An Integrated Approach to Improving the Quality of Civil Buildings

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Abstract: This work is intended to analyze and propose ways of streamlining operational qualities as elements that form the system of a civil building’s qualities. The author proposes an integrated approach to improving the operational qualities of cast-in-place and precast/cast-in-place civil buildings, which is implemented via the identification of priority objectives to be resolved in a concerted manner by different participants in the lifecycle of a building. The specifics of this approach deals with streamlining the key parameters of operational qualities through the interconnected use of methods and instruments at the command of different participants in the lifecycle of a building. The author has worked out an analytical method for defining the potential for having operational qualities streamlined by each participant in the cycle.

Key words: Operational qualities • Civil building • Integrated approach • Lifecycle of a building

INTRODUCTION

Ensuring the substantial improvement of the operational qualities (OQ) of civil buildings necessitates the use of new methodological approaches that would help bring about drastic changes at all stages of a building’s lifecycle with each participant making a maximum contribution to the desired result. One of the ways of resolving this objective is the integrated approach (IA). This approach is the methodological basis of system engineering, which has been widely employed in recent years in the best business projects in construction, machinery manufacture and other industries [1, 2, 3], as well as in many modern megaprojects [4, 5].

In this work, the author considers as structures to be streamlined residential apartment buildings with cast-in-place and precast/cast-in-place reinforced concrete framing, which have become the dominant construction systems in many Russian cities.

The IA methodology has found wide use in the study and improvement of processes in the stages of the lifecycle of building structures. When it comes to the organization of quality construction (e.g. residential construction) work, the IA is about ensuring that construction works are carried out in necessary volumes and with due quality at all stages of the investment phase [6], which boosts the consumer attractiveness of residential buildings and the activity of investors and developers on the market. In economic studies into the development of construction enterprises, the IA is construed as the management of the process of ensuring their consistent activity at different stages of their lifecycle [7], which in large part defines the viability of enterprises in market conditions. When it comes to the optimization of organizational-technological solutions, the IA is construed as the coordinatedness of their economic and technical parameters [8]. Thus, employing the IA in construction is normally associated with streamlining organizational, technological, economic and other processes, in relation to a specific building structure at all stages of its lifecycle inclusive of technical and economic requirements.

Main Part: It is expedient to view the IA as a process of managing the lifecycle of building structures, wherein priority objectives are identified and which reveals diversified potential for improving the effectiveness of resolving them through the use of methods and instruments at the command of different participants in the cycle. This variant of the IA helps employ the entire spectrum of professional capabilities for having OQ’s streamlined by participants in the lifecycle. Note that the activity of each participant is considered not in isolation but in interaction with others, which lets us expect a synergetic effect. Figure 1 provides a general scheme for the implementation of the IA.

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The potential of the IA for improving the OQ’s of cast-in-place civil buildings deals with the consistent improvement of OQ parameters at all stages of a building’s lifecycle with an optimum ratio of technical-economic indicators of their getting achieved by cycle participants. In such an approach, OQ’s should be viewed as characteristics that form the kernel in the system of the qualities of a civil building.

It follows from our definition that in the first stage of implementing the IA all the OQ’s of a building should be structured in such a way as to make it possible to:

- Assess the potential for improving OQ’s;
- Define the areas of influence and responsibility of each participant in the construction project for specific OQ’s;
- Define the aspects of interaction between participants in the construction project aimed at improving OQ’s.

To be able to implement the IA in working out proposals on streamlining OQ’s, we need to concretize our understanding of them. The existing approach to understanding the OQ’s of buildings defines them as follows:

- Distinctions and attributes characterizing a building, as well as the social-consumer and economic efficiency of its functioning [9];
- The actual physical-technical and technological qualities of buildings, facilities and their elements [10].

The international construction standard [11] does not contain a definition of OQ’s, but operational requirements are defined as the expected quality of work.

These definitions stress the fundamentals of OQ’s and their multi-facetedness. In this regard, it is clear that the essence of OQ’s deals with how well they ensure that buildings are employed in accordance with their intended use. Therefore, we suggest viewing the OQ’s of residential buildings as the fundamental characteristics of buildings at large and their separate spaces that possess consumer value and are the object of the activity of an organization using them.

As a result of the analysis of the experience of designing, building and using cast-in-place and precast/cast-in-place civil buildings, the author worked out the structure of OQ’s which is made up by two major groups: technical-economic and engineering-functional OQ’s. The first group (the investment stage) includes cost indicators as well as time expenditures, labor intensity, materials intensity, etc., which belong to resources needed for actualizing OQ’s at the stages of the lifecycle. Qualities in the second group (the operational stage) are regulated by norms and defined by the project and characteristics of the production-technological process, although their real parameters become known to the consumer only during use. The name and content of the second group of OQ’s meets the quality criteria of designing civil buildings, which are proposed in a monograph by British researcher M. Cook [12].

All the parameters placed in this group are divided into five primary integral OQ’s: reliability, safety, resource-effectiveness, functionality, comfort and sanitation. On the whole, all integral investment-
functional qualities contain 19 specific OQ’s, each of which possesses several parameters. Note that at least 70% of integral OQ’s can be improved only through the concerted efforts of lifecycle participants.

The second stage of implementing the IA defines central engineering-functional OQ’s (hereinafter just OQ’s) and their key parameters. The author suggests that we consider as central those OQ’s that have the largest amount of relations with others. We shall consider as the criterion of association between OQ’s the improvement of all interconnected OQ’s in the group when there is an improvement of at least one OQ from this group. To define central qualities, we employed the graph theory method, which helps construct and analyze the OQ system model containing binary relations. As a result, we recognized as central OQ’s qualities having, in the aggregate, relations with all OQ’s. These included structural durability and stability, structural longevity, economy in operational expenses and some others. In a similar manner, i.e. using the relation-formation criterion, the author analyzed central OQ parameters. The author recognized as key parameters those that had, in the aggregate, relations with all the rest of parameters in the volume of central qualities. There were seven such central OQ parameters: the deformation and design positioning of structures, the positioning of rebars and concrete inserts, the protective layer of concrete, the intermaintenance period and likelihood of the failsafe operation of structures and the technical level of engineering systems. For improving the last three parameters, we need the interaction of no less than three organizations: design, contracting and a construction industry enterprise. You will find a detailed description of the sequence and content of the structural analysis of OQ’s for cast-in-place civil buildings in an article mentioned in the list of literature [13]. Thus, at this stage of implementing the IA we ranked OQ’s and defined those of their parameters which need to be streamlined in the first place.

The third IA stage seeks to define the potential for the integrated improvement of, most importantly key, OQ parameters through the assessment of interactions between interested parties. In accordance with the concept of a building’s lifecycle, the author singled out the following participants in the implementation of the cycle: the designer – \( D \); the builder – \( B \); the manufacturer – \( M \); the operator – \( O \); the consumer – \( C \). The author deliberately left out such important participants in the investment stage as the investor and the customer, for their activity deals, most importantly, with streamlining technical-economic OQ’s, which is beyond the scope of this work. Thus, we are looking at the spectrum of interactions between three major phases of a cycle: design, production (construction) and use. Each interaction between the selected participants aimed at improving a particular OQ parameter can be evaluated as a binary relation and represented in matrix form. In this interaction, let us mark the party which initiates change and the party which implements it. Let us denote the initiating party with the index \( p \) and the implementing party with the index \( e \) (from the English words ‘pioneer’ and ‘executor’). Interaction (binary relation) between the parties will be evaluated as 0 or 1. If an interaction between the initiator and the implementor that can makes it possible to increase (improve) this parameter is possible, we enter 1 in a cell of the matrix, which is formed at the intersection of a row (the initiator) and a column (the implementor) and otherwise we enter 0. For example, Table 1 presents a matrix of interactions for implementing the integrated improvement of a key OQ parameter – the protective layer of concrete.

The matrix representation of the spectrum of interactions makes it possible to identify both evident (e.g. \( D \rightarrow B \)) and not evident (\( O \rightarrow B \)) relations that can be implemented only under certain circumstances. The total potential of interactions for the integrated improving of a parameter can be determined by summing all the cells of the matrix. The capability of a process participant to streamline an OQ parameter as the initiator is assessed by summing the values in a corresponding row and as the implementor by summing the values in a column.

By constructing interaction matrices based on the OQ parameters, we identify our priorities based on the potential for the integrated improving of these parameters through the interaction of the participants in a building’s lifecycle. Besides, matrices make it possible to establish the potential roles of each of them.

For each key OQ parameter we constructed interaction matrices and determined the total potential of participant interactions. We also assessed the potential for a specific parameter to be improved by a cycle participant acting as the initiator or an implementor. The values obtained were ranked and tabulated (Table 2).

The table shows that the highest potential for improvement is with the following OQ parameters: the likelihood of the failsafe operation of structures and the deformation and intermaintenance period of structures, as well as the technical level of engineering systems, since they help maximally attract all interested participants, both in the role of the initiator and that of the implementor. We should also note that with precast/cast-in-place structures the potential for improvement is higher in such OQ parameters as the positioning of rebars and concrete.
Table 1: Matrix of interaction for improving the protective layer of concrete OQ parameter

<table>
<thead>
<tr>
<th>Initiator</th>
<th>( D_i )</th>
<th>( B_i )</th>
<th>( M_i )</th>
<th>( O_i )</th>
<th>( C_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D_i )</td>
<td>-</td>
<td>1</td>
<td>1*</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( B_i )</td>
<td>1</td>
<td>-</td>
<td>1*</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( M_i )</td>
<td>1*</td>
<td>1*</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( O_i )</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>( C_i )</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: * denotes relations for precast reinforced concrete structures

Table 2: Assessment of the potential for the integrated improvement of key OQ parameters

<table>
<thead>
<tr>
<th>Key OQ parameter</th>
<th>Total potential for improvement</th>
<th>( D_i / D_s )</th>
<th>( B_i / B_s )</th>
<th>( M_i / M_s )</th>
<th>( O_i / O_s )</th>
<th>( C_i / C_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformation of structures</td>
<td>20*</td>
<td>4* / 4*</td>
<td>4* / 4*</td>
<td>4* / 4*</td>
<td>4* / 4*</td>
<td>4* / 4*</td>
</tr>
<tr>
<td>Positioning of rebars and concrete inserts</td>
<td>6</td>
<td>1/3</td>
<td>1/3</td>
<td>0/0</td>
<td>2/0</td>
<td>2/0</td>
</tr>
<tr>
<td>Design positioning of structures</td>
<td>12*</td>
<td>2* / 4*</td>
<td>2* / 4*</td>
<td>2* / 4*</td>
<td>3/0</td>
<td>3/0</td>
</tr>
<tr>
<td>Protective layer of concrete</td>
<td>6</td>
<td>1/0</td>
<td>2/3</td>
<td>0/0</td>
<td>2/1</td>
<td>1/2</td>
</tr>
</tbody>
</table>
|                                 | 10* | 2* / 4* | 2* / 4* | 2* / 4* | 2* / 0 | 2* /

Note: * denotes relations for precast reinforced concrete structures

Fig. 2: Stages and processes of implementing the integrated approach for improving the operational qualities (OQ) of cast-in-place and precast/cast-in-place civil buildings

Integrated approach (IA) to improving operational qualities (OQ) of cast-in-place and precast/cast-in-place civil buildings

Stage I: Defining structure of OQ’s that satisfies requirements for implementing IA

Stage II: Pinpointing central OQ’s and defining key parameters of central OQ’s

Stage III: Streamlining key OQ parameters through spectrum of interactions between participants (Pc) in lifecycle

Key parameter of central OQ’s improvement process

Pc2, Pc1, Pc5, Pc3, Pc4

We demonstrate the potential for implementing the IA for improving OQ’s in erecting civil cast-in-place and precast/cast-in-place buildings through the example of the apparatus of layered non-bearing exterior walls.

The practice of designing and erecting civil cast-in-place and precast/cast-in-place buildings has seen a wide use of three-layer masonry non-bearing exterior walls.

inserts, the design positioning of structures and the protective layer of concrete, since there is potential for additional improvement of quality on the part of the manufacturer of precast structures. Thus, the potential for the integrated improving of OQ’s is higher with precast/cast-in-place construction than with cast-in-place construction.

Let us demonstrate the potential for implementing the IA for improving OQ’s in erecting civil cast-in-place and precast/cast-in-place buildings through the example of the apparatus of layered non-bearing exterior walls.

The practice of designing and erecting civil cast-in-place and precast/cast-in-place buildings has seen a wide use of three-layer masonry non-bearing exterior walls.
In the Urals and Siberia, where winters are long-lasting and cold, it is common to employ exterior walls with the inner layer made of gas concrete blocks, the intermediate layer of a façade mineral wool heat insulator and the outer layer of facing, more frequently silica, hollow brick. For ensuring concerted work, the inner and outer layers are connected to each other with flexible connectors. Wide use has been made of flexible connectors of fiberglass dowels with a polyamide anchor which is inserted into brickwork. Flexible connectors are an important element of masonry, which in large part defines such key OQ parameters as the likelihood of the failsafe operation of the wall structure, its deformability (for the outer brick course), as well as the intermaintenance period of the whole wall. Consequently, a fundamental element in improving OQ’s is the $D_p \rightarrow B_s$ interaction. In practice, such an interaction does not occur frequently, since designers do not specify in drawings how polyamide anchors should be positioned in brickwork – whether they should be installed in the mortar joint (during bricklaying or after) or the body of the brick. Experiments we conducted [14] helped ensure quality design for three-layer walls. Our proposed template for drilling holes [15] under a new technological regimen for three-layer masonry will make it possible to establish relations with high accuracy, ensuring the attainment of improved OQ’s expected in the design.

Table 2 presents a full graph of implementing the IA for improving the OQ’s of cast-in-place and precast/cast-in-place civil buildings.

**CONCLUSION**

The IA can be viewed as a process of managing the lifecycle of a building structure, wherein we pinpoint priority objectives, which reveal a diversified potential for improving efficiency, which is actualized by virtue of the methodological and resource capabilities of participants in the cycle. The use of the proposed variant of implementing the IA is the most acceptable for large construction organizations that have design and construction units as well as their own enterprises in the construction industry.

Employing the IA for improving the OQ’s of cast-in-place and precast/cast-in-place civil buildings makes it possible to:

- Boost the rationality of using resources in the process of resolving the objective of streamlining OQ’s consequent on the identification of solution priorities;
- Define the strands and nature of interaction between participants in the lifecycle for conducting work on streamlining the entire complex of OQ’s, which ensure the improvement of the overall quality of construction;
- More clearly set out and augment the areas of responsibility of lifecycle participants for specific OQ’s of a building.

**REFERENCES**


