INCREASING THE CONSTRUCTION PRODUCTION EFFICIENCY BASED ON THE USE OF CYBER-PHYSICAL SYSTEMS AND TECHNOLOGIES

a Iuliia Artamonova, b Liubov Adamtsevich, c Ilnur Kharisov, d Nikita Morgunov

ABSTRACT

Objective: The article proposes a classification of cyber-physical systems and technologies at the stages of the life cycle of a construction project, considers an algorithm for choosing these technologies depending on the effectiveness of the project.

Theoretical framework: The study is based on the review of publications in international scientific journals, methodological literature on the topic of the use of digital tools in construction. The experience of different countries in the application of cyber-physical systems and technologies in construction was represented.

Method: The study was conducted based on materials published in open sources, including scientific articles, reports, regulatory documents. In addition, the study used the experience of several companies operating in the construction industry.

Results and conclusion: The main approaches to planning construction projects at the stage of the life cycle are studied. Approaches to the formation of a graphical hierarchical block diagram of a simulation model, consisting of different levels of nesting, are proposed. The results may be of interest to manufacturing companies that decide to implement digital technologies in construction, as well as individual scientists who study the problem of increasing the efficiency of production organization at the stages of the construction projects life cycles.

Implications of the research: The results of the study can be used by construction companies when planning the choice of cyber-physical systems and technologies at the stages of the life cycle of construction objects

Originality/value: The authors propose an approach that allows choosing tools for designing and building objects using cyber-physical systems and technologies at the stages of the life cycle. A hierarchical block diagram of the simulation model is proposed, which contains more than a dozen child diagrams that combine several hundred smaller typical modules.

Keywords: construction, cyber-physical systems and technologies, BIM, information modeling technologies, efficiency, mixed reality, augmented reality, life cycle.

a Phd in Economics, Penza State University of Architecture and Construction. 440028, Penza, st. G. Titova, 28, E-mail: clusterwings@mail.ru, Orcid: https://orcid.org/0000-0003-2219-6318
b Phd in Engineering, National Research University "Moscow State University of Civil Engineering", 129337, Moscow, Yaroslavskoe shosse, 26, E-mail: adamtsevichla@gmail.com, Orcid: https://orcid.org/0000-0002-5843-0076
c Graduate Student, National Research University "Moscow State University of Civil Engineering", 129337, Moscow, Yaroslavskoe shosse, 26, E-mail: zkhnur@gmail.com, Orcid: https://orcid.org/0000-0002-9753-0715
d Graduate Student, Penza State University of Architecture and Construction. 440028, Penza, st. G. Titova, 28, E-mail: nikmorg97@yandex.ru, Orcid: https://orcid.org/0000-0002-3535-7953
AUMENTAR A EFICIÊNCIA DA PRODUÇÃO DE CONSTRUÇÃO COM BASE NO USO DE SISTEMAS E TECNOLOGIAS CIBERFÍSICAS

RESUMO

Objetivo: O artigo propõe uma classificação de sistemas e tecnologias ciber-físicos nas fases do ciclo de vida de um projeto de construção, considera um algoritmo para a escolha dessas tecnologias dependendo da eficácia do projeto.

Quadro teórico: O estudo é baseado na revisão de publicações em revistas científicas internacionais, literatura metodológica sobre o uso de ferramentas digitais na construção. A experiência de diferentes países na aplicação de sistemas e tecnologias ciberfísicas na construção foi representada.

Método: O estudo foi realizado com base em materiais publicados em fontes abertas, incluindo artigos científicos, relatórios e documentos regulatórios. Além disso, o estudo utilizou a experiência de várias empresas que operam na indústria da construção.

Resultados e conclusão: Estudam-se as principais abordagens para o planejamento de projetos de construção na fase do ciclo de vida. Abordagens para a formação de um diagrama de blocos hierárquico gráfico de um modelo de simulação, consistindo em diferentes níveis de aninhamento, são propostas. Os resultados podem ser de interesse para as empresas fabricantes que decidem implementar tecnologias digitais na construção, bem como cientistas individuais que estudam o problema de aumentar a eficiência da organização da produção nas fases dos ciclos de vida dos projetos de construção.

Implicações da pesquisa: Os resultados do estudo podem ser utilizados pelas empresas de construção ao planear a escolha de sistemas e tecnologias ciberfísicos nas fases do ciclo de vida dos objetos de construção.

Originalidade/valor: Os autores propõem uma abordagem que permite escolher ferramentas para projetar e construir objetos usando sistemas e tecnologias ciberfísicos nas fases do ciclo de vida. Um diagrama de blocos hierárquico do modelo de simulação é proposto, que contém mais de uma dúzia de diagramas infantis que combinam várias centenas de módulos típicos menores.

Palavras-chave: construção, sistemas e tecnologias ciber-físicos, BIM, tecnologias de modelagem de informação, eficiência, realidade mista, realidade aumentada, ciclo de vida.

1 INTRODUCTION

Modern conditions of the construction industry development require new approaches to the organization of production in the implementation of investment construction projects, which increase its efficiency at all stages of construction processes.

The environmental conditions for construction companies are characterized by fluctuations in demand for construction projects both in the residential and commercial real estate markets. The following are also important factors:
- the changes in the legislative framework governing the construction industry;
- the introduction of new construction technologies and materials;
- the increase of the degree of enterprises dependence from their own mineral resource base, along with the already established dependence on suppliers and contractors responsible for importing materials and raw materials;
- the rising cost of building materials, components and logistics;
- the increased requirements for the qualification of engineering and management personnel;
- the changes in consumer preferences and etc.

Institutional transformations of the construction industry led to the changes in the conditions and factors of the external environment in which the construction company operates, and, as a result, the need to bring the internal environment into conformity with the external one.

Digital systems and technologies are currently widely used in construction, however, the issues of the effectiveness of the such tools choice depends on the stage of the construction object life cycle, the formation of an effective management system for their implementation in the production organization, and the evaluation of the effectiveness of their use need further research.

The analysis of scientific publications related to the study of the digital technologies integration in construction management revealed a commonality of approaches of various researchers and practitioners to the problems of introducing information systems and developing information strategies for the development of construction.

Attention is paid to impact of human resource management and innovative tools for financial and economic incentives for the companies’ transformation and etc. (Klimovskih et al., 2023, Garnov et al., 2022).

Information modeling of construction processes is currently one of the most urgent tasks of modern construction enterprises. According to the Russian National Portal of Draft Regulatory Legal Acts, a draft Decree of the Government of the Russian Federation has been developed, which provides a list of objects for the mandatory maintenance of an information model (Russian national portal of draft regulatory legal acts). Maintaining the information model for construction projects under the state order...
is mandatory. Thus, construction organizations should already be ready to implement software in the field of information modeling.

Scientific developments, new ideas, research, analysis of foreign experience in this area are needed, which will make it possible to present the direction of development of the Russian construction industry most fully, assess the risks and use the opportunities provided by information modeling, technology, choose means characterized by the optimal ratio of economic costs and the result obtained.

An analysis of the scientific base in the field of cyber-physical systems and technologies indicates a significant interest of researchers in this problem, including both from the standpoint of conducting broad review studies and for solving highly specialized problems.

This is also noted by several researchers, such as Lopez, L. and Lamas (Lopez et al., 2018), who set the task of studying the identification of the most significant publications, the evolution of interest in the topic of building modeling with a view to their subsequent reconstruction. According to their research, the combination of new data acquisition technologies based on methods such as photogrammetry, TLS ground laser scanning, point cloud method, semi-automatic and automatic modeling approaches is of greatest interest.

However, conventional photogrammetry does not allow you to make high-quality 3D models, since its result needs to be corrected. The authors (Reizgevičius et al., 2018) compare photogrammetry and computer vision algorithms, concluding that the best result will be obtained by combining these two methods and creating digital photogrammetry.

Ground-based laser scanning is the most efficient, high-performance means of obtaining accurate and most complete information about a spatial object: an architectural monument, a building and a structure.

But this method is always effective, because before the start of the survey, dismantling work should be carried out so that all supporting structures and networks are cashed out, and as practice shows, this method has proven only in industrial enterprises where there is no finishing. The use of this technique is studied by different researchers (Tsakiri et al., 2015; Glowacki et al., 2016; Brazzetti et al., 2019).

The point cloud method is to use remote sensing tools on the construction site and evaluate it using various metrics. The Bassier method (Bassier et al., 2019) evaluates the
quality of building construction through various metrics and considering vectors of systematic errors.

According to a study by ISSEK HSE (Abdrakhmanova et al., 2021), the prospects for digital transformation of the construction industry are based on the use of virtual and augmented reality (VR/AR), artificial intelligence, wireless communication technologies, and new production technologies. The volume of demand for modern digital technologies in construction will grow by 2030 to 296.7 billion rubles from 14.9 billion rubles in 2020.

Digital technologies are also used in construction control.

Construction control is carried out in the process of construction, reconstruction, overhaul of capital construction objects to verify the compliance of the work performed with the design documentation, the requirements of technical regulations, the results of engineering surveys, the requirements for construction, reconstruction of the capital construction object (Baulin et al., 2019).

Formally, construction control solves the following tasks:

• assessment of the compliance of the quality of construction, reconstruction or overhaul with design requirements, including control measurements and testing of finished structures, as well as materials and products used;
• supervising compliance with technological rules for the production of works, including instrumental control of compliance with technological maps, schemes and regulations;
• carrying out intermediate acceptance of critical structures and examination of concealed works, as well as participation in the acceptance of objects completed by construction, reconstruction or overhaul;
• drawing up reports on the results of construction control at construction, reconstruction or major repairs and timely informing the customer about all violations identified during construction control.

The combination of construction projects and information technology will open up new opportunities for the development of the construction industry and enable "smart construction".

Currently, information models are not created during the construction process. In fact, BIM is created at the design stage, but construction is carried out in classical ways, using 2D paper drawings.
In this regard, the information on the volume of work actually performed does not correspond to the real one, since the construction process uses such terms as, for example, “mounted, but not accepted”, which implies the presence of mounted structures, to which the construction control has claims for quality, and “mounted, but not handed over”, which means installation, delivery of the object to construction control, but the absence of executive documentation.

The main aim of the article to propose a classification of cyber-physical systems and technologies at the stages of the life cycle of a construction project, consider an algorithm for choosing these technologies depending on the effectiveness of the project.

2 METHODS

The study was conducted based on materials published in open sources, including scientific articles, reports, regulatory documents. This made it possible to identify and substantiate the problems of the study.

In addition, there was a survey of eight small and medium-sized companies operating in the construction industry in the Penza region (design organizations, construction and installation organizations), which showed that companies can use certain digital tools, for example, 3D scanning, specialized software for design activities, but did not even try to calculate the cost-effectiveness of the integrated implementation of BIM technologies in construction processes to justify its use.

The reasons given were:

- Lack of initial data for calculations;
- Non-obvious expediency of changes at individual stages of the life cycle of a building product;
- Lack of understanding of ways to link information technologies at the stages of the life cycle into a common system in combination with other participants in the construction process;
- Misunderstanding of methods for calculating the effectiveness of the implementation of information technologies;
- Resistance to changes in the presence of well-established production processes.

The results obtained became the basis for identifying issues and forming research directions.
3 RESULTS AND DISCUSSION

An analysis of studies related to the problem of introducing information technologies in the construction industry showed that their application depends on the type of construction, the construction object, as well as on the stages of the life cycle at which it is located. These integrated stages include design, construction and operation. Classification and approaches to the choice of cyber-physical systems and technologies should be used considering the phase of the life cycle.

According to the approach of Bilenko (Bilenko et al., 2020), there are six technological clusters of cyber-physical systems and technologies that can be applied and adapted for the construction industry.

Executive mechanisms. Used software and hardware to interact with physical objects. Such mechanisms include robots, production process control systems. The use of these tools is possible in the construction industry, as well as at individual stages of construction production.

Sensors. They provide the transfer of information from the physical environment to the information one. They are used in the collection of information for design, in surveys of facilities, in reverse engineering.

Human-machine interfaces. Tools that provide human interaction with the cyber-physical system, Interface for human interaction with the system. Technologies used: tablets, glasses, panels.

Data storage and processing infrastructure. Provides work with data within the digital environment. Includes cloud technologies, servers, blockchain. As a rule, it is most relevant at the design stage.

Data transfer technologies. Provide data exchange between the digital and physical environment. Technologies used: Ethernet, 4G, 5G, Bluetooth, WiFi. Used at all stages of the creation of a building object.

Analysis and data processing. Includes data processing systems for management decision making. They can be used both at the design stage and at the construction and operation stages.

In the process of implementing a project using BIM technologies, cyber-physical systems and technologies are an integral part of the toolkit.

The classification of cyber-physical systems and technologies from these technological clusters at the enlarged stages of the life cycle of a construction object is
combined according to the method of the leader in the production of software in the field of information modeling of construction objects of Autodesk, (Classification Systems and Their Use in Autodesk Revit) (Table 1).

<table>
<thead>
<tr>
<th>The life cycle stage of the construction object</th>
<th>Implementation of the project using cyber-physical systems and technologies</th>
<th>Tools of cyber-physical systems and technologies.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design of a building object, incl. development of a feasibility study, development and examination of project documentation, development of working documentation</td>
<td>Pre-project concepts, design specifications, project documentation using BIM. Development of a BIM model. Construction organization project based on BIM 4D. Project documentation + BIM model (BIM 5D). Design schedule, working documentation based on BIM model</td>
<td>Software, sensors, tablets, cloud technologies, servers, data transmission technologies</td>
</tr>
<tr>
<td>Construction, commissioning of the facility</td>
<td>Construction schedule integrated with BIM 4D, 5D model. Control of the scope of work (according to acts) based on the BIM model.</td>
<td>Sensors, tablets, scanners, panels, smart glasses, cloud technologies, servers, data transmission technologies, robots, additive technologies, industrial process control systems, software</td>
</tr>
<tr>
<td>Exploitation</td>
<td>Building control data. Executive documentation and updated BIM model Asset management, maintenance and repair, monitoring with BIM 6D model.</td>
<td>Software, sensors, tablets, cloud technologies, servers, data transmission technologies, data analysis technologies</td>
</tr>
</tbody>
</table>

BIM technologies allow the formation of three-dimensional models using specifications and technical drawings (2D), geometric properties in a joint model (3D), constructive timing programming (four-dimensional (4D)), scoping and costing (five-dimensional (5D)), project sustainability (six-dimensional 6D)), as well as maintenance and life cycle management (seven-dimensional (7D)).

This resulting information is stored in the BIM database and will allow the creation of a virtual parametric model that can simulate the characteristics and conditions of each element as if they were real.

An important technological aspect of the use of cyber-physical systems and technologies at the operational stage is the need to develop applications that provide...
interoperability with existing BIM models, which will lead to the optimization and unification of their use, as well as the acceleration of the provision of services for the maintenance of buildings and structures.

It is recommended that software development be based on the Building Operations Building Information Exchange (COBie) international standard for information exchange and storage. COBie's ability to support the IFC format makes it the BIM application with the best interoperability in terms of site administration and management.

According to the Russian Ministry of Construction, in 2020 only 7% of construction companies in Russia used BIM technologies, and by 2022 their number has increased slightly. Digital technologies are used in large cities for the implementation of large projects. Small regional companies use such tools only when participating in government contracts. The government sets the task of completely switching to digital technologies for managing capital construction by 2024.

According to the 2019 National BIM Report, 51% of construction companies say that digitalization is making the construction process more expensive.

The main costs of the company in this case are:
- technology implementation costs,
- training costs,
- expenses for internal examination,
- approval costs.

TIM (technology of building information modeling) or BIM (building information modeling) is used to solve problems related to building information management practices. Although it can be said that TIM is a 3D parametric modeling technique for the purpose of combining information obtained during the construction phase into a database to facilitate communication between data points. At present, it is mainly used for various evaluations and analyzes using 3D models, such as interference evaluation, sunlight analysis, field of view analysis, and power consumption analysis. Although BIM is effectively used for analysis using 3D models, it is not used to manage building information by consolidating building information and creating databases.

This may be due to the insufficiency of database systems for managing BIM information and the lack of means to effectively link digital and non-digital information.
Thus, the algorithm for choosing the tools of cyber-physical systems and technologies to improve the efficiency of the organization of production at the stages of the life cycle of a construction object will consist of the following stages.

Figure 1 - An enlarged algorithm for choosing tools for cyber-physical systems and technologies to improve the efficiency of production organization at the stages of the life cycle of a construction object

Source: Prepared by the authors (2023).

On fig. 1 presents an enlarged algorithm for choosing tools for cyber-physical systems and technologies to improve the efficiency of production organization at the stages of the life cycle of a construction object, the fundamental approach of which is a comparative analysis of the costs of implementing digital technology and the effect of its implementation. It should be borne in mind that the effect of the implementation should be considered in total for all stages of the project life cycle.

The implementation of process modeling at the stages of the life cycle of a construction object is carried out based on a decision support system.

The decision support system includes three elements: databases, software base and model base. The base of models also includes three subsystems:

Database management system - DBMS,
Model database management system - SUBM,
Control systems.

In information technology, decision making is supported by the timely processing of databases. The material can be processed using mathematical models for calculations. Digital tools are also used in the process of data collection and processing.

BRIO MRS tablets, lidars, UAVs, as well as some other operational level information systems transmit part of their data.
For the functioning of a decision support system, a company needs internal data on operations, such as engineering data or data on the movement of machines, personnel, mechanisms, etc., which require timely collection, introduction, and support.

At the upper levels of management, data from external sources, such as the market value of materials or ambient temperature, etc., are also of great importance for decision support.

Today, the inclusion of an additional data source in the database is being discussed. These are documents such as records, contracts, equipment passports, orders, passports for materials used, letters, as-built documentation, acts, etc.

The base of models of decision support systems includes models:
- Strategic
- Tactical
- Operational

In the BIM environment, the organization of architectural and construction projects is represented by a set of interdependent processes for creating an information model based on client requests.

It also reveals the problems of construction projects, as well as the factors that cause them.

In TIM, the technologies for designing, erecting and operating an object are always considered in the context of the product life cycle (from the English product life cycle, PLM), in this case it is a construction object. The information model (IM), which is a digital analogue, also has all stages of the life cycle, i.e. from idea to TIM design tools. This allows you to pull out various options for information materials from the structure model that are required to create drawings, as well as for other purposes.

These different materials are automatically matched and based on the same definition of any item instance. In TIM, objects are parametrically conditioned by software; they are defined as parameters and links to other objects. Because of this, if changes are written to the object associated with them, then the dependent objects are also automatically modified. All the components of the model can include attributes, both for automatic selection or their ordering, through the provision of cost estimates, as well as tracking the materials of the structure and considering the object before its reconstruction / dismantling. TIM is based on object-oriented design and the entire software model
working in this technology, based on a large number of pre-created objects, the so-called families, the main project operations are indivisible units, i.e., a kind of "components".

TIM is considered as the very process of building the final model, which carries all the information. An information model is information suitable for computer processing about a projected or existing building object, while IM:

- Coordinated and appropriately interconnected
- Suitable for calculations and analysis
- Interoperable
- Allowing necessary updates
- Having a geometric connection

In (CDE - common desktop environment) the development and development of the model is carried out in the common data environment, which means that all interested parties have constant access to the model, which contains useful and up-to-date information: engineering, chronological, financial.

When creating an object in the process of interaction, the delegation of access levels of persons participating in this for a different circle ensures the clarity and relevance of the data received for each task. Therefore, TIM filling with valuable information covers all stages of the life cycle of a building or structure, and this information content, in turn, reduces the cost of maintenance (OPEX) by several times, reducing the speed of construction, minimizing design errors, while providing all interested parties with quick access to information.

This information environment creates a selection and configuration of software tools, a corporate BIM environment (like templates, libraries, classifiers), gives a description of TIM processes, defines participants and their roles (managers, coordinators, masters, performers).

The use of complex simulations at the highest levels of management is required to establish the company's goals, the amount of resources needed to achieve these goals, the successful conduct of policies, the acquisition and use of resources. Data based on external sources often have an individual character. As a rule, in strategic models the planning horizon is measured in years. These are usually deterministic, descriptive ISs adapted to work in a particular company.

For the middle manager, tactical models are used to allocate and control the use of company resources. Their possible areas of use:
Resource-technological modeling (RTM)

Logistic modeling (LM)

Organizational and technological modeling (OTM)

Organizational modeling (OM)

Risk- and financial-economic modeling (RM, FEM)

When developing a simulation study, the main scenarios are worked out, which become the basis for the formation of an integrated model formed on the basis of various types of modeling.

Operational models to support the adoption of timely decisions are applied at lower levels of management. Applications of these models are human resource management, inventory management and production scheduling, etc. As a rule, operational models use internal data for construction management.

In the modern world, time has become decisive in the formation of an investment object, because the investor pays % for the use of credit money and the faster the investor delivers the object, the faster he can make a profit, this was especially evident when escrow accounts were introduced in Russia during the construction of residential houses. It is also worth noting that the reduction in construction time leads to a reduction in overhead costs associated with the maintenance of the directorate of the customer and the contractor, as well as the maintenance of the construction site (security, utility bills, crane rental, etc.). The use of 4D (4D is an additional measurement factor to 3D - this is time) information model allows you to more easily visualize the sequence of future work performed. After all, it is not always possible to imagine how the building should be built on a 2D drawing in your head. Accordingly, the customer receives a visual representation of the sequence of work. The use of lean manufacturing methods will significantly reduce construction time.

When planning the implementation of an investment project, the following levels of planning are distinguished.

The Level 1 Schedule or Contract Schedule (Project Master Schedule (PMS)) usually defines the main activities and milestones of the project, and fixes the start and end dates of work. It usually takes one page and is used as an attachment to the contract. However, during the implementation of the project, schedules for subsequent levels are developed on its basis.
The 2nd level schedule or the Summary Master Schedule (SMS) includes information from the 1st level schedule, but in a more expanded form, and it is a summarized 3rd level schedule suitable for reporting to the Customer, as well as for presentations without requirements for detail, but for better coordination of the work of subcontractors. It is also rational to use it in large projects, in which it is quite difficult to view the entire project.

The Level 3 schedule or Project Coordination Schedule (PCS) is an integrated overview of the critical path (CPM) of a project. It is used as a reporting project for management and the Customer (on request), and it also belongs to the integrated schedule of the 4th level. At the project execution stage, it determines the overall critical path, and it plays, in general, the role of the main tool for project coordination.

Level 4 Schedule or Working Schedule (WS)

More detailed level 3 schedule. This is the main work schedule. Provides for the loading of resources - people, materials, etc.

Based on the Work Schedule, the status of the project and its timing are tracked. The search for the critical path is also carried out at the level of a detailed schedule, while the work that is on the critical path is expanded to level 4 for optimization and execution control. Thus, the labor intensity of conducting the Production of works is optimized.

The use of the Gantt chart and the critical path method in the construction of calendar schedules does not reflect possible scenarios for changes during the construction period.

The Gantt chart involves painstaking work to maintain a complex network of hierarchical relationships and subtasks. With multi-tasking and complex-sequential tasks, managing the Gantt chart becomes a non-trivial task and its control becomes very laborious, the human factor of collecting data on actually performed work becomes decisive in the implementation of investment projects. The Gantt chart does not make it possible to predict the result when any initial data changes, namely the use of the Agile method in the implementation of projects.

As an alternative, we suggest using the network method of the generated representation of control systems. The essence of the network method is reduced to the construction of a dynamic network model. In this model, the entire process is divided into separate operations, located in a strict technological sequence of their execution. The parameters of work performance are set at the stage of BIM-model formation on the basis...
of technological maps or experience in performing these works and set such parameters as human resources, machines and mechanisms, costs.

When building a BIM model, there is a connection with a network dynamic graph, which reflects the structure of dependent and sequential links. As a result of this work, simulation modeling is launched using the Monte Carlo method. This method allows you to display the cause-and-effect relationships of the elements of the BIM model and the dynamics of changes in each element.

The Monte Carlo method refers to one of the methods of dynamic simulation. The distribution function, its characteristics, the number of values needed for generation are written to the random number generator. Next, the random number generator determines and sets the state of each parameter. Thus, each calculated parameter is assigned an exact quantitative value. This is the presence of imitation and modeling. Further, the parameter values are set within the interval using the distribution function.

This is the value that was assigned by the random number generator, one of the probable values from its interval estimate - it is called the instantaneous. Instantaneous values can characterize the state of one structure, one floor of the structure, and so on. Some instantaneous values may change over time, while others may remain the same over time.

Digital 4D graphics concept

The 4D plotting logic should be based on the Monte Carlo method. As the first pilot project, it is proposed to select the object: "Administrative building in the city of Innopolis" and consider the work only from the preparatory stage to the erection of the building frame.

To form this schedule, it was supposed to perform the following steps:

1. Digitize (set parameters using a simulation model) the operation of all machine mechanisms used at the construction site. These parameters must be dynamically changed depending on weather conditions, productivity, soil type or cargo dimensions and weight. To have the possibility of synchronous operation of two or more pieces of equipment. That, for example, one loads, the other takes away. These parameters are taken from ENIR and RATU (The book "Labor and material costs in construction work 2006" is cost data for planning production at construction sites, which collects aggregated RATU information on labor costs and material consumption of the Republic of Finland).

In doing so, the user must:
A. Set the boundaries, both the movement of equipment and the place of its installation, enter information on the productivity of machines, contours or the boundaries of the operation of special equipment, determine the sequence, and in case of earthworks, determine the depth of excavations indicating the type of soil and landfill for soil removal.

B. The system should support Yandex maps to determine the time of movement depending on the statistics of traffic congestion to the landfill or the import of inert materials, calculate the performance, support Yandex weather to determine the necessary plan of additional actions due to weather conditions (for example, snow control).

2. In the work on the installation of the reinforced concrete frame of the building, it is mandatory to include the following types of work, such as:

A. Arrangement considering the operation of the danger zone, the outreach of one or more cranes, both stationary and on caterpillar or automobile tracks.

The system must also keep track of the time of installation or dismantling of the crane, as well as consider the sequence of work, “know” which of the manipulations were performed by the crane before, and which ones it will have to perform, for example, this is: formwork - mortar - reinforcement - brick.

B. Selection of the installation site of the reinforcing shop and determination of the dimensions and composition of the equipment (along with productivity), storage area and, based on the number of one-time grips, formwork preparation.

C. Based on the number of workers working under the crane, division into grips, (for example, for one tower crane, the number of workers should not exceed 10 people). This includes workers involved in the installation of formwork, tying rebar and laying the concrete mixture, with subsequent care of it.

D. The place of installation of a stationary concrete pump, as well as a truck-mounted concrete pump.

Setting by the user the sequence of work of the system.

Determination of the time to complete the work, considering the machines and mechanisms used, weather conditions (determine based on Yandex weather data)

Delivery time of materials (based on the estimated delivery time according to Yandex navigator).

The purpose of the system is to conduct experiments to determine the optimal ratio of machines and mechanisms, the required number of personnel, determine the time of ordering and delivery of materials and equipment.
The system should issue a job order to the work foreman during the process of performing construction and installation works, in the form of weeks/daily work schedule, and produce predictive analytics based on:

- The number of workers employed at the construction site (based on data received from the CMS with FID, as well as data received from the system of accounting for material assets received at the construction site. Based on the specified parameters, the system must indicate the place of storage of materials;
- Data on the volumes of moved soil obtained from unmanned aerial vehicles;
- Data received from the BRIO MRS tablet about the actual mounted jobs.

When developing a simulation study, the main scenarios are worked out:

- Logical Modeling - modeling of the organizational work necessary to ensure the supply of material and technical resources:
  - Generated by backward calculation from the construction and installation schedule;
  - It is presented in the form of a schedule included in the complex model of the project;
  - Considers the order of material and technical support adopted in the organization;
  - Describes all stages of procurement activities for each assembly/purchase package/lot;
  - Contains information about the timing of each of the stages.

- Organizational and technical modeling - modeling of organizational work required to prepare for the implementation of technological processes.
  - One example is the formation of a schedule for the issuance of RD and CTD:
  - It is generated considering the construction and installation works schedule and the procurement schedule
  - Represented in the form of a graph included in the integrated project model
  - Considers the procedure adopted in the organization for the passage of documentation
  - Describes all stages (from the issuance of initial data (ID) for design to the issuance of RD and DTD for production)
  - Contains estimated deadlines for each stage
  - Allows you to issue weekly-daily tasks to designers, purchasers and other departments, ensuring their well-coordinated work.
The number of key production personnel is calculated in RTM based on the scope of work, production rates and geographical restrictions (capacity).

Organizational modeling - modeling of the organizational structure and staff mobilization plan:
- The number of AMS and the organizational structure is calculated and formed on the principles of manageability;
- The number of support staff and final overhead costs are determined by calculation from the number of AUP and production staff based on the standards of support;
- Linking OM with RTM allows you to create an optimal mobilization plan.

Based on the received simulation scenarios, the Risk Model (RM) is calculated through the inflation model and in conjunction with individual market solutions in the field of risk management. The resulting risk model is considered in the financial and economic model.

Financial and economic model (FEM):
- Calculated by direct resource method.
- It is formed from a set of financial and economic data of all previous models (BIM, RTM, LM, OTM, etc.)
- It is dynamically connected with the above models, which allows, when changing any data in them, to consider the impact of these changes on all financial and economic indicators of the project.

- At the beginning of construction, this model is optimized for a specific contractor, depending on its technical equipment, qualifications of the engineering and working staff.
- Computer graphics greatly increases the visibility and interpretability of output data, which is why it is becoming increasingly popular in decision support information technology.

The simulation model of 4D graphics is developed in the domestic simulation environment GPSS Studio. This environment is one of the most powerful tools for discrete event modeling. Systems like the construction schedule system are successfully explored with GPSS Studio. This tool is a Russian software product, tested in the development of many simulation applications.

Simulation model
As part of the work on the project, a graphic hierarchical block diagram of the simulation model was created, consisting of a maximum of 3 levels of nesting. In general, the graphic scheme contains more than a dozen child schemes that combine several hundred smaller typical modules together. The hierarchy allows you to move from general (enlarged) schemes to more detailed and closer to the structure of a real system. Within the GPSS Studio environment, the user can freely switch from one hierarchy level to another. This allows you to quickly jump to the required fragment of the circuit to analyze and make possible corrections when debugging the model.

The scheme includes a number of generalized elements of the model, task, links of the system and its data: elementary modules, data modules and composite modules, procedures in a special programming language.

Data modules contain information about all system parameters used in the model (they are shown as gray cylinders). Data can be of different types - constants, variables, cells or matrices for storing data, etc. For convenience, all these models are divided into several dozen data modules.

Elementary modules are the final elements of the hierarchy (they are represented by rectangles of any, but more often blue). Each elementary module contains a small-sized model in the GPSS language, which is convenient for the developer to analyze.

Composite modules do not have their own logic (model) but are some generalized level of the hierarchy (shown in the diagram as rectangles of any color, circled in purple).

The first levels of the graphic scheme are more general - they show the general construction, the structure of the system and contain fewer elementary modules. The lower the circuit level is a composite block, the more its circuit contains elementary modules. The division of the scheme into hierarchy levels ends when only elementary modules remain on all child schemes.

An example of the first level of the model hierarchy is shown in Figure 2.

More than fifty data modules (gray cylinders) describe different groups of source data. An example of the content of one of these modules "Movement of reinforcement to the workpiece shop".

In addition, the initial data are described by special matrices. An example of one of these matrices is shown in Figure 3.

This matrix is formed based on the building plan, automatically, for the subsequent calculation of the time for moving the cargo from one point to another.
The first schema level also contains 11 nested child schemas of the second level. An example of one of these child schemes - the module "Unloading transport, delivery of cargo to installation" is shown in Figure 4.

Figure 4 - An example of a child scheme of the second level Source: Prepared by the authors (2023).

Any elementary module contains its own GPSS model.

After building the block diagram, entering all the data, writing and debugging autonomous models for elementary modules, the entire model is automatically generated. As a result, a working model with a volume of more than a hundred thousand lines of source text is obtained.

The most important element of any simulation model is the indicators that the user observes in the model and which are important for understanding the quality of the simulated system and formulating recommendations based on the results of the study.

A feature of the GPSS simulation model is that for each object entered in the model, its own statistics are automatically collected: the final value of the indicator; the dynamics of its change over the simulation period; maximum and average value for the entire period.

For various types of objects, additional indicators are collected: for queues - the time spent in the queue, the current, maximum and average length of the queue; for service devices - load factor, times of occupation and release, etc.

In the model of the production system of the construction site, several hundred different objects are entered, for which statistics are collected. Thus, a huge array of primary statistics is accumulated, which is rather difficult to understand.
Let us give an example of the most important groups of indicators of standard statistics, the most important for the analysis of the efficiency of the system (Table 2).

Such an analysis will reveal the “bottlenecks” of the system, where queues accumulate, warehouses are underloaded, labor shortages, etc.

In addition to typical standard statistics, the simulation application also generates combined indicators. This is important, since the user does not always have the time and ability to analyze a huge amount of the smallest indicators. He needs to be provided with a generalized indicator that is understandable and used in his practical activities.

<table>
<thead>
<tr>
<th>№</th>
<th>Indicator group</th>
<th>Quantitative indicators</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Statistics about the queues of vehicles (with bricks, fittings, components, etc.)</td>
<td>Average time spent in line. Current, maximum and average length of the queue. The number of entries without delay in the queue.</td>
<td>The value of the indicator can be from 0 to an infinitely large number. Depends on the balance of arrival intensity and service performance</td>
</tr>
<tr>
<td>2</td>
<td>Statistics on single-channel and multi-channel service devices (checkpoint, quality assessment teams, reinforcement section, formwork section, reinforcement installation section, etc.)</td>
<td>Load factor. Moments of engagement and release. Average usage time.</td>
<td>The coefficient varies from 0 to 1. A value above 0.8 indicates an excessively increased load</td>
</tr>
<tr>
<td>3</td>
<td>Statistics on actual work performed</td>
<td>Load factor. The amount of work performed per unit of time.</td>
<td>Allows you to calculate the actual performance of the elements or the entire construction site as a whole</td>
</tr>
</tbody>
</table>

Since we are modeling a construction site system that is constantly moving trucks, concrete trucks, workers, etc., knowing how the vehicles and people inside the system are driving is extremely important. The user can step by step track when and where the vehicle appeared in the system, in which queues and for how long it was delayed, how much time the vehicle spent on various types of service, and finally when the vehicle left the system.

Such an indicator is the life cycle, which is output as an MS Excel file and has many tabs, books with life cycle tables for various types of vehicles and production iterations by people. They have differences as they are maintained in different locations, use different infrastructure, and capture slightly different lifecycle stages.
4 CONCLUSION

The analysis of scientific publications revealed a long-term significant interest of researchers in the implementation of information systems in construction to improve the quality of construction products and ensure the efficiency of construction processes from the standpoint of economics, organization and production technology. This led to the presence of a large number of approaches to the classification of information systems and technologies in construction.

Despite the considerable attention of researchers to this problem, the practical application of information technology in construction has significant growth potential. New areas of research are identified in the context of modern economic and technological trends.

In the process of research, the authors classified the main types of cyber-physical systems that can be applied in construction. This will allow you to choose the optimal types of systems in the design and construction.

The choice of an information system used in construction is based on the optimal combination of cost and effect obtained by the enterprise from using the system, and is carried out on the basis of an algorithm that takes into account the main stages of the life cycle of a construction object.

The design of building objects can be carried out on the basis of simulation modeling, which makes it possible to use statistical quantitative data on the use of building resources and, on their basis, optimize all construction processes.

The information model is designed by drawing up multi-level schedules: contract schedule, master schedule, project coordination schedule, work schedule. Thus, with the help of these schedules, you can manage the project at the level of detail of an individual work.

Approaches to the classification of information systems in construction should take into account both the main stages of the life cycle of the construction object and the tools and resources used, which is carried out on the basis of the system and tool selection algorithm.

A hierarchical block diagram of the simulation model is proposed, which contains more than a dozen child diagrams that combine several hundred smaller typical modules. Data modules contain information about all system parameters used in the model.
Such a modular analysis will reveal the “bottlenecks” of the production system, for example, where queues accumulate, there is not enough workforce, etc.

Thus, the proposed models optimize the processes of making managerial decisions at the main stages of the life cycle of a construction object.

The scientific study was carried out as part of the implementation of the program of strategic academic leadership "Priority-2030", a grant from the Industry Consortium "Construction and Architecture" for fundamental and applied scientific research, contract No. 17/k dated 05/16/2022.

ACKNOWLEDGEMENTS

The scientific study was carried out as part of the implementation of the program of strategic academic leadership "Priority-2030", a grant from the Industry Consortium "Construction and Architecture" for fundamental and applied scientific research, contract No. 17/k dated 05/16/2022.
REFERENCES


Novkovich N. et al. (2018) BIM standard and a set of related practical templates for design organizations and technical customer services that apply BIM technology in their work. M: Industrial buildings


