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FEATURES OF STANDARD TIME FORMATION TO IMPLEMENT CONSTRUCTION PROCESSES: A CASE STUDY

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Introduction. The current article is based on the theoretical analysis and experience in the construction processes standardization. The advantages and disadvantages of the existing automated process planning systems (APPS) and the system of computer-aided design and standardization of technological processes SPRUT-TP-Regulation are shown.

Problem Statement. The existing systems are mainly created for mechanical engineering. The APPS system has also been expanded for the production of metal building structures. However, an issue of the real standard time for construction processes at the construction site remains unresolved. Particular attention is paid to the problem of choosing the structures of formwork systems to optimize the installation of in-situ concrete structures.

Purpose. Development of a new method for determining the duration and complexity of construction processes that allows to consider any changes in the structure of processes and to determine the standard time by synthesis.

Materials and methods. The method of integer standardization of processes is considered which, in contrast to existing methods, makes possible to compare the various design solutions of formwork forms.

Results. The duration of formwork assembly and disassembly is proposed to be determined in whole numbers, depending on the number of formwork elements movements and the degree of responsibility for the reliability and quality of the processes. The article proposes the structure of the construction process and gives the main directions to create an information database regarding the standard time of construction processes implementation.

Conclusions. The new approach solves the problem of synthesizing the time of construction processes.

Keywords: standard time, construction process, action, synthesis, planning, automation, standardization method.

Nowadays, there are many advances in building technology. Robots-workers and 3D printed homes are now a reality. Building Information Modeling (BIM) has allowed the implementation of a new toolkit for management and planning of work processes, which is based on 3D-models of the project and allows to generate intelligent workflows at all stages of the building life cycle from planning and design to maintenance [1]. To achieve it, an appropriate system for the production processes regulation must be created. However, it is complicated to implement it in the field of construction processes on the basis of existing regulatory information base.

1. Analysis of the latest achievements and publications

An automated process planning system (APPS) has become a crucial element of process planning, which includes spreadsheets of standards for the time of the production process. APPS is considered as a key technology to integrate computer-aided design (CAD) and computer-aided manufacturing (CAM) systems. The work [2] considers the planning of the production process for the manufacture of steel building structures, taking into account the time standards. The aim of the current article is to incorporate time standards into the APPS CSB system. It is based on the empirical timing formulas for various steel structures in accordance with CAD files and process parameters.

Time-use studies during manufacturing and assembly allows to create a parametric model using Excel and integrate it into the APPS system. This will allow to automatically estimate the standard time of each process step and to provide more accurate estimation of process parameters. APPS system replaces the complex and low-productivity traditional manual process planning approach [3].

Back in the distant fifties of the last century, production processes standardization in technology was solved manually by synthesizing time standards in separate processes and actions [4]. Thereafter, with the advent of computers, the system of computer-aided design and standardization of technological processes SPRUT-TP-Standardization was created and successfully implemented [5]. The system is based on a number of algorithms for structural features analyzing (geometry of elements, shape, structure, dimensions, weight, etc.). To determine the duration in process planning the algorithms for the selection of appropriate operations types, their implementation sequence, types of technological equipment and tooling have been developed [6].

An issue of the base of real-time standards for the implementation of work processes at the construction site remains unresolved. The main problem is that the theory of construction processes lacks an integrated approach to understand the structure of the construction process. Thus, the process level as a set of separate operations was frozen in the process standardization. In accordance with this approach, the standard time for the implementation of operations remained unchanged in case of changing the operations structure and design solutions of technical means. In distant sixties, operations structure and design solutions of technical means of implementation almost have not been changed. This was suited to standardization system, which mainly showed appropriate values at different periods of time. The basis for standardization became catalogues in the form of single standard time and prices (ENiR) [7], as well as in the form of National standards [8].

Nowadays, the definition of standard time is one of the crucial stages of the process analyzing. It provides an important input for the improvement of productivity in companies [9]. One of the most relevant approaches to achieve productivity in the construction industry today is lean construction [10]. The essential features of lean construction include a clear set of objectives for the delivery process, parallel design, construction and application of project management throughout the project life cycle from design to commissioning. The application of additive manufacturing (AM) in construction has been increasingly studied in recent years. The current state of AM in construction is reviewed in [11]. Significant benefits of AM are the automation of the production process, a high degree of design freedom, and the resulting potential for optimization. The use of principal component analysis and signal processing techniques in construction are presented in [12]. Standardization efforts, including the relationship between knowledge dimensions, search processes and innovation outcomes are considered in [13]. Using an inductive case study of Vanke, a leading Chinese property developer, autors show how varying degrees of knowledge complexity and codification combine to produce a typology of four types of search process: active, integrative, decentralized and passive, resulting in four types of innovation outcome: modular, radical, incremental and architectural.

As it is described above, nowadays, nature and content of construction processes change more often due to the rapid development of digital technologies, satellite communications, robotics, etc. Thus, the problem of process regulation should be solved at the level of operations and actions [14]. It is more common for companies (construction organizations) to manage their own databases (more accurate proprietary standardization method) in some regions of the world. As an example, a regression analysis method to describe analytical dependencies [15]. This method is problematic because it is very complicated to determine the mathematical dependencies of variable parameters. The standard time is proposed to determine with the theory of neural networks with imitation of probability of deviation for one or several variable parameters. A neural network similar to network models of construction processes in which selected parameters are determined using a random number generator is created. It is quite complicated and problematic to use such a system in practice.

2.Main issue

In terms of the construction of a building or any other structure, the construction process is considered as a certain structural system with a multi-level subordination of its elements. The structure of the construction process corresponds to the building structure and represent hierarchy from a more complex level to a dismembered level. [16].

The complexity of the process is in the content and the number of constituent structural elements. Each next level of the process is more detailed and complete comparing the previous one. (Fig. 1).

The most complicated level of the process structure is the level of the final product (an erected building ready for use (TP_b)).

A new standardization system in construction should be created by means of transferring standard time consumption to the fourth level of structure, where a rather permanent structure of components is observed. Such structure contains approximately the same operations, such as gripping, moving, assembly, fixing, etc. (there are about 50 different operations in construction practice). In the case of establishing the mathematical dependencies between the duration of individual operations and its structure and complexity, it is possible to create an information database and an algorithm to synthesise standard time for third-level processes TP_b.

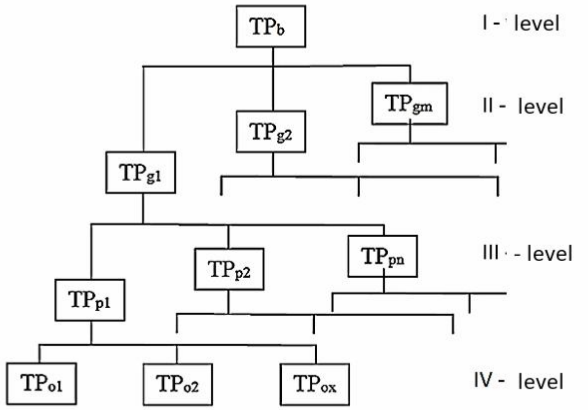

Fig. 1. Structure of the construction process: TP_b – first (highest) level construction process; TP_g – second level construction process; TP_p – third level construction process; TP_o – fourth level construction process (corresponds to the technological operation)

3. Materials and methods

The integer standardization expediency of time consumption at the fourth level of the construction processes structure has been proved in [14]. It takes into account the different options of the labour team, driving machines, equipment sets and design parameters of building elements.

To estimate the time of operations, a general methodology was applied [17]. There are two methods to determine the standard time of processes implementation: analytical-calculation (calculation of standard time based on the existing regulations) and analytical-research (field studies using timing, photographic recording, etc.). Both methods are used together sometimes. Relation of these methods to the regulations does not solve the problem.

Unlike existing methods, it is proposed to measure the elements of the process with integers. If we decompose the operations of mounting or dismantling of elements into the actions of labourers, whereas the actions are measured in whole minutes depending on the complexity of these actions, then we can determine the total time of operations, i.e. the duration of the third-level process according to the formula:

$$T_h = 0,01667 \cdot \sum_{j=1}^{m}\sum_{i=1}^{n} r_j \cdot W_{ij}, \qquad (1)$$

where T_h – time standard for the third level process, hour; r_j – the factor of complexity and responsibility of actions, expressed in integers from 1 to 5 minutes; W_{ij} – amount of x actions (elements) for j complexity.

The degree of responsibility is associated with ensuring the accuracy of objects position in relation to the given axes and dimensions, as well as ensuring the reliability of connections within the given forces (Table 1).

Table 1

Groups of the complex of actions

Group of the complex of actions	Number of actions in the complex	The degree of actions responsibility according to the accuracy and reliability of positioning	Complexity and responsibility factor, r_j
1	1-5	low	1
2	1-5	medium	2
3	6-10	low	3
4	6-10	medium	4
5	6-12	high	5

The first group of the complex of actions is characterized by the number of actions from 1 to 5 and a low degree of responsibility for the accuracy and reliability of positioning, which is not associated with the positioning of elements and with the provision of joints.

The second group of the complex of actions differs from the first one by the medium degree of responsibility for the accuracy and reliability of positioning, which can be associated with incomplete (approximate) positioning by accuracy and with the provision of joints without control of efforts.

The third group is characterized by the number of actions from 6 to 10 and by similar to the first group degree of responsibility for the accuracy and reliability of positioning.

The fourth group differs from the third one by the medium degree of responsibility for the accuracy and reliability of positioning, which can be associated with incomplete (approximate) positioning in accuracy and with the provision of joints without control of efforts.

The fifth group is characterized by the number of actions from 6 to 12 and a high degree of responsibility for the accuracy and reliability of positioning, which is associated with the alignment of objects and their elements, as well as with the control of efforts in joints.

The number of actions (movements and displacements) is determined in accordance with the number of engaged elements by labourers.

Example. The process of panel formwork assembly to build in-situ concrete wall structure is considered. The formwork of a German company PERI is taken [18] (Fig. 2).

The following complex of actions is defined in accordance with Figure 2: W_{12} – to set the struts to the formwork panels (there are 4 actions: to lift, to put on, to fix the bolts (medium responsibility), to roughly adjust); W_{22} – to place the general panels on the floor; W_{34} – to fix the struts to the floor (support); W_{42} – to set the corner panels; W_{52} – to fasten the corner and general panels with locks; W_{64} – to set and fasten the tie bolts; W_{72} – to set and fix the scaffold; W_{85} – to align the panels with adjusting bushings of struts; W_{92} – to set and lock the end panels (not shown).

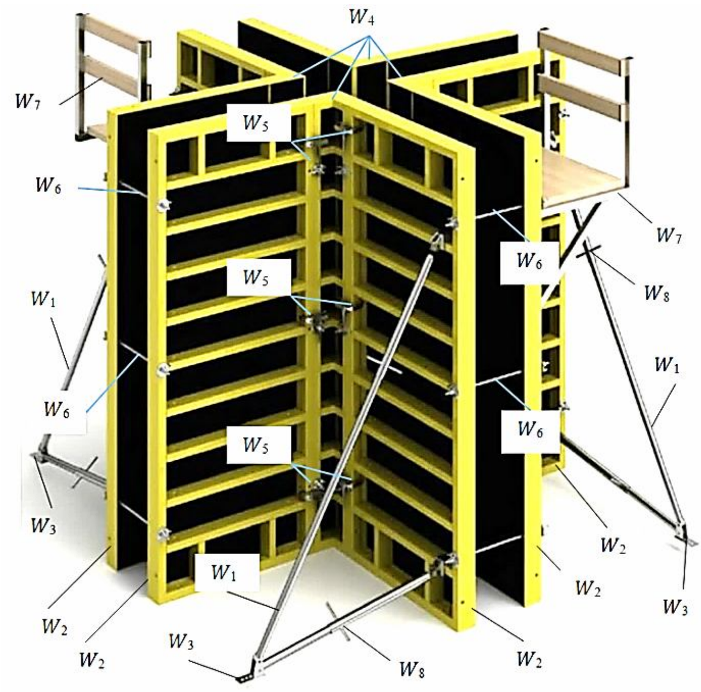

Fig. 2. A complex of actions to assembly panel formwork of the wall structure

Each complex of actions can be decomposed into smaller actions, depending on the number of prefabricated elements that enter the complex.

To clearly illustrate the method, it is recommended to analyze the time spent to set and fasten the tie bolts (Fig. 3).

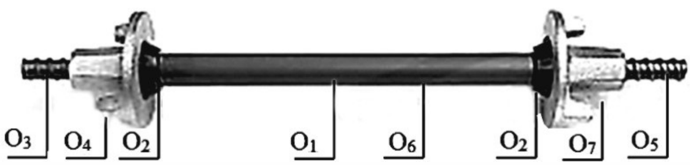

Fig. 3. W_{64} actions to set and fasten the tie bolts

The first step is to fix O_2 cones on the O_1 tube, which includes 3 actions. The degree of responsibility is low. Then nut O_4 is screwed onto the O_3 pin (2 actions). After that, the pin with the nut is inserted into the hole of O_5 panel and, at the same time, a tube with O_6 bushings is put on the pin (2 actions). Then the pin is inserted into the hole of the opposite panel and both panels are tightened with the O_7 nut (2 actions). The last action is performed with medium responsibility because the tightening force of the entire system is adjusted. As a result, we have 9 actions and medium responsibility of reliability, which corresponds to the 4th group of a complex of actions and a factor of complexity and responsibility r_j = 4 min (Table 1).

All other complexes of actions are analyzed in a similar way. The obtained data is filled into an Excel-table (Table 2).

Table 2

An example of calculating the duration and labour consumption of formwork assembly

Actions	Number of actions by the degree of responsibility					T_h, min	Labourers N_p	Labour consumption, θ_{md}, man-min
	$r_j=1$	$r_j=2$	$r_j=3$	$r_j=4$	$r_j=5$			
W_{12}		4				8	2	16
W_{22}		4				8	2	16
W_{34}				4		16	2	32
W_{42}		4				8	2	16
W_{52}		24				48	2	96
W_{64}				12		48	3	144
W_{72}		2				4	2	8
W_{85}					4	20	3	60
W_{92}		4				8	2	16
Results:						168	2,405	404

The duration of third level process TP_p is determined by the formula (1) and corresponds to the organization of actions arranged sequentially. In fact, actions can be performed with overlapping in time. Thus, it is necessary to take into account the combination of actions by means of factor which characterizes the efficiency of using working time and should be equal more than one in value. To determine the factors of combining actions, it is recommended to build network models. The network model for the current example is shown on the Figure 4.

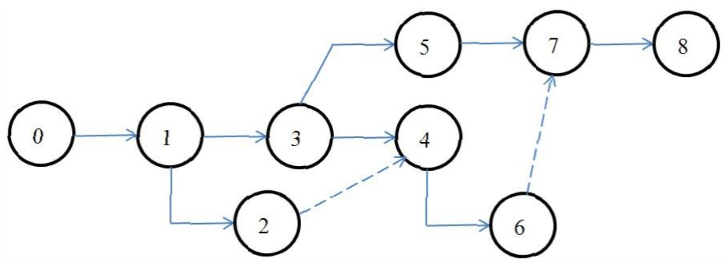

Fig. 4. The network model to assembly panel formwork of the wall structure

The overlapping factor for such a model is K_{co}= 1,5. Based on this, the duration of the formwork assembly process when the actions are combined T_{md} is determined by the formula:

$$T_{md} = T_h / K_{co} = \frac{0,01667 \cdot 168}{1,5} = 1,87 \text{ hours.} \qquad (2)$$

The labour consumption of the assembly process of panel formwork: $\theta_{md} = 0,01667 \cdot 404 = 6,735$ man-hours.

To derive the standard time to evaluate processes with similar formwork systems, the unit consumption must be determined. The unit in the current example is one square meter of the assembled panels. Thus, the standard labour consumption for this process will be the following:

$$R_h = \frac{\theta_{md}}{A_s} = \frac{6,735}{25,6} = 0,263 \text{ man-hours/m}^2.$$

4. Conclusions

1. With the rapid development of digital technologies and robotics, an issue of process standardization should be solved at the level of operations and actions. To achieve it, the article proposes the structure of the construction process and gives the main directions to create an information database regarding the standard time of construction processes implementation.

2. The use of a new method to determine the duration and complexity of construction processes allows to consider any changes in the structure of processes and to determine the standard time by synthesis, which makes it dynamic and more adapted to the rapid development of science and technology.

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ОСОБЛИВОСТІ ФОРМУВАННЯ НОРМАТИВНОГО ЧАСУ НА ВИКОНАННЯ БУДІВЕЛЬНИХ ПРОЦЕСІВ: ТЕМАТИЧНЕ ДОСЛІДЖЕННЯ

Вступ. Матеріал статті ґрунтується на теоретичному аналізі та досвіді нормування будівельних процесів. Показано переваги та недоліки існуючих систем автоматизованого планування процесів (САРР) та система автоматизованого проектування та нормування технологічних процесів СПРУТ-ТП-Нормування.

Проблематика. Існуючі системи нормування часу створено здебільшого для машинобудування. Система САРР розширено й у сфері виробництва металевих будівельних конструкцій. Невирішеним залишається питання реальних норм часу на робочі процеси на будівельному майданчику. Особлива увага приділяється проблемі вибору конструкцій опалубних систем для оптимізації процесів влаштування монолітних конструкцій.

Мета роботи. Розробка нової методики визначення тривалості та трудомісткості будівельних процесів, що дозволить розглядати будь-які зміни у структурі процесів та визначати нормативний час шляхом синтезу.

Матеріали та методи. Розглянуто методику цілісного нормування процесів, яка, на відміну від існуючих методик, дає можливість порівнювати різні конструктивні рішення опалубних форм.

Результати. Тривалість процесів монтажу та демонтажу опалубок запропоновано визначати цілими числами залежно від кількості переміщень елементів опалубки та ступеня відповідальності за надійність та якість виконуваних процесів.Запропоновано структуру будівельного процесу та надано основні напрямки створення інформаційної бази даних нормативного часу на виконання будівельних процесів.

Висновки. Новий підхід дозволяє вирішити проблему синтезу витрат часу на виконання будівельних процесів.

Ключові слова: норма часу, будівельний процес, дії, синтез, планування, автоматизація, методика нормування.

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