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THE ECONOMIC-MATHEMATICAL DEVELOPMENT OF BUILDINGS CONSTRUCTION MODEL OPTIMIZATION ON THE BASIS OF DIGITAL ECONOMY

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Abstract:
The article presented the scientific research of buildings construction optimization problems on the basis of interdisciplinary approach that provides synergy of modern approaches of construction organization and technology, economic theory and political economy, as well as applied mathematics. The formation and realization of the economic-mathematical model of optimal sequence groups of construction objects are considered on the basis of a method of sequential analysis of variants, based on dynamic programming. According to the provided research results the proposals were made for acceleration of these processes in construction through the development of program complex "Optimization of object construction process by the criterion of time" on the basis of mathematical modeling methods, which provided the opportunity to further optimize and obtain consistency and reduce the construction terms of this buildings groups for almost a year (360 days or 61%).

Key words: *digital economy, construction, interdisciplinary approach*

INTRODUCTION

The construction industry creates jobs, promotes formation of business infrastructure and makes about 6% of world GDP that is the engine of national economy development. Implementation of digital and information-communication technologies is an important factor of innovative development of the construction industry. The application of these technologies will provide the opportunity to architects, engineers, builders to achieve effective results in the realization of complex projects in capital construction. Managements of the construction industry on the principles of digital economy are not only the transforming data into digital space, but also a change of approaches, models, and methods of management decisions.

Digital economy is an economic activity, based on digital technologies that provides implementation of information technologies in all industries and fields of management and digital activity space. Therefore, it is expedient to allocate with the key purposes of digital economy: through automation of all basic industrial and economic business processes, development of the market production services and consumption, increase in cumulative efficiency of economic activity subjects, mobilization of knowledge through exchange, creation of new jobs in high-tech industries.

The digital economy is not limited to the IT sector and digital companies. The greatest economic returns are provided by the transition to digital processes and implementation of digital technologies within the value creation chains in all sectors of national economy, particularly in construction. Such digital technologies can be applied at all stages of cost creation, including construction of buildings of various types and sizes, promoting reduction of total period of their construction, growth of energy efficiency and comfort accommodation in rooms.

LITERATURE REVIEW

In their research, scientists R. Fokov, M. D. Spector and S. A. Ushatsky [4, 8, 9], presented the basic methodology of optimal buildings construction estimation variants, advantages and disadvantages of the different structures in construction management company, as well as the stages of building production preparation. In particular, the theoretical issues of organizational-technological models of construction development, including the streaming organizations of different buildings construction and structures are outlined. The article reveals the composition and methodical fundamentals of construction plans development (strategic, operational), peculiarities of construction in terms of reconstruction.

The scientific works of V. Kupriyanovsky [7] and T. Yudina [10] represent vectors implementation of basic fundamentals of the concept: "digital economy" in separate sectors of the national economy. T. Yudina [10] presented a model of digital economy and a scheme of changing the structure of the world economy that is influenced by industrial revolutions. The peculiarity of the digital economy is its rapid development, in which every few years there are technologies that bring changes in the economy of almost all countries and change the universe [11, 12, 13, 14, 15, 16].

The theoretical analysis of scientific sources [1, 8, 9, 10] made it possible to conclude that when constructing buildings of different types and sizes, the sequence of the construction objects has an impact on total period of their construction. Depending on the sequence of construction and different time of work, on the same stages on each object, there are different variations of their combination. The construction company, regulating by diversification the resource base of the construction objects and their complexes can influence on terms and efficiency of construction.

The provided data confirm considerable prospects of the digital-information and communication technologies in all branches of national economy, in construction, particularly (for example BIM). One of the problems that is often discussed in scholarly discussions by scientists is optimization of buildings construction terms in order to diversify the resource base, reduce costs, increase profitability and efficiency of the construction company.

The formations of scientific-theoretical and practical aspects of digital economy incorporation in the construction industry we offer to realize on basis of interdisciplinary approach of scientific research, particularly, on the principles of synergy of organization and construction technology, economic theory and political economy as well as applied mathematics. It should be noted that the determinant of the accelerated and effective development of digital economy is the introduction and use of digital technologies in conjunction with the development of the real economy and transition to an innovative model.

METHODOLOGY

Digitalization is a determinant of growth of the construction industry competitiveness in the domestic and world market according to the purpose of development of economic salary and transition to qualitatively new level of information technologies uses in all spheres of social and economic activity of the country. The breaking technologies produces new industrial revolution which was called "the Industry 4.0". Unlike the previous industrial revolutions, the industrial revolution 4.0 does not develop linearly, but exponentially.

As a result of the Industrial Revolution 4.0 the main value will be the information data. The influence of industrial internet-networks on physical objects, platforms, systems and applications with built-in technologies of data exchange among themselves, external environment and people become more active. According to the forecast of the Accenture [2] company, this sector will promote world GDP growth of $ 14.2 trillion, until 2030 (for the top of the world 20 economies this is plus 1% above the projected growth rate).

According to the International consulting company, International Data Corporation (IDC), the cost of digital transformation at the global level in 2017, compared with the previous year, increased by 16.8% and exceeded to $1.3 trillion. According to IDC, these costs will continue to grow by an average of 17.9% annually up to 2021 that means digital market will practically double and reach the turnover of $ 2.1 trillion dollars [2]. The Boston Consulting Group (BCG) predicts that the digital economy in the world by 2035 will surpass the production sector and will be 16 trillion [3].

Every year, Swiss International Institute for Management and Development (IMD) in Lausanne, makes the World Digital Competitiveness Ranking (Table 1) for 63 countries based on analysis of 50 indicators that take into account the level of digital transformation readiness of countries, state of regulatory policy, investments in research and development, education, potential of digital technologies, capitalization of IT industry. The top ranking is the United States, Singapore, Sweden, Denmark and Switzerland [5].

Table 1
Global Digital Competitiveness Rating 2018

Final results of ranking ranks – 2018 in brackets 2017	Country	Value index, %	The ranks of countries by main rating composition		
			Knowledge	Technologies	Readiness to the future
1(3)	USA	100	4	3	2
2(1)	Singapore	99.422	1	1	15
3(2)	Sweden	97.453	7	5	5
4(5)	Denmark	96.764	8	10	1
5(8)	Switzerland	95.851	6	9	10
6(10)	Norway	95.724	16	2	6
7(4)	Finland	95.248	9	4	8
8(9)	Canada	95.201	3	12	9
9(6)	Netherlands	93.886	12	8	4
10(10)	Great Britain	93.239	10	13	3

The "digital race" leader is the USA, where the digital economy reaches 10.9% of GDP, and existing capacities enable American companies to control individual segments of the world market in this area. In 2015, the U.S. adopted the state program of Digital Economy Agenda, which aims to create favorable conditions for the activities of American high-tech companies and promote their interests abroad [5].

On the basis of options sequential analysis method, based on dynamic programming of the problem, we propose to consider the economic mathematical model of optimum construction of group objects, in order to reduce the total term of their construction. When constructing a building (or its parts) through a consecutive number of stages (works), the degree combination of any couple of objects is defined by minimum possible approach of any two equal stages (works) of the considered objects.

For example: ε – (ε = 1,2,… ε_k… ε_n) – are numbers of objects; ρ – (ρ = 1,2,…m) – are numbers of stages (works); $\mu_{\varepsilon\rho}$ – the magnitude of possible deviation when combining objects of any stages, "on the left" given to duration of this object erection; $\omega_{\varepsilon\rho}$ – the magnitude of possible change when combining objects of any stage, "on the right" is given to the duration of the construction of this object; $\Delta\varepsilon_{k,}\varepsilon_k + 1$ – the magnitude of possible combination of any two objects; $t_{\varepsilon\rho}$ – work duration of the stage ρ of ε object; $T_\varepsilon = \Sigma_\rho t_{\varepsilon\rho}$ construction duration of ε object; $\mu(\varepsilon_1, \varepsilon_2…, \varepsilon_k…, \varepsilon_n)$ – sequence of construction objects. The calculation of indexes μ and ω can be defined by next formulas [1, 9]:

$$\mu_{\varepsilon\rho} = \mu_{\varepsilon,\rho-1} + t_{\varepsilon,\rho-1};\ 1 < \rho \le m \quad (1)$$

$$\omega_{\varepsilon\rho} = T_\varepsilon - t_{\varepsilon,1};\ \omega_{\varepsilon\rho} = \omega\mu_{\varepsilon,\rho-1} + \varepsilon_{\varepsilon,\rho-1};\ 1 < \varepsilon \le n \quad (2)$$

The total values of the first and second combination of objects are determined by the formula: $\Delta\varepsilon_{1,t2}$ = min $\rho(\mu_{\varepsilon 1\rho} + \omega_{\varepsilon 2\rho})$. Therefore, the problem of determination of optimum sequence construction process realization is to find such rearrangement of objects ($\varepsilon_1, \varepsilon_2…, \varepsilon_k…, \varepsilon_n$), in which their maximum combination is achieved, i.e.:

$$max\ \Delta(\varepsilon_n) = \sum_{k=1}^{n-1} \Delta\varepsilon_k, \varepsilon_{k+1} \quad (3)$$

If the general term of construction in a sequential summary of objects is defined as $T_\alpha = \Sigma_\varepsilon T_\varepsilon$, then the task of choosing the optimal sequence of objects construction with the purpose of optimizing the general term construction can be presented as follows:

$$\max T_\alpha = \sum_\varepsilon T_\varepsilon - \sum_{k=1}^{n-1} \Delta\varepsilon_k, \varepsilon_{k+1} \quad (4)$$

To solve the problem, the authors in their writings [4, 8, 9] suggest at each stage to determine by criterion max Δ optimal variants Z_k = [α = ($\varepsilon_1, \varepsilon_2…, \varepsilon_n$)]. Then on created basis variants are identified Z_{k+1} = [α = ($\varepsilon_1, \varepsilon_2…, \varepsilon_{k=1}$)]. According to the results of the performed calculations we get different variants which we divide on groups with the same ε_{k+1}. According to the criterion max $\Delta(\varepsilon_{k=1})$ from each group we choose one dominating. At the last stage, from many variants of z_n we choose $\sigma(\varepsilon_k)$ with maximum value $\Delta(\varepsilon_n)$, that provides an optimal solution to the problem. The determinants solving the modified tasks in the following statement are:

$$t^з_{\varepsilon\rho} = t_{\varepsilon\rho^n} + t_{\varepsilon\rho} \quad (5)$$

If the stage began to be executed, then the breaks, increase the established term therefore, breaks are not allowed; $t^з_{\varepsilon\rho}$ end of stage term; $t_{\varepsilon\rho}^n$ – start of stage term work;

$$t_{\varepsilon\rho^n} \ge t^з_{\varepsilon\rho-1} \quad (6)$$

that is, each stage starts not earlier than the previous one completed.

4. RESULTS OF RESEARCH

We suggest considering results of applied implementation of proposed economic-mathematical model. So, it is planned to build five objects that can be erected in any order. The process of each object construction consists of six stages, which are performed by various development companies.

Under the terms of construction technology each stage begins only after the completion of the previous one. In this case, the implementation duration of the same stages on each object is different (Table 2). It is necessary to define the construction sequence of all objects in which the total period of their construction will be the smallest.

Table 2
Duration of objects implementation stages

Work stages	Object number				
	1	2	3	4	5
	Duration work stages $t_{\varepsilon\omega}$, days				
1. Zero cycle	60	80	60	90	70
2. Frame	100	70	50	60	80
3. Walls and partitions	90	50	40	80	60
4. Roof	60	60	30	40	30
5. Floor	50	30	40	50	60
6. Finishing work	90	60	50	90	100
	Σ450	Σ350	Σ270	Σ410	Σ400

The object construction period magnitudes may vary (from left $\mu_{\varepsilon\rho}$ or $\omega_{\varepsilon\rho}$ from right) at each stage of the object implementation schedule combination with the construction schedule of any other object presented in Table 2. Let's clarify the estimation order of magnitudes $\mu_{\varepsilon\rho}$ and $\omega_{\varepsilon\rho}$. For example, the first object:

$$\mu_{1,1} = 0; \quad (7)$$

$$\omega_{1,1} = \sum t_{1,\varepsilon} - t_{1,\rho} = 450 - 60 = 390; \quad (8)$$

$$\mu_{1,2} = \mu_{1,1} + t_{1,1} = 0 + 60 = 60; \quad (9)$$

$$\varpi_{1,2} = \omega_{1,1} - t_{1,2} = 390 - 100 = 290; \quad (10)$$

$$\mu_{1,3} = \mu_{1,2} + t_{1,2} = 60 + 100 = 160; \quad (11)$$

$$\omega_{1,3} = \omega_{1,2} - t_{1,3} = 290 - 90 = 200; \quad (12)$$

$$\mu_{1,4} = \mu_{1,3} + t_{1,3} = 160 + 90 = 250; \quad (13)$$

$$\omega_{1,4} = \omega_{1,3} - t_{1,3} = 200 - 60 = 140; \quad (14)$$

$$\mu_{1,5} = \mu_{1,4} + t_{1,4} = 250 + 60 = 310; \quad (15)$$

$$\omega_{1,5} = \omega_{1,4} - t_{1,5} = 140 - 50 = 90; \quad (16)$$

$$\mu_{1,6} = \mu_{1,2} + t_{1,5} = 310 + 50 = 360; \quad (17)$$

$$\omega_{1,6} = \omega_{1,5} - t_{1,6} = 90 - 90 = 0. \quad (18)$$

To check the correctness of calculations it is used the following equation:

$$\mu_{\varepsilon\rho} + t_{\varepsilon\rho} + \omega_{\varepsilon\rho} = \sum t_{\varepsilon\rho} \quad (19)$$

The further process of solution consists in consecutive selection of the most perspective options until the sequence of objects construction is determined, at which their maximum combination in time is possible, with given conditions and restrictions. During the calculations, all possible combinations of three objects from their common, equal to five, are taken into account. For each combination of three objects, the common value of their possible combination is calculated. For example, to determine the magnitude $\Delta_{(2,3,1)}$ the quantities $\Delta_{(2,3)}$ = 190 and $\Delta_{(3,1)}$ = 180 are taken, summing up we get: $\Delta_{(2,3,1)}$ = 370.

Values of combinations for each couple of connections are identified, the first two numbers of objects are selected with the maximum value $\Delta_{(1,2,3)}$ is chosen as perspective. For other remained optimal variant similar calculations are carried out, but already at a combination with four objects. The common value of Δ(5524) is following: find the value Δ(542) = 550 (Example 24) and take the value Δ(21) = 300 add them, that is Δ(5524) = 550 + 300 = 850.

Table 3
The parametric characteristic of changing duration of buildings construction n the platform of the digital economy

Stages	Objects 1			2			3			4			5		
	$\mu_{\varepsilon\rho}$	$t_{\varepsilon\rho}$	$\omega_{\varepsilon\rho}$	$\mu_{\varepsilon\rho}$	$t_{\varepsilon\rho}$	$\omega_{\varepsilon\rho}$	$\mu_{\varepsilon\rho}$	$t_{\varepsilon\rho}$	$\omega_{\varepsilon\rho}$	$\mu_{\varepsilon\rho}$	$t_{\varepsilon\rho}$	$\omega_{\varepsilon\rho}$	$\mu_{\varepsilon\rho}$	$t_{\varepsilon\rho}$	$\omega_{\varepsilon\rho}$
1	0	60	390	0	80	270	0	60	210	0	90	320	0	70	330
2	60	100	230	80	70	200	60	50	160	90	60	260	70	80	250
3	160	90	200	150	50	150	110	40	120	150	80	180	150	60	190
4	250	60	140	200	60	90	150	30	90	230	40	140	210	30	160
5	310	50	90	260	30	60	180	40	50	270	50	90	240	60	100
6	360	90	0	290	60	0	220	50	0	320	90	0	300	100	0
		Σ450			Σ350			Σ270			Σ410			Σ400	

For other perspective variants of four objects, a combination of five objects with the maximum value $\Delta_{(1,2,3,4,5)}$ is formed in the same way and is chosen the best option. In the example of work [3] variant 36 was optimal, with the sequence of construction objects 54123 and value of Δ(54123) = 940. Total period of construction of this group of buildings was reduced almost by a month. However, using the methods of mathematical modelling, we have developed a program complex "Optimization of object construction process by the criterion of time" (Fig. 1), which provided the opportunity to further optimize and obtain the sequence Δ(54123) = 590 that reduced the construction terms of this group buildings for almost a year (360 days or 61%).

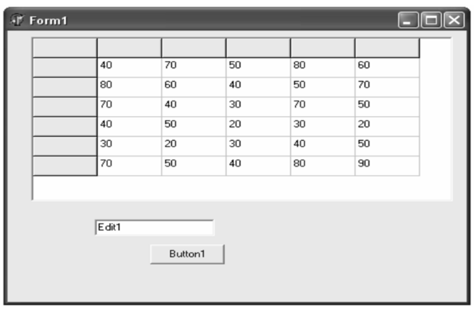

Fig. 1 Program complex "Optimization of object construction process by the criterion of time," data entry

In addition, according to the results of the calculations, other minimal sequences have been obtained (Fig. 2), which make it possible to distinguish the multivariate system of construction organization of this group of buildings.

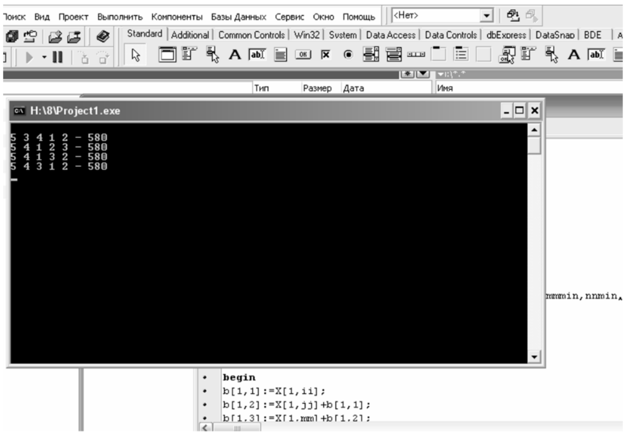

Fig. 2 Program complex "Optimization of object construction process by the criterion of time", conclusion results

Comparison of these schedules demonstrates that even with a small amount of objects (5) and a relatively insignificant difference in construction duration of each object, the optimum sequence is possible only due to the construction terms of this group of buildings by 61% of the total duration.

Thus, on the basis of program complex" Optimization of object construction process by the criterion of time "is developed by using the methods of mathematical modelling, additionally optimized and obtained the sequence of Δ(54123) = 590, which ensured the reduction group of buildings construction terms for almost a year (360 days or 61%).

5. CONCLUSIONS

In the article, the scientific research of the problems of optimization buildings construction reduction terms on the basis of interdisciplinary approach, which envisages synergy of organization and construction technology, economic theory and political economy, as well as applied mathematics is conducted. It is considered formation and realization of economic-mathematical model of optimal group sequence construction of objects on the basis of a method of sequential analysis of variants based on dynamic programming.

Proposals for acceleration of these processes in construction through the development of program complex "Optimization of object construction process by the criterion of time "on the basis of methods of mathematical modelling, which provided the possibility of additional optimization and receive the sequence and provide reduction of group buildings construction terms almost for a year (360 days or 61%).

Within the proposed economic and mathematical model, the parametric characteristic the duration of buildings construction changing on a platform of digital economy for five objects of construction on each of six given stages.

Clarifications of the calculating order values $\mu_{\varepsilon\rho}$ and $\omega_{\varepsilon\rho}$ for the first object of construction is determined, the equality for results verification is obtained.

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