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# Organizational and Technological Platform for Monolithic Construction Using Pneumatic Formwork

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**Abstract**

*Introduction*: The active implementation of digital technologies in various fields, including in the construction industry, leads to the development of technological platforms to sell multiple products. The study examines the prerequisites for the formation of an organizational and technological platform for monolithic construction using pneumatic formwork, which is a set of material and labor resources and organizational and technological solutions that, through their consolidation with modern digital technologies, allow the implementation of construction projects with specified technical and economic requirements. This study aims to systematize various production and construction solutions, presenting them as a unified organizational and technological system that allows for achieving optimal criteria for construction products. *Materials and methods:* The factors ensuring its effectiveness were selected and systematized to form an organizational and technological platform. A complex system decomposition is presented at three levels of a hierarchical matrix using the analysis of hierarchies. The level of the stages of the life cycle of buildings and structures is taken as the basis, followed by the level of components of the areas of activity that form the platform's effective formation. At the last, lower level, some factors ensure its effective formation. The analysis of the totality of material and labor resources and organizational and technological solutions that make up the platform for constructing monolithic buildings and structures using pneumatic formwork systems was carried out. *Results:* For an adequate analytical description, it is proposed to use the a priori ranking method, which makes it possible to decompose the indicated factors influencing the effectiveness of the formation of an organizational and technological platform and to obtain specific criteria and alternatives inherent in the construction of monolithic buildings and structures on pneumatic formwork. The detailed development of an analytical apparatus for obtaining an integral assessment will be the subject of further research. *Conclusions:* The organizational and technological platform for monolithic construction using pneumatic formwork is an innovative tool for interaction between all participants in implementing such projects, aimed at successfully achieving construction design indicators in terms of time and cost and ensuring the required level of reliability and safety of the constructed facility. The novelty of the proposed approach is determined by the combined consideration of material, technological, organizational, and managerial solutions within a single platform to increase the efficiency of construction product production processes.

*Keywords:* Organizational and Technological Platform; Monolithic Construction Technologies; Pneumatic Formwork; A Priori Ranking; Dispersed Reinforcement; Basal-fiber Reinforced Concrete; Construction Control; Major Repairs.

## 1. Introduction

Current trends in the development of the investment and construction complex are characterized by processes aimed at intensifying the construction of buildings and structures, ensuring the quality of appropriate construction products, and ensuring safe working conditions. A special place in the variety of modern construction trends is occupied by technologies that make it possible to automate work production within the space of a construction site. Such technologies

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include monolithic concrete construction. At present, this concept can consist of a wide range of materials with different properties and methods of constructing both individual structures and structures as a whole. An analysis of the construction products market offers allows us to highlight an emerging trend that deserves close attention: large manufacturers are focused on producing products in the form of integrated solutions that combine the materials and structures used and organizational and technological solutions for their use. Enterprises in the modern construction industry adhere to the production strategy of so-called "boxed" products, which ensures high efficiency of production control at the stage of product creation and its use, reduces the risks of human factor influence, and guarantees sufficient quality of the finished product.

Nowadays, similar strategies among full-cycle developers offering turnkey construction products can be noticed in the construction sector. When implementing such a strategy, conducting research in several areas simultaneously and paralleling the development of several production solutions tied to a complex result is necessary. An analysis of the modern investment and construction market [1] indicates the prospects of developing complex solutions that combine material, organizational, and technological spheres. One of the promising directions for developing the investment and construction complex is to improve technologies for constructing monolithic buildings and structures using pneumatic formwork systems [2, 3]. A detailed acquaintance with world experience in using pneumatic formwork in the construction of monolithic thin-walled structures shows the promise of this technology, updated based on modern industrial achievements in the production and use of polymer materials and composites.

The concept of an organizational and technological platform proposed by Timirgaleeva et al. [4] is a set of various resources and organizational and technical models based on the use of modern digital technologies. By ensuring rational interaction, it is possible to achieve high efficiency in the construction of facilities with given technical specifications and economic characteristics [5–9]. Technological platforms are formed to solve strategic problems of scientific and technical development. In the previous analysis by some researchers, they were considered one of the mechanisms for developing priority scientific and technological areas, defined within the framework of a long-term scientific and technical forecast. At the same time, there are no instructions on the possibility of using the methods under consideration for specific types of construction products, such as, for example, monolithic buildings and structures [10–13].

Also, when analyzing the works of Moustafa et al. [14], it was found that the existing information on the stated topic is fragmented and not presented by systematic studies. In addition, at the current level of technology, consolidated solutions for monolithic construction on pneumatic formwork using the advantages of digital modeling, demanded by the investment and construction markets, are practically not found. The solution we propose, based on the above studies, aims to develop the identification and comparison of critical factors that have the most significant impact on the effectiveness of the formation of an organizational and technological platform for monolithic construction using pneumatic formwork systems [15, 16].

This study is expected to solve several topical problems devoted to the consideration of relationships characterizing the totality of processes for the production of building components, calculation, and design of monolithic buildings and structures made of composite materials based on concrete, as well as the technology and organization of their construction. In this case, special attention is expected to be paid to formalizing the applied methods of justification and design using modern digital technologies.

## 2. Materials and Methods

The setting of the goal and objectives of this study is based on the need to formulate the sequence and mutual influence of components (areas of activity) and stages of formation of a separate type of construction product: buildings and structures erected from monolithic concrete and composites with similar properties using pneumatic formwork systems, as well as to justify methodological approaches to the implementation of individual stages. The multifactorial nature of organizational and technological solutions in construction is an obstacle to describing their interaction without using various methods of formalizing complex systems [17, 18]. The choice of research topics is determined by the need to develop effective mechanisms for managing the components of the organizational and technological platform, both about a large-scale investment and construction project and, in a particular case, about a specific type of construction product. This study considered a set of materials, technological components, methods of justification, and the construction and production of monolithic structures built using pneumatic formwork.

Within the framework of this study, it is proposed to perform a decomposition of the structure of the organizational and technological platform of construction, which will provide the opportunity to form the initial materials for a mathematical model of the project, implemented with a detailed study of the elements of this platform, their interactions, and their influence on the result. The subject of this study is considered a set of organizational and technological components (spheres) united by interconnections, tied to specific stages of the life cycle of buildings and structures, as presented in Figure 1.

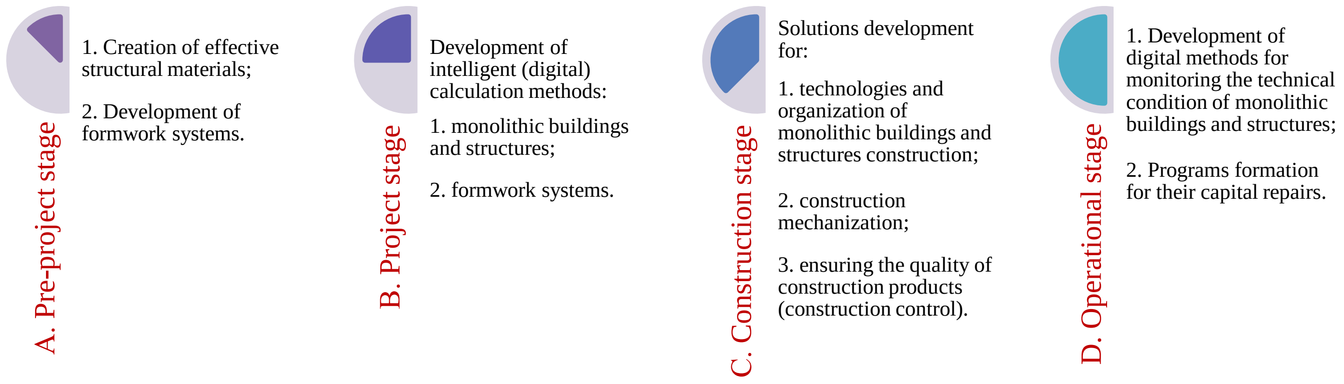


**Figure 1. Set of interrelations of components (spheres) of the organizational and technological platform by stages of the life cycle**

Considering the volume and multitasking nature of the proposed research, this article will consider conceptual approaches to substantiate key aspects of the organizational and technological platform.

## 3. Results and Discussion

When studying the set of interrelations of components presented in Figure 1, we can conclude that at each indicated stage, the effectiveness of the formation of an organizational and technological platform will be influenced by different factors. To systematize such factors and identify three of them that have the greatest impact, the method of a priori ranking (expert assessment), discussed in the works of Lapidus et al. [19], was used.

As part of compiling a list of factors, the available regulatory documents and the results of the study previously conducted by the authors on the topic of monolithic construction on pneumatic formwork [20–22] were summarized, a survey of specialists was carried out, and construction experience was studied.

It is also noted that conducting a priori ranking involves comparing indicators located at one hierarchical level, while in the considered hierarchy of influence, there are two such levels (Figure 2).

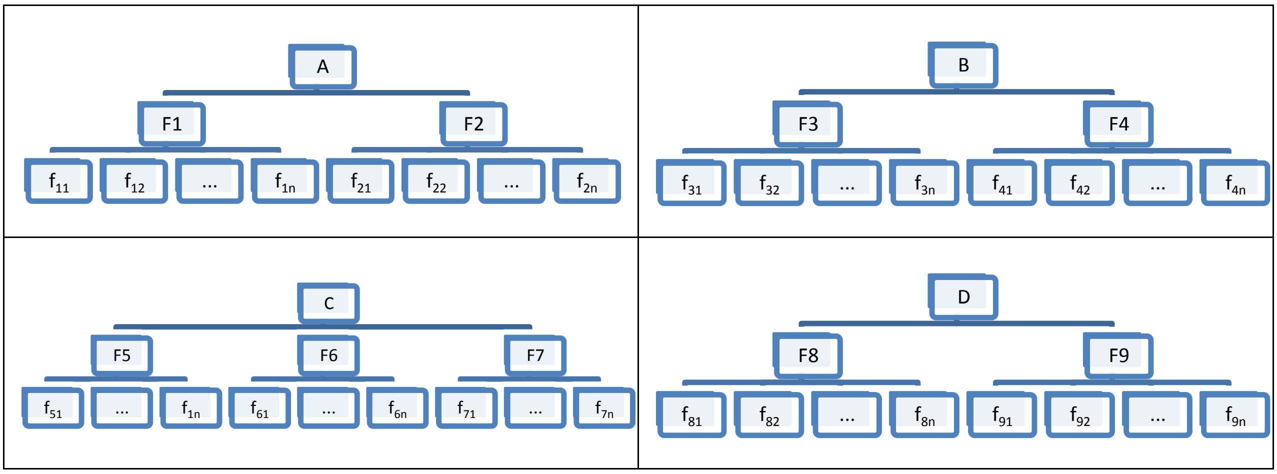


**Figure 2. Hierarchy of factors influencing the effectiveness of the formation of an organizational and technological platform**

The mutual influence of these factors can be presented in the form of a hierarchical matrix of the organizational and technological platform Table 1.

In order to determine the factors influencing the efficiency of the formation of an organizational and technological platform, solutions in the field of monolithic construction on pneumatic formwork, which showed positive efficiency, were considered.

Despite the apparent hierarchy of influence, it can be noted that all the components under study have a precise sequence. In the framework of this study, the assumption was made that the decomposition of the hierarchical matrix can be conditionally presented in a single-level version for the subsequent application of the method of a priori ranking (expert assessment) of influencing factors. At the same time, the possibility of identifying individual components by life cycle stages is taken into account.

Then, the total set of influencing factors taken into account by the hierarchical matrix can be represented as a linear sequence:

$f_{11} \ldots f_{1n}; f_{21} \ldots f_{2n}; f_{31} \ldots f_{3n}; f_{41} \ldots f_{4n}; f_{51} \ldots f_{5n}; f_{61} \ldots f_{6n}; f_{71} \ldots f_{7n}; f_{81} \ldots f_{8n}; f_{91} \ldots f_{9n} \rightarrow f_1 \ldots f_n$.

Thus, based on the analysis of regulations, generalization of existing experience, and a survey of specialists, a list of 18 influencing factors requiring ranking was generated (Table 2).

**Table 1. Hierarchical matrix of factors influencing the effectiveness of the formation of an organizational and technological platform for monolithic construction using pneumatic formwork systems**

| Life cycle stages | | Components (areas) of the organizational and technological platform | | Influencing factors |
|---|---|---|---|---|
| A | Pre-project stage | F1 | Creation of efficient structural materials | $f_{11} \ldots f_{1n}$ |
| | | F2 | Formwork systems development | $f_{21} \ldots f_{2n}$ |
| B | Project stage | F3 | Development of digital methods for calculating monolithic structures | $f_{31} \ldots f_{3n}$ |
| | | F4 | Development of digital methods for calculating formwork systems | $f_{41} \ldots f_{4n}$ |
| C | Construction stage | F5 | Solutions development for technology and organization of construction | $f_{51} \ldots f_{5n}$ |
| | | F6 | Solutions development for construction mechanization | $f_{61} \ldots f_{6n}$ |
| | | F7 | Solutions development to ensure the quality of construction products (construction control) | $f_{71} \ldots f_{7n}$ |
| D | Operational stage | F8 | Development of digital methods for monitoring technical condition | $f_{81} \ldots f_{8n}$ |
| | | F9 | Formation of capital repair programs for monolithic buildings and structures | $f_{91} \ldots f_{9n}$ |

Note: *n* is taken to be the number of factors for each component, obtained as a result of a survey of experts and analysis of the existing level of technology and technology

**Table 2. List of influencing factors**

| | | | |
|---|---|---|---|
| A | F1 | $f_1$ | Development of new structural and thermal insulation materials based on basalt fiber concrete (BFC) for monolayer and multilayer structures |
| | | $f_2$ | Materials development for additive construction technologies |
| | F2 | $f_3$ | Pneumatic frame formwork structures development from modern materials |
| | | $f_4$ | Improving automated life support systems for pneumatic formwork |
| B | F3 | $f_5$ | Creation of a calculated analytical model of the operation of a vaulted monolithic structure, taking into account changes in the stress state |
| | | $f_6$ | Development of a BIM model for the construction of a monolithic vault |
| | F4 | $f_7$ | Creation of a computational analytical model of the operation of pneumatic frame formwork for a circular vault |
| | | $f_8$ | Software development for automated pneumatic formwork systems |
| C | F5 | $f_9$ | Improving the technology of constructing vaults using pneumatic (air-supported) formwork |
| | | $f_{10}$ | Improving the technology of using pneumatic frame formwork systems |
| | F6 | $f_{11}$ | Improving automatic systems for monitoring technological parameters of pneumatic frame formwork systems |
| | | $f_{12}$ | Develop digital complexes for monitoring the design geometric characteristics of a monolithic structure during the construction process |
| | F7 | $f_{13}$ | Development of special regulatory and technical solutions for quality control of the construction of monolithic thin-walled vaults |
| | | $f_{14}$ | Formation of a list of controlled compliance parameters and a construction control algorithm |
| D | F8 | $f_{15}$ | Develop digital algorithms for monitoring the technical condition of monolithic vaulted structures |
| | | $f_{16}$ | Creation of software and hardware systems for monitoring technical condition |
| | F9 | $f_{17}$ | Regulatory framework development for major repairs of thin-walled monolithic buildings and structures |
| | | $f_{18}$ | Management mechanisms development to ensure the introduction of digital technologies for monitoring and major repairs of thin-walled monolithic buildings and structures |

To justify the selected list, we present the results of our research:

***The creation of advanced materials:*** The specific technology for constructing monolithic thin-walled structures on stump formwork places unique demands on the materials of which they are built. Such special requirements will include, in particular, distributed (dispersed) reinforcement coupled with a small grain size of the filler. In addition to the technological parameters of the concrete mixture used, its operational qualities will be no less critical: strength and thermal efficiency. As part of the research on the stated topic, the scientific team, with the participation of the authors of the article, developed an original structural and thermally efficient material - basalt fiber concrete (from now on referred to as BFC) with a porous filler introduced into its composition. According to the research results, it is clear that the use of foam glass as a heat-efficient additive in the BFC mixture reduces the thickness of the structural material by six times [3, 23-25]. BFC with perlite filler also has relatively low thermal conductivity; the thickness of the structure is 3.5 times less compared to the indicators of BFC with quartz sand filler (see Figure 3).

Based on the results obtained, it is possible to determine factors that have a positive impact on the formation of components F1 and F2, presented in Table 2 and corresponding to the pre-project stage (A) of the implementation of the organizational and technological platform.

***Development of calculation models of vaulted structures:*** The formation of an organizational and technological platform for the construction of monolithic thin-walled structures is impossible in the absence of the necessary analytical and digital models of both the primary device for their building and the structure as a whole.

Despite the fact that the methodological basis for calculating pneumatic structures was laid quite a long time ago [26], nowadays it has been possible to obtain only empirical models that reflect only exceptional cases of digital calculation of the stress-strain state of pneumatic frame formwork.

The development of automated solutions that provide the ability to vary sizes, external (temporary loads), and internal (material characteristics) influences is an integral part of the organizational and technological platform, which allows us to formulate factors influencing components F3 and F4, corresponding to the design stage (B) of the implementation of the organizational and technological platform (Table 2).

***Improving models for the construction of monolithic buildings and structures using pneumatic formwork:*** One of the achievements of the scientific team (in which the authors of this paper participated) is the developed and patented technology for the construction of fiber-reinforced vaults on pneumatic frame formwork [27], which is presented in Figure 3. Its features include the use of pneumatic frame formwork modules with a circular outline, the operability of which is ensured by the system's automatic control of technological and geometric parameters.

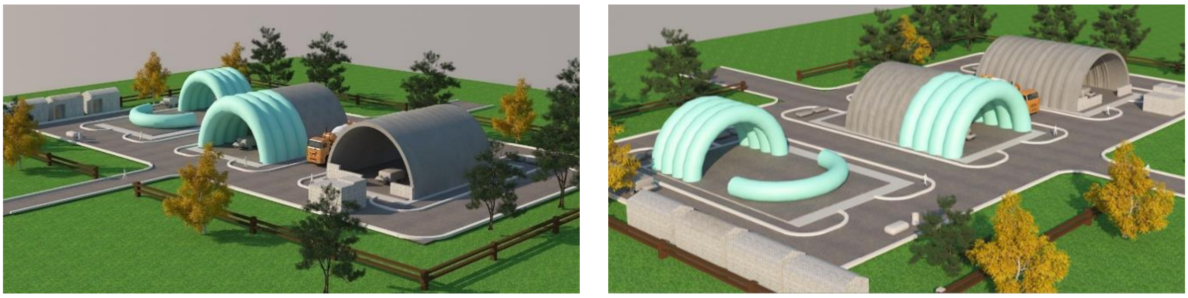

**Figure 3. Visualization of the patented technology for constructing vaults on pneumatic frame formwork**

The solutions provided by this technology make it possible to formulate factors that influence components F5 – F7, corresponding to the construction stage (C) of the implementation of the organizational and technological platform (Table 2).

***Improving methods for monitoring the technical condition of buildings and structures in use:*** Currently the inspection of buildings and structures is not limited to specific geometric measurements but is aimed at the most complete reflection of reality. Today, it is possible to measure the position of millions of geometric points on the surface of a building (inside/outside) or one of its components very accurately [28, 29].

The continuous evolution of surveying technology is a natural development vector that will contribute to the expansion of various topics around digitization, such as implementation in BIM or large-scale virtual tours. Integrating 3D scanning into the BIM process can revolutionize collaboration on a construction project. High-definition scanned images can be used as a basis for developing existing BIM models, with the advantage that they provide highly complete and accurate information. In the case of structures with geometry based on shells of revolution, the use of traditional control methods, as a rule, does not allow for obtaining sufficiently reliable control results. In addition, the existing regulatory framework for monitoring technical compliance often lags behind the development of the level of technology and technology. As a result, it is possible to use high-tech construction processes, but there is no regulatory justification for measures to control the quality of work performed. The above justifies the group of factors that influence components F8 and F9, corresponding to the construction stage (D) of the implementation of the organizational and technological platform (Table 2).

To systematize the factors that influence the effectiveness of the formation of the organizational and technological model and to identify three of them that have the most significant impact, the a priori ranking method (expert assessment) was used. For this purpose, preparatory organizational measures were carried out, and expert qualification requirements were determined. The expert survey was conducted with the participation of 5 experts. The number of experts to participate in the a priori ranking was determined based on the sensitivity of the Pearson statistical criterion, which was: $\chi_p^2 = 66.9$ and $\chi_p^2 = 79.4$, which is greater than the tabulated value $\chi_p^2 = 33.4$, therefore, the number of experts remained equal to 5, and an increase in their number was not required.

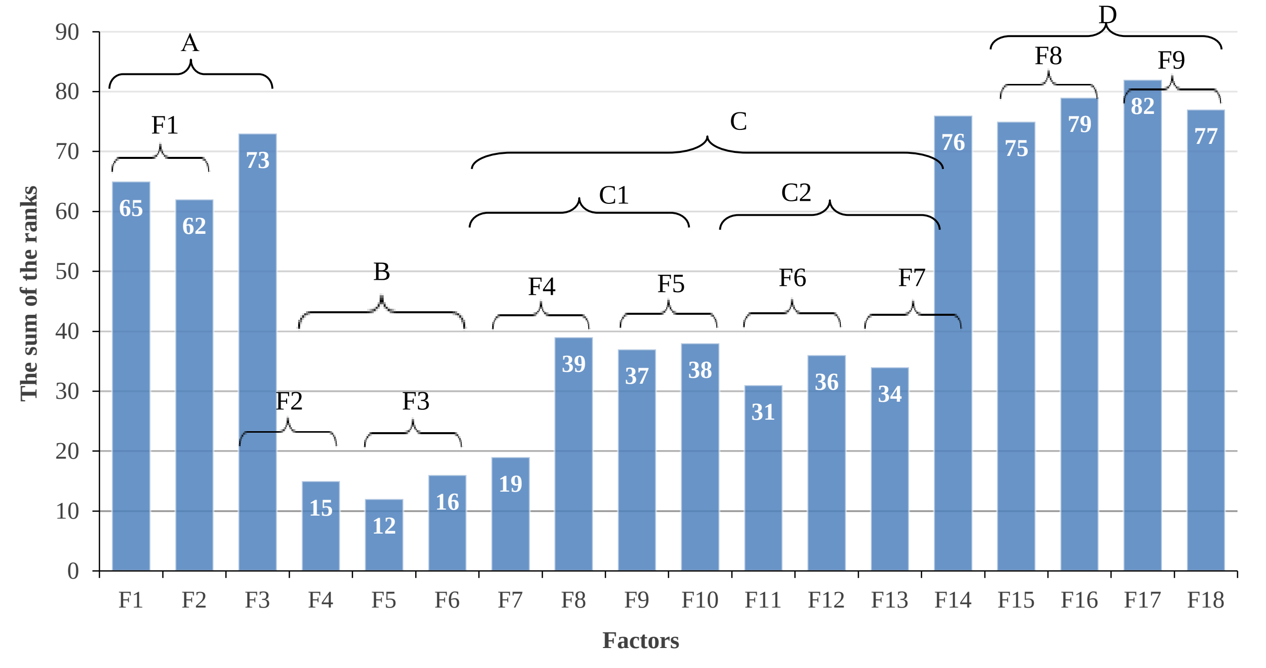


**Figure 4. Diagram of a priori ranking of factors influencing the effectiveness of the organizational and technological platform**

To determine the consistency of expert opinions, the value of the Kendall concordance coefficient was calculated:

$$Wi' = \frac{12 \times 11311}{5^2 \times (18^3 - 18) - 5 \times 1} = 0.93 \quad (1)$$

To check the non-randomness of agreement between experts, the value of the Pearson criterion was calculated:

$$\chi_p^2 = W \times m \times (i - 1) = 0.93 \times 5 \times 17 = 79.4 \quad (2)$$

Now we compare the calculated value of the Pearson criterion with table one given in the work of Sklyar [30] at the level of statistical significance $\alpha = 0{,}01$. since $\chi_T^2 = 79{,}4$, Then, the inequality is true $\chi_p^2 > \chi_T^2$, Which confirms the hypothesis that expert agreement is non-random. In addition, the concordance coefficient is significantly different from zero, and the calculated value of the Pearson criterion is greater than the tabulated one $\chi_p^2 = 33{,}4$, Therefore, expert opinions are sufficiently consistent and non-random, and the results can be used in the study.

Based on the results of an expert survey about the combination of factors that influence the effectiveness of the organizational and technological platform, taking into account pronounced jumps in the a priori ranking diagram; experts identified groups of factors, which made it possible to systematize them into complexes [31]. Because the experts distributed the work by rank in descending order of the degree of their influence on the resulting attribute - the effectiveness of the organizational and technological platform, complex C was identified as a priority for achieving the implementation result, which, based on the nature of the work included in it, assigned the code name “Construction Stage.”

About this combination of factors, taking into account the data of the a priori ranking diagram, the work in Complex C “Construction Stage” was divided by experts into two groups - Complex C.1 and Complex C.2, which, based on the nature of the work included in them, were assigned conventional names “Technological events” and “Organizational events.” All works included in these complexes have a sum of ranks below the average sum of 73, which further confirms the correctness of their choice as a priority for the efficiency indicator of the organizational and technological platform.

## 4. Conclusions

The proposed approach to effectively forming an organizational and technological platform for monolithic construction using pneumatic formwork systems will make it possible to efficiently implement construction projects, avoid various losses, and ensure the required reliability and safety of constructed objects. The study used a method of a priori ranking of influencing factors based on existing regulatory documents, previous studies' results, and surveyed specialists, considering the current level of technology and construction technologies. The results obtained can be used in the formation of other specialized organizational and technological platforms. In contrast to previously completed studies on this topic, the essence of which was to establish the broadest mechanisms for the formation of organizational and technological platforms in the construction of large-scale systems, the main focus of this study was to assess the possibility of using the above approaches to evaluate the effectiveness of the venue for the construction of monolithic buildings and structures, carried out using pneumatic formwork systems. The results of the study include the following:

- The concept of an organizational and technological platform for the monolithic construction of buildings and structures made of composite materials using pneumatic formwork has been developed;
- A mechanism for determining the degree of influence of various factors at all stages of the implementation of the organizational and technological platform has been developed. The mechanism makes it possible to identify the most significant parameters for a specific capital construction project;
- A fundamental algorithm for analytical modeling of the relationships between influencing factors, allowing them to be controlled to increase the efficiency of construction production processes, has been described.

The results make it possible to apply methods for assessing the effectiveness of organizational and technological platforms in a large-scale investment and construction project during specific construction projects. The possibility of taking into account factors that are diverse in the area of occurrence and nature of influence discussed in this article makes it possible to use the resulting assessment mechanism for various types of construction products and projects implemented in different social, political, economic, and other conditions, which, in the opinion of the authors, is a definite contribution to the modern research community.

The prospect for further research in this sphere can be called a detailed study of the critical components that make up the organizational and technological platform of monolithic construction, as well as the development of various solutions that ensure the effectiveness of its formation. In this case, the criteria determining compliance with the design indicators of construction time, reliability, safety, and efficiency can be the subject of further detailed consideration. It can also be suggested that research on forming an organizational and technological platform for construction control during the construction of structures and buildings using the proposed technology will be especially relevant. The direction of major repairs to civil and industrial buildings, including those erected on pneumatic formwork, seems no less promising. The research direction described in this work is significant for increasing the efficient construction of monolithic buildings and structures, and its development represents an urgent scientific problem.

# 5. Declarations

## 5.1. Author Contributions

Conceptualization, M.V. and L.A.; methodology, M.V.; software, T.D.; validation T.D., M.V., and K.D.; formal analysis, K.D.; investigation, T.D.; resources, M.V.; data curation, M.V.; writing—original draft preparation, K.D.; writing—review and editing, K.D.; visualization, K.D.; supervision, T.D.; project administration, K.D.; funding acquisition, L.A. All authors have read and agreed to the published version of the manuscript.

## 5.2. Data Availability Statement

The data presented in this study are available in the article.

## 5.3. Funding

The research, the result of which is presented in this paper, was carried out as part of the implementation of the Strategic Academic Leadership Program "Priority - 2030", a grant from National Research Moscow State University of Civil Engineering No. 12307130012-8.

## 5.4. Conflicts of Interest

The authors declare no conflict of interest.

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