation of the design solutions and their quality. Qualimetric analysis makes it possible to improve the accuracy of quality evaluation and rationally choose the best design solution. A procedure for qualimetric evaluation as well as an algorithm for calculating weight coefficients and quality indicators have been developed. In the experimental part, a qualimetric analysis of three options for the project of an apartment building has been performed. A “quality tree” of the investigated object has been developed, weighting coefficients have been determined for each project quality indicator. The absolute, relative, and complex indicators of the quality of the assessed objects have been calculated, the best out of three options for the construction implementation has been determined. As a result, the methodology has been designed, tested, and formulated for further usage.

1 Introduction

The quality of construction is defined as the level of consumer satisfaction from the implementation of design solutions. The level of project efficiency is determined by the rationality of each design solution, which predetermines the complexity of a comprehensive evaluation of the construction project in general [1]. A design solution is the result of solving engineering problems in the design of objects in a form of technical documentation (calculations and graphic representation – sketches, drawings) [2]. A large variety of construction projects and the specificity of design solutions complicate the problems in choosing a universal and objective method for evaluation the quality of design solutions. In modern conditions, evaluation of the quality of design solutions is problematic since there are no objective assessment methods. Therefore, the development of quantitative methods for assessing the quality of design solutions in construction is relevant and indicates practical interest [3, 4].
The purpose of the study is to develop a methodology for qualimetric evaluation of the quality of design solutions in construction industry. To achieve this goal, several tasks have been identified: analysis of methods for quality evaluation and choosing the best possible option; justification of the model for quantitative assessment of a design solution quality; development of a procedure for qualimetric assessment of a design solution quality; development of a methodology for qualimetric quality evaluation to select the best possible design solution in construction industry.

1.1 Methodological approaches to evaluation of the quality of design solutions

The quality of design projects directly affects the properties and reliability of the construction object. Modern conditions and trends set higher requirements for the quality of proposed construction projects compared to the ones in the near past. In the process of architectural design and construction, specialists evaluate design solutions at all stages of its development: master plan, space planning and constructive solution, floor plans, facades, interiors, load-bearing and enclosing materials, etc. [5]. The purpose of this evaluation is to select the best possible option. Each assessment is carried out according to specific criteria and requirements. Therefore, before comparing project evaluation methods with each other, it is necessary to determine the requirements that these methods must meet [6]. We analyzed the requirements for the assessment method for selecting the best possible option [5]. Unlike well-known evaluation methods, the qualimetric method allows to quantify the quality of the design solution [9, 10].

The qualimetric method for evaluating design solutions is a set of methods and techniques for obtaining a quantitative assessment according to a certain system of procedures and choosing the most effective solutions for a construction project. The accuracy requirement involves quantitative calculations. The requirement of absolute reliability of the quality assessment results suggests that the decision should be based on considering not one but all the parameters of the evaluated projects [11]. Thus, the qualimetric method can quantify the quality of the design solution. Due to the lack of a qualimetric assessment methodology, expert assessment methods are the most used; they can also be used for qualimetric analysis [12].

Major principles of the qualimetric method are: priority of the consumer while choosing project quality indicators; presence of a basic standard or options for comparing the design solutions; development of a hierarchical structure of project quality indicators: single indicators of the simplest properties, generalized quality indicators, integral indicator; reduction of different-sized indicators of properties to one dimension or to dimensionless units of measurement based on qualimetric scales; using of weights coefficients for each indicator to determine the integral one [5].

Even though the qualimetric method is widely applicable, the practice of its application in the construction industry has several methodological problems, including [6]: lack of an algorithm for quantifying the design solutions and lack of a methodology for a comprehensive assessment of the design solution quality.

2 Materials and methods
2.1 Grouping construction projects for qualimetric quality evaluation

To identify quality indicators, all construction projects can be grouped. By the complexity of the construction and installation work required, construction projects are divided into new construction, reconstruction, and major overhaul. By class – mono projects (construction, reconstruction, technical reorganization, or major repairs of individual buildings) and complex projects (comprehensive housing development of territories, construction or expansion of enterprises, complex reconstruction of existing enterprises or building a res, etc.) [7, 8]. By scale – small projects (construction or reconstruction of small and simple individual objects), medium, large, giant projects can be grouped. By the duration – projects with a short, medium, and long construction period [5].

2.2 Description of the procedure for qualimetric evaluation of construction projects quality

The quality assessment procedure was developed and consists of the following steps:

1. Announcing a task for the development of a layout and assigning responsibilities.
2. Defining the assessment situation.
3. Forming the groups for layout development.
4. Identification of properties indicators.
5. Development of a property tree.
7. Selection of reference and rejection values of indicators.
8. Calculation of values for absolute and relative indicators of properties.
9. Calculation of quality indicators values.

At the second stage the strategy for developing and applying a quality assessment methodology is determined to achieve maximum accuracy and reliability of the assessment results. At this stage, the characteristics and properties of the project are evaluated are identified, and members of the organizational, technical, and expert groups are formed.

The fifth stage includes building a graphical model of quality properties hierarchy. When constructing a “property tree”, first the quality is characterized by generalized properties, then the generalized properties are divided into smaller ones (simple, quasi-simple) [5].

2.3 Calculation of the quality indicators of the evaluated object

The values of the weighting coefficients are calculated for the quality indicators, which are included in the structure of the “property tree”. Two types of weight coefficients are calculated – group and tiered.

Group non-normalized weight coefficients \( G_{i} \) determine the weight of the indicator of each property in each group of properties are calculated with the following formula:

\[
G_{i}^{'} = \frac{\sum_{k=1}^{r} G_{i,k}^{'} \cdot r}{n_{i} \cdot r}
\]

where \( i = 1, \ldots, n \) is the number of indicators in the property group. For group normalized weight coefficients \( G_{i}^{''} \) the following formula is applied:

\[
G_{i}^{''} = \frac{G_{i}^{'} \cdot n}{\sum_{i=1}^{n} G_{i}^{'} \cdot n}
\]

For group normalized weight coefficients \( G_{i}^{''} \) the following formula is applied:
\[ \sum_{i=1}^{n} G_{i} = 1,00 \]

Tiered normalized coefficients \( G_{j} \) determine the weight of the indicator of each property with the following formula:

\[ G_{j} = G'_{k-1} \times G'_{k} \]

where \( G'_{k} \) is the property weight coefficient on the \( k \)-th tier of the “property tree”, equal to the group weight coefficient of the same property and \( G'_{k-1} \) is the weight coefficient of the corresponding property on the previous \((k-1)\)-th tier.

Weight coefficients are normalized by formula (2), their value sits within 0 and 1.

Within each tier of the “property tree”, the following condition is provided: \( \sum = 1 \). The calculation of group coefficients \( G_{i} \) is determined by an analytical or expert method [6, 14]. Next, weight coefficients \( G_{i} \) are calculated for each tier of the tree.

The definition of reference and rejection quality indicators for comparison with the absolute (actual) value of the indicator depends on the assessment situation and the estimated indicators of the object properties. They accept the minimum and maximum rejection values of the indicator, or the allowable values ranges of the absolute (actual) property indicator. The values of reference and rejection indicators are established by measuring, analytical, expert or documentary methods.

Relative quality indicators \( K_{ij} \) are calculated based on absolute, reference and rejection values with the following formula:

\[ K_{ij} = \frac{Q_{ij} - q_{ij}}{q_{ij} - q_{ij}^{r}} \]

where:

- \( K_{ij} \) – relative quality indicator;
- \( i \) – the number of the assessed quality property;
- \( j \) – the number of the evaluated design solution;
- \( Q_{ij} \) is an absolute indicator;
- \( q_{ij}^{r}, q_{ij}^{r} \) – reference and rejection value of the property indicator.

The complex quality indicator \( K_{j} \) is defined as an average weighted arithmetic, geometric, harmonic sums [5] with formula (6):

\[ K_{j} = \sum_{i=1}^{n} K_{ij} G_{i} = 1 \]

where \( K_{ij} \) is the relative indicator of the \( i \)-th property of the \( j \)-th object, and \( G_{i} \) is the weighting factor of the indicator.

3 Results

Based on the developed methodology, a qualimetric quality evaluation of three design solution options for the construction of a 6-storey, 12-apartment one-section brick residential building for large families has been carried out. The goal was to choose the best possible design solution for the construction of a residential building. Design solutions of three organizations have been evaluated: 1 – Inzhproekt LLC, 2 – Stroytap LLC, 3 – StroyLab LLC. A brief description of the design solutions is represented in table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Design option 1</th>
<th>Design option 2</th>
<th>Design option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Wet” facade</td>
<td></td>
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</tbody>
</table>
The level of integral project quality has been determined by functional, architectural, constructive, hygienic, aesthetic, economic and many other complex and single quality indicators. They can be expressed both quantitatively and qualitatively. Quality indicators must ensure the comfort of living in families with many children. Based on the results of the survey of future residents of the home, a “property tree” has been developed. During the surveys, the main consumer quality indicators have been identified, including: the quality of residential premises and premises for collective use.

The quality of premises for collective use is determined by functionality and aesthetics. Therefore, group indicators of quality, including the functionality of communications, have been evaluated. Individual indicators are set for all group indicators. For example, the group indicator “functionality of communications” of premises of collective use is determined by indicators: functionality of the entrance node, stairwell, elevator, and common utility rooms (Figure 1).

The rest of the estimated quality indicators of project solutions have been determined similarly. More than 50 indicators have been evaluated:

1. Functionality of entrance node
2. Functionality of staircases
3. Functionality of elevator
4. Functionality of basement
5. Functionality of wheelchair space
6. Functionality of rooftop
7. Aesthetics of communications rooms
8. Aesthetics of utility rooms
9. Aesthetics of external appearance in relation to the environment
10. Aesthetic compatibility with the environment
11. Quality of residential premises, etc.

According to formulas (1) - (6), weighting coefficients are calculated for all quality indicators, absolute and relative indicators, complex indicators and an integral quality indicator for each variant of the design decision.

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Fig. 1. Fragment of the “property tree”: Functionality of premises for common use.
4 Discussion

\[ \sum_{i=1}^{n} K_{ij} G_i^j \]

For the property #35 ("Economy"—projected costs of house building and operation), the reference value of the absolute indicator was calculated with the formula:

\[ q_{i35}^{rf} = P = C + M \times T \]

where P is reduced costs for the construction and operation of the house for its payback period, referred to 1 m² of the total area of the house; M is annual operating costs per 1 m² of the total house area (M = 3.73 units/m²); C is estimated cost of 1 m² of the total area of the house (C = 87.0 units/m²); T is the standard payback period for the construction of a building (T = 8.33 years).

The reference value for indicator #35 "Economy" \( q_{i35}^{rf} \) is 118.0 units.

The results of the qualimetric evaluation of design solutions made it possible to justify the choice of the best possible design solution for the construction of a residential building.

5 Conclusion

The study of quality assessment methods has shown that qualimetric analysis makes it possible to quantify the quality of a design solution. At the same time, the problem of practical application of the qualimetry methodology is associated with the lack of a methodology for qualimetric analysis of design solutions quality in construction.

A procedure for conducting a qualimetric evaluation of the quality of construction objects and an algorithm for calculating weight coefficients and quality indicators have been developed. In the experimental part, the qualimetric evaluation methodology has been implemented.
While conducting the qualimetric analysis, a “quality tree” of the studied object has been developed, weight coefficients have been determined for each quality indicator. Weight coefficients were determined by analytical and expert methods. The calculation of absolute, relative, and complex indicators of quality has been carried out.

Comparative analysis of the complex quality index values of three options for design solutions determined the best possible project for the implementation of construction.

A methodology for qualimetric analysis has been developed to assess the quality of construction projects and select the best possible design solution. Qualimetric analysis improves the accuracy of assessing the quality level based on the calculated indicators and allows to make a rational choice of the best available option.

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