Energy systems modeling and assessment of the efficiency of quality management systems in high-rise construction

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Abstract. Construction reorganization, as a type of construction of high-rise buildings, is a part of a basic reorganization cycle. Features of renovation of built-up areas and issues of energy modeling are considered. The experience of assessing the efficiency of quality management systems for the organizational structures of construction management and common approaches to solving this issue are currently insufficient. Loft style methodology is used: the integrated performance indicator of organizational and technological operational reliability (OTOR) in high-rise construction. The possibilities of the construction method using 3D printing technology are considered. Comparative analysis of cost indicators for the construction of walls made of concrete blocks with plaster, brick cladding and ApisCor technology is made. These circumstances allow formulating the scientific task of the study. On the basis of the well-known BIM technology for information modeling of objects, a bank (information base) of standard implementation plans (IP) is created, from which the most rational IP for this type of work is selected using the criteria research method based on modified genetic algorithms (GA). The issues of choosing a method of construction work by the totality of implementation plans of construction and installation works are considered.

1. Introduction

The concept of the public sector efficiency, forming the basis of public administration reforms in this area, faces a number of outstanding methodological and organizational problems. In particular, such problems include the absence of a generally accepted notion of public sector’s economic efficiency in scientific literature and practice; lack of established economic efficiency criteria and indicators. Methodological approaches and principles of the economic efficiency determination in public and commercial sectors must be uniform. We believe that this approach is untenable in view of fundamental differences of the principles and objectives of the non-profit sector, and its deep-rooted economic and social distinctions, and requires some additional research in the field of financial accounting and reporting. A critical indicator of economic efficiency is “net assets”. The key purposes of assessment of a non-profit organization should include not only the achievement of maximum social impact, but also the optimization of budget resources and economic performance. In this regard, special significance is acquired by the “net assets” category, which allows, on the one hand, a review of the investment process in the public sector, and, on the other hand, an estimation of increase in the total value of a non-profit enterprise. This indicator can also be used traditionally as a measure of growth of retained earnings from chargeable operations of a non-profit organization [1-10]. The efficiency of construction production, its final results are largely determined by the degree of
organization of the construction processes, which in turn depends on the quality of solving the design problems of the organization of construction and work and, first of all, the formation of models for the construction of objects and choice based on the most rational organizational and technological solutions (OTS). In this regard, there is a need to improve methods for solving the problems of designing the organization of construction and work, taking into account the requirements of construction practice, in particular, modeling the construction of facilities and choosing the most rational organizational and technological solutions. This gives rise to a problem associated with the need to develop new national and international accounting models and tools for net assets in the non-profit sector, and to adapt the existing ones, as well as to develop effective methodologies based thereon [11-19].

2. Methods

One of the advanced technologies today, which allows creating prototypes of models based on the digital version of the object, is 3D printing technology. This technology allows erecting buildings of small and medium height. Implementation plans (IP), which are part of the Method Statement, are usually developed for complex types of work and work performed by new methods. They are the basis of the scientific organization of construction processes and are developed in accordance with existing Russian standards (SNiP, GOST, ENiR, instructions). An implementation plan is a set of rules, norms, instructions and schemes for the implementation of a given project or part of it. Using IP allows excluding different variations and interpretations of a particular mode of action in this situation. This is an instruction that allows you to most effectively and quickly do a given type of work [16-19, 25-30, 34].

The structure of an implementation plan: scope; organization and technology of work; requirements for quality and acceptance of work; calculation of labor costs, machine time and wages; work schedule; material and technical resources; safety precautions; technical and economic indicators. The main purpose of the IP is to assist builders and designers in the development of technological documentation. According to the Labor Code, the technological sequence of construction processes is established, weekly-daily schedules and work orders are compiled. They are used to justify the duration of the construction of facilities in calendar plans and network schedules. IPs are developed by leading design and construction companies to carry out general construction and specialized work. In some cases, IPs are developed for integrated construction and installation processes. It is possible to facilitate the development of IPs, improve their quality and reduce development time only through the use of the most modern information technologies. By linking the automated selection algorithm for a typical IP with an information modeling program, it becomes possible to use the methodology not only for design, but also for the actual production of work. For example, in the production of stone work with the help of masonry robots, the work of which is carried out on the basis of the information model of the building by selecting the necessary IP [16-19, 20, 21, 25, 29, 30, 31, 32, 33, 34, 35].

1. As a criterion, one of the indicators that has a clear dominance over other indicators (for example, task completion time or project cost) is taken. Such a criterion is called simple.

2. A criterion is formed by two or more indicators by their convolution into a composite criterion. The latter, as a rule, has the form of a function where the relative importance of indicators is not taken into account (they are accepted as equally valuable). An example of such a criterion is the rate of work \( V \), which is the ratio of the volume of work \( Q \) to the time of their completion \( T \):

\[
V = \frac{Q}{T}.
\]

3. The criterion is formed from \( n \) particular criteria \( K_i \), the relative importance of which can vary. For this, a generalized criterion \( K_o \) is used:
\[ K_n = \sum_{j=1}^{n} \alpha_i K_j \rightarrow \min(\max), \]  

(2)

where \( \alpha_i \) — weight of each \( i \)-th criterion \( K_i \).

When forming a generalized criterion, two problems must be solved:

- determine the significance (weight) of each particular criterion, i.e. set the value of \( \alpha_i \);
- overcome the “dimension problem” of particular criteria, i.e. fulfill the first criterion requirement.

The significance of particular criteria can be established in two ways:

An expert method (or an expert survey method), the essence of which is described in the mathematical literature. Briefly, it can be described as follows: a group of experts is interviewed, each of which gives its own assessment of the significance of each particular criterion. Then, the obtained data are processed by the methods of mathematical statistics, and a certain average (or compromise) value of \( \alpha_i \) is found:

The method of “relative preferences”, which is a special case of the expert method (this is the method of one expert - the decision maker). Its essence is in the following actions.

The decision maker, individually or with the help of colleagues, arranges each of the particular criteria in a row in descending order of their importance.

For example, if four particular criteria are used and they are arranged in the order: \( K_1 > K_2 = K_3 > K_4 \), this means that \( K_1 \) is more important than \( K_2, K_3 \) is equivalent to \( K_3 \), and \( K_3 \) is more important than \( K_4 \). Such a record is called an “order relation”.

If \( K_1 \) is more important than \( K_2 (K_1 > K_2) \), then criterion \( K_1 \) is assigned an importance factor \( \beta_{12} = 3 \).

If \( K_1 \) is equal to \( K_2 (K_1 = K_2) \), then \( \beta_{12} = 2 \).

If \( K_1 \) is less important than \( K_2 (K_1 \leq K_2) \), then \( \beta_{12} = 1 \).

3. Results

To calculate \( \alpha_i \), a scoring square matrix is constructed in which the partial criteria \( K_i \) are arranged in rows and columns (Table 1).

| Criteria | \( K_1 \) | \( K_2 \) | \( \ldots \) | \( K_n \) | \( \sum_{i=1}^{n} \beta_{ij} \) | \( \alpha_i \) |
|----------|----------|----------|-----------|----------|-----------------|--------|
| \( K_1 \) | \( \beta_{12} \) | \( \beta_{1n} \) | \( \sum_{i=1}^{n} \beta_{1j} \) | \( \alpha_1 \) |
| \( K_2 \) | \( \beta_{21} \) | \( \ldots \) | \( \beta_{2n} \) | \( \sum_{i=1}^{n} \beta_{2j} \) | \( \alpha_2 \) |
| \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) |
| \( K_n \) | \( \beta_{n1} \) | \( \beta_{n2} \) | \( \ldots \) | \( \sum_{i=1}^{n} \beta_{ij} \) | \( \alpha_n \) |

\[ \sum \beta_{ij} \sum_{i=1}^{n} \alpha_i = 1.0 \]

In each row, at the intersection of a row and a column, values of \( \beta_{ij} \) are assigned that correspond to the order of preference of the row criterion over the column criterion. As a result, for each \( i \)-th row, one
can get the sum of the significance coefficients for the criterion \( K_i (\sum_{j=1}^{n} \beta_{ij}) \). Summing up these results by columns, we get

\[
A = \sum_{j=1}^{n} \sum_{i=1}^{n} \beta_{ij} .
\] (3)

The coefficient of significance of the criterion \( K_i \) will be equal to:

\[
\alpha_i = \frac{\sum_{j=1}^{n} \beta_{ij}}{A} .
\] (4)

**Example:** Calculate the coefficients of significance of the criteria, if the ratio of their order is established: \( K_1 > K_2 > K_3 = K_4 \).

**Solution:** Let’s build a scoring matrix (table 2).

| Criteria | \( K_1 \) | \( K_2 \) | \( K_3 \) | \( K_4 \) | \( \sum_{j=1}^{n} \beta_{ij} \) | \( \alpha_i \) |
|----------|----------|----------|----------|----------|----------------|--------|
| \( K_1 \) | 3        | 3        | 3        | 9        | 0.375           |
| \( K_2 \) | 1        | 3        | 3        | 7        | 0.292           |
| \( K_3 \) | 1        | 1        | 2        | 4        | 0.167           |
| \( K_4 \) | 1        | 1        | 2        | 4        | 0.167           |

\[ A = 24 \quad \sum_{i=1}^{n} \alpha_i = 1.00 \]

In cell \( K_1 – K_3 \), we will write the number 3, because \( K_1 > K_3 \). Since \( K_1 \) will be more important than all other criteria in the row (transitivity property, if \( K_1 > K_2 \) and \( K_2 > K_3 \), then \( K_1 > K_3 \), i.e. set of ordered pairs of elements of this set), then the number 3 should be written in the two remaining cells of the first row. Thus, the sum of the numbers of the first row will be 9. Similarly, fill in all the other cells of the scoring matrix (in cell \( K_4 – K_1 \), there will be the number 1, because \( K_4 < K_1 \); in a cell \( K_4 – K_3 \) there will be the number 2, since \( K_4 = K_1 \) ).

Summing up the numbers in the column \( \sum_{j=1}^{n} \beta_{ij} \), we get \( A = 24 \). Hence \( \alpha_1 = 9/24 = 0.375; \alpha_2 = 7/24 = 0.292; \alpha_3 = \alpha_4 = 0.167 \).

The condition \( \sum_{i=1}^{n} \alpha_i = 1.00 \) is satisfied.

To solve the problem of “dimension” in equation (7), not the absolute values of \( K_i \) are used, but their normalized values calculated by the formula:

\[
K_i^n = \frac{K_i^a}{K_i^\text{lim}},
\] (5)

where \( K_i^a \) and \( K_i^\text{lim} \) - the actual and limit (or normative) values of the criterion, respectively. Using formula (10), different-dimensional criteria are reduced to one-dimensional (in fractions of a unit).

In practice, there are often situations where not all criteria have the same way of optimization (i.e. all tend to either minimum or maximum). For example, expenses, losses, deadlines for putting objects into operation tend to a minimum, and profit, pace of work, profitability and others – to a maximum. In this case, equation (7) is divided into two parts: minimized criteria are collected in one part, and
maximized criteria in the other. If we denote the first group by $K_i \ (i = 1, 2, \ldots, m)$, and the second through $K_j \ (j = 1, 2, \ldots, l)$, then formula (10) takes the form:

$$K_o = \sum_{i=1}^{m} \alpha_i K_i^n + \sum_{j=1}^{l} \alpha_j \frac{1}{K_j^n} \rightarrow \min,$$

and $m + l = n$.

4. Discussion

Application of international standards and accounting principles is based on the following groups of documents: 1. for commercial organizations – International Accounting Standards (IAS) and International Financial Reporting Standards (IFRS) developed by the Council for IASB (IASB); 2. for public sector – International Public Sector Accounting Standards (IPSAS) developed by the Council for IASB OS (IPSASB) under the International Federation of Accountants (IFAC). Definition of the targets and application of both groups of standards is based on the principle of prevalence of economic substance over legal form. This allows qualification of a commercial entity for the purpose of applying the IFRS OS solely on the basis of the objectives of the enterprise and its functions to be implemented in the economic and social environment, regardless of the legal form of ownership and the structure of investment by the state. Therefore, recognition of assets and funding sources in the paradigm of IFRS is based solely on the criteria of their use for achievement of the main goals of the enterprise[1,2,3,4,5,6,7,8,9,10]. The calculation of managerial effectiveness was carried out by assessing the degree of implementation of the management functions of the system using points (1÷5).

A survey of construction company officials showed that all functions have equivalent meanings. Thus, managerial effectiveness was: $K_m = (0.8 + 0.8 + 0.8 + 0.6 + 0.6)/5 = 0.72$. Social efficiency in this study was considered as the degree of satisfaction of workers with social working conditions. The assessment was carried out through a survey of employees. According to the survey, the criterion of social efficiency was calculated: $K_{soc} = 0.7$. Given the above calculations, the efficiency of the quality management system of ICC “Zapad”[31-35].

Analysis of the calculations of the results obtained within the fourth stage of the methodology showed that it is necessary to carry out corrective measures to increase the effectiveness of the processes (analysis by the management, internal audit, management of documents and records, measurement of customer satisfaction, etc.). For a more thorough analysis of the economic efficiency of the system, processes and measures to improve them, it is necessary to allocate costs in these areas from the general financial statements. Considering the fact that this performance assessment is the first for this construction company, it is possible to take this value as a base and use it for analysis in subsequent assessments - how much the system's performance indicators have improved or decreased[31-35].

5. Conclusions

An analysis of the results (PARTI Table 2, Efficiency calculation results) shows that the efficiency of the system in IC “Garant” is higher than in ICC “Zapad”. However, the generalized indicator says that the QMS functions more efficiently in ICC “Zapad”, although each of the assessed companies needs to carry out activities aimed at improving the quality processes. In construction, perspectives in imitation of construction production and a visual project for the organization of construction, a project for implementation of construction operations; spatial and temporal coordination of construction participants; planning, management and control (plan/actual); site optimization and logistics; improvement of geodetic alignment works; deviation control; monitoring of labor protection and industrial safety: in the modular digital production of building structures and products with assembly at the construction site; rationalization of executive documentation and its full reflection in the information model of the object. Efficiency is a comprehensive concept that includes several private
types of efficiency. From this it follows that assessing the efficiency of the quality management system is a multicriteria task in which production, economic and other criteria must be present. Taking into account the above terms, as well as the foregoing, we can formulate *methodological foundations for assessing the efficiency of the quality management system*, which can come down to the following provisions [25-30]: 1. Since efficiency is the degree to which goals are achieved, it is necessary to formulate a goal for the achievement of which a management system has been created and make its decomposition. An example of target decomposition is shown in figure 1. By definition of the concept of “efficiency”, it is legitimate to talk about the efficiency of achieving each individual goal. In other words, it is possible to assess the efficiency of quality management of construction products as a whole, as well as the efficiency of tasks, for example: “Ensure compliance with product requirements”, “Process quality management”, etc.

**Figure 1.** An example of decomposition of quality management goals.

2. Since the goals are of a different nature (production, economic, environmental, social, etc.), it’s also wrong to reduce efficiency only to economic efficiency, because it (efficiency) can be industrial, economic, etc. The relationship between the categories of “goal” and “efficiency” is shown in figure 2.

3. Achievement of each goal is assessed by a system of indicators (cost, labor, time and others). In the theory of efficiency, these indicators are usually divided into two groups: *criteria and restrictions*.

A methodological approach to justifying the system of criteria and restrictions is presented in figure 3.

**Figure 2.** The relationship between the categories of “goals” and “efficiency”.

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**Figure 1.** An example of decomposition of quality management goals.

**Figure 2.** The relationship between the categories of “goals” and “efficiency”.
Figure 3. The diagram of forming a system of criteria and restrictions.

All this should ultimately lead to a reduction in the time of building construction; reducing the cost of creating an object; provide access to reliable information on the progress of construction; reduce waste; reduce injuries at the construction site, and increase the reliability and quality of the construction facility [22,23,27,28,31-35].

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