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COST REDUCTION IN CONSTRUCTION INDUSTRY BASED ON BIM TECHNOLOGIES

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Abstract

The article discusses methodological approaches to information modeling technology application to reduce costs in the investment construction projects (ICP) implementation. The relevance of the chosen topic is due to the need in digitalization construction processes to optimize them and, as a result, to minimize costs. The literature review has shown the effectiveness of using BIM technology for these purposes since this technology allows to reduce the design time, form a single base for storing and prompt of relevant information exchange, and reduce the ISP cost. The article analyzes economic and mathematical models that optimize resources in the ISP implementation, taking into account the existing restrictions. The author's optimization model has been developed to reduce the implementing ICP costs based on the BIM implementation, which takes into account the costs at the stages of design, construction and installation works and completed facility operation, and allows minimizing additional costs arising at these stages of the ICP life cycle as a result of errors and object model. An economic efficiency assessment and practical applicability of the proposed economic and mathematical model is presented on the example of a real ISP. When solving the problem using the proposed model, the minimum possible value of additional costs was obtained at all project stages.

Keywords: BIM, construction costs, mathematical modeling

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1. Introduction

The main trends in economic development in the past two decades are associated with widespread digital technologies. Almost all sectors of the economy came under their influence, which significantly changed management methods and made possible direct interaction between business and consumers, minimizing intermediaries' participation in exchange processes. As economic practice shows, digital technologies are most widespread in the service sector (finance, banks, insurance, transport, trade, health care, education, public services), where online platforms are becoming the main driver of development. In the construction segment, information modeling of buildings and structures is one of the most promising and revolutionary technologies that optimize buildings and structures' design, construction, and operation. The widespread use of BIM (Building Information Modeling) technologies, which are aimed at increasing productivity and improving the final results of the construction process, is also due to some advantages, among which it is necessary to highlight the following: classic drawings are replaced by detailed, intelligent and fully interactive 3D models; all the necessary information about the project is accumulated in one place, eliminating the need for a systematic multi-stage release of drawings and specifications; buildings are increasingly being supplied with a "digital twin", a structured database and geometric information that monitors critical parameters such as cost, waste or energy use; the possibility of using the technology itself for a long time after the completion of construction, in particular to build management and maintenance; allows you to coordinate the activities of clients and contractors more effectively. Thus, this technology makes it possible to solve complex problems of management of investment and construction projects (hereinafter - ISP), as well as to ensure the prompt exchange of comprehensive and reliable information about the construction object between the participants of the ISP at all stages of the project life cycle. BIM technology allows you to improve and optimize each stage of the life cycle of an ICP through the development and application of regulations, process optimization and integrated modeling technology.

BIM completely changes the approach to project management and implementation. The BIM technologies peculiarity is to work with an information model that contains all the data on the project and quickly extracts them and makes calculations on them. All COI participants involved in a specific stage of the project life cycle initially see the intended end result and can make adjustments promptly, saving time and money. The main purpose of using BIM tools is to reduce technical and financial risks within the COI at all stages of its life cycle.

Simultaneously, optimizing the ICP costs in the BIM implementation is an urgent task, which hasn’t received proper coverage in the scientific works of researchers devoted to the information modeling technologies introduction in the Russian construction industry.

2. Problem Statement

The literature analysis shows that applying the mathematical modeling method is quite common for the construction sector. This is due to some specific construction characteristics as an economic activity. For example, mathematical models in the form of integer linear programming are used to optimize construction work in the context of the several contractors’ participation (Ngowtanasuwan,

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2018). A class of fuzzy mathematical models is used to determine the duration of construction schedules and assess contingencies created as a result of irregular supply or shortages of building materials, as well as for multi-purpose optimization of project schedules under time and cost constraints (Castro-Lacouture et al., 2009; Gonzalez, 2007). Mathematical models are widely used in construction to predict the cost of complex objects, especially when data and information are insufficient at the stage of feasibility studies of construction projects (Al-Zwainy & Hadhal, 2016). To assess a number of economic characteristics, for example, such as inflationary expectations, fluctuations in supply and demand, assessing the availability of credit resources for consumers and suppliers, various mathematical models have been developed based on time series, trend assessment and regression analysis using both linear and nonlinear multiple regression equations, as well as using the sigmoidal function of an artificial neural network (Bulykina, 2020). Fuzzy-set mathematical modeling techniques are also used to manage large-scale construction projects (Zvyagin, 2019). This method is also widely used to calculate the optimal parameters of building structures, the transfer of passive impurities in water, etc. (Koshev & Kuzina, 2019). As for the Russian segment of research, it is necessary to highlight the work related to the optimization of planning costs for implementing investment and construction projects (Zhuravlev & Solomakhin, 2007). The work (Lushnikov, 2018) considers in detail the economic and mathematical model of reducing the cost of implementing ICP based on a multi-criteria approach, which is based on the criteria for ensuring quality, cost and reducing construction time, based on the advantages of implementing information modeling: increasing accuracy and eliminating project errors, reducing the risks of poor-quality design, the ability to quickly make changes to the project and control costs at all stages of the implementation of the ISP. The advantage of this model is that it considers many factors for optimizing ISP costs.

2.1. BIM applications in the construction industry

A relatively new direction is buildings information modeling, which aims to clarify the impact of the changes in engineering, transport networks, building communications systems, and geodynamic risks at all stages of the buildings life cycle (Minaev et al., 2019). In (Sharmanov et al., 2017), BIM technologies are considered a modern effective digital tool for managing construction costs. The features of using 4D BIM or visual modeling to track the sequence of events within the project and control its estimated cost during its implementation are described in detail in (Mamaev, 2017). The advantages and disadvantages of using BIM modeling in Russia's modern construction industry are considered in work (Rakhmatullina, 2017). The role of BIM as an innovative digital technology for the design, construction and operation of capital construction facilities based on integrated software is discussed in detail in the study (Talapov, 2017). Some researchers believe that BIM technologies can significantly simplify management decision-making in the management of projects in the construction sector due to the ability to visually visualize systems and all elements of a projected building in 3D, bring them into exact compliance with the requirements of current standards, calculate different layout options and analyze operational characteristics of the future capital construction object. With the help of a visual model of the construction sequence, designers, contractors and investors can use real-time navigation to analyze the construction process and make the necessary management decisions. The modeling of the process of implementing the ISP is carried out both for the entire project at once and partially, in the visual model formation at a specific point in time (Dronov et al., 2017). The effectiveness issues and implementing information modeling technology benefits are discussed in detail in (Astafieva et al., 2017).

Other studies paid attention to information modeling not only as an effective tool for the design of an object and the performance of construction and installation works, optimizing and increasing the efficiency of the architect, designer and engineers, but also monitoring the implementation of an investment and construction project (Bernstein et al., 2010). The practice of implementing the Open BIM concept is described on the example of individual countries of the European Union (Talapov, 2017).

The automated control systems use by Russian construction organizations today is at a fairly low level, and the cost of their implementation is available to large holdings. For construction organizations in the field of small and medium-sized businesses, the introduction of these technologies is often economically impractical (Ablyazov & Asaul, 2018).

At the same time, most authors of the scientific works under consideration lose sight of the effectiveness of the use of BIM technologies during the operation of completed construction sites.

2.2. The effectiveness of the BIM technologies

A number of analytical reviews of consulting agencies and individual authors are devoted to the study of the practical results of reducing the costs of implementing ISP when implementing BIM. For example, in the work (Bernstein et al., 2010) it is said that in 85% of cases the incentive to use BIM is the owner's requirement, and in 76% it is the desire to save time and financial resources. At the same time, 41% of representatives of the surveyed organizations believe that after the introduction of BIM, their profits increased; 55% are confident that BIM can reduce the cost of the project (39% of them mention a decrease by more than a quarter); 41% believe that BIM does not lead to a change in the number of employees; 21% - that after the implementation of BIM, less staff is required, and 13% - which is more.

According to a study of the BIM-technologies effectiveness by foreign and Russian organizations, conducted by MGSU in conjunction with the consulting agency KONKURATOR LLC, the use of BIM-technology contributes to increasing the economic efficiency of ICP due to a number of indicators. Including noted: growth of indicators of net discounted income (up to 10-25%); growth of the project profitability index (up to 14-15%); internal rate of return for BIM projects growth (up to 14-20%); reduction of the payback period of an investment and construction project (up to 15-17%) in comparison with projects that are implemented using traditional management and design technologies; reduction in the cost of the project associated with a reduction in costs at the construction stage (up to 30%) (Rakhmatullina, 2017). Based on the experience of already implemented domestic and foreign projects in the construction sector, BIM technologies allow to reduce design time by 30%, create a single base for storing and prompt exchange of relevant information, as well as save up to 20% of the cost of an investment and construction project by reducing errors and subsequent their elimination. At the same time, the growth of organizations' experience in the application of BIM technology is accompanied by an increase in the economic effect.

Basis for the optimizing the costs task of investment and construction project can be based on the following target setting - minimizing the construction objects cost by determining such time and resource

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parameters (or their combination) of the project management process in time and space, which form the project schedule meeting the established requirements.

3. Research Questions

The main research question is how to develop a new model for costs optimizing of investment and construction projects based on the BIM implementation, taking into account the implementation benefits at the main stages of the investment and construction project life cycle, taking into account the stages of building design, construction and installation works execution and completed construction site operation.

4. Purpose of the Study

The study aims to develop a model that can be used to justify the BIM technologies implementation in construction organizations work, in the design, construction, and operation of capital construction facilities to increase the implementation efficiency of investment and construction projects based on the digital technologies usage.

5. Research Methods

When constructing an economic and mathematical model at the separate investment and construction project level, the optimization criterion is based on a reduction in costs or an increase in profits. In the scientific literature, various models and management methods are used, taking into account cost optimization problems in the production process, in particular:

- optimization models necessary to determine the indicators of the optimal production plan, to update the technical base of the enterprise under the established restrictions. With their help, it is possible to assess the sufficiency of resources, but the models do not take into account the time interval and the influence of environmental factors, and, therefore, their use at the level of operational planning and monitoring in construction becomes more complicated;
- models of volumetric scheduling, with the help of which it is possible to take into account the timing of design work related to the performance of one type of work, and to build an objective function with a number of restrictions on resource costs (rent of additional trains, equipment, attracting loans and investment funds, personnel for overtime works, cooperation with other enterprises, etc.). At the same time, the main purpose of these models is a continuous, constantly repeating rhythmic production process that does not have a complete result;
- scheduling models that allow limited resources to be pre-allocated based on timelines for each phase of the construction process. Their feature is flexibility and adaptability to project management, which provides for the implementation of a completed set of interrelated works aimed at achieving a set result, control over the correct progress and sequence of these works, and assessment of the completion date (Castro-Lacouture et al., 2009; Gonzalez, 2007).

A construction project is a complex socio-economic system, for the normal functioning of which coordination of participants is necessary, which is difficult to implement without calendar and network schedules. Lack of coordination entails personnel irregular work and cost increase of construction

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projects, violation of the terms of delivery of the object. Scientists Zhuravlev, Solomakhin cost optimization means the definition of such parameters of time and resources (or their combination) of the process of managing an investment and construction project in time and space, which form a project schedule that corresponds to the real construction conditions, the investor's requirements and the contractor's capabilities (Al-Zwainy & Hadhal, 2016). The authors name the following main ways (methods) to reduce the construction time:

- edistribution of labor resources;
- control of the sequence of work on the sections in non-rhythmic flows;
- combination of technological processes in time;
- attraction of additional resources to carry out the most long-term works (increase in intensity);
- change of design solutions;
- a decrease in the intensity of some processes (Al-Zwainy & Hadhal, 2016).

The optimization methods listed above allow it to be carried out either by time or by resources. Joint optimization isn’t carried out due to lack of methods.

Proceeding from this, the basis task of costs optimizing in investment and construction project can be based on the following target setting - cost minimizing of construction objects by determining such time and resource parameters (or their combination) of the project management process in time and space, which form the project schedule that meets the established requirements. At the same time, the authors overlook the expediency of using BIM in the implementation of ISP as a tool for optimizing costs at all stages of the project life cycle.

Zhuravlev, Solomakhin offer the software use to create, calculate and visualize network diagrams. The technique is based on editing the parameters of tasks (jobs). Solving the problem will provide significant financial and material reserves for a large construction corporation (Al-Zwainy & Hadhal, 2016). However, the considered development does not allow to control costs during the construction process and change the schedule of design work during the project implementation period, which is its main drawback.

Vorobovich considers a number of optimization mathematical models of scheduling and construction problems for facility complexes aimed at minimizing the timing of completion of construction work, maximizing profits, the priority of facilities being built, minimizing resource costs, taking into account various constraints corresponding to the conditions of the problems. At the same time, the considered developments do not pay enough attention to the rational use of resources and the risks of exceeding the budget of an investment and construction project, taking into account the introduction of BIM technologies (Castro-Lacouture et al., 2009; Gonzalez, 2007).

Lushnikov proposes to consider indicators of quality, timing and cost of construction when implementing projects using information modeling technologies as a target optimization criterion (Lushnikov, 2018). The model developed by the author does not allow to optimize costs at the stage of operation of a capital construction facility, which is important at the current stage of implementation of information modeling technologies and the presence of a significant number of implemented ISPs using BIM.

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6. Findings

As the target criterion, it is proposed to choose the profitability index of an investment and construction project, which includes the costs of design, construction, and operation of the facility.

$$RI = \frac{NPV}{I_n + I_c + I_o} \rightarrow \max \quad (1)$$

With the same NPV, other things being equal, the financial costs of design when implementing BIM are significantly reduced, the likelihood of errors and, accordingly, the time and resources for their elimination are also reduced. Let us express through formula (2) the sum of the costs of designing a capital construction facility as a deviation between the planned costs and the actual ones, which include the amount of unforeseen costs arising from probable errors.

The system of restrictions is as follows:

$$\begin{cases} I_n^{pr} \le I_n^{act} \\ I_n^{act} = I_n^{pr} + I_n^{add} \end{cases} \quad (2)$$

$$I_n^{pr} \le I_n^{act} \quad (3)$$

where I_n^{add} - costs arising from the need to make changes to an existing project after it has been agreed and approved at the design stage of the facility.

We construct the objective function in the form of minimizing the deviation of the actual cost of designing a capital construction object from the planned one:

$$I_n^{add} = I_n^{act} - I_n^{pr} \rightarrow \min \quad (4)$$

The construction work cost with using BIM is also reduced by increasing the planning accuracy, therefore, the likelihood of unplanned costs in the deviations course of the real project parameters from the projected ones should be minimal:

$$I_c^{add} = I_c^{act} - I_c^{pr} \rightarrow \min \quad (5)$$

The system of constraints for the objective function (5) is as follows:

$$\begin{cases} I_c^{act} = I_c^{pr} + I_c^{add} \\ I_c^{pr} \le I_c^{act} \end{cases} \quad (6)$$

where I_c^{add} - additional costs associated with the use of raw materials and materials, remuneration of workers, as well as the elimination of violations during construction, as a result of incorrect formation of the initial project, ineffective monitoring and construction control or non-compliance with building codes and standards. Note that BIM technologies allow you to quickly track such facts and violations, and promptly respond to them.

Similarly, we express the objective function of minimizing the costs of operating the facility, taking into account the BIM technology:

$$I_o = I_o^{act} - I_o^{act} \rightarrow \min \quad (7)$$

The system of constraints for the objective function (7) is presented as follows:

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$$\begin{cases} I_o^{act} = I_o^{pr} + I_o^{add} \\ I_o^{pr} \le I_o^{act} \end{cases} \quad (8)$$

where I_o^{add}- additional costs arising at the stage of operation of the facility associated with the cost of materials and personnel for the repair and routine maintenance of buildings and structures, as well as possible costs of utilities that exceed similar costs when using BIM.

The restrictions on the investment and construction project are also the strict time frames for the implementation of design and construction works. Work on the operation of the facility will not be included in the system of restrictions, since the operation process is accompanied by its own schedule related to another stage of the project life cycle.

Each stage of the schedule for the implementation of an investment and construction project is characterized by certain costs. Let us denote by c_i the unit costs per unit of time for each stage of the project implementation, i – ordinal number of the project implementation stage, T - total project implementation period until commissioning, $t_i = \overline{1,T}$.

When implementing an investment and construction project, total costs are taken into account, taking into account BIM technology, which allows you to more efficiently plan and control costs.

Thus, the time limits will look like this:

$$\sum_{i=1}^{N} c_i \cdot t_i \ge (I_n + I_c), t_i = \overline{1,T} \quad (9)$$

The problem formulation of minimizing costs in investment and construction project implementation is a tool for strategic planning. Moreover, this model can be used in construction monitoring and control. To optimize the implementing investment and construction projects costs, it is advisable to use modern modeling capabilities, in particular, optimization models.

6.1. Approbation of the obtained results

As a conclusion about the practical applicability of the developed optimization model, its approbation on the example of a real investment and construction project is presented below. Information on costs is presented in accordance with design estimates and management reporting. According to the study, the structure of the cost of the project under consideration in the construction sector at various stages of the life cycle and The estimated cost of construction and operation of the facility is presented below in Table 1.

The cost amount includes the costs calculated at the design stage of the facility and the actual ones, adjusted during construction and installation work based on acts of work performed.

The cost structure of the design phase is shown in the table. During the project's implementation, additional costs arose, as a result of which there is an excess of actual costs from the design ones. The amount of excess of the estimated cost amounted to 477 632 rubles. With the help of the "Search for a solution" tool in the MS Excel environment, an objective function was built that minimizes additional costs for a given profitability index at the design stage (0.759).

Table 1. Cost structure in the building object design and Total cost of building object construction and operation

Cost structure			
№	**Name of works**	**Total for the project (Ippr), rubles**	**Actual total (Ipact), rubles**
1	Site preparation	5 363 420	5 379 510
2	Installation of the necessary equipment to start construction	26 817 100	26 870 734
3	Pit formation	6 323 420	6 342 390
4	Transport works	2 601 000	2 608 803
5	Pouring the foundation	4 036 098	4 048 206
6	Procurement work	18 408 000	18 444 816
7	Construction and installation works	45 225 620	45 293 458
8	Erection of vertical structures	26 817 080	26 870 714
9	Installation of floors	2 045 366	2 051 502
10	Installation of outdoor curtain panels	17 453 660	17 488 567
11	Outdoor decoration	21 771 950	21 815 494
12	Interior decoration	23 543 910	23 579 226
13	Installation and adjustment of equipment	36 217 100	36 271 426
14	Special work	5 363 420	5 374 147
	TOTAL	**241 987 144**	**242 713 105**
Total cost			

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№	**Cost item**	**Amount, rub.**	
1	Raw materials and basic materials:	I_c^{pr}	I_c^{act}
	a) raw materials and basic materials	38 600 049	38 715 849
	b) water and technological purposes	286 080	286 652
2	Fuel for technological purposes	77 760	77 993
3	Energy for technological purposes	451 221	452 575
4	Utilities:		
	a) space heating	20 158	20 158
	b) lighting of premises	315 875	315 875
5	fuels and lubricants	660 650	661 971
Total material costs		40 411 793	40 533 028
6	Operation and maintenance of construction equipment	4 858 464	4 868 181
Total Subcontracting Costs	4 858 464	4 868 181	
7	Salary	40 942 132	41 003 545
8	Social contributions	12 282 640	12 301 064
Total labor costs		53 224 772	53 384 446
9	Rent	21 984	21 984
10	Insurance premiums	109 920	109 920
11	Operating costs, incl. labor costs	6 007 641	6 025 664

12	Land acquisition	87 363 342	87 363 342
Total costs for add. expenses		93 502 887	93 689 893
Total full cost of the construction and installation phase		191 997 915	192 475 548
Cost at the design and construction stages		433 985 060	435 188 653
	Net cash flow (NPV)	329 340 000	329 340 000
	Investment and construction project profitability index	0.759	0.757

When solving the problem using modeling, the minimum value of additional costs at all stages of the project implementation (providing the necessary profitability) was obtained, which amounted to 321,500 rubles. (or 0.05% of the approved estimated cost) compared to the actual (1,203,594 rubles, or 0.2% of the approved estimated cost). As a result of the implementation of BIM, the reduction of additional costs at all stages of the implementation of the ISP will be 73.3%. Thus, the use of information modeling technologies makes it possible to reduce the costs of implementing ISP at all stages of its life cycle, which confirms the feasibility of using this technology.

7. Conclusion

Based on a critical analysis of existing optimization methods and models of project management in construction, a model has been developed to optimize the costs of investment and construction projects based on the implementation of BIM. As the target criterion, the index of profitability of the investment and construction project was chosen, which includes the facility's costs of design, construction, and operation. The restrictions system was built due to the information modeling technology usage, the number of additional costs arising from various errors at the design, construction, and operation stages should be minimal. The introduction of BIM technology advantage at all major stages of the ICP life cycle is cost optimization in building design, the construction and installation work performance, and completed construction operation. The calculation showed that additional costs arising at all ISP implementation stages will decrease by 73.3% as a result of the BIM technology introduction.

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