Basic stages of creating a BIM model for transport infrastructure objects

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Abstract. This study discusses computer-aided design systems used by design organizations and created on the basis of modern computer systems and automation methods. Deficiencies of existing systems and complexes are identified, which necessitates further work on design automation. The next stage of automation and increase in labor productivity of design engineers is considered. The important problem is considered in detail when increasing the role of information and computing systems and processes in designing, namely, the need for automated verification of information models to search for errors and to bring them into accordance with rules and regulations.

1. Introduction

Analysis of the current state of the construction industry shows that one of the factors for accelerating scientific and technological progress is improving quality and reducing time for design, which means introducing new systems [1, 2, 3]. In the Russian Federation, a significant surge in interest in information modeling technologies is associated with raising the issue of applying BIM (Building Information Modeling - information modeling of buildings and structures) to the state level. On December 29, 2014, the head of the Ministry of Construction signed an order “On approving a plan for the phased implementation of information modeling technologies in the field of industrial and civil construction”. In modern realities, the widespread adoption of BIM technologies is a matter of time, and design in this case is not an exception.

An obstacle to improving the quality and preserving the terms of project development is the growing discrepancy between the increasing cohesion of construction projects, on the one hand, the prevailing methods and design systems on the other. This problem cannot be solved due to a simple increase in the number of design organizations and designers of various specialties [4, 5, 6]. Therefore, in modern conditions, improving the quality and reducing the design time can be achieved on the basis of computers and other technical means of architectural design in design organizations and workshops.

The introduction of automation technologies has now made it possible to save a designer from a routine, painstaking and tedious mental activity and improve his mental potential at the time of decision-making [7, 8, 9].

At the same time, the Government of the Russian Federation, represented by the Ministry of Construction, proposed an action plan (“road map”) for the adaptation of BIM-technologies in construction, which was, also with some delay, approved by the Deputy Prime Minister in April 2017. The experts consider the main significance of this document to be the addition of an investment justification stage in the list of construction stages: it has not been approved by law before.
The “roadmap” was developed in several stages, and at the same time created seven sets of rules for a specific period of the building’s life cycle. For the moment several of them were approved:

SP 404. “Information modeling in construction. Rules for the development of project plans implemented using information modeling technology”

SP 328. “Information modeling in construction. Rules for the description of the components of the information model”

SP 333. “Information modeling in construction. Rules for the formation of an information model of objects at various stages of the life cycle”

SP 331. “Information modeling in construction. Rules for the exchange between information models of objects and models used in software systems”

SP 301. “Information modeling in construction. Rules for the organization of work by production and technical departments”

Domestic integrated solutions for designing using information modeling technology have appeared. The pioneer was Renga Software, a common product of ASCON and “1C”, the developer of Renga Architecture (BIM-system for architectural and structural design), Renga Structure (for the structural part of buildings and structures: reinforced concrete and metal structures), Renga MEP (for design internal engineering systems of buildings).

In fact, BIM technologies are a further development and deepening in the functional areas of computer-aided design (CAD) systems, although most CAD systems are focused on traditional design, based on the simulation of two-dimensional drawing using graphic elements of lines, hatching, texts, etc. [1-3]. Drawings created in CAD are autonomous from each other as well as regular paper drawings, therefore, all changes in the project must be made manually on each drawing to which these changes relate.

BIM modeling applications are designed to simulate the construction process of real buildings. The difference from the process of creating 2D drawings is the virtual modeling of buildings using the similarity of real elements (walls, windows, ceilings, roofs and others). Thanks to this, architects are given the opportunity to analyze the entire model of the building as a whole. Storage of all data in a single database, any adjustments made are automatically reflected in all drawings created on the basis of the model. This BIM approach not only significantly improves productivity, but also serves as the basis for better control of the design process [10, 11, 12]. The transition from CAD to the use of BIM modeling gives great privileges at the design stage, which subsequently can be clearly seen at the stages of construction and operation of buildings [13, 14, 15].

2. Research methods

As an example of using information modeling of the modern level of development of automation systems when designing transport construction objects (using CAD as a generation of information technologies preceding the advent of complex BIM technologies), we will calculate the stress-strain state of the supporting structures of a garage complex located in Moscow. The calculation was performed using a design and computing complex that implements finite-element modeling of static and dynamic calculation schemes, stability testing, selection of disadvantageous force combinations, selection of reinforced concrete structures, and verification of the bearing capacity of steel structures [16, 17, 18]. The design was idealized in the appropriate form: the system is presented in the form of a set of bodies of a standard type (rods, plates, shells, etc.), called finite elements and attached to nodes (Figure 1). A node in the calculation scheme of the displacement method is represented in the form of an absolutely rigid body of infinitely small size. The position of the node in space during deformations of the system is determined by the coordinates of the center and the rotation angles of the three axes rigidly connected to the node. The node is presented as an object with six degrees of freedom - three linear displacements and three rotation angles [19, 20, 21].

All nodes and elements of the design scheme are numbered. The basic system of the displacement method is selected by superimposing all the connections in each node prohibiting any nodal displacements. The conditions for equality to zero of the forces in these bonds are the resolving
equilibrium equations, and the displacements of these bonds are the main unknowns of the displacement method.

In the general case, in spatial constructions in a node, all six movements can be present: linear movement along the X axis; linear movement along the y axis; linear movement along the Z axis; rotation angle around the X axis; rotation angle around the Y axis; rotation angle around the Z axis.

The true shape of the displacement field inside an element is represented by various simplified dependencies. In this case, the error in determining stresses and strains is of the order \((h/L)^k\), where \(h\) — is a maximum grid pitch; \(L\) — is a characteristic area size. The rate of convergence in building a solution is determined by an exponent \(k\), which has different meanings for displacements and various components of internal forces (stresses) [22, 23].

During the rendering and calculation of the building, linear and angular displacements are calculated from combinations of different loads presented according to the current regulatory and technical documents.

Figure 1. The calculated finite element diagram of the building.

After determining the displacements, according to the known relations of structural mechanics, the values of forces and stresses in the elements are determined. For bar elements, the counting results are the forces that are calculated for the section plane belonging to the end of the bar, i.e. the group of efforts with which the discarded (initial) part of the bar acts on the remaining part (the end of the bar) and in the center of the elastic part, and if there is a user request in intermediate sections along the length of the elastic part of the bar, is determined. The calculated forces correspond to a given type of the core procedure from the general tensor of forces \(V = \{N, M_x, M_y, Q_z, M_z, Q_y\}\).

As a result of calculations for plate, volume, axisymmetric and shell elements, the displacements of nodes in the general coordinate system, as well as the forces at the center point (center of gravity) of the element in the local coordinate system (by default) or in any other (at the user's discretion) coordinate system are found whose position is determined by the given data. In addition, stresses at the element nodes and nodal reactions can also be printed.

Figures 2 and 3 illustrate the obtained efforts using isopoles and isolines for the temperature load in the form of a gradient of values at 40 °C.
Figure 2. Longitudinal efforts $N_i$ of the design scheme elements for temperature effects with a gradient of 40 ° C.

Figure 3. Shear forces $T_{xy}$ of the design scheme elements for temperature effects with a gradient of 40 ° C.
From a comparison of the isopoles of effort shown in Figure 2, 3 it is seen that stresses occur from the effects of temperature differences, not exceeding the design resistance of concrete of class B30 with axial compression of 15.28 MPa <17 MPa and tensile of 1.37 MPa <1.8 MPa.

Isopoles (Figure 2, 3), show the most dangerous places of stress concentration, these are the points near the junction of the longitudinal and transverse monolithic reinforced concrete diaphragms of rigidity, as well as the points of contact of the overlap elements to these diaphragms, the interface points of the main volume of the building and the annexes in which staircases are located.

In the course of solving the described engineering problem, the values of the main stresses from various loads and their combinations were calculated, their maximums are shown in Figure 4. On passing through an arbitrary point on the body and arbitrarily oriented area, the normal \( v \) to which has \( l, m, n \) guide cosines with \( x, y, z \) axes, the normal stress \( \sigma_n \) and tangential stress \( \tau \), act with a resultant \( S_v \).

There are three such mutually perpendicular sites where tangential stresses are equal to zero. On these sites, called the main, there are main stresses \( \sigma_1, \sigma_2 \) and \( \sigma_3 \). Moreover, it is understood that \( \sigma_1 \geq \sigma_2 \geq \sigma_3 \). It is also known that the main stresses have extreme properties, namely, the resulting stress at any site is \( S_v \leq \sigma_1 \) and \( S_v \geq \sigma_3 \).

Figure 4 shows the isopoles and isolines for the main stresses on the inner surface of the finite elements (their values are maximum on it). Visible are the places of concentration of the main stresses at the junction of the floor elements and columns. Other concentrators are the junction of the elements of the diaphragms, ceilings, external walls, this is due to the redistribution of efforts near the elements with greater rigidity.

**Figure 4.** The main stresses in the elements of the design scheme at temperature effects of a gradient of 40 ° C.

3. **Conclusions**

In accordance with the structural analysis of the seven-story monolithic reinforced concrete building on the action of the main combination of loads, in the absence of defects affecting the strength characteristics, we can conclude:

1. The maximum equivalent stress calculated by the theory of the highest normal stresses and the
The greatest linear deformations is lower than the strength characteristics of reinforced concrete (B30 concrete, A-I, A-III reinforcement). In unreinforced places, the maximum tensile stress is less than the calculated concrete tensile strength of 1.57 MPa <1.7 MPa, and the maximum compressive stress is less than the calculated concrete compressive resistance, 14.56 MPa <17 MPa. Therefore, the application of a full load will not cause destruction in the first and second group of limiting states of individual structural elements and the entire building as a whole.

2. Several places of concentration of tensile stresses arising under the action of a static load and displacements of individual columns caused by sludge were revealed. The appearance of stress concentrators is associated with the complex geometry of some nodes, up to 5 elements adjoining to them, and the difference in the stiffnesses of individual elements.

3. It is necessary to pay attention to the indicated stress concentration points during subsequent operation in order to detect cracks in a timely manner and to take measures to prevent their development, especially for elements that may be exposed to atmospheric influences, since here the situation may be aggravated by a rapid decrease in the strength characteristics of reinforced concrete against corrosion.

4. Under the influence of the temperature difference and the normative temperature change, the design stresses do not exceed the standard values, therefore, when constructing a building, you can do without a temperature joint.

The above example of calculation in a software and computer complex fully showed not only the advantages, but also the lacks of the modern stage of development of simulation systems and automation. One of the disadvantages is associated with the complexity of entering the nodes of the design scheme and compiling the finite element model of the structure. There are no software tools at the moment to fully automate this process. When setting the initial data, errors may occur, including due to the human factor, the relevant issue is the verification of the compiled information model of the structure.

To implement automated verification of both the calculation model and the design documentation as a whole, all available data must be presented in a machine-readable format. However, each information modeling program has its own priority data storage format. Therefore, to use a complex of information models, it is necessary to ensure their interoperability, that is, the ability of two or more information systems or components to exchange information and use it. The most promising area is the use of open standards for the exchange of data of information models (currently it is IFC (Industry Foundation Classes, Industry Base Classes).

The IFC standard was developed and supported by the National Alliance for Interoperability (IAI), which was renamed buildingSMART in 2005. IFC is currently an internationally recognized standard in the construction industry (ISO). A Russian version of this standard has been released in the Russian Federation. The IFC format is based on the EXPRESS language developed by the International Organization for Standardization as part of the implementation of the STEP standard (Standard for the Exchange of Product Model Data). This language is used to model products in various industries, including construction.

The IFC data scheme is represented by four conceptual levels that define entities (information classes with common attributes and restrictions). The lower level (main and resource level) represents the totality of all variants of schemes containing resource definitions. It consists of a core scheme and expansion schemes of the basic conceptual level, containing the most general definitions of entities. The next level (the level of interoperability) contains schemes defining the essence of specific universal types of products, processes, or resource details. The upper level (the level of functional areas), more specific, consists of data schemes that define entities that are details of products, processes or resources of a particular area of the construction industry.

The advantage of the IFC format is that it supports the transfer of all three types of model information: geometry, relationships, and properties. Regarding the transfer of geometry, the IFC format provides almost all the needs in building design. In addition, IFC implements a fairly wide range of relationships that can be conditionally divided into classification groups.
The verification methodology of information models of construction objects is based on the algorithm considered above and consists of the steps:
1) the formation of verification rules based on a modeling language;
2) the formation of requirements for filling the information model;
3) obtaining requirements for filling the information model;
4) preparation of a model of the object in which information is collected for verification;
5) preliminary check of the model for completeness for the main stage of verification;
6) the formation of lists of rules for checking the model depending on the type of object;
7) the implementation of the rules (verification itself);
8) creating a report on the results of the verification of the information model.

The problem of adapting to a promising level of BIM technologies is the need for interaction in a single environment for all project participants. The difficulty of working in a unified environment is the transfer of information between project participants (it is necessary to organize the maintenance of model data in an up-to-date form, as well as lossless data exchange, there is a problem of isolation on a single software manufacturer).

Thus, after analyzing the results of the analysis of modern automation capabilities and one of the most popular information and computing systems, it can be noted that the use of monitoring and control systems in BIM models will increase the efficiency of building process management and help to identify deviations from the set parameters, thereby allowing corrective actions to be taken in a timely manner. Verifications directly affect the quality of design, construction and operation and are a priority in the development of information technologies.

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