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BIM TECHNOLOGIES AS A TOOL IN EFFECTIVE IMPLEMENTATION OF THE CONSTRUCTION PROGRAMS IN THE ARCTIC ZONE

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Abstract

BIM is the rapidly growing technology of information support in design, development, construction and operation of various facilities. In terms of its capabilities to take into account various risk characteristics and the influence of components under study, this information model makes it possible at a higher qualitative level to justify economic and technological decisions during construction in the Arctic zone and to maintain a particular facility entire life cycle. This model is best suited to be introduced in this complex high-risk construction area. BIM technology makes it possible to operate with the most detailed information, when making investment decisions difficult under conditions of building in the Arctic zone. Systemic integration of the BIM technology capabilities with models of the geoinformation systems' geodynamic risks and technologies ensures design, construction and maintenance of modern buildings and facilities at the fundamentally new level of quality and safety assurance, as well as to monitor stability and safety thereof in relation to the Arctic conditions. Mathematical model of the deformation energy migration is presented to evaluate geodynamic stability in the construction areas. It is advisable to take into account geodynamic factors in information simulation using the mathematical model that describes construction area in the form of a system of nodes and of the geological medium tectonic fault abnormalities connecting them and represented in the aggregate in the form of the Kolmogorov system of differential equations

Keywords

Arctic zone, BIM technology, simulation, geodynamic risks, construction, territory stability

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Introduction. When managing safety in construction, issues related to threats of engineering, technical, social, economic, medical and biological nature that emanate from the environment geological component, commonly called the geodynamic risks, are becoming more and more urgent. Such risks are especially relevant in relation to the Arctic zone, which development is facing great attention given its importance for Russia in the social, economic, military and political aspects.

Construction practice in recent years reflects the trend of more and more frequent allocation of land territories with contrasting terrain reliefs and higher risks of geodynamic alteration in the lithosphere upper layer.

Damage caused to population, buildings, facilities and communication networks in such territories in the Arctic zone is significantly increasing due to hazardous geophysical processes, i.e., landslides, devolutions, subsidence, karsts, mudflows, floods, under flooding, earthquakes and tsunamis in the northeastern part of the Arctic due to instability in this part of the Earth.

Action of these processes is constantly or periodically exposed to physical fields of natural and technogenic origin affecting navigation, communication and telecommunication systems in the Russian North.

Anomalies in physical fields caused by natural processes and associated with tectonic faults in the Earth lithosphere could not always be easily identified using geological research. At the same time, bioactive range field distribution in relation to the Arctic territories, its quantitative evaluation, as well as fields of tectonic stresses and deformations arising from uncontrolled disturbance in the near-surface soil structure, which directly affects stability of buildings, facilities and communication networks, require a careful study.

It should be noted that the need for more accurate and detailed solution to the problem of geodynamic risk evaluation in relation to the Arctic zone is determined by enormous oil and gas deposits in these territories. In this regard, volume of oil and gas field facilities increased there, including oil pipelines, gas pipelines and gas liquefaction plants. In addition, such increasingly hazardous strategic facilities as nuclear power plants, including those mobile offshore platforms, are positioned in the Arctic.

The foregoing determines the need to substantiate and create a methodology that makes it possible to set and solve complex problems of evaluating the geodynamic risk complex problems in a rigorous mathematical language, as well as to design and develop new and improve existing strategies in risk management.

Work objective is to analyze the influence of these processes on landscape territorial complexes and facilities located on them, to highlight main problems in assessing their geodynamic risk, and also to determine the geodynamic hazard level.

Complex construction projects, BIM (Building Information Modeling) technologies. Complex construction projects (CCP) are an important application in creation of justified economic decisions when introducing the innovative technologies [1].

CALS technologies are a well-known example of generating such kind of solutions [2]. These technologies are aimed at raising labor productivity, quality of industrial enterprises production and significant reduction in the terms required to bring new products into production.

CCP model (see [2]) is modified in this work (Fig. 1), and CCP model layers involved in the CALS technology implementation are highlighted in color. Let us note that layers 1 and 7 are not participating in the simulation process, since investors do not participate in these layers' development under the CALS technology.

CCP
1. Product consumer
2. Product (traditional or innovation)
3. Building facility equipment
4. Technological platform
5. Buildings and facilities
6. Engineering and transport networks, buildings and facilities communication systems in the location territory
7. Location territory (geographical position, geodynamic situation, safety in building construction and operation, natural resources, climate, human resources, etc.)

Fig. 1. CCP model in the context of modernizing an industrial enterprise through introduction of the CALS technology [2]

Let us note that the missing entire cooperation of stakeholders in the project, especially in the difficult Arctic zone conditions, could lead to a failure in its implementation. Combining all the CCP model layers (in particular, layer 7) in implementing CALS technologies is possible when using the BIM modern building information modeling technology [3]. This technology, which appeared in the 1970s, is rapidly evolving and is reflected in modern standards. For example, the US National BIM Standard (NBIMS) defines it as follows: "Building information model (BIM) is physical and functional representation of a structure. BIM model is a general source of information that helps in making responsible decisions and accompanies the entire life cycle of a building from its concept to demolition" [2].

BIM technology belong to the CALS family; however, unlike its other representatives, it operates with infographic (visual) presentation of models*. Such presentation makes it possible to organically combine accurate object shape description and various interpretations of its functional content.

In contrast to CAD (Computer-Aided Design) widely used in construction design and development, BIM technologies are distinguished by two advantages:

1) providing new opportunities in making optimal construction decisions, which makes it possible to automatically create drawings and reports, analyze the project, simulate the work and facility operation schedules;

2) maintaining distributed use of its capabilities and allowing builders and operators to share technology resources (tools and information) throughout the entire life cycle of a building, as well as eliminating duplication, loss and re-entry of data, errors in their transfer and transformation.

It should be noted that 3D models for visualizing objects found wide application, but only in the recent years such characteristics as information support and professional openness inherent in BIM models and their databases were actualized [3]. Specified models and bases, as well as tools, were realized in a complex program containing the CDE (Common Data Environment) integrated information environment, which is constantly updated and improved within the design process. This makes it possible to design a construction asset as systemic whole, where any specific alteration automatically leads to a change in all its associated parameters, objects and documentary support up to the level of drawings, visualizations, specifications and schedule. Facing tight work schedule, complex interdependencies and interactions between the construction object and the territories under development in the Arctic zone, such systematic approach appears to be the most appropriate.

BIM technologies make it possible to work with a building model in any form (plans, sections, specifications) automatically introducing synchronized changes and correct updates. BIM technologies introduction increases the quality of project documentation and reduces design time; allows working with a unified database of objects with constant update of information about them; makes it possible to operate with a visual model; increases coordination of participants in design and construction processes; raises efficiency of the software used.

Consequently, building information simulation is a new approach to managing its life cycle, i.e., to design, construction, technical maintenance, operation

* Infographic model is an object information model (subject or process), which is specified in terms of geometry and graphics (images of abstract space, figures and bodies of real space) [4, 5].

and repair. Obviously, this approach presupposes comprehensive collection and systemic processing of relevant and, what is very important, of interrelated architectural, design, technological, technical, economic and other information on the building and on its location territory. Building approximate life cycle provided using the BIM technologies and combined with the territory life cycle [3, 6] is presented in Fig. 2. Creation of the CDE facility accurate digital model enables all participants in the investment and construction process in accordance with regulations to receive required information about the construction object at any time and to exchange it during design and modernization.

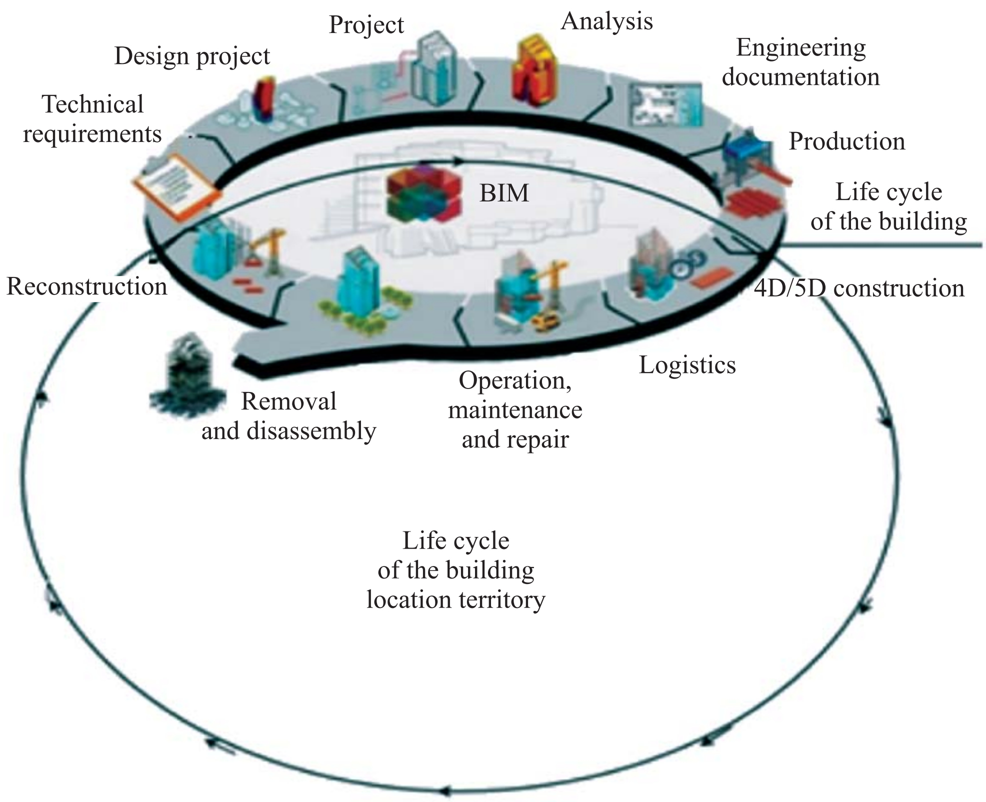

Fig. 2. Combining life cycles of the building and the territory of its location [3, 6]

Due to CDE, BIM technologies allow the investor to control the use and expenditure of funds at all stages of the construction project implementation. And integration with the territory life cycle makes it possible to take into account alterations introduced by changes in the territory characteristics in the building parameters and vice versa.

Geodynamic risk simulation. Any building location territory depends on its geographic position, climate, geodynamic features and other factors, and requires additional research to ensure its safe construction, operation and maintenance. BIM technologies make it possible to account and qualitatively analyze all diversity of the factor complex that determines risks and specifics of construction in the Arctic zone, including the geodynamic risks.

The number of hazardous serious anthropogenic disasters and dangerous natural phenomena in the recent years was steadily increasing. Risks of emergencies arising in the course of economic activity and global Earth alterations pose a significant threat to buildings and facilities. According to the *Antistikhiya Center* of the EMERCOM of Russia [7], the greatest risk of buildings and facilities collapse due to manifestation of the geodynamic cataclysms is forecasted in a number of territories that are fully or partially located in the Arctic zone. They include districts of the Arkhangelsk Region, Yamal-Nenets Autonomous District, Komi Republic, Sakha-Yakutia Republic, etc.

Safety and security threats are also associated with the life cycles of buildings, facilities and territories of their location, with deterioration in engineering and transport networks, communication systems. For obvious reasons, these cycles are much shorter in the Arctic zone compared to other territories.

Locations of buildings and facilities destruction in a particular territory could be determined with sufficient accuracy based on calculations using the geodynamic risk models. Main idea underlying such models is related to description, analysis and evaluation of seismic deformation processes in the territorial dynamic aspect [8–13].

Such models make it possible to evaluate territories before development thereof at the stage of designing the master plans, which is of significant practical value. Such models (let us call them the complex ones) take into account topography, heterogeneous density of territories and distributed static load from buildings and facilities on them. At the same time, taking into account the influence of tectonic faults is also very important in evaluating geodynamic stability of the construction area. It is along these faults that deformation energy is transferred both after any geodynamic event occurred, and during its preparation. At the same time, considering the points of faults intersection, the so-called tectonic nodes, is of particular importance.

If initial model information is unavailable on distribution and predicted values of shift geodynamic stresses and rates of vertical displacements in the development territory, then years later, when the houses are already inhabited, and industrial and office buildings are functioning, catastrophic situations could arise leading not only to material losses, but also to human casualties, sometimes significant.

When designing buildings and facilities, it is necessary to determine deformation energy stored in a particular volume of the geological medium, as well as released during a geodynamic event and transmitted through the system of tectonic faults [9]. It should be noted that fault nodes play the role of specific "valves" that regulate transmission of the deformation energy in one or another direction.

According to this concept, any territory is displayed as a number of nodes connected to each other by tectonic faults in the geological medium. Further, the specified system of nodes and faults interconnection is described by the Kolmogorov system of differential equations reflecting the probabilistic "migration" trajectories of deformation energy causing geodynamic events in the form of holes, subsidence, landslides, etc. in the study area.

Let us consider an example of the Arctic zone territory in the form of four nodes connected to each other by tectonic faults in the geological medium. The number of nodes depends, firstly, on the territory tectonic heterogeneity; secondly, it is necessary to take into account its taxonometric gradation reflecting hierarchical level of identifying separate blocks in the geological medium structure; and thirdly, total length of the territory under study should be taken into account.

Geodynamic state sequence of a certain volume of the geological medium (tectonic node) is a flow of homogeneous events that satisfies conditions of independence, homogeneity and ordinariness, i.e., it is the simplest flow [8, 10–12]. Let $P_k(t)$ be the probability that the k requirements (different geodynamic processes) would be presented to the process of various geodynamic states realization in a certain geological medium volume (tectonic node) during a certain time interval of the t duration. It should be taken into account that this probability would not depend either on selection of the frame of reference or on prehistory of the geological medium volume; therefore, it is possible to unambiguously construct formulas to determine the indicated probabilities.

In this case, interaction of tectonic nodes according to model constructions [8, 10–12] could be described by Kolmogorov system of equations:

$$\begin{aligned}
&p_1'(t) = \beta_{31}p_3(t) + \beta_{21}p_2(t) + \beta_{41}p_4(t) - (\beta_{13} + \beta_{12} + \beta_{14})p_1(t);\\
&p_2'(t) = \beta_{12}p_1(t) + \beta_{32}p_3(t) + \beta_{42}p_4(t) - (\beta_{21} + \beta_{23} + \beta_{24})p_2(t);\\
&p_3'(t) = \beta_{13}p_1(t) + \beta_{23}p_2(t) + \beta_{43}p_4(t) - (\beta_{31} + \beta_{32} + \beta_{34})p_3(t);\\
&p_4'(t) = \beta_{14}p_1(t) + \beta_{24}p_2(t) + \beta_{34}p_3(t) - (\beta_{41} + \beta_{42} + \beta_{43})p_4(t);\\
&p_1(t) + p_2(t) + p_3(t) + p_4(t) = 1.
\end{aligned} \tag{1}$$

Let us introduce the following notation: $\gamma_1 = \beta_{13} + \beta_{12} + \beta_{14}$; $\gamma_2 = = \beta_{21} + \beta_{23} + \beta_{24}$; $\gamma_3 = \beta_{31} + \beta_{32} + \beta_{34}$; $\gamma_4 = \beta_{41} + \beta_{42} + \beta_{43}$. Discarding one of the system equations (1), let us write down the system of algebraic equations with zero derivatives:

$$\begin{aligned}
&-\gamma_1 p_1 + \beta_{21} p_2 + \beta_{31} p_3 + \beta_{41} p_4 = 0;\\
&\beta_{12} p_1 - \gamma_2 p_2 + \beta_{32} p_3 + \beta_{42} p_4 = 0;\\
&\beta_{13} p_1 + \beta_{23} p_2 - \gamma_3 p_3 + \beta_{43} p_4 = 0;\\
&p_1 + p_2 + p_3 + p_4 = 1.
\end{aligned} \qquad (2)$$

Solving system (2) with respect to probabilities, the following calculation formulas are obtained:

$$\begin{aligned}
&p_1 = \frac{\varepsilon_1 \delta_{22} - \delta_{12} \varepsilon_2}{\delta_{11} \delta_{22} - \delta_{12} \delta_{21}};\\
&p_2 = \frac{\varepsilon_2}{\delta_{22}} - \frac{\delta_{21}}{\delta_{22}} p_1;\\
&p_3 = \frac{\beta_{43}}{\gamma_3 + \beta_{43}} - \frac{\beta_{43} - \beta_{13}}{\gamma_3 + \beta_{43}} p_1 - \frac{\beta_{43} - \beta_{23}}{\gamma_3 + \beta_{43}} p_2;\\
&p_4 = 1 - p_1 - p_2 - p_3,
\end{aligned} \qquad (3)$$

where

$$\delta_{11} = \gamma_1 + \beta_{41} - \frac{(\beta_{41} - \beta_{31})(\beta_{43} - \beta_{13})}{\gamma_3 + \beta_{43}}; \quad \delta_{12} = \beta_{41} - \beta_{21} - \frac{(\beta_{41} - \beta_{31})(\beta_{43} - \beta_{23})}{\gamma_3 + \beta_{43}};$$

$$\delta_{21} = \beta_{42} - \beta_{12} - \frac{(\beta_{42} - \beta_{32})(\beta_{43} - \beta_{13})}{\gamma_3 + \beta_{43}}; \quad \delta_{22} = \gamma_2 + \beta_{42} - \frac{(\beta_{42} - \beta_{32})(\beta_{43} - \beta_{23})}{\gamma_3 + \beta_{43}};$$

$$\varepsilon_1 = \beta_{41} - \frac{(\beta_{41} - \beta_{31})\beta_{43}}{\gamma_3 + \beta_{43}}; \quad \varepsilon_2 = \beta_{42} - \frac{(\beta_{42} - \beta_{32})\beta_{43}}{\gamma_3 + \beta_{43}}.$$

Presented method of the geodynamic risk probabilistic evaluation makes it possible to construct a “migration” scheme of deformation energy in the construction area providing opportunity to forecast the course of hazardous geodynamic processes. Deformation energy “migration” schemes are required to adopt the well-founded long-term development plans and the evaluation of the developed territories in carrying out routine maintenance to improve their safety.

Consequently, information simulation in construction, taking into account geodynamic factors, requires sufficiently high information support. In turn, this leads to the need for systematic monitoring of the construction area and of each facility constructed or under construction [14].

Geoinformation systems and BIM technologies. Let us note that BIM technologies on layers 2–7 of the CCP model facilitate creation of a geoinformation system (GIS) that is able to operate with the most detailed information on these layers and to support investment decisions.

GIS of the CCP model design and development allows investors to obtain an accurate idea of the CCP model layers readiness in regard to material and financial investment. It should be noted that each investor is able to finance only in his own layer: however, the entire CCP model, as a result, is being filled with information on layers and would allow to have an accurate idea on the state of construction (reorganization) project to be invested.

When creating spatial information on each layer 2–7 of the CCP model, BIM technologies make it possible along with traditional methods of geodetic surveys to use high-performance measuring systems of ground and air mobile laser scanning. Laser scanning data in combination with other sources of information about the modernization object (drawings, patterns, photographs, videos, available databases, etc.) are the initial data for creating information layers of the CCP model layers, as well as geodynamic models of construction and modernization risks.

It should be mentioned that it is impossible to use all the CCP layers and to build adequate models of geodynamic risks, if additional investment is not attracted in creating specialized software for BIM technologies support [15].

Conclusion. Information model of a building or facility makes it possible at a new qualitative level to substantiate economic and technological solutions during their construction in the Arctic zone and to support the entire life cycle of a building or facility from its concept design and development to demolition. Building information modeling is a new approach involving integrated information collection and processing during its design. In this case, the building and everything related to it are considered as a unified object.

BIM technologies allow operating with the most detailed information when making investment decisions that are more complicated in the Arctic zone construction conditions and obtaining an accurate idea of the building or facility readiness at its various implementation stages to be invested with material and financial resources by the investors.

Systemic integration of the BIM technology capabilities and the geodynamic risk models using GIS makes it possible at a fundamentally new level to ensure quality and safety, design, construct, operate and maintain modern buildings and facilities, monitor their stability and safety in relation to the Arctic conditions.

It is advisable to consider geodynamic factors in the information simulation process using a mathematical model that describes construction area in the form of a system of nodes and geological environment tectonic faults connecting them. These nodes are represented in the form of the Kolmogorov differential equations system making it possible to construct a probabilistic trajectory of the deformation energy "migration", which causes geodynamic events in the form of holes, subsidence, landslides, etc.

Schemes of deformation energy "migration" in the Arctic zone constructed using simulation are of great importance in making decisions when developing plans for prospective development and evaluating already developed territories, and in planning the routine maintenance work to ensure safety in the construction areas.

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