A typical digital model of the construction process

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Abstract. Based on the practical experience of developing digital models of technological processes for the production of construction and installation works, a hypothesis about the similarity of digital models of construction processes is formulated. To prove the existence of this hypothesis, studies have been carried out, the purpose of which is to typify digital models of construction processes. When constructing a typical digital model of the construction process, the conceptual apparatus is clarified, mathematical models are proposed, which are most often found in the practice of modeling. The practical application of a typical digital model of the construction process greatly simplifies the processes of software development (computer codes), can be used to automate procedures that are used in the preparation of working organizational and technological documentation. In addition, standard digital models can be used to find such solutions for construction production that reduce the duration of construction and installation work with a significant reduction in cost.

1 Introduction

The relevance of the research topic is beyond doubt, since it considers the issues of expanding the scope of digital technologies. In construction, the practice of using digital models of buildings and structures in the form of 3D BIM models has developed. The advantages of such models are well known and are described in some detail in open sources. At the same time, the 3 D BIM model describes the stationary position of the capital construction object and is not able to show the dynamics of the processes of construction and installation work. Construction of 4D and 5D models are designed to manage material, technical and financial resources in the process of construction of buildings and structures. Such models do not describe the production processes of construction and installation works and are not intended to solve the problems of choosing the most efficient technologies and construction machines. In addition, 4D and 5D BIM models cannot be used for mechanization and robotization of construction processes. A detailed description of the technological process of construction and installation works is achieved by constructing a digital model (clause 3.23 of GOST R 57700.37).

The study of the published research results allows us to conclude that digital models are most often used in the construction of digital terrain models [1], vehicle movement [2], as

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well as in urban planning [3]. Quite often, digital models are used in the economy, for example, in nonlinear capital modeling [4], as well as in assessing the effectiveness of cost dynamics in the construction of capital construction projects [5].

It is important to emphasize that the published research results consider the construction and practical application of digital models of individual construction processes, which should include:

- placement of leading construction machines on the construction site [6-7];
- facade devices [8];
- preparation of building mortars [9];
- installation of precast reinforced concrete [10];
- the device of reinforcing frames [11].

Most often, when constructing digital models, researchers suggest the use of digital doubles [12]. Attempts are being made to generalize approaches to numerical modeling of technological processes [13, 14],, control procedures [15] and communications [16], economic efficiency assessment [17], labor productivity monitoring [18], as well as robotization of construction processes [19, 20], . Unfortunately, these studies do not provide a general (typical) approach to building a digital model of any construction process. To fill this gap in the research, this work has been done.

2 Goals and objectives

The purpose of the work: to substantiate a typical digital model of the construction process. In order to achieve the stated goal, the following scientific tasks were solved in the course of research:

- the conceptual apparatus used in digital modeling of construction processes is systematized;
- the mathematical method that is used to build a digital model of the construction process is substantiated;
- a typical digital model of the construction process has been developed, which takes into account the fundamental differences in the technological processes of construction and installation works.

3 Research methods

Within the framework of this study, the formation of the conceptual apparatus was carried out on the basis of state standards and building regulations in force on the territory of the Russian Federation. At the same time, the author considered it reasonable to clarify the definitions of some terms.

A well-known analogy method was used to select the mathematical apparatus used to build a digital model. As an analogue of the digital model of the construction process, dependencies were used that describe the movement of a material point. As the main equation describing the motion of a material point, the expression is most often used:

$$V = \int_{t_0}^{t} v(t)dt \quad (1),$$

where V – in the equation of motion denotes the distance, and in the digital model of the construction process – the amount of work performed;

- v – is the speed of movement of the material point, and in relation to the digital model of the construction process – the speed of construction and installation work (or the intensity of work);
- t – is the time during which the movement is performed – for a digital model of the construction process – the duration of construction and installation work.

Taking into account the possibility of changing the speed (or intensity of construction and installation work) at each time interval, it is necessary to take into account such a feature of the movement of the material point. For this purpose , the expression is used:

$$v(t) = v_0 + \int_{t_0}^{t} a(t)dt \quad (2),$$

where v_0 is the speed (intensity of construction and installation work) at the initial moment of time;

- $a(t)$ is the magnitude of the change in the speed (intensity of construction and installation work) in each period of time.

To bind the movement of a material point to the coordinate axes, the expression is used:

$$\vec{v} = \frac{dx}{dt}(\vec{i})^2 + \frac{dy}{dt}(\vec{j})^2 + \frac{dz}{dt}(\vec{k})^2 \quad (3),$$

where x, y, z are respectively coordinates along the X, Y, Z axes;

- i, j, k – respectively, the magnitude of the displacements along the X, Y, Z axes.

The use of the well-known mathematical description of the movement of a material point in space as an analogy allows us to build digital models of construction processes that fairly accurately describe the technological processes of construction and installation work during the construction of buildings and structures. It is important to note that such models provide a quantitative description of the construction process with reference to space in accordance with a given time interval.

4 Results

The conceptual apparatus used to build a digital model of the construction process consists of a system of definitions of key concepts. Such concepts include: "digital model" (clause 3.23 GOST R 57700.37), "numerical modeling" (clause 2.2.12 GOST R 57188) and "mathematical modeling" (clause 7.1.21. ISO 6707-1:2014, NEQ, GOST R 58033), "numerical method" (Clause 2.2.13 GOST R 57188), and "numerical solution" (Clause 2.2.13 of GOST R 57188). For the concept of "front of work" (p. 3.55 SP 48.13330) the author's clarification was required, since this term occupies an important place in the digital model of the construction process.

The work front is the volume (area) on which building materials, structures and products are used to create finished construction products, and the volume (area) is described by points, each of which has uniquely set coordinates x, y, z.

When constructing digital models of construction processes, it is advisable to provide for a division into fully mechanized, partially mechanized and manual technological processes. This separation is caused by the need to take into account the result of comparing the value of the operational productivity of construction equipment (most often a crane) and the value of the total productivity of construction workers. The proposed division of technological production of construction and installation works can be expressed mathematically by analytical writing of an expression that describes the speed of work.

In fully mechanized work (for example, excavation by an excavator [21]), the front of the work is the movement of the working body of the earthmoving machine. In this case, the speed of work does not depend on the construction workers, but depends on the qualifications of the excavator operator and can be written as:

$$v = W_M = \frac{V_1}{t_G} \quad (4),$$

where v – is the speed of work (amount of work per unit of time), and WM is the operational productivity of the construction machine (amount of work per unit of time);

- V_1 – a single volume of work established by the regulatory and technical documentation (GESN);
- t_G – the duration of a unit volume of work, established by the regulatory and technical documentation (GESN – state standard).

If the work is carried out manually, without the use of construction machines (for example, the installation of drywall sheets), then the speed of work depends on the normative value of labor costs, which is set in state standards (GESN), and the equation of the speed of work will have the form:

$$v = W_R = \frac{V_1}{R_G} \quad (5),$$

where v – is the speed of work that is performed manually (the amount of work per unit of time), and W_R is the normative productivity of the construction worker (the amount of work per unit of time);

- V_1 – a single volume of work established by the regulatory and technical documentation (GESN);
- R_G – labor costs required to perform a single amount of work (man-hour), established by regulatory and technical documentation (GESN – state standard).

If construction equipment (most often a crane) is used in the technological process of construction and installation works, then it is necessary to combine equations 4 and 5 to mathematically describe the speed of the technological process. The result of such a union can be written as:

$$W_M - \frac{N_R V_1}{R_G} = \begin{cases} > 0 \Rightarrow v = \dfrac{N_R V_1}{R_G} \\ < 0 \Rightarrow v = W_M \end{cases} \quad (6),$$

where N_R – is the number of construction workers who perform the technological operations of the construction process, and the expression describes the total productivity construction workers.

Special attention should be paid to equation 6. There are such construction processes for which an increase in the number of construction workers does not lead to an increase in the speed of construction and installation work. For example, the installation of precast concrete building structures. This technological process in general can be represented from 2 main technological operations:

- moving the reinforced concrete structure from the warehouse to the installation site;
- installation in the design position and temporary fixing of the reinforced concrete structure.

The duration of the installation of a reinforced concrete structure is the sum of the duration of the movement of the structure from the warehouse to the installation site and the duration of installation in the design position and temporary fixation. If the duration of

moving the structure from the warehouse to the installation site completely depends on the technical characteristics of the crane, then a certain number of construction workers are required to install the structure in the design position and temporarily fix it. An increase in the number of workers, for example, by 2 times, will not increase the speed of construction and installation work at all. At the same time, the use of a crane for other construction processes is usually excluded. This feature is taken into account by equation 6.

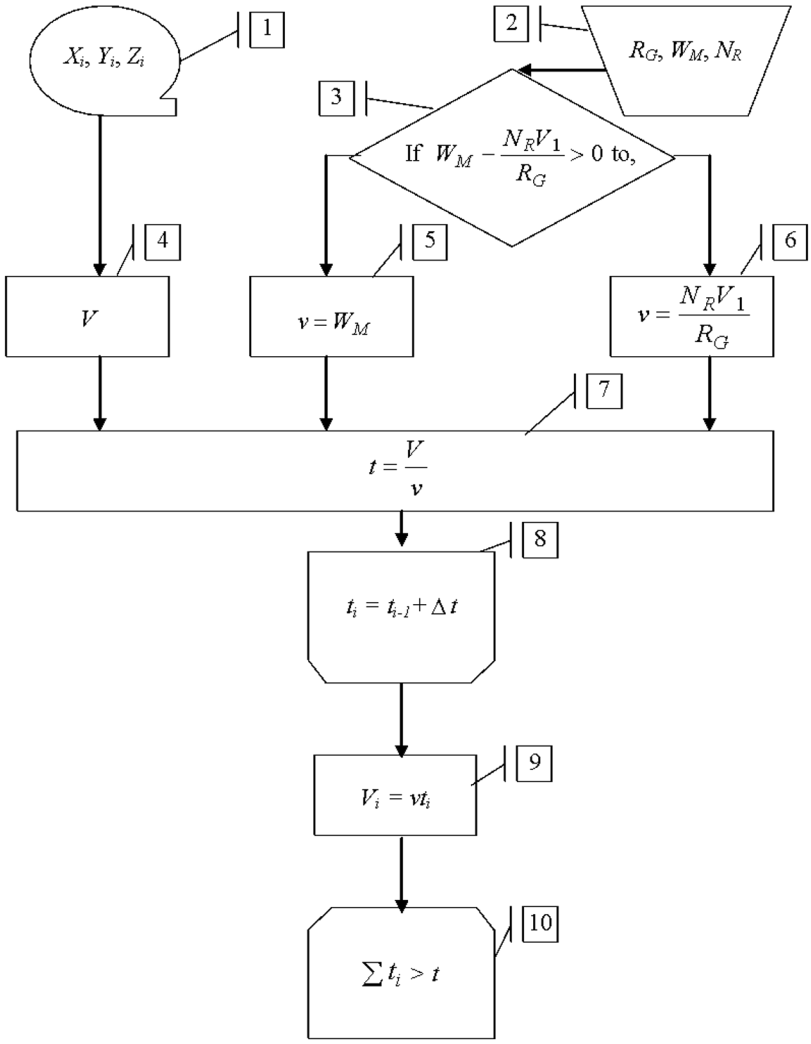

Figure 1. Block diagram of a typical digital model of the construction process

It is necessary to pay attention to such technological processes for which the crane performs the function of supplying the materials necessary to perform the work. For example, masonry walls made of bricks, the device of reinforcement frames made of individual rods and others. In other words, the operational productivity of the crane significantly exceeds the standard productivity of the construction worker. In this case, the crane can be used for several construction processes that are carried out in parallel. It should be emphasized that using Equation 6 for such construction processes, such a number

of construction workers can be calculated that is able to ensure the operation of a crane without downtime only for the maintenance of one construction process.

It does not require proof, the statement that if the number of construction workers is equal to zero ($N_R = 0$), then using equation 6 it is possible to describe a fully mechanized process. Similar reasoning at $W_M = 0$ will allow us to describe the construction process, which is performed manually, without involving construction machines.

To build a digital model of any construction process, it is advisable to use a block diagram (Fig. 1), which is built according to the rules of GOST 19.701 (ISO 5807-85).

A typical block diagram of a digital model of the construction process (Fig. 1) consists of:

Block 1 consists of geometric dimensions of building structures that represent a 3D BIM model of a capital construction object and are stored on magnetic media.

Block 2 – characteristics of the construction process, which are entered into a digital model from the keyboard. It is important to emphasize that with the development of digital modeling of construction processes, manual data entry that describes the construction process can be automated. When automating, the characteristics of construction processes are the results of choosing the most preferred technologies and construction machines from the database of available equipment.

Block 3 – calculates the intensity of work for the construction process, which is performed manually, with partial or complete mechanization of technological operations.

Block 4 – determination of the scope of work for the construction process using data obtained from the 3 D BIM model.

Blocks 5 and 6 represent the results of calculating the calculated value of the intensity of construction and installation work for the construction process.

Block 7 – calculation of the duration of construction and installation works in volume V with intensity v.

Blocks 8, 9, 10 represent a cyclic calculation of the amount of work (V_i) for each specified time interval (t_i).

The digital model of the construction process generates an array of work volume values V_i for each time interval t_i. Such an array of values may consist of the same values of elementary volumes, or may vary depending on changes in the intensity of work v_i. As a result, for each time interval ti, it is not difficult to obtain quantitative coordinate values that describe the position of the work front. Coordinates describing the position of the work front as a function of time (t_i) provide a representation of the position of the construction process in space and time.

5 Conclusions

The proposed digital model of the construction process is capable of solving practical problems in several directions that are related to the management of the process of construction of a capital construction object. These areas include:

1. At the design stage, the use of a digital model of the construction process increases the reliability of calculating the duration of construction and installation work, taking into account the characteristics of the applied technological processes of machines and mechanisms.

2. When performing the functions of monitoring compliance with the duration, which is set by the calendar plan, it becomes possible to form conclusions based on a comparison of the calculated and actual coordinates of the front of the construction process.

3. When developing working documentation and making a final decision on the technology used and the construction equipment involved, it is possible to find an option that satisfies the preferences that are formed by the user.

4. Procedures for compiling reports on the performance of construction and installation works, as well as on the use of building materials, structures and products, are greatly simplified.

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