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Alexander Ginzburg
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Building Life-cycle Management. Information Systems and Technologies

Selected Papers

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Preface

The proceedings of the International Conference "Building life-cycle management. Information systems and technologies" submitted for publication are focused on the critical issues of managing capital development projects on the base of information modelling technologies. Nowadays, worldwide the specialists in the sphere of automation and informatization of construction industry are likely to address the issues related to formation and filling the information models at various stages of project's life cycles, to the content of the issues solved on the base of these models, and to technical and organizational interaction of all participants of investment construction process.

In the papers included into the proceedings, the specialists representing more than 10 countries are dealing with the most relevant issues in the following areas:

- Theoretical, methodological and integrating approaches to management of capital development projects life cycles;
- Managing the information models data capital development projects at all the stages of their life cycle, including collection, storing, integration and transfer of data, their monitoring, actualization and analysis, validation and verification;
- Modelling information processes and structures, algorithms of visualization, transformation and analysis of information, synthesis of virtual and augmented reality;
- Creation and development of issue-driven management systems on the base of digital intellectual support for effective decision-making, fuzzy modelling, optimization of capital development projects functioning at all stages of their life cycle;
- Designing organizational structure of enterprises, organizing manufacturing processes and system of their management;
- Information modelling of building systems aimed at the effective management of capital development projects and their complexes at all stages of their life cycle;
- Design management and planning of production processes, including those under conditions of uncertainty and risks;

- Methods and algorithms of managing organizational and information processes in construction;
- Technical rationing and regulation of organization, management and information modelling processes for capital development projects and building systems at all stages of their life cycle.

The International Conference "Building life-cycle management. Information systems and technologies" was dedicated to the 50th anniversary of the Department "Information systems, technologies and automation in construction", the leading department of the National Research Moscow State University of Civil Engineering (NRU MGSU), that is specialized in teaching and conducting scientific research in the sphere of information modelling technologies, automation of management and design in construction industry. Enhanced collaboration of the department with the leading Russian and foreign scientists enabled to compile the current proceedings that provides a picture of the contemporary state of scientific and practical approaches to life-cycle management of construction projects.

I strongly believe that the current proceedings will be of great interest for both scientists and practitioners, as well as for undergraduate and postgraduate students who are knowledgeable about the issues of applying information technologies in construction.

Moscow, Russia Alexander Ginzburg

Contents

Information Modeling Technologies in Building Life-cycle Management

Industry 4.0 Technologies for Ensuring the Functionality of Urban Infrastructure Socially Significant Elements: A Review

Liubov Adamtsevich

Abstract The concept of Industry 4.0 was introduced in Germany in 2011. The purpose of the paper is to analyze the publication activity devoted to research in the development of Industry 4.0 technologies in relation to the construction industry to ensure the safe and reliable functioning of socially significant elements of urban infrastructure. A bibliometric and bibliographic review of international scientific publications was carried out in the paper. The study included collecting data on scientific publications on the research topic, conducting bibliometric analysis to develop a cluster map of the relationship of keywords and conducting bibliographic analysis to select scientific publications for their review. As a result 688 publications remained in the sample. The analysis of the publications made it possible to identify the following key technologies of Industry 4.0 in relation to the set goal: information modeling technologies, IoT and 3D printing.

Keywords Industry 4.0 · Urban infrastructure · BIM · IoT · 3D Printing

1 Introduction

For a long time, the economic model of the society development was unstable, creating significant risks for the development of subsequent generations. Environmental and social issues were not given sufficient attention. All this became the impetus for the development of the concept of sustainable development and measures aimed at the optimal use of limited resources and the use of environmentally friendly - nature, energy, and material-saving technologies, as well as aimed at maintaining the stability of social and cultural systems.

The considered concept contains several goals and objectives, while the most interesting goal for the construction industry sustainable development of cities and towns. At the same time, the modern development of science and technology enables to achieve openness, safety, resilience, comfort and environmental sustainability of

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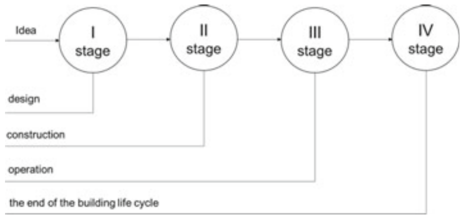


Fig. 1 Generalized diagram of the building life cycle

cities and towns using advanced technologies of Industry 4.0. This concept was presented in 2011 in Germany [1–7], the main goal of which was the development of "smart" factories.

Moreover, despite the skeptical assumptions about the prospects for the introduction of the technologies of this Concept [8], it must be remembered that it took centuries to fully implement the first industrial revolution, but the second revolution took only 100 years, the transition to the third scientific and technological revolution took about 70 years, and the concept of Industry 4.0 was announced 40 years later. Today there could be found already publications devoted to the concept of Society 5.0 and technologies driving its development [9–15, etc.].

In the construction industry, within the framework of the new industrial revolution, its own concept has arisen - Construction 4.0, which involves the digital transformation of the industry [16–20]. In the paper, under the socially significant elements of urban infrastructure, it will be assumed a building, structure, or their interconnected complex.

In accordance with regulatory documents, the life cycle of a building or structure is the period when engineering surveys, design, construction (including conservation), operation (including current repairs), reconstruction, major repairs, demolition of a building or structure are carried out, such the life cycle of a building or structure can be represented in the form of an enlarged diagram presented in Fig. 1:

The largest amount of time in the life cycle of a building or structure falls on the operational stage. In this regard, in the presented work, the choice of promising technologies will be made in relation to this stage of the life cycle of a building and structures. Thus, the purpose of the article is to analyze the publication activity and the choice of Industry 4.0 technologies in relation to the construction industry and socially significant elements of urban infrastructure at the stage of operation.

2 Methodology

To achieve this goal, a bibliometric and bibliographic review of international scientific publications presented in the Scopus database was carried out.

The generalized scheme of the study is shown in Fig. 2 and includes several stages:

1. Collection of data on scientific publications by keywords (Industry 4.0 and Construction 4.0);

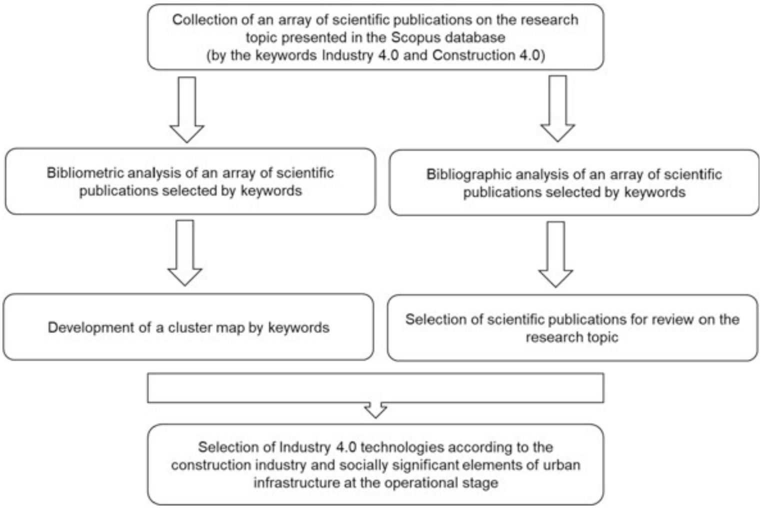


Fig. 2 Generalized research scheme in accordance with the set goal

Table 1 Keyword search statistics for scientific publications

Samples		Number of publications		
		For all time	2011–2020	2021
1	Industrial revolution 4.0 and construction 4.0	114	93 (2016–2021)	21
2	IR 4.0 and construction 4.0	29	17	4
3	Industry 4.0 and construction 4.0	729	593	95

2. Analysis of selected scientific publications:
   2.1. Bibliometric analysis of publications for the development of a cluster map of the relationship of keywords;
   2.2. Conducting bibliographic analysis to select scientific publications for their review.
3. Selection of promising technologies of Industry 4.0 in relation to the construction industry and socially significant elements of urban infrastructure at the stage of operation.

At the first stage, three samples were carried out. Collected data on scientific publications presented in Scopus, including the following keywords and their combinations: the fourth industrial revolution and the construction industry (Table 1).

- Sample 1 - Industrial revolution 4.0 and construction 4.0;

- Sample 2 - IR 4.0 and construction 4.0;
- Sample 3 - Industry 4.0 and construction 4.0.

Further analysis will use sample 3 with 688 publications, selected for the period from 2011 to 2021, since the Industry 4.0 concept was presented in 2011. In addition, using MS Excel, it was found that publications from the previous two samples are also included in sample 3 which is the most complete.

3 Results

3.1 Bibliometric Analysis of the Scientific Publications Array

In Fig. 3 shows a graph demostrating the dynamics of the growth in the number of publications for sample 3, from which a significant increase in interest has been observed since 2016–2017, the most interesting of these publications is discussed below.

If we consider publications by country, then Fig. 4 (a) shows that Germany is the leader with 66 publications, Italy is in second place with 64 publications, China closes the top three (61 publications). Authors from the Russian Federation ranked 6th. The first place could be given to the authors from Germany, in the author's opinion, is since it was this country that first coined the term and concept of Industry 4.0.

The distribution of publications by subject area is shown in Fig. 4 (b). The diagram shows that the largest number of publications is attributed to the engineering and computer science branches. This fact gives the evidence that Industry 4.0 involves digital transformation in various areas of human life.

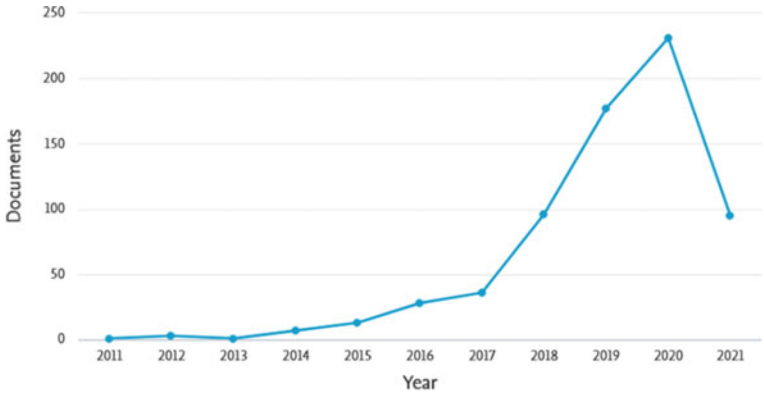
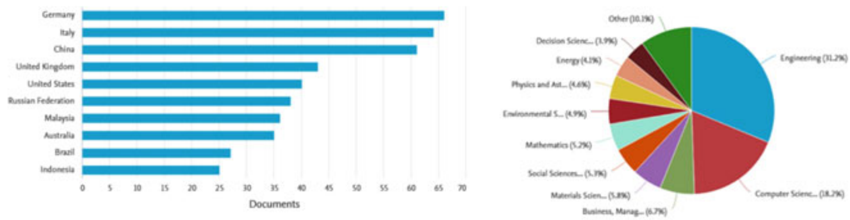


Fig. 3 Documents by years



(a) Documents by country or territory (compare the document counts for up to 15 countries/territories)

(b) Documents by subject area

Fig. 4 Publication statistics

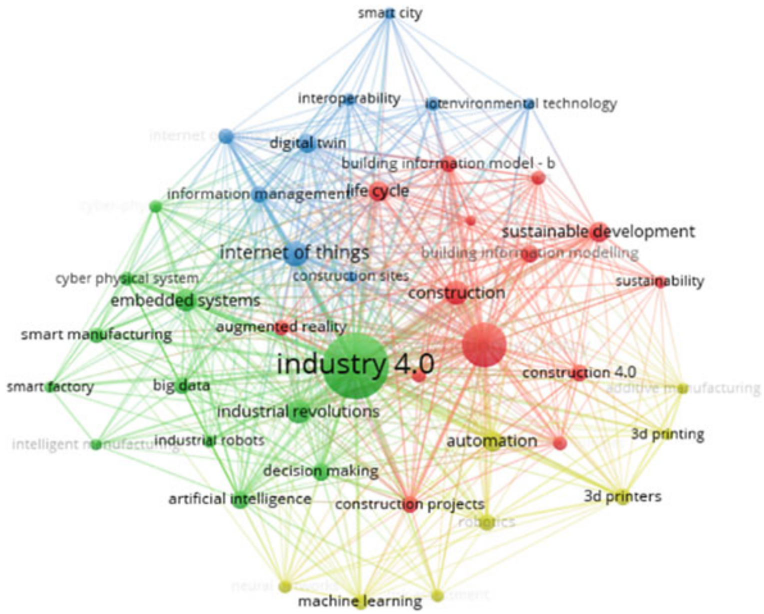


Fig. 5 Cluster map formed by keywords: Industry 4.0 and Construction 4.0

Information about 688 publications was transferred to the RIS format for further analysis in the program Vos view and visualization of bibliometric parameters.

Figure 5 shows the relationship between the keywords of the sample 3. The minimum number of matching keywords in the selected publications was set equal to 10. The threshold value corresponded to 135 words out of 5806. For each of 135 keywords, the program calculated the frequency of simultaneous links with other keywords used in publications. The keywords with the highest frequency and relevant to the research topic were selected. After checking the proposed keywords, 43 most relevant options were selected within the framework of the stated research goal.

Table 2 The most relevant publications in the framework of the presented study from sample 3

Link	Summary	Technology of Industry 4.0
[21]	**The research is aimed at developing a model for managers of construction companies to assess and predict the financial performance of companies. To develop the proposed model in the study, the genetic algorithm method is integrated with a neural network**	**Neural networks (artificial intelligence)**
[22]	The article presents a classification of the construction stages: mechanization, automation, digitalization, and intellectualization. It is noted that automatic control and modeling technologies lead to the fact that the concept of dam construction is changing from a human-centered model to a digital and intelligent mode, which will contribute to the transformation of the type of construction from digitalization to intellectualization	Smart manufacturing
[23]	The article discusses possible cyber-attacks in relation to objects using the technology of the Internet of Things	IoT
[24]	The study examines the positive impact of 3D printing technology on the path of industrialization of construction	3D printing
[25]	The article provides an overview of Industry 4.0 technologies in relation to supply chain management of building materials	3D printing; BIM
[26]	The article is devoted to the analysis of the Internet of Things technology in relation to the construction industry	IoT
[27]	**The study focuses on defining a framework to support the systems engineering of IoT applications**	**IoT**
[28]	The article identifies the types of IoT applications used in the construction industry in Malaysia	IoT
[29]	The article presents a context-sensitive information system of the Industrial Internet of Things (IIoT), which provides decision support for mobile or static operators and supervisors	IoT; cyber physical systems
[30]	**The article presents a load balancing algorithm in big data processing systems**	**Big Data**
[31]	The study aims to integrate BIM-based approaches to improve the management of construction equipment maintenance operations	BIM

(continued)

Table 2 (continued)

Link	Summary	Technology of Industry 4.0
[32]	The article is devoted to determining the merits of BIM together with the technologies of the fourth industrial revolution	BIM
[33]	The article describes the problems and opportunities of 3d printing in the framework of the development of industry 4.0	3D printing (additive technologies)
[34]	The paper discusses potential hazards to consider when assessing the suitability of a UAV or robot for a specific application in the construction industry	Unmanned Aerial Vehicle Robotic
[35]	**The paper presents a solution for identifying gaps and failures of an operator in real time, predicting possible errors in work, based on a comparison of the sequence of actions, considering the experience of a highly qualified operator**	**Augmented Reality; Smart Manufacturing**
[36]	The paper contains the results of a study devoted to the definition of the criteria by means of which organizations are implementing BIM in Malaysia	BIM
[37]	The paper substantiates the need for the training of highly qualified personnel using BIM technologies for the development of the construction industry in the light of the development of the concept of construction 4.0	BIM
[38]	The paper confirms the possibility of integrating BIM with promising technologies in Industry 4.0	BIM
[39]	The paper illustrates the main possibilities of using BIM in relation to the restoration of railways	BIM
[40]	**The study focuses on developing a framework for assessing the life cycle of building materials using building information modeling**	**BIM**
[41]	The paper provides a comprehensive review of the literature and a critical analysis of existing research on Digital Twin applications with the aim of identifying the potential of this technology for research and construction applications	Digital Twins; Cyber Physical System
[42]	The paper provides a study on the gaps that industry needs to fill in the transition to smart manufacturing	Smart manufacturing;

(continued)

Table 2 (continued)

Link	Summary	Technology of Industry 4.0
[43]	The paper presents a bibliometric analysis of issues related to digital production, with an emphasis on the use of a digital twin, as well as research related to monitoring systems with the transfer of information in real time	Digital twin; IoT
[44]	The paper provides an overview of 3D construction printing technology	3D printing
[45]	The paper provides an overview of the current state of the use of augmented reality technologies in construction	Augmented reality
[46]	The paper presents a study on the prospects, opportunities, and limitations in the field of housing design using advanced 3D printing technologies with CAD/CAM systems	3D printing
[47]	The paper presents a summary of the current documents regulating the implementation of BIM in the Czech Republic	BIM
[48]	The paper presents the main trends of modern urbanization associated with the development of smart cities based on the fourth industrial revolution	Smart city
[49]	**The paper proposes an integrated architecture based on CPS for intelligent manufacturing and provides information on its deployment**	**Cyber-Physical System; IoT**
[50]	In this study IoT vulnerabilities have been explained by classifying the types of attacks that threaten the physical layer, network layer, data processing layer, and application layer	IoT
[51]	The paper presents a study on the development of the concept of big data and the possibilities of its use	Big Data
[52]	The paper discusses additive technologies as the main digital technology in the framework of the Construction 4.0 concept	3D printing (Additive technologies); BIM
[53]	The document introduces a new cost-effective BIM-based manufacturing system designed to tackle productivity shortcomings in construction	BIM
[54]	**The study shows the design and implementation of machine learning modules for the web CPS building assistant**	**Cyber-Physical System**

(continued)

Table 2 (continued)

Link	Summary	Technology of Industry 4.0
[55]	The paper focuses on the life cycle of the documentation of product design components, which can be a digital copy, digital shadow, and digital twin of a product, which is performed at different stages of product design	Smart factory; Digital Twins; Digital Shadow
[56]	The aim of the study is to demonstrate the savings in formwork costs by reducing the time using the Internet of Things technology in the construction of floors	IoT
[57]	Study explores possibilities of using the Digital Twin model to improve plant efficiency	Digital twins
[58]	The paper discusses the possibility of collaboration in the BIM environment	BIM
[59]	The paper discusses the Internet of Things and additive manufacturing for the creation of intelligent manufacturing systems in Industry 4.0	IoT Additive technologies
[60]	**The system proposed in the paper is a platform for collaboration between humans and robots at a construction site. Platform follows the operator and moves heavy loads**	**BIM** **Robotic**
[61]	The document is devoted to the first design protocol for a modular anti-seismic home that is 3D printed and assembled on site using a mixture of recycled materials	3D printing
[62]	The document summarizes Industry 4.0 related technologies used in the construction industry based on an analysis of industry characteristics. In addition, this study presents the structure of a cyber-physical system to integrate these technologies and improve the overall capabilities of the organization of construction and management	Cyber-Physical System
[63]	The study is divided into four parts. The first part describes the mathematical apparatus for parametric modeling of complex concrete surfaces. The second part is aimed at describing modern architectural trends in the production of complex concrete structures, modeling and analyzing the possibility of realizing complex surfaces. The third part describes the materials for the technique. The fourth part is a demonstration of the entire manufacturing process, formwork processing and concrete pouring	Robotic

(continued)

Table 2 (continued)

Link	Summary	Technology of Industry 4.0
[64]	This article synthesizes the current state of the practice of the digital twin in construction by reviewing the existing literature and proposes a framework that classifies the level of integration in construction into three subcategories: digital model, digital shadow, and digital twin	Digital twins
[65]	Using 128 responses from industry practitioners, the paper explores the integration of AR between various stakeholders in construction and throughout the lifecycle of a construction project	Augmented reality
[66]	The paper discusses the prospects for using big data as an element of the fourth industrial revolution and the future of the construction industry	Big Data
[67]	The paper examines the Digital Twins of the presentation of concrete modules in the interdisciplinary context of the construction and manufacturing industries	Digital Twins
[68]	Taking advantage of the BIM model and 3D laser scanning technology, the paper suggests that their combined use will help improve the accuracy and efficiency of the quality management process in the construction industry	BIM; 3D laser scanning
[69]	The paper attempts to explore the potential of BIM as a tool to promote greening of existing non-green buildings	BIM
[70]	The study focuses on artificial intelligence and its ability to improve knowledge management in the UK construction industry	Artificial intelligence
[71]	**The paper demonstrates the process of designing a factory robot using post-installed anchors under load in concrete based on BIM as part of the development of Industry 4.0 technologies**	**BIM** **Robotic**
[72]	The paper discusses the potential hazards that should be considered when assessing the suitability of a UAV or robot for a specific application and provides recommendations for the use of hazard recognition tools	Unmanned aerial system Robotics
[73]	The article describes the possibility of using BIM technologies at the stage of decommissioning an object	BIM

(continued)

Table 2 (continued)

Link	Summary	Technology of Industry 4.0
[74]	The paper discusses the transfer of the concept of digital twins to the production of precast concrete products in the construction industry	Digital twins
[75]	This article presents preliminary studies to identify potential uses of Building Information Modeling for supply chain management in construction	BIM
[76]	To improve the management of environmental monitoring of smart cities garages, this study proposes an approach to integrating a wireless sensor network and BIM and develops an advanced environmental monitoring system for underground garages using digital twin technologies	BIM Digital twins IoT
[77]	The paper provides an overview of the current state of development of Industry 4.0 technologies in Brazil	
[78]	The paper presents a study on the use of BIM to improve construction safety	BIM
[79]	The paper provides an overview of Industry 4.0 technologies applied to the construction industry	
[80]	Automation of construction production processes using digital BIM objects is presented in the paper	BIM
[81]	**This paper shows that specific 3D printing processes, and CONPrint3D technology, have advantages over traditional wall designs, with proven cost and time savings**	**3D printing**
[82]	The research is prepared to study the contractors understanding and readiness of additive manufacturing within the scope of a Malaysian state's construction industry, Penang	Additive technologies
[83]	The article aims to analyze the definitions of the digital twin to clarify this concept in the related fields of architecture, engineering, and construction	Digital twins
[84]	An overview of the applicability of BIM technologies at various stages of the life cycle of a construction object	BIM
[85]	The study identifies and evaluates the problems of IOT implementation in construction projects	IoT

(continued)

Table 2 (continued)

Link	Summary	Technology of Industry 4.0
[86]	The paper comprehensively examines the description of 3D printers within Construction 4.0 with an emphasis on transport construction	3D printing
[87]	This paper presents a curriculum for teaching UAV flight dynamics based on the conceptual framework of educational mechatronics	UAV
[88]	The paper provides an overview of promising Industry 4.0 technologies within the construction industry	3D printing Big Data; IoT Virtual reality
[89]	The study aims to understand and develop a theoretical framework for Industry 4.0 through machine learning integrated into automatic construction progress detection and data collection technologies	Machine learning
[90]	This paper presents two projects that explore how machine learning can revolutionize production data generation in the construction industry	Machine learning
[91]	The study promotes a deep understanding of BIM-based modular integrated design	BIM
[92]	The paper presents the prospects for the use of additive technologies in the development of the construction industry	Additive technologies
[93]	The paper provides an overview of the possibility of applying BIM technologies to transport infrastructure	BIM
[94]	The paper presents the reproduction of a virtual warehouse using parametric digital modeling, with which all control data is associated	BIM
[95]	The paper provides an overview of 3D printing technology	3D printing
[96]	This publication provides insights into the Industrial Revolution and Industry 4.0, including information on IoT, IIoT, and cyber-physical systems for smart environments	Cyber-physical systems IoT Industrial IoT
[97]	The paper formulates the principles and methods of integrating BIM technologies and digital twins within the framework of the so-called “Factories of the Future”	Digital twins BIM
[98]	This study aims to identify and rank the perceived level of importance of the main areas of research related to the Internet of Things and the construction industry	IoT

(continued)

Table 2 (continued)

Link	Summary	Technology of Industry 4.0
[99]	The article provides a literature overview of the integration of BIM technology and the Internet of Things	BIM IoT
[100]	This article presents the main differences between the digital twin and the digital shadow	Digital Twins

Figure 5 shows 4 interconnected clusters. The first cluster (marked in green) is built within the framework of the Industry 4.0 Concept and includes technologies such as cyber physical system, embedded systems, decision making, artificial intelligence. The second cluster (highlighted in red) describes the Construction 4.0 Concept and sets its main goal - sustainable development, where information modeling technology is one of the priorities. The third cluster (marked in blue) combines the concepts of Industry 4.0 and Construction 4.0 and includes technologies such as smart city, digital twins, internet of things, etc. The fourth yellow cluster describes additive technologies as one of the most dynamically developing areas in construction.

3.2 Bibliographic Analysis of the Scientific Publications Array

To select promising technologies of Industry 4.0 in relation to the construction industry and socially significant elements of urban infrastructure at the stage of operation, from the general array of publications, 80 publications were selected for analysis. A summary of the publications and the key technologies of Industry 4.0, which they contain, are presented in Table 2.

Table 2 shows the results of the analysis of publications presented in sample 3 for key technologies. Papers containing research or proposals for the development of Industry 4.0 technologies in Table 2 are highlighted in bold [21, 27, 28, 35, 40, 49, 54, 60, 71, 81]. Thus, it should be noted that, in accordance with Table 3, most publications are reviews.

Table 3 Keyword search statistics for scientific publications

Technology \ Year of publication	2014	2015	2018	2019	2020	2021	Summary
BIM			1	10	11	4	**26**
3D printing			2	4	6	1	**13**
IoT			5	3	5	3	**16**
Robotic					3		**3**
Augmented reality				2	2	1	**5**
Cyber-physical systems			1	3	1	1	**6**
Digital Twins				2	6	2	**10**
Digital Shadow				1			**1**
Machine Learning					2		**2**
Artificial Intelligence	1						**1**
UAV				1	1		**2**
Big Data				2	2		**4**
3D laser scanning					1		**1**
Smart city				1	1		**2**
Smart manufacturing		1		3			**4**

4 Conclusions

The analysis made it possible to determine the most used technologies of Industry 4.0. However, the purpose of the study was to identify promising technologies to ensure the smooth functioning of socially significant elements of urban infrastructure. In this regard, let us consider the technologies with the largest number of references in the sample under consideration:

– Building Information Modeling (BIM)- the process, because of which the information model of the building is formed.
– Internet of Things (IoT) - the concept of a data transmission network between physical objects equipped with built-in means and technologies for interacting with each other or with the external environment. At the same time, the key feature of this technology is the ability to eliminate the need for human participation from part of operations.
– 3D printing (additive technologies) - Technologies of layer-by-layer building up and synthesis of objects using a 3D construction printer.

The author has already published some papers about development and application of BIM technology to ensure the reliability of building structures [101]. Since the elements of urban infrastructure are considered at the operational stage, the 3D printing technology in this context is not relevant for consideration, too.

Consider the relationship of the Internet of Things with other key technologies of Industry 4.0 (Fig. 6).

As seen from Fig. 6, IoT technology is a link between other technologies featuring the fourth industrial revolution, such as digital twins, smart cities, cyber-physical systems, etc. Thus, further research will be devoted to the issues of determining new

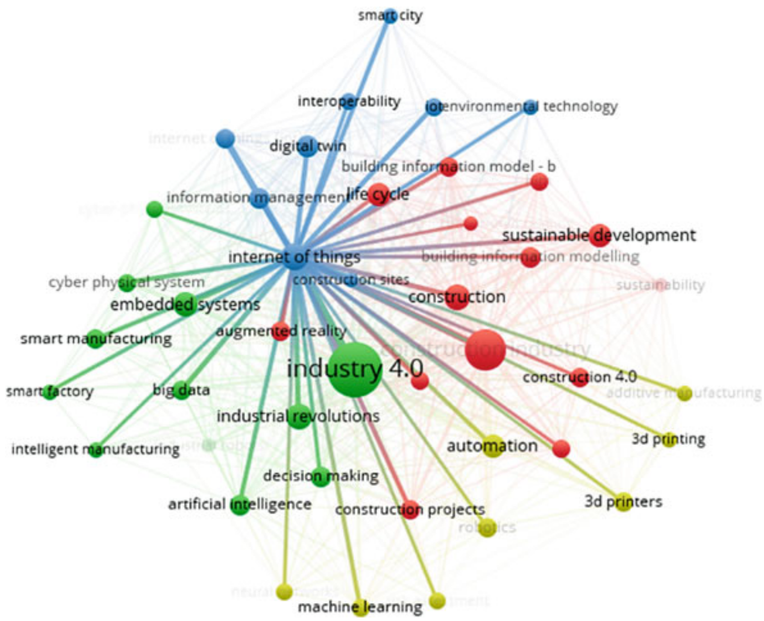


Fig. 6 Relationship of the Internet of Things with other key technologies of Industry 4.0

properties of building objects applying these technologies, as well as identifying possible risks during their integration at the facilities.

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BIM-Technologies in Digital Modelling of the City Water Utility Operation

Tatyana Alekseeva and Stanislav Alekseev

Abstract To speed up the process of the national economy's transition to new technological paradigm, there emerges the urgent need for upgrading of all the economy's spheres, in particular water and sewage utilities, on the base of digital technologies. The development of digital models on the basis of the approach proposed by the authors is regarded as one of the trends of digital transformation for water utilities. The innovative approach is based on the ontological model technology, BIM- and GIS-technologies and presupposes digital modelling of water utility operation in its interconnection with BIM-models of the objects of the water and sewage utilities systems as well as the information models of technological equipment for these systems. The present paper specifies the following notions: "BIM-model of the object of water supply and disposal system" and "Information model of technological equipment for water supply and disposal systems". Application of the research results in water utilities' operation will enable to improve the quality and reduce the working cost of provided services, will ensure the saving of infrastructure investments pumped into water and sewage facilities and facilitate the accelerated transition of the domestic economy to new technological paradigm.

Keywords Digital transformation · Digital model of a water utility · Facility upgrade · BIM-technologies · Service life

1 Introduction

In order to accelerate the transition of the national economy to a new technological paradigm, it requires modernization and digital transformation, in particular of the sphere of water and sewage utilities. The scientific works [1–20] are dedicated to this issue.

Digital transformation of enterprises responsible for the maintenance of water and sewage utilities systems (water utility) includes modernization of the main and

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supportive processes related to their production and economic activities, upgrade of the management system for the water and sewage utilities by applying BIM-technologies, altering the relationship with resource suppliers, consumers and other subjects, assimilation of new technologies, etc. [1–7]

The evidence from practice shows that many organizations are gradually getting aware that their digital transformation is supposed to start from the creation of a conceptual model of its activity rather than acquisition of cutting-edge costly software and hardware complexes. Along with that, there could be a need for modernization of existing technologies, managerial processes, etc. For them to operate automatically, it is essential to obtain efficient software that must be integrated inter se and with the software already in use at an enterprise.

Thus, development of digital models of water and sewage utility operation by making use of information and other modern effective technologies could be regarded as one of the crucial tasks.

The notion of "digital model of water utility operation" and the approach to this model formation were introduced by the authors in the journal "Water supply and sanitary technique", issue 2, 2020 [5]. This term presupposes the entire model evolving throughout its service life that is developed with the aid of ontological modelling technology and the effective tools of modernization of urban water utility operation (BIM- and GIS-technologies, management techniques for the facilities of water and sewage utility system, and others) factoring in the provision of software and hardware complexes cross-linked in the united informational space [5].

Digital model of water utility operation enables to account, accumulate and pass on the expertise throughout its development. While developing such a model, the conceptual model of water utility operation is primarily formed, all the elements are structures and cross-linked. On its base, information system of water utility operation supported by IT-applications is modelled, information and technological infrastructure of water utility is formed. The latter comprises hardware and general software for IT-applications.

Conceptual model of water utility operation represents structuring and describing the activity of water and sewage utility enterprise:

- According to the performed tasks related to the principal activity of water utility (for example, the tasks connected with potable water supply, waste water disposal, maintenance and repair of technological facilities, water supply and sewerage systems, etc.), and also referred to supporting activities (for instance, the tasks related to investment activity of an enterprise of water and sewage utility, financial operations, accounting, acquisition, etc.).
- Under the subjects related to water utility operation, including external subjects (consumers of water and sewage services, suppliers, regulatory bodies, various organization acting as mediators, consulting and insurance companies, and others) and internal subjects (enterprise departments of water and sewage utility, their employees and others).
- According to the facilities of water supply and sewage systems, other material and non-material objects.

– In compliance with document procedure of enterprise activity for water and sewage utility. It reflects managerial models of tasks fulfilment related to water utility operation as well as the relations between the subjects under the certain conditions. In-house documentation includes internal codes of an organization, rules and procedures, instructions, etc. External documentation comprises international codes, state and industry-specific standards, norms, and contracts executed with other organizations, etc.

All the elements of the considered model of water utility operation are interrelated and cross-linked. When forming the digital model of water utility operation, it should be considered that the model is developed in space and time (both geographical and infrastructural) [5].

In relation to enterprise activity of water and sewage utility operation, the zone of water utility's operational responsibility is assumed as space.

In relation to the model of technological equipment operation, a building or a structure where the proposed installation takes place is assumed as space.

When creating a model of managing service life of a building or a structure, for example, water pumping station, geo-information system of water utility is regarded as space.

The duration of enterprise service life for water utility, service life of a building, a structure, water or sewerage network, technological equipment, and other could be considered as the notion of "time".

According to our reckoning, modernized management system for water and sewage utilities with the aid of BIM-technologies should be incorporated into the digital model of water utility operation.

This will enable to plan the possible scenarios of information model development for water and sewage utilities and technological equipment as well as the digital model of water utility operation in the large throughout further stage of their service life.

1.1 Materials and Methods

The major part of water utilities in Russian cities applies similar technological, organizational, managerial and other processes in their production and commercial activity.

Having studied the issue, the authors considered activity of many enterprises operating the systems of water supply and sewage in the towns located in Central, North-Western and Ural Federal districts.

The results analysis has shown that many manufacturing, organizational and managerial mechanisms and methods used at water utilities in the framework of their operation are in need of upgrade.

It is worth mentioning the presence of worn-out state of water utility capital assets accompanied by the shortage of investments. The high degree of wear and tear of technological equipment, construction and special machinery, vehicles and other capital assets leads to the growth of expenditures allocated to their maintenance and to increase in self-cost of the services provided by water utilities.

Solution of this issues requires development of new mechanisms accelerating upgrade rate of the water utility capital assets.

In the course of the present study, there were considered the methods and technologies applied when enterprises of water supply and sewage utility interact with design organizations. The analysis has shown that so-called "traditional" technologies of estimate documentation preparation are mainly used. This clearly demonstrates the issue of many organizations, i.e., a cost consultant joins the design process at the very last stage that leads to extending the design phase, and consequently, the life cycle of the entire investment construction project.

Modernization of the construction documents development process with the aid of BIM-technologies is urgently required in the considered enterprises.

It is worth mentioning that scientific literature studying the issues of digital modelling in the sphere of water supply and sewage utilities is rather scarce at the moment.

2 Results and Discussion

Conceptual modelling of water utility operation is considered the first priority step in the process of their digital transformation.

While developing such a model, the authors of the present paper proposed to ensure its interrelationship with BIM-models of water supply and sewage utilities and also with the information models of technological equipment for these systems (Fig. 1).

It is assumed that a BIM-model of the object of water supply and disposal systems is a model of a technologically connected object (structure, building, linear object, and other) with other facilities of water supply and sewage systems an evolving throughout its service life that represents the summary of physical, functional and other digital characteristics of this facility and cross-linked to both information models of technological equipment for these systems and the digital model of water utility operation.

BIM-technologies ensure development of multi-dimensional information models of building and structure as well as of linear objects. In the process of designing the facilities of water supply and sewage systems, their 3D-, 4D-, 5D-, and 6D-information models are elaborated.

The Fig. 2 demonstrated the scheme of information model development for the facility of water supply and sewage system in full compliance with the principal and supporting processes of water utility operation as well as the other information models, etc.

3D-model of the facility of water supply and sewage system represents a dimensional information model of the given facility. It includes its geometric parameters,

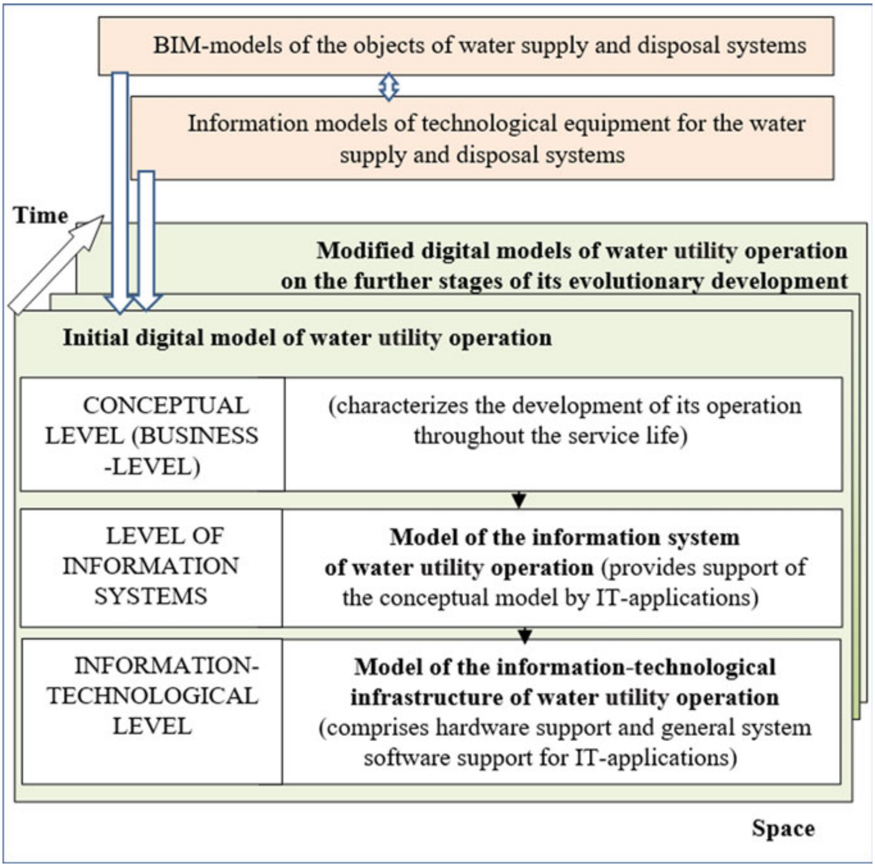

Fig. 1 The diagram showing formation and development of a digital model of a water utility operation in its interconnection with BIM-models of the objects of the water and sewage utilities systems as well as the information models of technological equipment for these systems

the data on its structure, the materials used, installed technological equipment, etc. On the base of a 3D-model, a 4D-model is formed factoring in the data on time. When the data on the object cost is accounted for, 5D-models are developed.

On the basis of the information incorporated into 5D-model and considering the data on prospective maintenance of the system of water supply and sewage utility, the 6D-model is elaborated.

While simulating an object in the BIM-model, all amendments should be taken into account in full compliance with actual performance of a project. Using the information obtained on the base of executive schemes and fieldwork, executive BIM-model of water supply and sewage system is created.

When the facility is constructed and delivered to a contractor, the BIM-model is passed on the operation department of water utility. This department develops

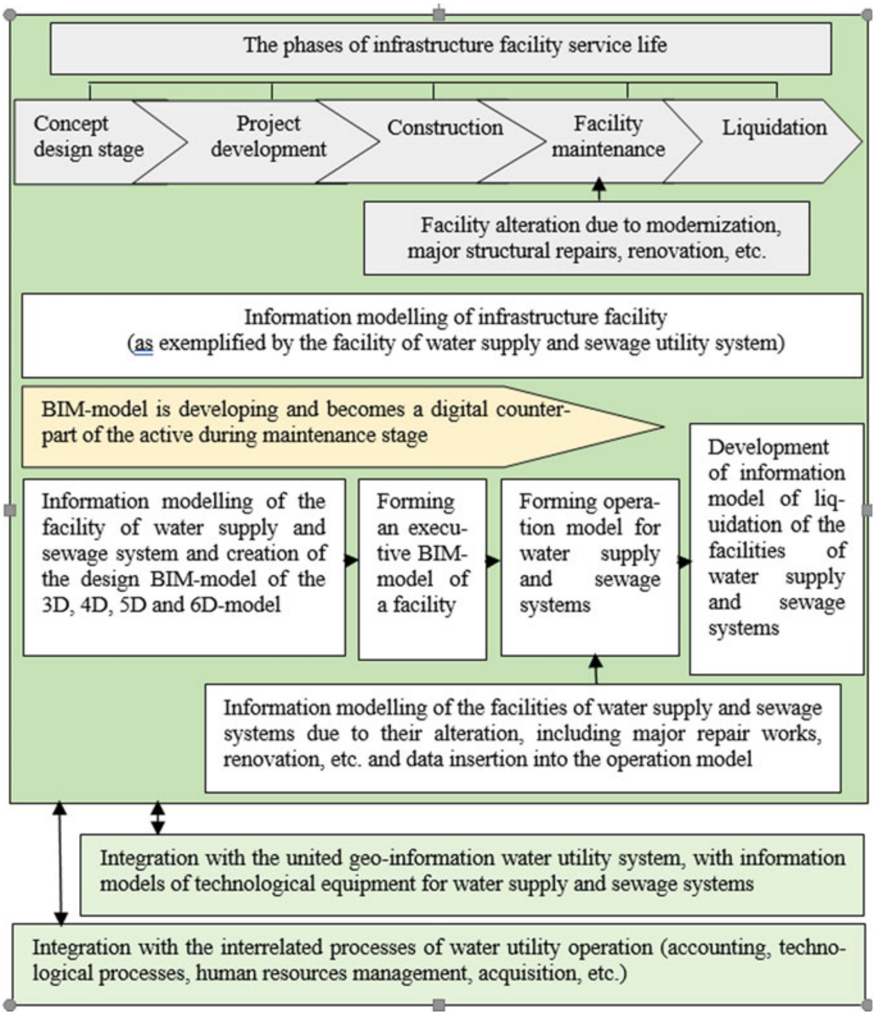

Fig. 2 The diagram of BIM-model development for water supply and sewage system object factoring in its interrelationship with information model of technological equipment for these systems as well as the principal and supporting processes of water utility activity

the protocol of technical maintenance and repair of the facility of water supply and sewage utility systems, makes the necessary amendments to the BIM-model, etc.

During the maintenance of such a facility on the base of the BIM-model data, the maintenance service of water utility can exercise the control of the state of its structural members, engineering systems, and technological equipment. If a utility undergoes major structural repairs or renovation, the necessary amendments are done to the BIM-model as well. When a facility of water supply and sewage system becomes unserviceable, a project of its liquidation is designed.

By applying BIM-technologies, the process of preparing cost-estimate documentation is accelerated; thus, documentation could be easily amended if design solutions are subjected to change. The parameters of efficiency of design work organization are improved, the effectiveness of finance management is increased, etc.

Modern technologies ensure the possibility of integrating the developed information model of a building or a structure with geo-information system of water utility and other digital models (Fig. 2). These interrelated information models should be integrated into the general digital model of water utility operation.

The research results have shown that stumbling renovation of capital assets due to the investments shortage could be regarded as one of the issues in production and commercial operation of city water utilities.

Unfortunately, the actual service life of capital assets in the operation of the considered enterprises exceeds their standard service life. Increasing the age of technological equipment, construction and special machinery leads to the growth of operational costs attributed to capital assets. This results in the increase in self-cost of water supply and sewage services provided by water utilities. All the above-mentioned factors precondition the need for developing effective system for managing capital assets on the base of digital models' formation.

The model of technological equipment evolving throughout its service life and technologically related to facilities of water supply and sewage is assumed as an information model of technological equipment for water supply and sewage systems. The model represents the summary of physical, functional, cost-related and other characteristics of this facility in a digital format and is interrelated with a digital model of water utility operation.

3 Conclusion

Development of digital models of water utility operation with respect to the proposed approach is regarded as the first priority task of digital transformation.

Formation of digital models of water utility operation should be implemented with respect to their interrelationship with BIM-models of water supply and sewage systems, and also with information models of technological equipment for these systems. This will enable to plan more effectively the possible scenarios of models' development throughout further stage of their service life.

The effectiveness of applying the research results for city water utilities lies in the fact that formation of construction projects of water supply and sewage facilities will be accompanied by the financial risks lowering, project timing reduction, and will ensure the quality of layout arrangement while arranging the main and supporting technological equipment. It will enable to prepare cost estimate documentation on the sidelines of project development, the control is ensured at all the stage of water supply and sewage facility's service life and timely amendment management, etc.

Also, an opportunity of effective solution of urban planning issues is provided. The coordination processes for new construction sites would be eased, the control over the state of engineering infrastructure would be improved, etc.

Adaptation of the research results into water utility operation will facilitate quality improvement of provided services of water supply and sewage, will lower their self-cost, ensure the saving of infrastructure investment into water supply and sewage sector and facilitate the transition of the national economy to a new technological paradigm.

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Theoretical Basis of the Development and the Possibility of Monitoring Systems Design Automation for Load-Bearing Structures

M. V. Emelianov

Abstract Currently, the number of complex construction projects, unique, high-rise and large-span structures (the category of buildings and structures of "high responsibility") is growing in the world. Preventing accidents of these types of buildings and structures is an important task due to possible negative consequences: human, material and moral losses.

This article discusses the existing theoretical provisions on the design of a structural condition monitoring system (SHM). This system is necessary to monitor the safety and reliability of load-bearing structures.

A variant of automation of data analysis processes at some stages of the development of the SHM system project is proposed.

In the course of the research, the analysis of Russian regulatory documentation on the design SHM system, the methodology for building control and measuring systems, as well as the results of scientific research in the field of SHM development was carried out.

The main stages of the development of the SHM system and the possibilities of automating work on some of them are determined.

Keywords Monitoring · SHM · SHM system development · Automated monitoring · Real-time monitoring · Automated SHM system design

1 Introduction

The modern trend in construction around the world is an increasing number and complexity of the 'high responsibility' category of building objects being built.

The accidents including a partial or a total destruction of building structures still occur. Therefore, the developments in technical monitoring of building structures are relevant.

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Automation of structure health monitoring systems (hereinafter - SHM) development in particular is an urgent task due to the increase in the number of objects of increased responsibility and the need to equip them with the SHM. This is also the case in regulatory documentation in Russia.

Currently, information models (Building Information Model) are used in the design of construction objects – an open database for storing and exchanging information about the object. Creating a BIM model of an object allows you to reduce costs during the reconstruction and restoration of the object. Equipping a facility with SHM system allows us to obtain current data about the load-bearing structures of the object. These data are used to update the BIM model [7, 12].

In this paper, the existing provisions on the design of SHM are considered, the automation of data analysis processes at some stages of SHM development is proposed.

2 Methodology

As a part of the current research, the Russian regulatory documentation on the design of SHM, global research in the field of methodology for the measuring systems construction and information for development of SHM were analyzed. In addition, the main stages of the development of SHM were defined.

The data decomposition method was used during the analysis of the stages of SHM development in order to determine the possibility of automation during the development of the SHM project at various stages.

Methods of algorithmizing and data structuring were used to automatically determine the monitoring mode and determine the most loaded elements of the structure.

3 Results

According to the results of the analysis of global research data [1, 3–6, 8–11, 14–21] it was noted, that currently the control of load-bearing structures is the most efficiently performed using a system for monitoring the technical condition of structures, including automatic monitoring systems operating in real-time mode.

According to various regulatory documents, the SHM system must be installed on construction objects of 'high responsibility' category, objects of complex design and unique objects [13]. The SHM systems must be developed for each object individually.

The threat models, the implementation of which will worsen the technical condition of the object, should be determined at the beginning of the design of the SHM. Based on the threat models, a list of controlled elements, controlled parameters and criteria for assessing the technical condition of an object were determined. A finite

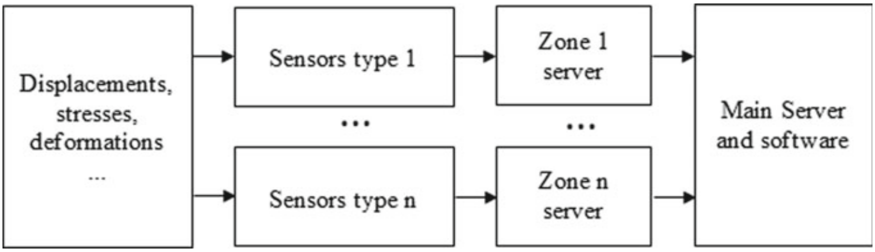

Fig. 1 The structure of the SHM and SHM communication scheme

element model was used to determine ranges of parameter values corresponding to various technical conditions of structures.

Based on the results of the analysis of the global research data on the SHM design, the SHM structure and SHM communication diagram can be represented by the following structure scheme (Fig. 1):

The main elements of the SHM system are:

– The transducers and sensors;
– Data acquisition and recording systems;
– Main server and software.

A transducer and sensors are used to register various parameters that determine the stress–strain state of structural elements of a construction.

The data acquisition system is used to convert signals from analog to digital and store data.

The main server and software are used for:

– Operating data acquisition process;
– Processing and analysis sensor data;
– Notifications about exceeding the set limit values.

The development of the SHM system is carried out according to one of the schemes: concentrated and distributed (Fig. 2a, b). (In Fig. 2, the dots indicate the sensors of the SHM system, the lines indicate the elements of the data collection system).

In process of designing the SHM system according to a concentrated scheme, data acquisition and processing are performed on a single main server, therefore, increased requirements are needed for the necessary reliability and performance of the main server [8].

When designing a SHM system using a distributed management scheme, data acquisition and analysis are performed on several servers. The failure of one of them does not lead to the failure of the entire system. Using a distributed scheme (Fig. 2b), the requirements for the speed of the data processing and analysis system are reduced, but this scheme is more complex compared to the concentrated scheme (Fig. 2a).

Automating of the SHM design for buildings and structures of a high responsibility category will reduce the time needed to develop the system by optimizing the design process.

The main stages of the development of SHM systems [3, 5–8] and the possibilities of automating at these stages are shown in Table 1.

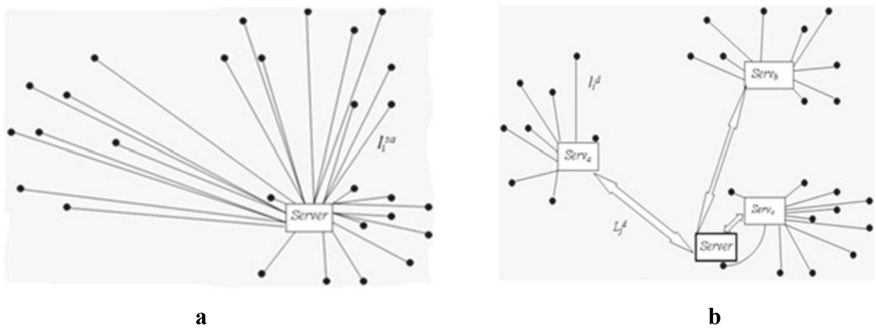

Fig. 2 **a** The concentrated scheme. **b** The distributed scheme

Table 1 Stages of work on the development of the SHM system project and automation

The main stages of the development of the SHM system project	Possible automation
Collecting data about the construction object and the construction site	No automation. Automated processing of questionnaires is possible
Monitoring mode selection	The development of an algorithm and a program for determining the rational mode of monitoring is possible
Identification the threat models	No automation. Determines the expert estimates based on information about the object and the location of the construction site
Generating a list determining the list of controlled structural elements Determination of control parameters	Performed by an expert based on the analysis of design documentation and the results of finite element modeling Simplification of the analysis of the FEM is possible with the use of an automated macro for determining the most loaded elements or the maximum elements displacements
Calculation of ranges of values of controlled parameters corresponding to different modes of operation of a building or structure	No automation. Calculation of the ranges of controlled parameters is performed for each sensor based on the results of FEM
Determination of the rational measuring equipment list	Automation is possible. It is necessary to develop a methodology on the basis of which the composition of measuring equipment is analyzed, as well as a program for analysis

Automated analysis of data about the object and the results of engineering surveys is possible when developing a digital form of the questionnaire.

Determination of the rational monitoring mode in automatic mode is possible using the comparison method for construction object and the requirements of regulatory documents according to the algorithm (Fig. 3). The result of the algorithm is the conclusion about the rational monitoring mode of the construction object.

Controlled elements and controlled parameters are determined by experts based on the results of the analysis of the FEM of the construction [2].

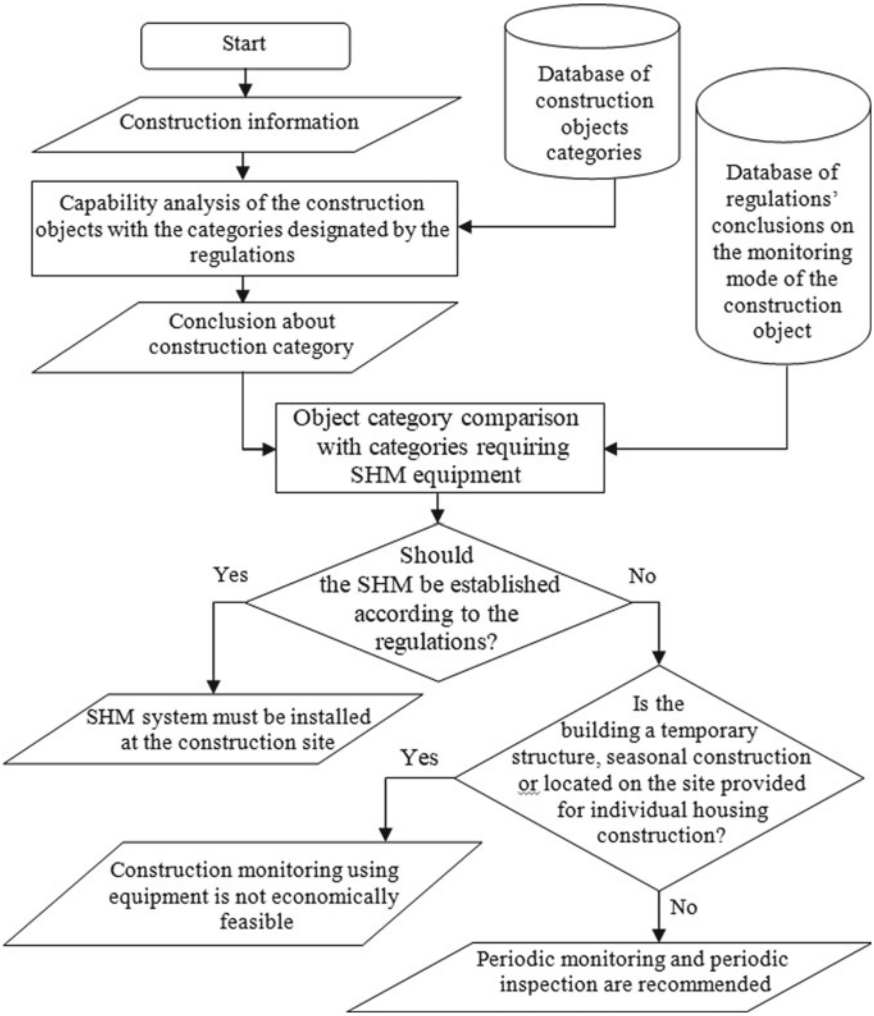

Fig. 3 Algorithm for determining the monitoring mode [2]

Simplification of the analysis of the FEM is possible by applying a macro for determining the most loaded elements (Fig. 4).

The use of this macro enables to automatically determine the nodes and elements of the FEM model with stresses and displacements, the values of which make up a specified percentage of the permissible maximum values. In addition, the use of this macro allows determining in automatic mode the most loaded zones of structural elements, which is necessary to determine the control parameters and requirements for the accuracy of measuring equipment.

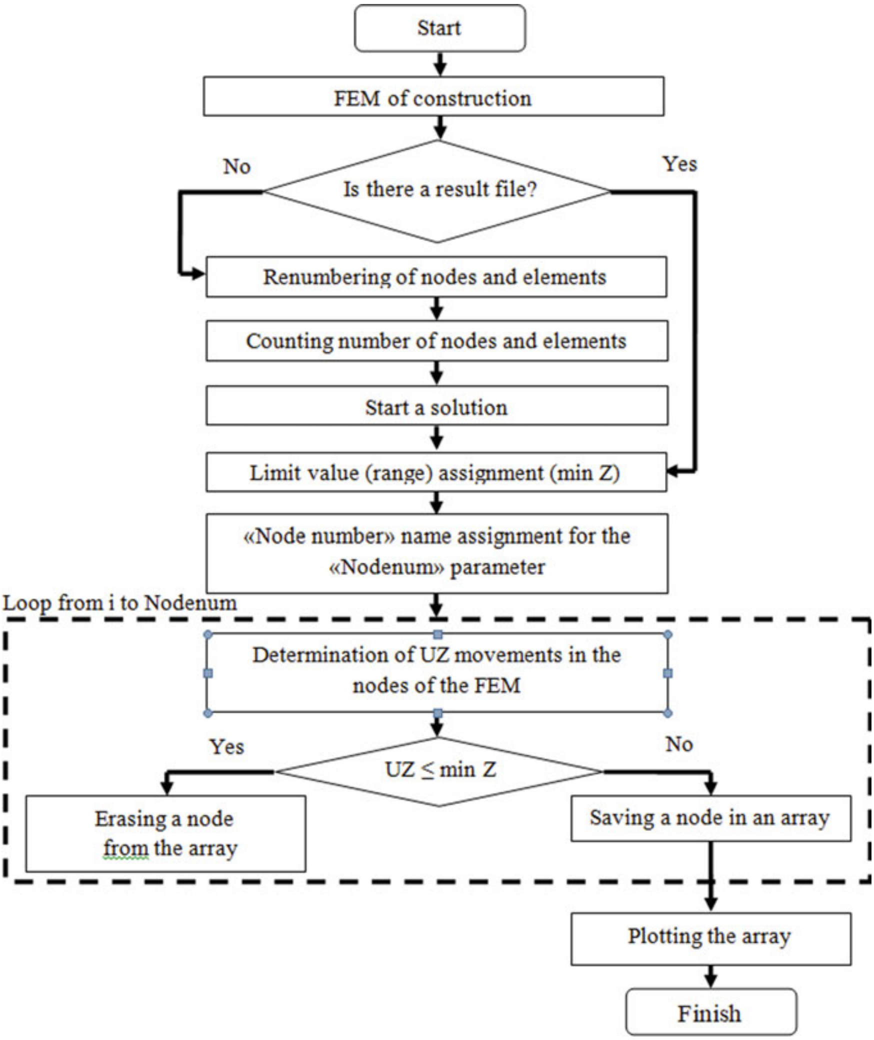

Fig. 4 The algorithm of the macro for determining the most loaded elements [2]

4 Conclusions

Based on the results of the analytical research, the main provisions for the development of the SHM and the possibilities of automation in the process of designing SHM systems have been determined.

Algorithms have been developed for high-quality automated data analysis performed at the stage of development of the SHM systems projects.

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Automated Information System for Monitoring Technical Condition During Operation of Production Buildings

S. I. Evtushenko and T. A. Krahmalniy

Abstract The authors conducted an analysis of the work in the field of assessing the technical condition of industrial buildings and found out that in Russia there are no uniform criteria for assessing the technical condition and calculating the residual resource of industrial buildings, which is especially relevant for buildings that have worked their standard life. Based on the experience of the AIS "Accounting and Systematization of the Characteristics of Reinforced Concrete Bridge Structures through Water Supply Channels of the Rostov Region," which allows recording and monitoring the technical condition of reinforced concrete bridges, the authors propose AIS for monitoring the technical condition of building structures of industrial buildings. The analysis of damage occurred to building structures of production buildings allowed the authors to identify areas of possible formation of defects and damages, systematize them, identify the causes of formation and develop standard recommendations for their elimination. The AIS developed with due account of all possible defects and damages of building structures of industrial buildings, according to the results of the inspection it enables to automatically fill in the list of defects of the building, accumulates information and to monitor the technical condition, development of damage over time, and the timing of scheduled inspections. The criteria developed by the authors for assessing the technical state of building structures depending on the degree of damage allow AIS to automatically assign the technical state to the structure, as well as propose repair options. The application of AIS will allow at the state level the service of Rostekhnadzor, the Ministry of Emergencies and other supervisory organizations to monitor the technical condition of production buildings throughout their life cycle, and the operating organizations to allocate funding for ongoing and major repairs in a timely manner.

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Keywords Monitoring system · Operation of industrial buildings · Defects and damage to building structures · Criteria for assessing the technical condition · Prolongation of the life cycle of an industrial building

1 Introduction

Throughout the entire life cycle of a production facility, including the design and construction stages, defects and damages occur in construction structures due to design errors, insufficient quality of installation work performed, production processes, operating conditions or transport load, which affect the technical condition of production buildings. At the same time, many industrial buildings in our country have already fulfilled their standard service life. The extension of the service life of such buildings takes place on the basis of a visual-measuring survey and an expert assessment of the possibility of its further operation. Currently, individual authors have developed many methods for assessing the technical condition of industrial buildings [1, 2], which in turn are based on the results of visual and instrumental control and subjective expert assessment [3]. At the same time, there are no uniform criteria for assessing the technical condition of the structure, the expert assigns the technical condition to the object based on his experience and knowledge of regulatory documentation, and these estimates may differ for the same object from different experts. The analysis of works carried out by the authors in the field of assessing the technical condition of industrial buildings [4–7] showed that in our country there is no unified methodology and an integrated approach to the issue of safety of industrial buildings and structures, especially for those that have already fulfilled their standard service life. Currently, there is no systematic control over the technical condition of building structures of industrial buildings and structures in Russia. Thus, the relevance of the use of new automated information systems (AIS) for monitoring the technical condition of building structures of industrial buildings is obvious, which will allow for a gradual accumulation of information about the building, and will lead the use of the system to determine the need for maintenance. The development of uniform criteria for assessing the technical condition of building structures of industrial buildings with defects and damages is becoming relevant.

2 Methods

In 2014–15, the authors have already developed an automated information system (AIS) "Accounting and systematization of the characteristics of reinforced concrete bridge structures through the water supply channels of the Rostov region" [8], which allows you to keep records and monitor the technical condition of reinforced concrete bridges through channels that are on the balance sheet of the Federal State Budgetary Institution "Rostovmeliovodkhoz Management". The program contains a register of bridge structures, information about the technical parameters (dimensions) of the load-bearing structures of the structure, allows displaying the results of the last survey of a particular bridge, the results of the survey for a certain year or display the results of surveys for all years. When registering a new bridge structure, the location of the bridge, the year of construction, the design organization, the year of repair, overall dimensions, the type of bridge, the type of its supports, the type of its bridge beams and the dimensions of bridge beams, the type of pavement and pedestrian walkway are indicated. The registration of a new structure is carried out after the measurement work, after a detailed visual and instrumental examination, information is entered on the identified defects and damages, and an important factor is the input of the dimensions of the identified damages, since on the basis of these data, the AIS assigns the technical condition of each building structure and the entire structure as a whole. Determination of the technical condition of building structures of mobile structures is carried out on the basis of comparison of the parameters of defects and damages with tabular values [9]. Based on the results of the survey and the assigned technical condition, the program calculates the remaining service life of the bridge, outputs standard recommendations for the elimination of identified defects and damages, timely notifies of the need for the next inspection or routine repair of the bridge. Currently, the use of AIS allows the operating organization to monitor the technical condition of bridge structures, monitor the remaining service life of structures, and allocate funding for ongoing and major repairs.

In continuation of this work, the authors analyzed the identified defects and damages of building structures of industrial buildings and identified the main zones of their formation.

In the soil foundations of industrial buildings, the main damages are precipitation and subsidence of soil [10]. The sedimentation of the foundation soils leads to cracks in the enclosing structures, the roll of columns and crane beams, disruption of crane equipment. The reasons for the subsidence of the soil of the production building at the stage of operation are non-project crane loads, additional vibration loads or soaking of the soil with technical waters.

The most common damage to the foundations of industrial buildings is damage to concrete with or without exposure of the reinforcement frame [11]. The causes of such damage are transport loads: road or rail transport can damage the head of the column, a bridge crane inside the building can damage the head of the foundation with a load. Another frequent defect is the damage of foundation beams or the basement part of the ribbon foundation located above the ground, the causes of which are atmospheric influences or mechanical damage by transport.

For reinforced concrete columns of the building frame, the most characteristic is damage to the protective layer of concrete in the form of chips with or without exposure of the reinforcement frame [12]. The causes of such defects are mechanical damage by transport or soaking of columns by leaks from the roof or technical drains. Bridge cranes often touch the columns of the frame with a moving load. Sometimes concrete chips are caused by the process of reinforcement corrosion, penetrating through the smallest cracks in the concrete to the reinforcement of the frame, moisture leads to its corrosion, increasing in size, reinforcement corrosion products create stresses capable of tearing concrete. It is also necessary to note the damage to reinforced concrete columns in the form of chips and cracks on the consoles for crane beams and in the form of cracks in the crane part of the column.

For metal columns, the most characteristic damages are surface corrosion of metal, bending of the elements of the connecting grid as a result of mechanical shocks, cutouts of individual elements of the connecting grid due to technological necessity, bending of the upper part [13, 14].

No less important part of the production building, ensuring its stability, are the vertical stiffness connections between the columns. The most frequent damages of vertical stiffness bonds are the bends of the elements of the connecting grid [15]. Less frequent damage is the absence of elements of the connecting grid. Just as often there are bends of the branches of vertical stiffness bonds from a mechanical impact when moving a load by an overhead crane. The rarest are the damages in the form of a cut branch of a vertical bond or completely cut vertical stiffness bonds.

Frequent damages of reinforced concrete crane beams are concrete chips at the corners and edges with the exposure of the working reinforcement and without exposure. Rare damages are the destruction of the shelves of the crane beams and inclined cracks in the support zones. A common defect is the corrosion of embedded parts in the attachment points of crane beams and exceeding the minimum allowable gap between the beams on the supports.

A common defect of metal crane beams is the destruction of the anticorrosive coating, surface and layered corrosion of the beam elements. Another common defect is the death of transverse stiffeners from mechanical impact and the bending of the supporting ribs of crane beams.

The most frequent damages of reinforced concrete coating trusses are concrete chips at the corners and edges of the trusses, most often these chips are formed at the installation stage. Soaking of iron-tone coating plates in support nodes is also common.

In metal trusses of the coating, frequent damages are the destruction of the anticorrosive coating, surface corrosion of the elements of the truss, the destruction of the elements of the truss. Less common are defects in the form of the absence of bolts securing the truss to the column, the destruction of welds between the connecting strips and the compressed elements of the trusses, the loss of stability of the compressed elements of the trusses.

The most frequent damage to precast concrete slabs of the coating is soaking due to roof leaks. Penetrating from above through the concrete, moisture leads to peeling of concrete in the shelves and edges of the coating plates, the development of a defect leads to cracks along the longitudinal and transverse stiffeners of the plates. The processes of freezing and thawing lead to the opening of cracks and the destruction of ribs, concrete chips, exposure and corrosion of the reinforcement frame of the coating plate.

Damage to the edges of the coating plates by mechanical means by the personnel of the operating organization for fixing any technological equipment is also frequent. Once there was a case of mechanical damage to the shelf of the coating plate as a result of a falling tree.

When examining the facades of industrial buildings, the following types of frequently encountered defects and damages were found [16]: destruction of the protective layer of concrete wall panels, exposure and corrosion of the reinforcement frame, loss of mortar from the seams and opening of the seams between the panels, destruction of cornice slabs, corrosion of fire escape structures, lack of glazing on windows and light-aerating lanterns. The analysis of the results of the inspection of facades of industrial buildings made it possible to identify the characteristic zones of the most likely occurrence of defects.

3 Results

The analysis of the results of the survey of building structures of industrial buildings made it possible to identify the characteristic zones of the most likely occurrence of defects. Probing of building structures allows conducting a quick survey of a building and automatic filling out a summary list of defects. However, the assessment of the technical condition of the structure requires the development of uniform criteria. The authors carried out a systematization of defects and damages identified during the survey of buildings and structures and developed criteria for assessing the technical condition of structures based on damage parameters (Tables 1, 2 and 3).

Table 1 The effect of defects on the technical condition of reinforced concrete columns

Name Damages	Serviceable	Efficient	Limited operability	Disabled	Emergency
Concrete weathering, m^2	0.1	0.1–0.5	0.5–0.8	0.8–1.0	1.0–1.5
Destruction of protective layer of concrete, m^2	–	0.1	0.1–0.3	0.3–0.4	0.4–0.6
Loss of cross section of reinforcement, % of section area	–	0–5	5–10	10–15	15–25
Crack opening width in the base, mm	0.5	0.5–1	1–2	2–3	3–5
Width of longitudinal cracks in concrete body, mm	0.5	0.5–1	1–3	3–5	5–7
Length of concrete chips at the corners of the column, cm	10	10–25	25–50	50–80	80–120
Destruction of column concrete body, % of cross section area	–	5	5–10	10–15	15–20

Table 2 The effect of defects on the technical condition of exterior walls

Name Damages	Serviceable	Efficient	Limited operability	Disabled	Emergency
Defrost depth of masonry, mm	5 / 8	5–15 / 8–25	15–35 / 25–50	35–50 / 50–75	50–80 / 75–100
Stratification and weathering masonry, m^2	–	<0,1 / <0,2	0,1–0,2 / 0,2–0,5	0,2–0,5 / 0,5–0,8	0,5–0,8 / 0,8–1,2
Falling of individual stones/bricks, pcs	–	1 / 1	1–3 / 1–4	3–5 / 4–6	5–8 / 6–10
Crack opening width, mm	0,3 / 0,4	0,3–1 / 0,4–1	1–2 / 1–3	2–4 / 3–5	4–8 / 5–10
Destruction of masonry, m^2	–	0,5	0,5–1,0	1,0–1,5	1,5–2,0

Note: the table above the line shows the values for masonry walls, below the line - the values for brickwork

Table 3 The effect of defects on the technical condition of precast reinforced concrete ribbed coating plates

Name Damages	Serviceable	Efficient	Limited operability	Disabled	Emergency
Length of concrete chips in slab shelf, cm	<10	10–20	20–30	30–50	50–80
Concrete destruction in slab shelf, m^2	–	<0.1 / <0.2	0.1–0.3 / 0.2–0.3	0.3–0.5 / 0.3–0.6	0.5–0.8 / 0.6–1.0
Concrete destruction in slab ribs, m^2	–	<0.1 / <0.2	0.1–0.2 / 0.2–0.4	0.2–0.4 / 0.4–0.6	0.4–0.6 / 0.6–0.8
Loss of section area of plate reinforcement, %	–	<5	5–10	10–20	20–30
Width of crack covering in plate ribs, mm	0.5 / 0.4	0.5–1 / 0.4–0.8	1–3 / 0.8–2	3–5 / 2–4	5–10 / 4–8
Solution falling out of seams between plates, cm	10 / 15	10–20 / 15–25	20–40 / 25–50	40–80 / 50–100	80–140 / 100–180

Note: in the table above the line values are given for prefabricated reinforced concrete slabs of coating with measures of 1.5 × 6.0 m, under the line - for coating slabs with dimensions of 3.0 × 6.0 m.

Currently, an application for registration of the program has been submitted to the industry fund of algorithms and programs of the Russian Federation. After receiving the certificate of registration of the program, it will be implemented at a number of large plants in the Rostov region for testing.

4 Conclusions

Thus, the result of the authors' work is an automated information system that enables at the state level to monitor the timeliness of surveys of industrial buildings and the quality of repairs carried out. The use of automated control systems will allow the Rostechnadzor service, the Ministry of Emergency Situations and other supervisory organizations to monitor the technical condition of industrial buildings, monitor the remaining service life of structures, distribute funding for ongoing and major repairs. For the organizations with production buildings on their balance sheet, the automated control system will enable to streamline and systematize the available information about them, perform timely and high-quality inspections of production buildings, perform routine repairs without bringing them to an emergency state.

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Automating the Process of Organizing a Common Data Environment for Information Model

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Abstract There was analyzed structure formation process of the automatic directory within the framework of information modeling technology at the design stage. The design stage of construction is considered as a set of business processes. First, the design process, divided into smaller ones using decomposition methods, is considered in order to determine the place of the automated process in the overall structure. Based on the analysis of the design process, the sequence of subprocesses is revealed. This allowed further decomposition of its separate part, namely, the preparation of the working environment. To represent the results of the study graphically, maps are compiled in the Business Process Management Notation, which allows you to visually track sequences, relationships and separate data flows. The highlighted subprocess of creating a directory structure in a shared data environment is automated using visual programming tools. A Dynamo script that automates the specific process of forming a directory structure is developed; the location and functionality of it are shown in business process diagrams. For ease of use, the created program uses a predefined structure in the MS Excel environment as a template, which allows the user to flexibly change and customize the organization of directories for specific goals and objectives. The convenience of editing the algorithm as a whole and its individual parts is achieved by visual tools, generally accepted standards for designing information systems and object-oriented programming. Individual nodes are combined into semantic blocks to improve the readability of the code. The created program enables to rapidly create a large number of nested named directories in a common data environment (CDE).

Keywords BIM · Design automation · Construction management · Information modeling · Business process

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1 Introduction

As part of the implementation of state programs for the transition to the digital economy, including in the construction industry, the tasks of implementing information modeling technology at all stages of the building life cycle are becoming urgent. Given the large amounts of data and high requirements for the accuracy of information models, the automation of source data processing and the formation of a shared data environment come to the fore.

2 Methods

2.1 Business Process Management Notation

BPMN (Business Process Management Notation) – it is a business process modeling language serving as a link between formalization/visualization and business process implementation.

BPMN-process – is any business process displayed with a specific notation. Processes consist of elements, each of which is indicated on the diagram by a special icon. (Fig. 1.)

2.2 Dynamo and Design Script

Dynamo — an open-source visual programming platform for civil engineers. Dynamo supports its own programming language Design Script, which allows writing code inside a universal node Code Block. By such an algorithm entry, one can make the program more efficient (Table 1).

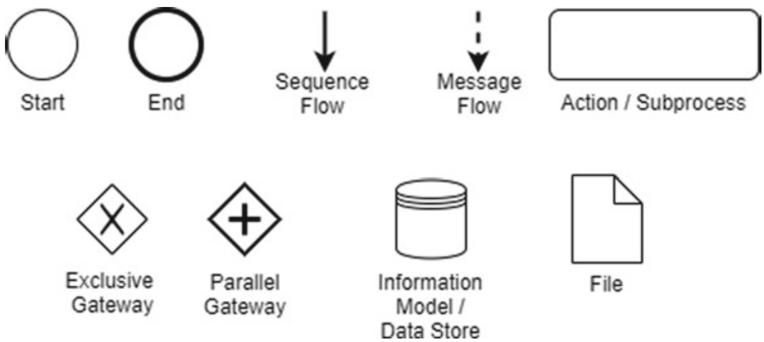

Fig. 1 BPMN notation

Table 1 Tools used

Type	Name	Functional
Dynamo standard nodes	String	Creates a string
	Save as	Saves the file
	Open From	Gets the file path
	String.Concat	Concatenates multiple strings into a single string
	File From Path	Reads a file from a selected path
	Data.ImportExcel	Imports an Excel file
	Directory From Path	Creates a directory in a selected path
Design Script	def StrRemDec(a:var[])	Remove decimal places after the decimal point a – list of values
	CreateDictionary(data)	Create a Value:Key dictionary data – imported Excel spreadsheet
	DecodeDictionary (afterCheck, dictionary,PathDevider:string)	Generate a dynamic part of the path from the dictionary dictionary – dictionary without processing PathDevider – "\"
	ConnectPath (directoryPath,pathList,pathDevider)	Connect the static and dynamic part of the path directoryPath – static part of the path pathList – dynamic part of the path PathDevider – "\"
	Double type check	Check whether variables are Double type, remove decimal zeros when converting to String type
	Null type check	Check whether variables are Null type, remove such elements

2.3 Decomposition Methods

Decomposition is the division of the whole into parts. Decomposition is also a general problem-solving technique that comprises dividing a big problem into a set of particular problems, also tasks that do not exceed the complexity of the original problem in aggregate, whereas the combination of their solutions forms the solution of the original problem.

3 Discussion

Figure 2 shows "design" BPMN business process card. For a visual representation of the result, schemes in the BPMN notation system according to GOST R 10.0.03-2019 [1–5] were used.

The process begins with obtaining the source data, which is placed in the CDE. Before proceeding directly to the modeling process, BIM specialists should prepare a working environment, within which all subsequent processes will be carried out, and place it in a shared data environment. After the preparation of the working environment, designers do the modeling, then analyze design solutions and update information in the general data environment. The chain of subprocesses is cyclical and repeats until the design work is fully completed. In parallel with the BIM modeling process, specialists provide modeling support, including direct support and consulting of users on emerging current issues, the elimination of technical problems, as well as the preparation and maintenance of documentation. The design process ends with the results uploading. On the designers' part – 2D drawings and text documentation, and on the part of BIM specialists – 3D design model [2, 3, 6–9].

Within the topic, the process of "Preparation of the working environment" is considered in detail (Fig. 3) [10–13]. This process is completely carried out by BIM specialists using CDE.

Upon receiving the source data, the project directory structure is created and placed in the CDE. Later, all information models will be structurally stored in a shared data environment. Before setting up information models, it is necessary to configure the operating programs. Pre-checking the software reduces the chance of failure during further work. The basic project file is created for subsequent linking of all sections of the model in a single coordinate system. Coordination and disciplinary files of the model will be obtained from this file in the future. The coordination file contains information about the horizontal (axes) and vertical (levels) breakdown of the model. It is possible to use one of the disciplinary models as such file. [14–18] The discipline files contain the models themselves. Here the designers will provide the modeling process. Then, all models are linked in a single coordinate system by transferring coordinates to each model file from the base file. For coordination purposes, cross-references to files of related sections may be added to disciplinary files. Verification of the correct configuration and functioning of the system is done during the assembly of a consolidated interdisciplinary model. [19, 20]

For an example of automation, the process "creating a directory structure of the project" is selected (Table 2).

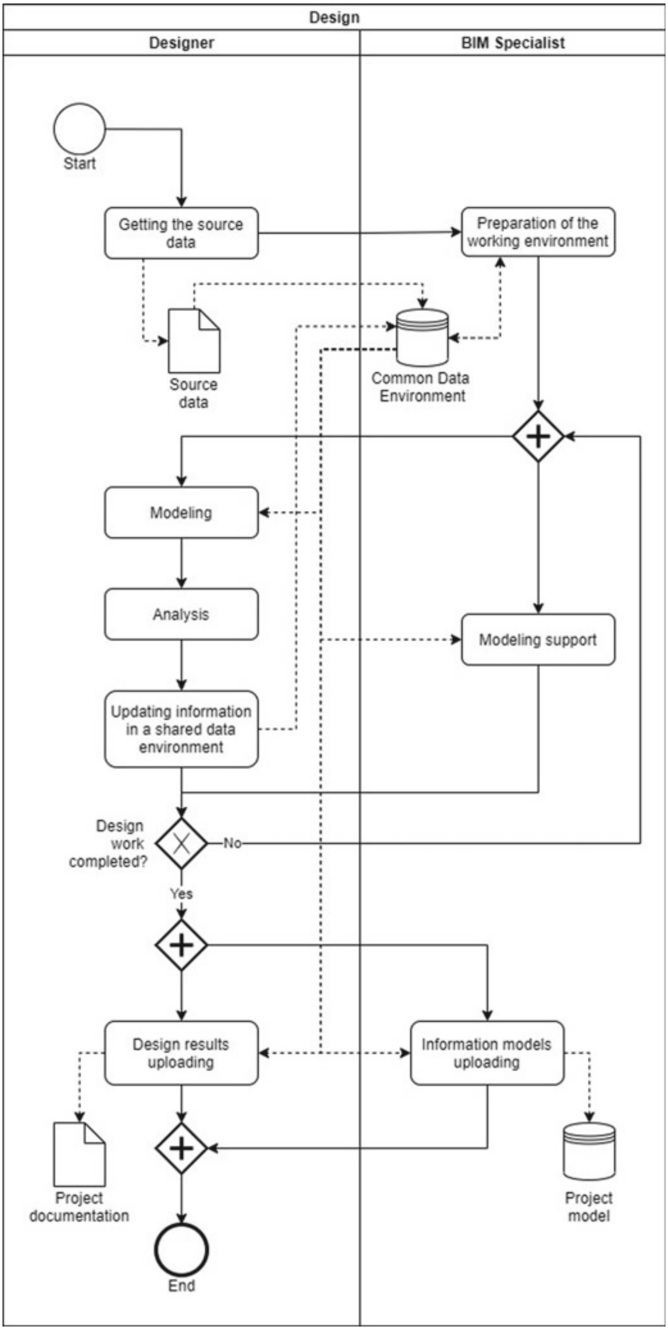

Fig. 2 "Design" business process

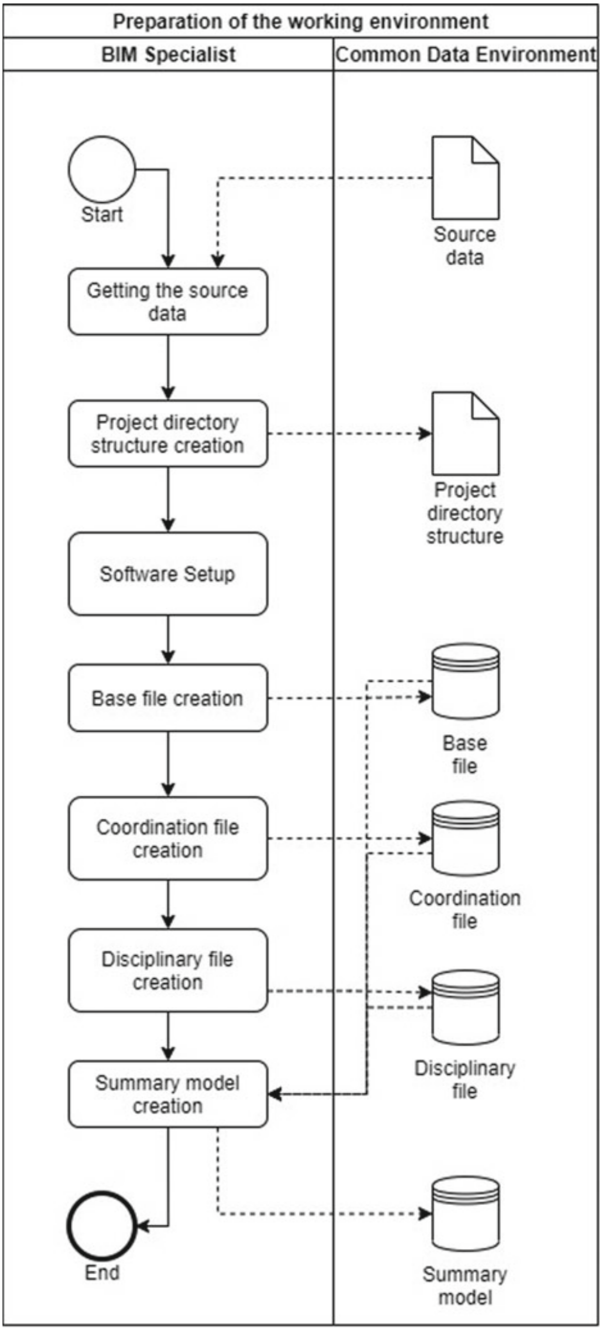

Fig. 3 "Preparation of the working environment" business process

Table 2 Script attachment and tools used

Name	Process	Subprocess	Tools
Creating directories by Excel	Preparation of the working environment	Creating a directory structure	Standard Dynamo nodes, DesignScript program code

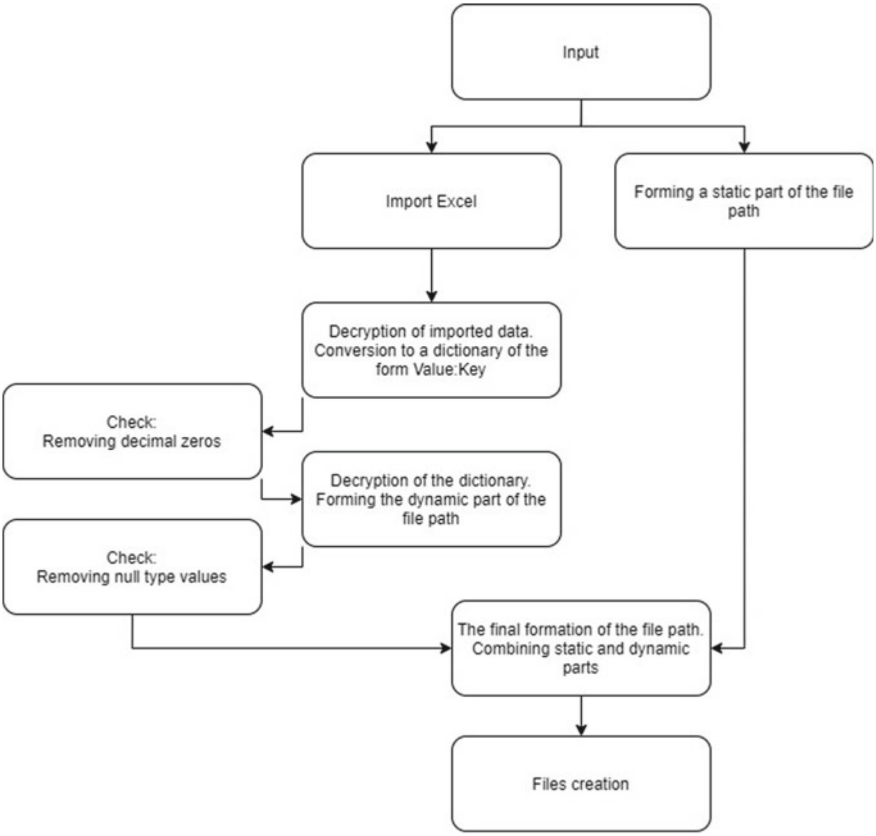

Fig. 4 "Creating directories by Excel" script structure

4 Conclusions

The research and decomposition of the process of designing and preparing the working environment in information modeling is performed. A script that automates the process of creating a directory structure is created (Fig. 4).

The script is designed to automate the process of creating a folder structure in the MS Windows 10 environment. The Dynamo visual programming tool is selected

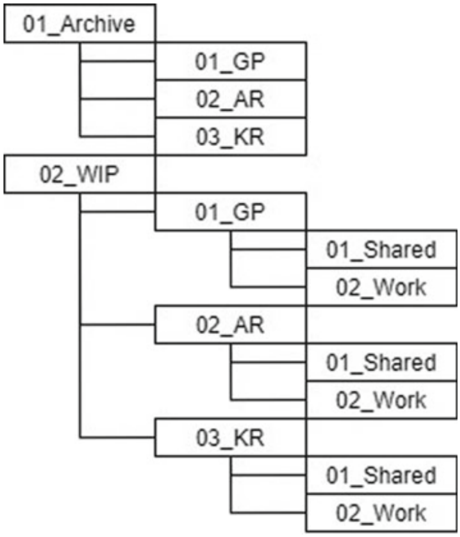

Fig. 5 Template structure

as the development environment. In the development process, standard nodes were used, as well as the built-in Design Script programming language.

A MS Excel sheet is used as a template for the directory structure and filled in according to following rules (Fig. 5):

1. The cells contain directory names.
2. There are no empty rows and columns between the data.
3. Each line contains only one filled field.
4. Directories located on the left contain directories located to the right.

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Information Support of Integrated Security for Capital Construction Projects

A. V. Ginzburg and S. I. Kozminykh

Abstract The paper is dedicated to information support of integrated safety and security for capital construction project. The paper provides analysis of the factors affecting security of capital facilities. The requirements for integrated project security are outlined. The list of the problems encountered by integrated security system is given. For information support of capital facility's security, there was defined the set of the requirements ensuring security; these requirements are essential throughout the entire life cycle of a capital facility. Based on the proposed flow diagram solving the issue of integrated security provision, the mathematical model for assessment of security level was developed. Security level is expressed in the form of a security matrix. Also, the matrix of preventive measures for possible threat removal and the matrix of consequences relieving for realized security threats are considered. There were proposed the approaches to assessment of economic consequences of threat realization and the effectiveness of preventive protection measures. It was noted that capital facility should be considered in the format of the BIM-model describing all the stages of its life cycle. This approach enables to regard a capital construction project as an information system containing the sufficient data for the analysis of the problems solved in the system. The aspects considered have an impact on enhancing organization and technological reliability of a capital facility. It was mentioned the importance of specifically integrated methods for security support. It was concluded that when introducing integrated security system on a capital construction project, one should go by the main principles of security organization such as consistency, security continuity, complexity, reasonable sufficiency, management flexibility, open governance of mechanisms and protection algorithms, common use of various security measures.

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Keywords Integrated security system · Systems security level · BIM-model

1 Introduction

The purpose of the present work is to identify the main principles of information support of integrated security for capital construction projects. The security threat model is presented for a capital facility.

The implemented analysis of literature sources dedicated to the issues of security [1–3], reliability [4] and information modelling of capital construction projects [5, 6] enabled to come up with the number of statements determining protection of capital construction projects from various adverse internal and external factors.

Integrated security system is understood as the system protecting a facility from all possible threats. Integrated security system of capital construction projects is the summary of tools and methods with the common purpose that provide adequate efficiency of a facility.

The purpose of an integrated security system is ensuring business continuity, sustainable functioning of capital construction projects and security threats countermeasures.

Integrated security system is aimed at providing protection of organization's legitimate interests against wrongful acts:

1. Protection of staff life and health.
2. Non-admittance of destroying financial, material and technical resources and their unauthorized removal.
3. Protection against breach in security, disclosure and unauthorized access to the restricted information.
4. Non-admittance of serviceability failure of technical facilities providing productive activity of the organization, including information technologies.
5. Facility protection against natural disasters, technogenic and anthropogenic threats.

In the light of the objectives of the integrated security system of a facility, the following tasks could de outlined:

1. Forecasting and early recognition of security threats to organization resources and staff, removal of causes and conditions causing damages.
2. Attributing information to the category of restricted access, proprietary or other confidential information that is subject to protection against unauthorized use.
3. Creating conditions and algorithms for immediate security threat response, for manifestation of negative trends in facility's functioning.
4. Effective suppression of intruders' violation targeted at staff or facility resources on the base of organizational, legal and engineering measures and application of security support tools of an organization.
5. Creating conditions for maximum possible and immediate reparation of damages caused by wrongful acts.

Information security are security aspects of every kind related to identifying, maintaining integrity, confidentiality achievement, accessibility, accountability, fault-tolerance, fidelity, and authenticity of information.

Identifying the factors affecting security system of a computer system and information technologies serves as the framework for applying and planning the effective measures aimed at enhancement of integrated security system level of an organization [7–9].

Information system is the system designated for information storage, retrieval and processing, and corresponding organizational resources that provide and disseminate the information.

Ensuring information system's security requires implementation of protective measures, such as removal of adverse impacts on information system causing organization security breach [10].

Protection should be separated. The separation principle represents such an order of ensuring organization security when all the protection lines would consist of successive security zones, with the most important one placed inside the integrated system [11].

The security improving task is characterized by indeterminedness, complexity, the presence of the great number of interrelated external and internal factors affecting security [12].

In order to select the effective measures increasing facility's security, it is required to account for the number of factors effecting the elements of its protection at all phases and stages of functioning.

2 Materials and Methods

For information support of capital construction project security, there was formulated the set of requirements determining facilities' security, these factors must be accounted at all stages of facility's life cycle:

1. Sufficient number of the levels of factor's classification that allows forming the complete set of factors.
2. Sufficient flexibility of factors' classification that enable to broaden the number of factors and features as well as to introduce the necessary amendments without any structural damage of factors' classification.

Establishment and development of the effective security system of capital construction projects must rely on the following principles:

1. The principle of systemization. The organization assets represent the summary of the elements that serve for ensuring effective functioning of a facility.
2. The principle of rationality. The present principle preconditions a meaningful activity aimed at effective provision of facility's security, rational coverage of

information, resource, ecological, technological, regulatory-metrology, financial, economic, and social requirements by organizational and managerial decisions;
3. The principle of confidentiality. The given principle presupposes the full accessibility of assets and processes of the organization information system for authorized users, and what is more, organization assets must be kept secure and inaccessible to unauthorized users.
4. The principle of consistency, accumulation of expertise and trainability. Security system must sufficiently ensure the consistency of secure functioning of all parts of an organization.
5. The principle of functional interrelatedness and predictability. Security is an integral part of common issues of various systems assets functioning, including the area of informational and technological processes, the processes of resources use, as well as social, financial, economic, ecological and other processes.
6. The principle of timeliness, adequacy and prompt response. This principle presupposes timeliness of detecting the threats that could affect organization assets' security and further immediate response aimed at blocking and removing threats aftermaths.
7. The principle of controllability stating that only those protective measures must be applied for which the proof of validity could be validated.

During the era of information technologies explosive development, almost all capital construction projects are regarded as computer systems [13, 14].

Computer system is the summary of information resources, tools and systems for information processing used in compliance with the given information technology, as well as the means of their provision, premises, buildings or structures where these means and systems are installed.

The flow diagram of the solution of ensuring integrated security problem for such facility could be described as follows:

1. The problem area, the objectives of ensuring integrated security of a computer system.
2. The factors influencing security of organization's information system.
3. Measures and technologies providing integrated security of the information system.
4. Methodology of ensuring integrated security of information system, the strategy of integrated security provision.
5. Identifying the information system's assets, defining parameters and criterion of ensuring information security effectiveness, developing the procedures of evaluation of theses parameters and criteria, and developing the model of integrated support of information security.
6. The principles of integrated support of information system security (rationality, consistency, confidentiality, transparency, continuity, accumulation of expertise and trainability, predictability and functional interrelatedness, timeliness, adequacy and immediate response, controllability).
7. Economic, information, organizational and technological decisions.

3 Results

The study of approaches to ensuring security of capital construction projects has resulted in the development of the mathematical model for security level assessment.

Security level of information system could be characterized by the security matrix:

$$B = \begin{pmatrix} K_1 & F_1 & V_1 & T_1 & S_1 \\ K_2 & F_2 & V_2 & T_2 & S_2 \\ \underline{K_3} & \underline{F_3} & \underline{V_3} & \underline{T_3} & \underline{S_3} \\ K_n & F_n & V_4 & T_n & S_n \end{pmatrix} \quad (1)$$

where:

K_i – a parameter of system's security level under the *i*-criterion;

F_i – the tendency to the *i*-criterion change (increase, decrease and neutral);

V_i – the rate of the *i*-criterion change, for example, low, below average, average, above the average, and high;

T_i – time, typical for the *i*-criterion that enables to interpret the values of V_i parameter;

S_i – the degree of critical effects at risks realization that deteriorate the value of the *i*-criterion.

The matrix could be presented as the set of block matrices – B_j that describes the state of assets security of the organization's information system A_j ($j \in [1, N]$, where N – the number of assets). Each tuple (K_i, F_i, V_i, S_i, T_i) characterizes the security state under the *i*-criterion.

The expected potential damage to the *j*-asset caused by the impact of the *i*—threat could be presented in the form:

$$D_{ij} = PU_i \times F\left(U_i \to A_j\right) \times r_j = D_{ij}\left(PU_i, U_i, B_j, r_j\right) \quad (2)$$

where:

PU_i – probability of the *i*-threat occurrence.

$F(U_i \to A_j)$ – the value of the impact U_i of the threat on the A_j-asset, security of which is described by the block matrix B_j;

r_j – the value of the j-asset.

Thus, the expected damage is equal to:

$$\mathrm{D} = \sum_i \sum_j D_{ij} \quad (3)$$

It is worth mentioning that possible threats to information security should be divided into primary and secondary ones. Primary security threats exist regardless the system's state and have specified probability of occurrence. Probability of secondary threats occurrence depends on the parameters of external environment and the state of the system [15, 16].

Probability of primary threats $\overline{PU_i}$ occurrence does not depend on users; preventive summary of security measures enables to weaken the impact of threats on the information system security level.

The given fact could be described by the matrices of preventive measures:

$$Z_j = \begin{pmatrix} z_{11} & z_{12} & z_{13} & z_{14} & z_{15} \\ z_{21} & z_{22} & z_{23} & z_{24} & z_{25} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ z_{n1} & z_{n2} & z_{n3} & z_{n4} & z_{n5} \end{pmatrix} \tag{4}$$

where:

$j = \overline{1, M}$, a M – the total number of preventive measures.

Regardless the preventive measures of security, the certain number of primary security threats are realized resulting in consequences occurrence. Thus, it is required to undertake the measures for relieving the consequences, i.e. to reduce the matrix deviation B of the given state of the system from the secure state of the system B_s.

The events of the present block could be realized by means of the matrix of relieving the consequences:

$$L = \begin{pmatrix} l_{11} & l_{12} & l_{13} & l_{14} & l_{15} \\ l_{21} & l_{22} & l_{23} & l_{24} & l_{25} \\ l_{31} & l_{32} & l_{33} & l_{34} & l_{35} \\ \dots. & \dots & \dots & \dots & \dots \\ l_{n1} & l_{n2} & l_{n3} & l_{n4} & l_{n5} \end{pmatrix} \tag{5}$$

The cost of all the events for relieving consequences could be called "the value" of the matrix of consequences relief and denominated as PR_L. In a similar way, the particular "value" of protection method must be calculated under the formula:

$$PR_Z = \sum_{j=1}^{M} PR_j \tag{6}$$

where:

PR_j – the cost of the preventive security measure j.

Thus, the aggregate expenses on measures aimed at security support account for:

$$PR_j = PR_z = PR_L \tag{7}$$

It should be mentioned that from the point of economic feasibility, the following condition must be met:

$$PR < D \tag{8}$$

where:

D – the expected damage estimated under the formula (3).

4 Discussion

Capital construction project could be considered as a BIM-model, i.e. information system. When researching the area prone to threats, it is necessary to be aware of the tasks solved in information systems. Information model of capital construction projects is characterized by the scope of all stage of life cycle: investment foundations, engineering surveying, project design, its erection, maintenance, major capital works, decommissioning, demolition, and waste utilization [17]. The specific feature of such module is a long timeframe (60–100 years) that never occurs in production and non-production industries. Significant number of participants, creators and users of the model, exacerbates creation and effective use of these models [18, 19]. For this very reason, it is important to lay down parameters ensuring integrated security of capital construction projects in accordance to the proposed mathematical model at earlier stages.

During the life cycle of capital construction project, in the case of predicting security threat occurrence for information system assets, it is necessary to undertake measures weakening the threats' impact, continuing until removal of consequences of threats or their complete blockage. When the necessary protective measures are realized, security level is increased that enables to retain facility's operability and ensure its unimpaired operation.

In order to upgrade the system to a higher security level, various methods applying the summary of various protective measures could be used. Therefore, there arises the possibility of problem statement for the selection of optimal set of the measures ensuring sufficient efficiency of the organization system assets, from the point of expenditures. It is necessary to ensure the reduction of the objective function PR (PR_Z, PR_L) at constraints imposed on the values of security matrix elements B.

The specific feature of construction systems, from the point of security of their functioning, is the presence of fractional malfunction rather than incomplete system failures in the case of realization of some or other security threats. Malfunction, as opposed to failure, determine breach of targeted indicators and deviations from the given parameters rather than stoppage of system functioning. The account of specific features is reflected in the theory of organizational and technological reliability (OTR) applied for evaluation of organizational solutions quality in construction industry [20]. The proposed model of ensuring integrated security provides augmentation of organizational and technological reliability (OTR) due to minimizing of possible faults and deviations from the targeted indicators on all stages of life cycle of a capital facility.

5 Conclusions

On the base of implemented research, it could be concluded that the problem area in ensuring integrated security of capital construction projects comprise the following: solvable problems, subject area, goals or research, possible strategies that will be used for achievement of the set goals.

The use of technologies of information modelling throughout all stages of life cycle of a capital construction facility allow implementing the detailed analysis of objectives and tasks of a facility as an information system.

The mathematical model evaluating security level of a capital construction project proposed on the basis of the initial data from information model enables not only to assess security level but also to consider the possible set of preventive measures for localization various types of threats as well as economic effectiveness of the proposed events.

The implemented study has shown interrelatedness between the enterprises providing enhancement of integrated security of a capital construction project and augmentation of its organization and technological reliability.

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Organizational-Technological Genesis as the Basis for Information Modeling of the Building Systems Changes

Elena A. Gusakova

Abstract Global economic concepts are increasingly focusing on the renewability and sustainability of the product life cycle. These approaches in relation to the final product of the construction industry (building and its life cycle) require analysis, accounting and information modeling of the causes and impact of changes at different stages of the life cycle of buildings. In terms of content, exploring the possibilities and ways of accommodating future changes in building maintenance requirements and designing the building's innovative receptivity is consistent with genetic research methods. Genesis is effective for information modeling and project development of the life cycle of building systems, since it meets the specifics of construction and the life cycle of a building. The application of organizational and technological genesis as a methodology for studying the emergence, formation and subsequent development of an engineering facility and building systems is considered. The article analyzes the groups of factors influencing the life cycle of the building and the information models of building systems necessary for the analysis of their changes. It is shown that the genetic method of information modeling allows building systems to adequately and quickly reflect technological and organizational innovations and to increase the overall adaptive resource of the designed building. This will help to increase not only the innovative susceptibility of building subsystems and the adaptive resource of the building, but, as a result, to raise the efficiency of the entire life cycle of the building.

Keywords Construction project · Full life cycle · Information model · Organizational-technological genesis · Innovative receptivity · Adaptation resource

1 Introduction

Modern economic concepts are focused on the renewability, efficiency and environmental feasibility of the product life cycle. Before construction science, they set the urgent tasks of strategic planning of the full life cycle of a construction object and the

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search for appropriate approaches, criteria and information models of the life cycle of projects [1–4].

Volumetric structural, planning solutions and other parameters of building systems are determined by the functional requirements for buildings. At the same time, the operation life of the overwhelming majority of construction projects is dozens of times longer than the service life of other investment objects. As a result, the aggregate of operating costs for the entire period of the building's existence significantly exceeds the one-time costs of its construction. This ratio is determined by the objective specifics of the construction project, according to which design solutions almost unambiguously determine the constructive adaptability of the building to the requirements and functions of the operational stages of its life cycle. At the same time, the building project in the process of construction and operation is exposed to a large number of diverse influences. Recently, the processes of moral and physical deterioration of buildings have been significantly accelerated. This is connected with the deterioration of the natural environment and with innovations - the emergence of new design solutions and engineering systems for buildings. Analysis of engineering-geological processes of densely built-up areas, examination of a large number of emergencies of operated buildings in recent years allows us to conclude that the impact on the building of the external environment and the results of man-made human activities is becoming more dynamic and complex [5].

Novations are also becoming an increasingly important reason for changes at different stages of the life cycle of buildings [6–9]. Innovation makes it necessary to change any parameters of the building (volumetric-structural and planning solutions, engineering subsystems, the functional purpose of the premises, management goals and much more) [10]. In general, the development of real estate has already become an objective and permanent factor in the global economy. Real estate transformation needs are inevitable and necessary in the face of accelerating change, market dynamics and demand patterns. They can occur at any stage of a building's life cycle. At the same time, as experience shows, the innovative susceptibility of the life cycle of a building as a whole is directly related to how well thought out in the project the possibilities of changing and developing all structural, engineering, technological and planning subsystems of the building [11].

2 Materials and Methods

The substantive analysis and substantiation of the possibilities and methods of accounting for future changes in the operational requirements for the structure in the project corresponds to the genetic research methods. Taking into account the globalization of processes and the growing methodological unity of various scientific disciplines, it can be assumed that genesis is effective for information modeling and design of the life cycle of building systems [12]. In structural analysis and other applied methodological approaches, direct data connections prevail - information from the previous stage serves as an entrance to the next stage [13, 14]. In contrast to them, the genetic approach makes it possible to implement functional analysis in the information model of a building not only directly, but also to give feedbacks of the stages of its life cycle. This meets the specifics of building systems associated with the determining value of the initial stages of design with, as a rule, a minimum amount of initial data about the future building [15, 16]. The genetic approach also makes it possible to orient the information model to the project. That is, unlike other industries, take into account the significant industry-specific difference in construction, in which the content and target basis of the activity is a unique object (building, complex of buildings, built-up area) [17]. Genesis, from a functional-system point of view, rethinks the goals of information modeling in construction and focuses on strategic information models of the life cycle of a capital construction object, buildings and structures.

3 Results

With regard to building systems, organizational and technological genesis is defined as a methodology for studying the emergence, formation and subsequent development of an engineering facility. Genesis focuses on information modeling of the life cycle strategy of a building project, considers it as an evolving system, all characteristics of which are determined by cause-and-effect relationships and adequate to changing environmental conditions. The increased requirements of such a methodology for predicting the life cycle of a building to the volumes and quality of analyzed data are provided by the capabilities of modern information technologies and construction systems engineering. [18–20]. For this, new classes of information models are used (dynamic, logical-semantic, neural network, and others), and the traditional cognitive scheme is supplemented by the anticipatory consideration of counter information flows and feedbacks. It is based on engineering forecasting of the patterns and parameters of the life cycle of a building at the initial stages of design. The sequence of the emergence, formation and subsequent development of an engineering facility or organizational and technological genesis as a whole is preserved for various types of buildings and structures.

The analysis of the object's compliance with numerous diverse requirements and cyclically arising innovations constitutes a multi-criteria, recurring task during the life cycle of a building. To solve such problems, information modeling of the organizational and technological cycles of construction objects can be used, based on the study of the full life cycle of the object and its relationship with the external environment, including technological innovations, infrastructural, social, engineering and natural factors of influence. The goal of the information model is to assess the viability of the project in the full life cycle of the construction object, from the appearance of the project idea to its completion, as well as its adaptability (manufacturability) to the most probable and potentially possible changes during the life cycle. In this case, the life cycle of a construction project is modeled as a function of four arguments:

$$C = F(\Sigma N;\ \Sigma G;\ \Sigma S;\ \Sigma T_s),$$

where

$\sum N$ – justified socio-economic needs;

$\sum G$ – goals of the project and its investment opportunities;

$\sum S$ – number of organizational and technological cycles;

$\sum T_s$ – time of implementation of organizational and technological cycles.

Unlike structural research methods, this functional model allows you to analyze the viability of a construction project not only at the implementation stage, but also during its operation and completion, and may include, inter alia, such stages as dismantling of structures, disposal of construction waste and site reclamation. Design solutions in the genetic information model are analyzed from the point of view of organizational and technological criteria for the compliance of the building with the future conditions of its construction, operation, modernization, redevelopment and liquidation. In this case, the full life cycle of the project is modeled as a limitedly increasing sequence of interconnected information objects. The goal tree or scenario for the development of the project life cycle is determined by the target settings of the project participants, the forecast of innovations and other influencing factors. The methodological commonality lies in the fact that at each sequential stage, an information object or model is a software environment for determining the scope of work for a given stage. The specific scope of work on design, manufacture, transportation, installation, repair is determined, as well as the complexity of work, performers, costs, etc. The functionality of a single industry BIM platform allows solving these problems. The analysis of the accumulated experience shows that the functionality of the unified industry BIM platform allows solving these problems of information modeling of changes in building systems.

In practice, the full life cycle of each building and structure develops under the influence of a huge variety of influencing factors, which, nevertheless, can be divided into three groups: deterministic factors, probabilistic factors and hard-to-predict (situational) factors (Fig. 1). In accordance with this, information models of organizational and technological genesis combine models of engineering forecasting of deterministic and probabilistic factors of influence and models for monitoring difficult-to-predict (situational) factors of changes in the functional subsystems of an object. In order for such a combination to be possible in practice, information objects and models must be regulated, including modeling tools, application protocols, APIs for accessing shared data, and data exchange formats [21–25].

The genetic method of information modeling and substantiation of design decisions is based on the functionality of BIM technologies and includes organizational and technological justifications at the design stage and operational monitoring at the operational stage.

In turn, the organizational and technological justification in the project involves:

1. Forecasting the operational cycle;
2. Determination of the appropriate adaptation resource of the main volumetric-structural parameters of the building;

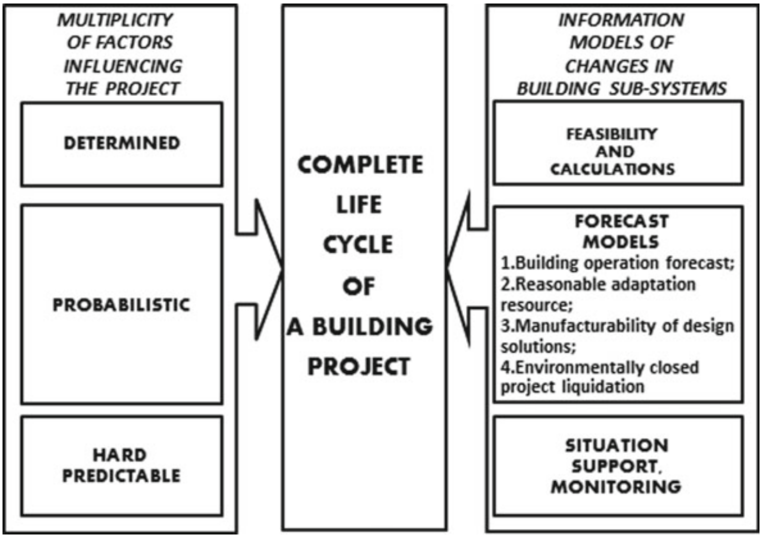

Fig. 1 Influencing factors and information models of changes in building systems

3. Analysis of construction, operational and dismantling manufacturability of design solutions;
4. Designing an ecologically closed (autotrophic) liquidation of the project (returnable materials, land reclamation, costs).

At the first stage, the operational cycle of the building is predicted, including the forecast of trends in the development of the surrounding buildings and territories and the most likely change in the external requirements for the object during the planned service life. The best functional use of the land plot and adequate duration of operation and periods of reconstruction are determined. At the second stage, on the basis of predicting the development of the capital construction object and probable changes in the requirements for the architectural, construction and engineering subsystems of the building, a reasonable adaptation resource and the possibility of increasing it in design solutions are identified. The relevance of the justifications for this stage, as mentioned above, is associated with the acceleration of the emergence of innovations, in the conditions of which a modern building is exposed to obsolescence associated with innovations in each of the industries accumulated in the subsystems of the building. At the third stage in the project, all engineering and construction solutions are worked out from the point of view of their manufacturability to the implementation of construction, maintenance and dismantling works during the life cycle of the building. At the fourth stage of the organizational and technological genesis, the possibilities of ecologically closed liquidation of a construction object are being considered. Here the technologies of dismantling, utilization and recycling of construction waste and reclamation of vacated land can be justified and taken into account.

In this understanding, the organizational and technological genesis allows construction subsystems to accept technological and organizational innovations adequately and cost-effectively. As a result, this increases the overall adaptive resource of the designed building. Following the organizational and technological features of the genesis of the object, it is possible to most fully and reasonably calculate the terms of obsolescence of engineering subsystems, space-planning and structural solutions of the building, functional filling of the building, changes in the requirements of the surrounding area and social needs. Based on the organizational and technological genesis, it is possible to more reasonably plan the duration of the stages of the life cycle of a building, taking into account the projected rates of physical and moral deterioration of subsystems and options for further development. Organizational and technological genesis effectively works towards a collective understanding of the overall goal of the project and awareness of their place in the project by each participant. And information and communication technologies currently have a well-developed functionality that is in demand for specific industry tasks of information modeling of a long project life cycle:

- data is stored and generated in a distributed network built and maintained by network users;
- cloud technologies allow changing project participants to work with project data from different devices and easily manage the interaction of participants;
- data have an open history, which allows you to control the authenticity and origin of information, while the information is copied in multiples, which ensures high stability and security of data storage.

Collaboration and consolidation of multiple models, including algorithms, methodologies, approaches and other IT technology tools, creates completely new opportunities for strategic planning, organization and management of the entire building life cycle.

4 Discussion

The concept of an industry digital platform that is currently being formed in construction should provide data for the management system for capital construction objects and make it possible to add, update and change information presented in different data formats throughout the entire life cycle of a building. The practical use of the methodology of organizational and technological genesis for these purposes has great prospects. At the same time, as international experience shows, genesis, like other new approaches or technologies, requires special research, including organizational and financial mechanisms for the implementation of relevant innovations.

With the very rapid development of digital technologies that directly affect all aspects of construction, such studies are necessary in order to combine efforts on the goals of the project life cycle. This includes: overcoming the inertia of thinking and traditional design approaches, overcoming investor uncertainty in long-term investments, uniting the goals of the project life cycle participants, and understanding the place and contribution of the project participants in the full life cycle of the building. This will help to increase not only the innovative susceptibility of building subsystems and the adaptive resource of the building, but also, as a result, to raise the efficiency of the entire life cycle of the building. Corresponding scientific and technical programs aimed at introducing new developments are being developed in many countries not only within the corporation and industry, but also at the state level.

Organizational and technological genesis as a methodology for research and design of building systems refers to the level of subject-scientific methodologies, therefore, the development of applied methods and tools requires an appropriate subject interpretation. Applied research in the field of information models of the organizational and technological genesis of building systems makes it possible to assert that when taking into account the genesis of the full life cycle of the designed buildings, it is possible to significantly increase their adaptive resource and innovative susceptibility, as well as to increase the efficiency of the project life cycle.

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Additive Manufacturing Based on Building Information Model Data

Elena Ignatova and Pavel Kirichek

Abstract Additive manufacturing in construction has many applications in the construction of low-rise buildings. The most common example is printing by extrusion on 3D printers of portal design. Information about the geometry of the building can be transmitted from the Building Information Model (BIM) in STL formats. Researchers are looking for a method of transmitting information using the AMF and IFC formats. It is noted that 3D printing imposes conditions and restrictions on the parameters of the information model. The most of modern studies is devoted to the choice of material for printing. Traditionally, concrete is used, but it is possible to use other eco-friendly and ergonomic materials. The purpose of this study is to use an information model of a building to prepare an additive production of a building. The experiment was carried out under model conditions for the construction of a two-storey cottage on a scale of 1:100. The information model of the cottage was created in the Autodesk Revit program. Preparation for the printing was carried out in the Ultimaker Cura software. An Creality Ender-3 Pro portal FDM printer was used. During the experiment, the BIM parameters that need to be stored were determined. It is noted that BIM helps to calculate the volumes of materials and the moments of time when the types of work are changed or added. In addition, it is possible to simulate the printing process based on the information model of the building, as with other construction technologies.

Keywords Building information modeling · BIM · 3D-printing · STL

1 Introduction

Additive manufacturing on a 3D printer refers to the new production technologies of the digital economy. In various fields of human activity, the method of 3D printing by extrusion (by the method of layer-by-layer deposition of material) is successfully

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used. For example, in architecture, 3D printing is used to build and demonstrate layouts of future buildings. In particular, collapsible layouts are required with the ability to view the internal space of buildings. Layout elements can be printed at any convenient orientation in space, and then glued together in the desired position [1]. It should be noted that the order of printing of such layouts differs from the order of construction of real buildings on the construction site.

For real buildings, decorative elements, small architectural forms, individual enclosing structures, modules of prefabricated structures are mainly printed on a 3D printer. You can print an entire box consisting of walls and ceilings. However, further construction work, including finishing, remains unchanged. There is considerable experience in printing single-storey buildings in the world and in Russia [2–4]. In rare cases, 3D printing is used in the construction of two-story buildings. In 2019 a two-storey office building with an area of 650 sq. m was printed in Dubai. This building is listed in the Guinness Book of Records as the largest building entirely printed on a 3D printer.

Since January 1, 2021, a preliminary national standard has been put into effect in Russia, which sets out general requirements for the use of 3D printing in construction. Since April 1, 2021, state standards for materials for additive construction production have been put into effect. Additive manufacturing in construction is only gaining experience in using it, demonstrating the benefits, features and limitations of 3D printing technology [5, 6].

The purpose of this study is to use 3D printing in conjunction with technology of building information modeling.

2 Materials and Methods

2.1 Construction 3D Printing

The method of 3D printing in construction does not differ in any way from the method of 3D printing by extrusion with molten plastic, only instead of plastic, a special material based on concrete and reinforcing additives is used. The extruder of a construction 3D printer lays concrete along a pre-planned trajectory. The main task of a construction 3D printer is to form walls of a given geometric shape. The design of the printer and the quality of concrete are of great importance for additive technology [7, 8, 10, 11]. Studies show that it is possible to use other various materials instead of concrete, such as bioplastics obtained as a result of processing grain crops, soil (clay, peat and sand), salt, rice husk, etc. [12–14].

The most common construction of a 3D construction printer in the world consists of a movable portal structure, along which an extruder with a concrete mixture moves. The full version of the technology provides a completely automated process when fittings and communications are installed using robot manipulators during printing

Fig. 1 Portal 3D printer with a robot manipulator [15]

(Fig. 1) [15]. The average printing speed of a modern construction printer is from 7 to 10 m^2/min.

For all the apparent simplicity and speed of 3D printing, it is necessary to think about the process and to prepare it in advance. The preparation process includes the creation of a geometric model of the future construction object, the development and verification of 3D printing technology. For 3D printing, it is necessary to cut the geometric model into layers using a slicer program. It is also necessary to set the printer parameters: temperature, speed, print sequence, method of filling the contours. If possible, you need to conduct a computer simulation of the printing process to eliminate the errors.

Additive manufacturing imposes a number of conditions on the parameters of the building. The height and area of the object, the thickness of the structures, and the options of the materials have restrictions. The construction technology can combine prefabricated and monolithic technologies for the construction of structures. Prefabricated elements can be pre-printed in the factory. The sequence of printing monolithic structures on a construction site, as a rule, has a layered character.

The 3D printing technology should take into account the openings in the walls. It is possible to set the contours for windows and doors in advance (Fig. 2) [16]. However, the nozzle of the extruder cannot get close to these contours. A special material that increases in volume or the horizontal position of the 3D printer nozzle is required.

The wall of the building can be solid monolithic, it can be hollow with stiffening ribs. At certain points in time, prefabricated elements of the building (stairs, window lintels, beams) should be installed. Voids in the walls are regularly filled. Floor slabs

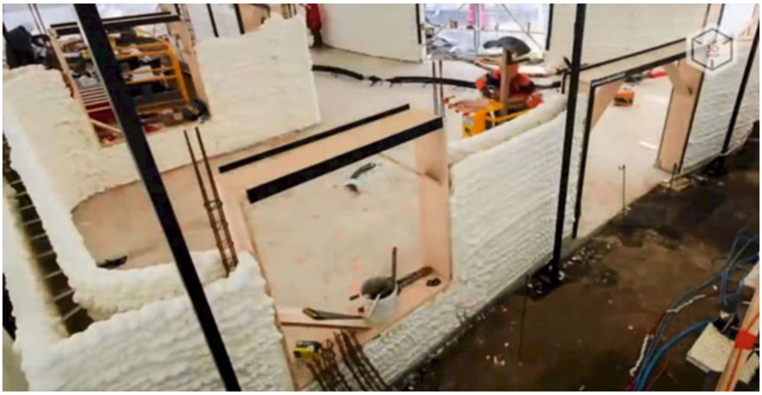

Fig. 2 Installing frames around the window and door [16]

are manufactured at the factory or printed on a pre-installed non-removable formwork (Fig. 1).

2.2 *Information Modeling*

To create a 3D printer control program, you need information about the geometry of the object, presented in a certain format (often STL). The geometric model of the building can be obtained from the digital information model of the building (building information model - BIM) [17–19]. The information model of the building helps to solve the problems of design, construction and operation of the building. Since the project documentation is formed on the basis of the information model, it is necessary and possible to record information about the type of printer, printing technology and materials used.

In addition to the physical characteristics of individual materials of multilayer structures, it is possible to store information about the overall strength of the printed structure, taking into account the internal structure, the composition of materials, the presence of non-removable formwork, the thickness of the printed layer of the material and printing technology. You can store information about additional processing of an object before use, for example, about cleaning, plastering, painting, etc. A digital information model is actually a digital double of an object with accurate geometric data. It is possible to use more complete information about the building in the AMF (Additive Manufacturing file) and IFC (Industry Fund Classes) formats [18].

The most well–known BIM software is Autodesk Revit. The transfer of geometric data to a digital information model can be carried out from the Revit program in several ways:

– use the additional add-in "STL Exporter for Revit";

– export the model in DWG format to the Autodesk AutoCAD software, and then export to the STL format;
– export the model in SAT format to the Autodesk Inventor software, and then export to the STL format;
– export the model directly to the STL format (available starting from Revit version 2021).

In the Revit software, it is possible to selectively transfer model elements by controlling the visibility of parts of the model. The joint use of building information modeling technology and additive manufacturing technology of buildings can be very successful. However, it is necessary to already understand the purpose of its use during information modeling. The article [20] shows that the choice of construction technology affects the composition and values of the data of the digital information model of the building and the methods of using the data.

The purpose of this study is to use the data of the building information model to prepare the additive manufacturing of the building.

2.3 *Experiment*

The research method is an experiment in model conditions for the additive production of a low-rise building.

A two-storey cottage was created as an object for information modeling and its additive production. Its overall dimensions ware 12,695 × 13,579 × 10,709 mm. The floor plans are shown in Fig. 3.

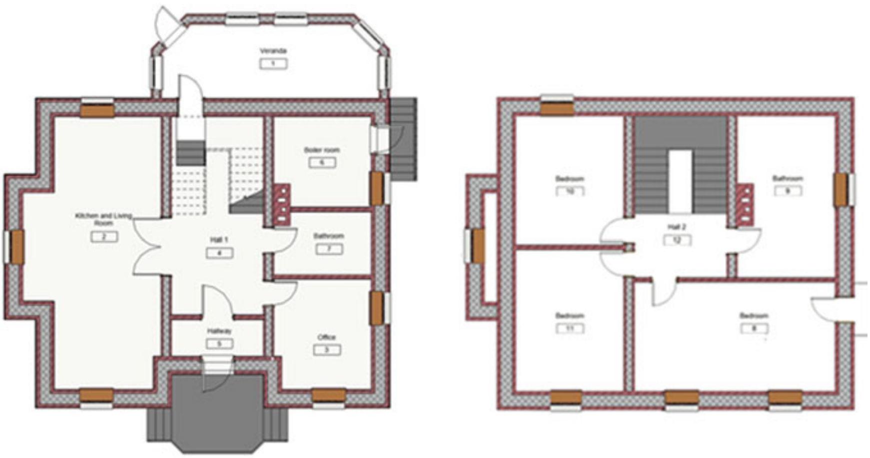

Fig. 3 The plan of the first and second floor

To create an information model, the Autodesk Revit 2022 software was used. Before printing, the model was cleared of minor small details. Windows and doors were left as support for printing lintel.

A direct method of transferring data from the Revit program to the STL format was used.

To divide the geometric model into layers, the Ultimaker Cura 4.8.0 slicer software was used. The program allows to set the placement of the object and the possible printing scale, allows to selectively set the method of filling the walls with material (hollow or solid) and specify the percentage of filling of the hollow walls. The Ultimaker Cura software creates a control program and calculates the required amount of material and printing time. Based on these parameters, you can calculate the average speed of the printer.

The following characteristics were introduced: scale 1:100, layer height 0.2 mm, line width 0.4 mm, wall thickness 0.6 or 0.8 mm, bottom/cap thickness 0.8 mm, filling with the material 20% (Fig. 4). Technological parameters were set depending on the type of material and the recommendations of its manufacturers: nozzle temperature 225 °C, table temperature 60 °C, printing speed of 50 mm/sec.

Based on all the data, the software slices the model and generates a control program for the 3D printer in GCODE format.

To print the model, there was used a printer Creality Ender-**3 Pro** was used with the following characteristics:

Printing Technology: FDM. Number of print heads: 1
Construction area, mm: 220 × 250
Maximum nozzle temperature: 255 °C. Maximum table temperature: 110 °C
Thread diameter, mm: 1.75. Accuracy: ± 0.1 mm

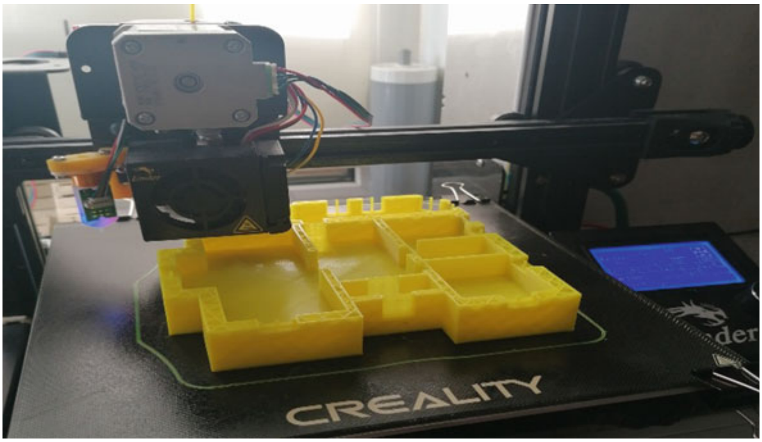

Fig. 4 The filling of hollow walls

The entire model was printed as one zone. The printer selected the order of wall traversal automatically.

3 Results

As a result of the experiment, a 3D digital information model of the building was created. In the specification tables, the volumes of the material of walls and ceilings ware calculated.

There were defined the levels at which the work is changed or added. For example, installing a window lintel or laying a floor slab (Fig. 5).

Parameters for production on a 3D printer (material, temperature, printing speed, percentage of filling, height and width of the layer) were entered in the description of the structures.

Fig. 5 The moment of floor slab installation

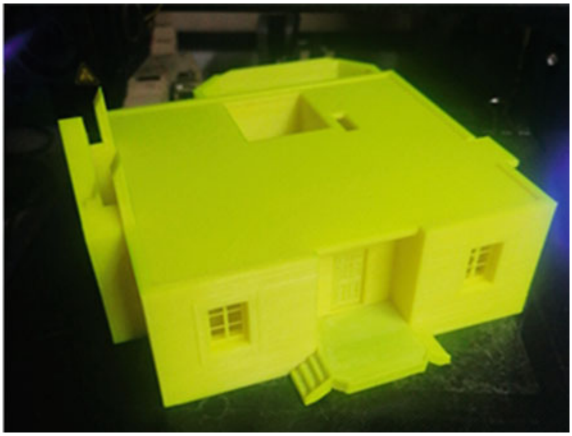

Fig. 6 Completed building model

The data of the information model was converted into a program for a 3D printer in the STL format. The walls of the building ware printed. Floor slabs, stairs, chimney, roof ware separately printed and installed (Fig. 6). The printing process lasted 35 h.

4 Discussion and Conclusions

The experiment of printing under model conditions gives a very approximate idea of the real characteristics of the materials and structures of the building. However, it enables to see and take into account the parameters necessary for use in the building information model.

An information model can store any information which is necessary for creating building structures. However, this information cannot be completely transmitted via the STL format. It is important to be able to work with other data formats, for example, with the AMF format.

To account the amount of material in hollow walls, you can use a multi-layer wall model. At the same time, it is necessary to know the percentage of filling the wall volume with the material. The percentage of filling can be automatically calculated in the Revit program for a conditional model of a multilayer wall with a length of 1 m.

The Revit software does not take into account the presence of openings when calculating the volume of wall materials. Traditionally, additional algorithms are used to refine the volume of wall materials. In these algorithms, you can also enter the percentage of filling the wall with material.

Knowing the speed of printing and the volume of material helps to calculate the moments of time when there is a change or addition of work. Therefore, it is possible to make a schedule of work and conduct a simulation of the work progress.

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Predicting the Elements Operation of Buildings' Engineering Equipment Using the Big Data Analysis Technologies

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Abstract Approaches related to the processing, storage and analysis of large data arrays, with a change in the technology of data processing and analysis, development of distributed storage and information processing systems, and the departure from traditional databases and banks. As an example of such an approach, a model for predicting the operation of elements of engineering equipment of buildings using big data analysis technologies is considered. As a result, such forecasting is aimed at reducing costs in the design and implementation of engineering equipment systems for buildings by eliminating multi-level duplication and simplifying the work of maintenance personnel. The presented forecasting model can be freely extended to any intelligent system in construction, the elements of which collect telemetry about their work and state. This approach to predicting failures of technical means is suitable for any area where it is possible to monitor the performance of devices (equipment, aggregates) either in real time, where the use of the device is critical, or it is possible to accumulate data within a reasonable time frame. The use of this technique is advisable only in relation to devices, the fact of failure of which cannot be correlated with predetermined indicators.

Keywords Big data · Data mining · Data classification · Engineering equipment of buildings · Forecasting equipment failures

1 Introduction

At present, approaches related to the processing, storage and analysis of large amounts of data have become quite widespread. This direction, associated with a change in the technology of data processing and analysis, development of distributed systems for storing and processing information, and departure from traditional databases and banks, received the general name Big Data [1–3]. The term DataMining, which is often translated as "mining" or "data mining", describes a

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system for finding patterns in data and, possibly, predicting trends in their manifestation. Increasingly, this approach is used in construction in connection with the further development of digital technologies in the industry [8–22].

As an example of such an approach, let us consider the proposed mathematical model, which, as a result, is aimed at reducing costs in the design and implementation of engineering equipment systems for buildings by eliminating multi-level duplication and simplifying the work of maintenance personnel.

2 Methods

Organization of data. The data storage structure of the model includes three main blocks.

1. Basic part - consists of two types of parameters: 1) parameters are constant characterizing elements of equipment: cost; the number of activations declared by the manufacturer (pcs.); 2) parameters are variables entered into the database regularly: actual MTBF (hours); actual number of operations (pcs.) (see Fig. 1).
2. A reference model, where a dynamic reference model is modeled based on data collected from failed products and cluster analysis methods.
3. Prediction block, where on the basis of the reference model from the second block and the initial data from the first one, using qualimetric analysis, a forecast of product failure is created and a recommendation to check or replace it.

Has the following algorithm of actions (see Fig. 2):

Before entering data into the base part, do we check if the device is working? If it works, we transfer the data to the forecasting unit, if it does not work, we take data dumps and transfer it to the reference model unit and delete the failed product in the base unit.

	Dynamic indicators	
Device	Actual MTBF (hours)	Actual number of operations
device #1	34944	56420
device #2	34944	57630
device #3	34944	55371
device #4	34944	57510
device #5	32808	51630
device #6	33528	51435
device #7	29880	41115
device #8	32088	49705
device #9	31344	44825
device #10	34944	54035

Fig. 1 Basic data

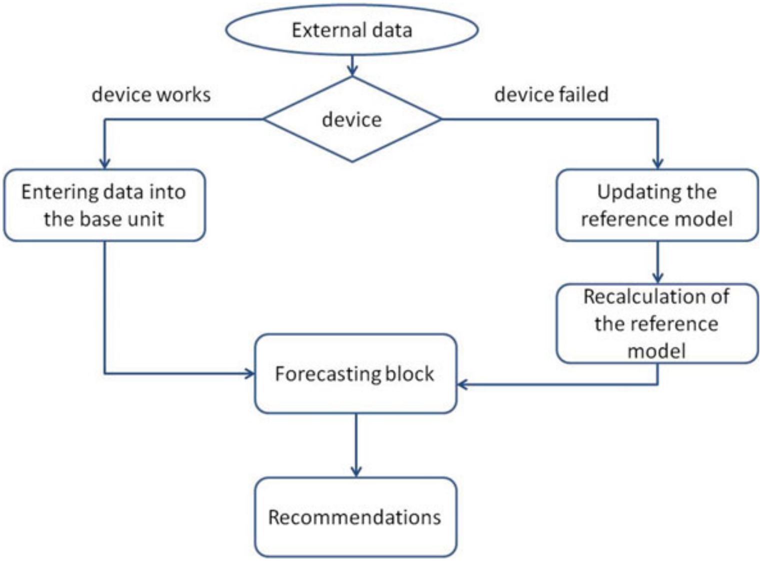

Fig. 2 The scheme of the algorithm of the model

If there were no failed devices in a month, the base model remains unchanged, it goes into the prediction block. If faulty products appear, the reference model is recalculated, and the modified model goes to the forecasting unit.

The prediction unit, based on the initial data and the reference model, issues recommendations for checking or replacing according to the results of checking a product that has approached the critical point [6].

3 Results

Input data types.

Each object is described by a set of its characteristics, called parameters. Parameters can be numeric or non-numeric.

Various parameters can be used and their values can differ by orders of magnitude. In order to bring them to comparable values, before starting the analysis, the data normalization method is used according to the following formula:

$$t_j = \frac{t_i}{\sum_{i=1}^{n} t_i} \quad (1)$$

where t_j – normalized parameter,

t_i – unnormalized parameter,

$\sum_{i=1}^{n} t_i$ – the sum of the initial values of the parameter t to be normalized.

Each object is described by the distance to all other objects in metric space.

Clustering goals - dividing the sample into groups of similar objects makes it possible to simplify further data processing and decision making by applying its own analysis method to each cluster.

Compression of data. If the initial sample is excessively large, then you can reduce it, leaving one most typical representative from each cluster. Identifying the novelty. Untypical objects are identified that cannot be allocated to any cluster.

Hierarchical clustering is used, when large clusters are split into smaller ones, which in turn are split even smaller, etc. Such tasks are called taxonomy tasks. The taxonomy results in a tree-like hierarchical structure. Moreover, each object is characterized by a listing of all the clusters to which it belongs, usually from large to small ones [7].

Due to the small amount of initial data in the reference model, a method is used to compress all objects into one super-cluster and create a reference model on its basis.

At the first stage, indicators from the source data, the reference model are tabulated and the percentage of error is calculated (based on data from the reference model and indicators) using the formula:

$$q\% = \left| t_s - \frac{\bar{t}}{t_s} \right|, \quad (2)$$

where q% – percentage error,

t_s – parameter reference value,

i = 1…n – range of current parameters,

$\bar{t}$ – geometric mean of parameters, calculated by the formula

$$\bar{t} = \sqrt[n]{t_1 \times t_2 \times \ldots . t_n} \quad (3)$$

In the second step, we normalize the data using the formulas:

1. Deviation from the reference value of the parameter (Δt_i)

$$\Delta t_i = \left| \frac{(t_s - t_i) \times 100}{t_s} \right| \quad (4)$$

where t_i – initial parameter.

2. Integral quality index (Qint)

$$Qint = \left(1 - \frac{q\%}{\Delta t_i}\right) \times \ln \frac{\Delta t_i}{q\%} \quad (5)$$

where Δt_i deviation from the standard, q% error percentage [6].

			Status
device #8	0,60		Replacement recommendation
device #6	0,96		
device #4	1,25		Regular mode
device #7	1,31		
device #1	1,31		
device #2	1,43		
device #10	1,55		
device #3	1,70		
device #5	7,46		Very good condition
device #9	15,73		

Fig. 3 Final table of the prediction block

4 Discussion

At the final stage, using the system function, we find the average value over the objects, distribute them in ascending order, calculate the intervals in the resulting sequence and find the geometric mean of the intervals.

Based on the calculated geometric mean, divide the resulting sequence into 3 clusters (Fig. 3). In this example:

1. The first cluster of device # 5, 9 is in excellent condition.
2. The second cluster of device # 4,7,1,2,10,3 - normal operational state.
3. The third cluster of device # 8, 6 - attention is required in the form of a current check and, based on the results of the check, either a replacement or an extension of the period of operation with a periodic check of the state [7].

5 Conclusions

The presented forecasting model can be freely extended to any intelligent system in construction, the elements of which collect telemetry about their work and state. This approach to predicting failures of technical means is suitable for any area where it is possible to monitor the performance of a device (equipment, unit) either in real time, where the use of the device is critical, or it is possible to accumulate data within a reasonable time frame. The use of this technique is advisable only for devices, the fact of failure of which cannot be correlated with predetermined indicators. Otherwise, the decision to use classical cybernetic algorithms will be correct.

The forecasting model is based on the use of modern algorithms. At the same time, forecasts must be treated in a recommendatory rather than a declarative way, but, as the actual data accumulate, the attitude towards the system can radically change.

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About the Distortion Model of Operational Compressed-Bent Bars with Induced Anisotropy

Sergey Kalashnikov, Elena Gurova, Renat Kuramshin, and Batyr Yazyev

Abstract In the present paper, the distortion model of compressed-bent straight bar is proposed, whereas the stressed state in each cross section was initially homogeneous. At the various stages of life cycle, any external disturbance causing even the minor bending leads to the additional bending stresses, the stressed state is becoming nonhomogeneous that results it the strain constraints. In the proposed problem setting, non-homogeneity of the stress field causes variability of material's elastic properties leading to alteration of the design parameters of a structure. The corresponding solution of the bar's axis in a deflected state was obtained, the algorithm for analyzing bar's stability was proposed.

Keywords Inhomogeneity · Stress fields · Small curvature · Transversal isotropy · Longitudinal bending

1 Introduction

The study of such complex physical and mechanical phenomenon as the distortion process and the material's transition into the ultimate state would be impossible without the use of significant simplifications. In its turn, schematization of strained medium is directly determined by the objective of the study and the properties of the real material.

In series of researches [1–6], there was stated the dependency of material's behavior in the studied point on the stressed state of nearly points of continuum. This relationship could be characterized by factoring in the gradients of stress tensors and

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strains referring to dimensional coordinates. When the stressed state is nonhomogeneous, strain constraint takes place (or the effect of the “casing”). The less stressed bulks of the material “support” more stressed ones, thus increasing their resistance to distortion. The more nonhomogeneous stressed state, the higher the interference degree of various-stressed areas of a material.

In the papers [7–12], such an influence of elastostrained areas of a material was accounted for at the level of elasticity conditions. In [13, 14], there was simulated the behavior model of elastic isotropic material in the general case of dimensionally-nonhomogeneous stress–strain state. The model is developed on the assumption that the constraint of shearing deformation takes place along favorably oriented areas. The vector-gradient of the scalar field of stresses is used as the non-homogeneity measure.

Let us assume that the stressed state of a body made from an isotropic material with standard mechanical properties is known. Within the geometric dimensions of a body, it is always possible to single out some particular surface representing geometric locus of points with the same level of shearing strains’ intensity.

For any point on the surface U of the same level of shearing strains’ intensity T could be uniquely drawn the tangential plane P (Fig. 1). The direction of the vector-gradient T will appear normal to P and shows the direction of the maximum change of T in the neighborhood of the selected point. The material’s layers are “compacted” along this direction, thus constraint would affect distortion in the tangential plane at a greater extent, whereas at a lesser extent – at distortion along the plane orthogonal to the surface U. The minimum value of elasticity modulus E0 determined by tensile tests corresponds to longitudinal distortion along the orthogonal planes. For the area in the plane P, elasticity modulus has the greatest values from all possible values of Egr for the considered point, being a function of gradient modulus, but it cannot exceed the greatest elasticity modulus possible at deformation of the given

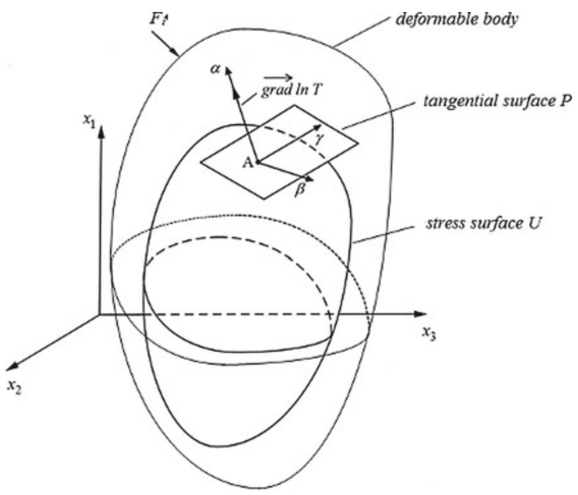

Fig. 1 Stress surface and local reference frame

material in nonhomogeneous field of stresses. The modulus of shearing and coefficients of lateral distortion undergo the corresponding changes. While transferring to any other point on the surface U, tangential plane changes its orientation, but the value and combination of the moduli of elasticity, shearing and the coefficients of lateral distortion are not altered along the above-mentioned directions. Along the direction of gradient vector, the axis a is the elastic symmetry axis of infinitely high degree, while the plane P is the isotropy plane [15]. Thus, local transverse isotropy takes place in the point. In general, an elastic body distorted in the conditions of nonhomogeneous stressed state should be considered as anisotropic one.

Making transition from local axes of point anisotropy to the customary coordinate system, we obtain the group of physical equations of incremental elasticity theory. Incremental dependences represent the peculiar type of non-linearity when the tensors of strains and stresses are not in direct proportion, and increment of one or another parameter are included into the determining ratios. In our approach, we operate the gradients of stresses. The complete system of the existing equations cannot be solved analytically. Under the known initial linear solution by means of the linear approximation method, it is necessary to readjust elastic properties while realizing the system of resolving differential equations each time around. There could be the multitude of stress surfaces U within a deformable body. Some particular cases occur at the symmetric stress–strain state when the surface of stresses coincides with the coordinate surfaces of the customary global system of coordinates. For example, at pure bending or off-center compression of a cross-beam with arbitrary cross-section. In this case, the sum total of isotropic planes somewhat coincides with the longitudinal layers of a material. Columnar compression of a flexible bar of small stiffness is regarded as a more complex problem even for symmetric cross-section.

2 Results

Let us consider a bar of rectangular cross-section loaded by the compression force F (Fig. 2), in the center of the cross-section.

In building codes, practices and technical regulations, while calculating stability of bars, it is assumed by default that the members are ideal perfect bodies, whereas loading and stresses are evenly distributed along the length and lateral cross-section, the material is homogeneous and isotropic in each point. Let us assume that due to some external disturbance a bar acquires curvature with the deflection y. This disturbance occurs simultaneously with application of the force F and could represent the initial deflection, random eccentricity or applying small accidental lateral loading. In a deflected state, a bar would be exposed to longitudinal loading infinitely as the indicated disturbances are unavoidable. In this case, apart from compression, its stressed state is characterized by tensile stresses as well, thus, non-homogeneity of stressed state is present. Considering lateral force arising in a bar from the bending moment induced by the initial imperfections, the intensity of shearing stress

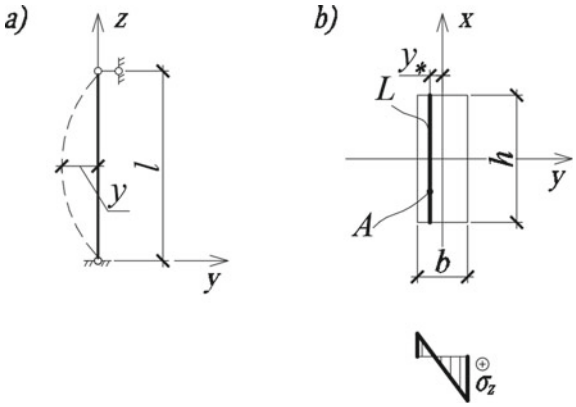

Fig. 2 Computational scheme of a compressed-bent bar

$$T = \frac{1}{\sqrt{3}}\left(\sigma_z^2 + 3\tau_{zy}^2\right)^{\frac{1}{2}} = \frac{F}{\sqrt{3}A}$$
$$\left\{\left(1 \pm \frac{12y}{b^2}\right)\cdot y_* + \frac{3}{h^2b^4}\left[12\left(\frac{hb^2}{8} - hy_*^2\right)\right]^2\left(\frac{\partial y}{\partial z}\right)^2\right\}^{\frac{1}{2}} \quad (1)$$

In the last expression, accounting for the lateral force complicates the computational process immensely, along with that, the final result insignificantly deviates from the result, which does not allow for shearing stresses. This is due to the fact that lateral force in equal to Nil in the point of maximum deflection in the middle of bar length. Along with that, within the cross-section, the second summand in (1) does not have a pronounce impact on non-homogeneity of stressed state: in the most stressed fibers, shearing stress is equal to Nil, whereas the maximum value is found in the vicinity of the neutral axis. Referring to this, let us consider that within mathematical accuracy stressed state is rather precisely characterized by the first summand in the radical expression (1). I.e., with neglect of shearing stresses, then in the arbitrary point A

$$\sigma_z = \frac{F}{A}(1 \pm \frac{12y}{b^2}\cdot y_*). \quad (2)$$

Non-homogeneity of stressed state is formed along the height of transverse cross-section «b». Along with that, in each cross-section the degree of non-homogeneity is different due to the various deflection value along the bar's length. Thus, transverse anisotropy is created that is induced by the deflection «y», functionally depending on the coordinate along the cross-section y_*. The surface of the same level of stresses U degenerates into the line L (Fig. 3). The plane P tangential to it coincides respectively with the plane tangential to the deflection curve S. The direction of the vector-gradient T (that means that σ_z also) is normal to the plane S and, inevitable, to the line L. Having denoted this as the axis α, we assume the direction the axis γ coinciding with the line L, whereas the axis β is normal to the line L in the plane S (i.e., tangential).

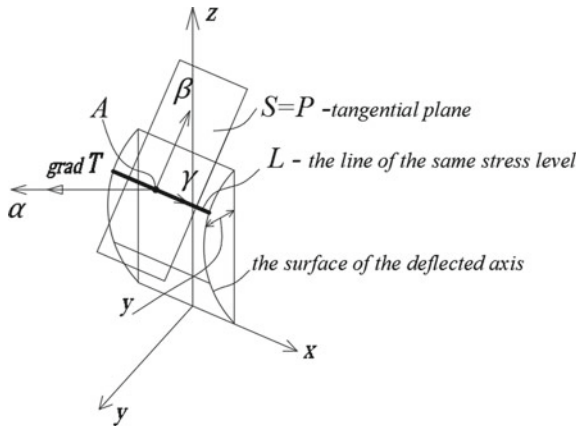

Fig. 3 Stress surface at columnar deflection of the bar

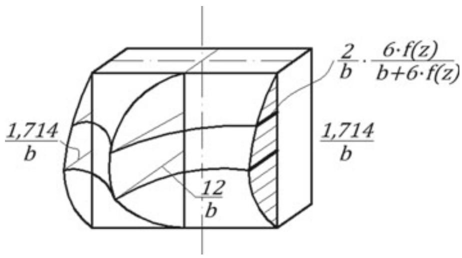

Fig. 4 Distribution curve for function of non-homogeneity measure of stressed state

It is worth noting that the material's layers are compacted in the direction α, that means elasticity moduli $E_{\beta} = E_{gr,}$ and $E_{\alpha} = E_0$.

Modulus of vector-gradient with account for (2)

$$gradT = \sqrt{\frac{\partial}{\partial y_*}(\frac{1}{\sqrt{3}}\sigma_z)^2} = \frac{1}{\sqrt{3}} \cdot \frac{F}{A} \cdot \frac{12y}{b^2}. \quad (3)$$

The measure of stressed state non-homogeneity is characterized by the function

$$g = \frac{gradT}{T} = \frac{2}{b} \cdot \frac{6y}{b + 6y}, \quad (4)$$

also, for the cases of pure and lateral deflection is reciprocally proportional to the cross-section height (in this case, in the plane with the least stiffness). However, it is complicated by the second multiplier that gives an accurate account of non—homogeneous distribution of function along the length and lateral cross-section of a bar. For example, having assumed that deflection is equal to the cross-section size $y = b$, we obtain the distribution demonstrated in the Fig. 4. Respectively, elastic properties of a material would change according to the complex law.

In the works [13, 14], according to circumstantial experimental data [2] it was shown that elasticity modulus is slightly higher at bending as opposed to the case of uniaxial tension. It is conceived that in non-homogenous fields of stresses elasticity modulus has a variable value. There were proposed symptom-free dependences describing the law of elasticity modulus change for such cases:

$$E_{gr} = E_0 + (E_m - E_0) \cdot \frac{g}{\lambda_E + g'} \tag{5}$$

where E_0 – elasticity modulus of a material determined from the results of the uniaxial tension tests; E_m – the greatest elasticity modulus, possible at non-homogeneous stressed state; λ_E - some elastic property of a material determined experimentally and measured in $[M^{-1}]$. Assuming that $E_m = 1{,}5E_0$, then from (4) and (5) it follows

$$E_{gr} = E_0(\frac{\lambda_E + 1,5g}{\lambda_E + g}). \tag{6}$$

The approximated differential equation of deflection axis of a bar describing the relationship between bending moment and curvature,

$$y'' = \frac{M_x}{EJ_x}.$$

factoring in (6), the equation takes a form of homogeneous differential equation of second order

$$\frac{d^2y}{dz^2} + \frac{F}{E_0J_x} \cdot \frac{a+y}{a+1,5y} \cdot y = 0, \tag{7}$$

differs fundamentally from the classic one.

In (7), it is given that

$$a = \frac{\lambda_E h^2}{12}.$$

It does not seem possible to integrate it in closed form. Obtaining a satisfactory solution (7) in the Euler's path is also unreachable. The issue of its numerical realization represents not only mathematical but also meaningful problem as the second cofactor reflects complication of the structure's performance due to possible defects of manufacturing and assembly. Its equality should be ensured by the real betweenness of loading and shifts corresponding to it.

3 Conclusion

Simulation of a distortion model of the material outlined in the present paper give the evidence that throughout the lifecycle of capital construction projects, at the stages of erection and maintenance, shearing deformations take place in the real longitudinally compressed bars from the initial moment of loading due to technological faults arising at manufacturing and assembly.

Arising non-homogeneity of stressed state leads to the induced curvilinear transverse anisotropy, with elastic properties changing in a complex manner in the limits of bar's dimensions.

The proposed distortion model is not independent and does not represent a particular case of non-homogeneity or curvilinear anisotropy.

Complication of the resolving equation preconditioned by the presence of initial disturbances removes the problem of compressing a simple flexible bar from the stability problem of the 1st order. Moreover, the announced causes of non-homogeneity of stressed state causing deflection from the very initiation of distortion would complicate the Eq. (7) (the initial factory-originated deflection, random eccentricity, etc.) reducing it to non-homogeneous one. In this case, the problem represents the study of the stability problem of the 2nd order. It is worth noting that paper [16] emphasizes the hopelessness of dividing the process of stability loss into orders.

One should judge about stability factor depletion for bars basing on exceeding the maximum depletion of variated values for the relevant technical regulations. It seems advisable to apply the obtained theoretical results for practical evaluation of stability margin of bars. The simultaneous provision of parameters of project's mechanical safety could lead to lowering materials' consumption.

Approximation methods could be used as a means of realization. For instance, the Bubnov-Galerkin's method [17] or the method of variable elasticity parameter [1].

Using variational approach and the Birger's method, we will technically carry out numerical modelling of the distortion process by calculation the dependency "loading-deflection".

Scientific work in such a research area is of novelty, the obtained results give plausible evidence about the necessity of dissemination of the developed proposals to a wider scope of problems.

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Restoration of the Historically Valuable Town-Forming Object "Shevaldyshevskoe Courtyard, the Second Half of XVIII Century" Using Building Information Modeling

Alena Kazarova, Leonid Shilov, and Liubov Adamtsevich

Abstract The paper presents an analysis of the experience of using building information modeling in the restoration of cultural heritage objects (CHO) and historically valuable town-forming objects (HVTFO). It is noted that this direction is at the stage of development and formation, both in Russia and abroad.

The VOSviewerTM program and a selection of publications collected in the international Scopus database using the HBIM keyword are used for determining the promising technologies used in the restoration of such objects.

It has been confirmed that the integrated use of Industry 4.0 technologies makes it possible to reduce the time required for the creation of an information model of an object and the development of drawings necessary for operation.

The methodology of using Industry 4.0 technologies in the process of restoration work according to the HVTFO is described, which can also be applied to the CHO.

The results of the methodology application are presented in relation to the historically valuable town-forming object - Shevaldyshevskoe courtyard. The integrated use of Industry 4.0 technologies allows specialists to reduce the development time of information models and to control the quality of work during the development of the design CHO and HVTFO, which allows collisions in design and construction costs.

The richly decorated facades of the object have lost elements, the recreation of which requires particularly accurate measurement drawings and the creation of templates for future restoration works, the reconstruction of lost fragments, as well as the addition of elements with missing parts. The basements of the object, which are complex in architecture, represent a huge variety of vaults with a conservation status: cylindrical, sailing, cross, collapsed, cross-domed, etc. It is not possible to carry out collision-free installation of engineering equipment in such spaces without a detailed information model.

These technologies significantly reduce the time required for the development and release of scientific and design documentation for the CHO and HVTFO.

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Keywords HBIM · BIM · Industry 4.0 · Scopus · Cultural heritage objects · Historically valuable town-forming objects

1 Introduction

The development of science and technology has led to a change in construction materials and building technologies. In place of wooden buildings, stone ones appeared. Over time, they switched to standard construction, where not enough attention was paid to the architectural appearance of building objects. As the population was growing, the historical planning structure of the city could not cope with urban traffic, and the integrity of the historical zones was destroyed. And only today people began to think about the problem of preserving cultural heritage objects (CHO), historically valuable town-forming objects (HVTFO) and their historical appearance.

The regulatory documentation defines that CHO are real estate objects with territories historically associated with them, arising because of historical events, which are of value in terms of history, architecture, urban development, art, science, technology and are evidence of eras and civilizations. HVTFO are buildings and structures that have an independent historical and town-planning value, form a development front; being "background" or "ordinary" buildings, they form the surroundings of the monument and the historical environment. At the same time, most of the objects described above are currently in need of restoration, which is understood as research, survey, design and production work carried out in order to identify and preserve the historical and cultural value of a cultural heritage object.

At the same time, in the era of the fourth industrial revolution, design tools continue to improve that enable to solve the problems associated with the restoration of CHO and HVTFO more efficiently. A significant number of publications, both in Russia and abroad [1–15, etc.], are devoted to the issues of restoring the CHO and HVTFO.

For example, to preserve a building as an object of cultural heritage, the authors of [1] used building information modeling to restore the history of construction and stages of construction.

Interesting is the research work [2], devoted to the digital representation of the unrealized work of the architect S. Hutter, which was presented in 1964 at an international competition. Digital reconstruction of the project was carried out based on the remaining documentation and layout.

The paper [3] examines the possibilities of the integrated use of information modeling technologies and UAVs for modeling and documenting the forgotten heritage on the example of The Isabel II dam, built in the middle of the nineteenth century in Spain.

In paper [4], building information modeling technologies are used to represent building solutions for roofs, floors and walls, as well as decorative details and finishes for the palace in Lisbon.

The development of a participatory digital management system to support the asset management of historic buildings is the latest innovation in the conservation and restoration of historic buildings in Indonesia, presented in paper [5].

Another example of the use of information modeling technologies is the research presented in the paper [6]. The research project evaluated the application of the building and structure information modeling paradigm to study the architectural history and state of conservation of the Church of St. John the Divine, an important object belonging to the Cypriot historical heritage.

Figure 1 shows the distribution of publications by years, according to the keywords "BIM" and "restoration" (sample 1) and HBIM (sample 2) in the international knowledge base Scopus. For the first sample, 216 publications are displayed, for the second – 479, correspondingly. At the same time, a comparative analysis was carried out, which showed that the articles from sample 1 are fully covered by sample 2. In this regard, in the future work only sample 2 will be used.

Figure 2 shows the top 10 countries by the number of publications for the keyword HBIM. In the first place are authors from Italy (196 publications), second - from Spain (68 publications), third - from China (42 publications). In terms of the number of publications, Russia is on the 20th place.

At the same time, the largest number of publications relates to Computer Science -178 and Engineering-167, which confirms the hypothesis of a close relationship between information technology and the construction industry.

At the same time, for comparison, Fig. 3 shows a sample demonstrating the dynamics of publications growth for the BIM keyword. The annual growth in the number of publications in the field of application of information modeling technologies indicates that their use in the restoration of cultural heritage objects is still at the stage of development and formation, both in Russia and abroad.

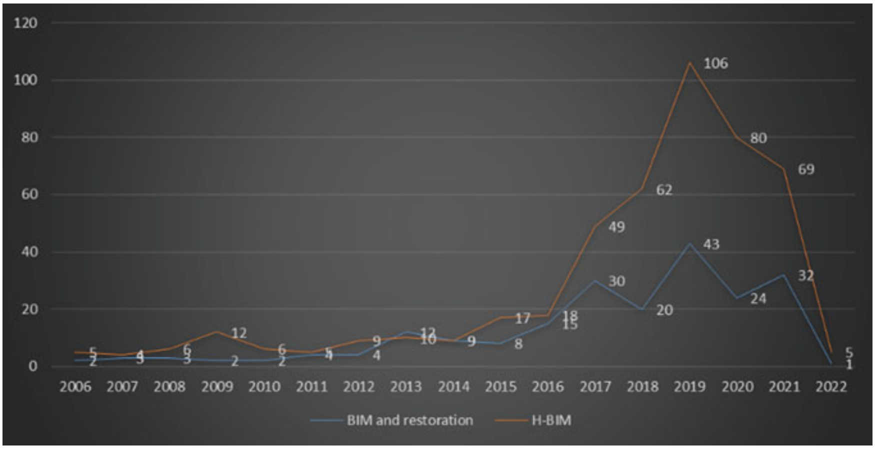

Fig. 1 The dynamics of changes in the number of publications in the Scopus knowledge base for given keywords

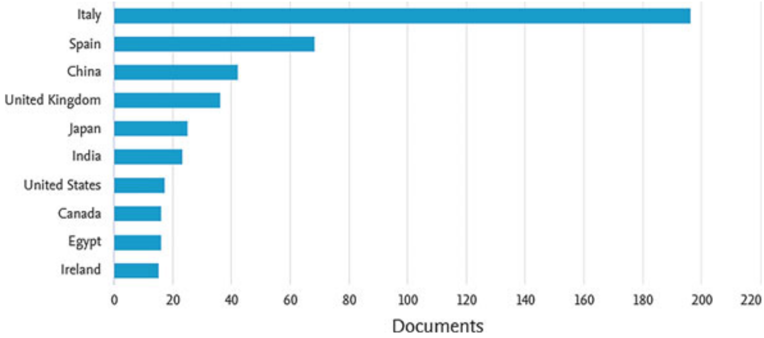

Fig. 2 Documents by country or territory

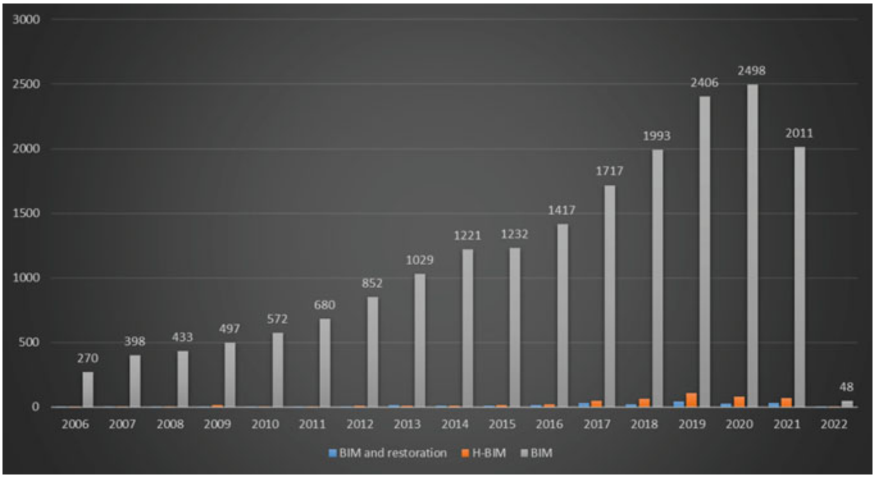

Fig. 3 Dynamics of changes in the number of publications by the keyword BIM

2 Methodology

2.1 Identification of Promising Technologies for the Restoration of CHO and HVTFO

To identify promising technologies used in the restoration of CHO and HVTFO using information modeling technology, sample 2 is used. This sample is collected using the HBIM keyword. In total, there were 479 publications in the sample, with the information further converted into *.RIS format for further analysis in the VOSviewerTM program and visualization of bibliometric parameters.

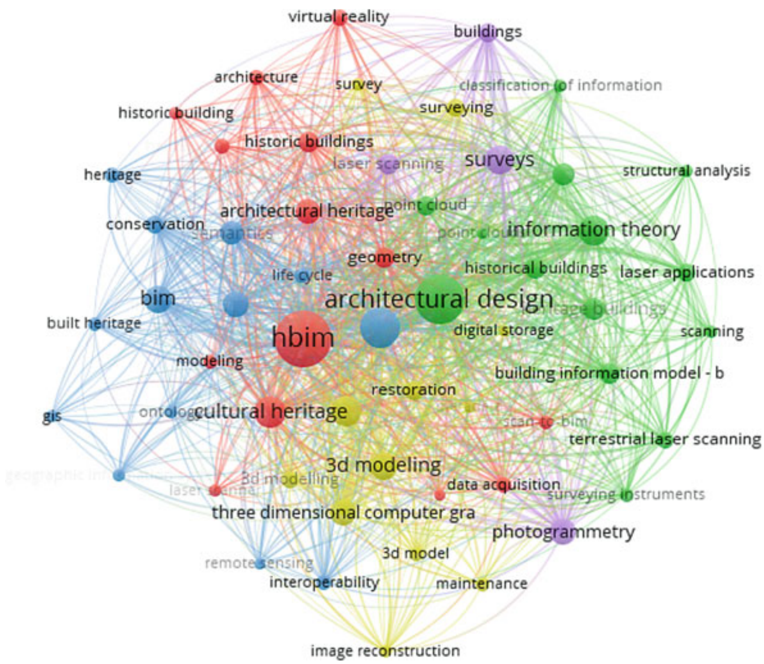

Fig. 4 Relationship of keywords in sample 2 in the form of a cluster map

Figure 4 shows the relationship between the keywords in sample 2. The minimum number of matching keywords in the selected publications was set to 10. The threshold value was 73 words out of 3356. For each of the 73 keywords, the program calculated the total strength of concurrent links with other keywords. Having checked the proposed keywords, 62 most relevant options were selected within the framework of the research topic.

As it can be seen from the obtained cluster map, the key areas for the development of the use of information modeling technologies for the restoration and restoration of the CHO and HVTFO are:

- **terrestrial laser scanning** is a survey system that measures at a high speed the distance from the scanner to the surface of the object and registers the corresponding directions with the subsequent formation of a three-dimensional image in the form of a cloud of points,

- **photogrammetry** is a scientific and technical discipline dealing with the determination of the shape, size, position and other characteristics of objects from their photographs,

- **laser scanning** - the process of obtaining data about an object using laser radiation. As a result of measuring distances and angles to the points of laser reflections, the spatial coordinates of these points are calculated.

2.2 The Methodology for Creating an Information Model of CHO and HVTFO Using Industry 4.0 Technologies

Industry 4.0 technologies, which include building information modeling and the use of UAVs, make it possible to create an information model of an object based on the obtained models in the form of a point cloud combining into a single whole the preliminary design of the restoration and the design of the adaptation with the simultaneous release of working documentation. Information models allow specialists to work simultaneously in several directions and sequentially create models of the draft design of the restoration of the monument and the model of the project of adaptation reflecting all decisions on the restoration, redevelopment, and modification of the monument building [16].

Each element of the information model is an editable component that enables specialists to create existing architectural, structural and engineering elements of the monument. Using information modeling technologies, it is possible to obtain not just three-dimensional graphic objects but also planar drawings, reports, specifications, as well as perform a comprehensive analysis of all information on a cultural heritage object according to various criteria, practically excluding possible collisions [16].

The created unified information models of monuments are created on a 1:1 scale and are a full-fledged digital copy of a cultural heritage site.

Sequence of Work

1. At the first stage, it is necessary to measure the construction object with geodetic instruments, which will allow obtaining three-dimensional coordinates of the main elements of the CHO or HVTFO and eliminate possible inaccuracies in the construction of the existing architecture of the CHO, and using the UAV specialists can create a model of the CHO in the form point clouds.
2. Using software tools enabling to create information models (Autodesk Revit, Bentley OBD, Archicad etc.), the obtained data are combined into a single information model that describes the existing state of the CHO or HVTFO; on their base, plane drawings of the object can be produced.
3. Based on the created information model, a draft design of the restoration and a project of adaptation are developed, whereas all the architectural and decorative elements are linked with each other. A restoration project is issued from a single information model in the form of planar (2D) drawings (facades, plans, sections, fragments, templates, etc.)
4. Further, a historical and cultural examination is carried out on the preliminary design of the restoration and the project of the adaptation. In case of positive outcome, the draft design is sent for approval to the state authorities for the protection of monuments.
5. Working documentation for the restoration of CHO or HVTFO is carried out based on a unified information model (on a scale of 1:1) of the preliminary design of the restoration and the project of adaptation.

6. The information model of CHO or HVTFO allows calculating the volumes of materials and dimensions of elements, based on these data, estimate documentation is issued.

3 Results

The methodology described above was used in the restoration of the historically valuable town-forming object “Shevaldyshevskoe Podvorye”, located at 4/5 Nikolskaya Street.

The history of the object can be traced back to the seventeenth century when the courtyard of the Khvorostishin’s princely family was located here. Prince Yu.D. Khvorostishin was mentioned among the homeowners on Nikolskaya Street as early as 1638, and a century later, according to the census book of 1737, the property was registered with the princes Golitsyn, who received it from their grandmother, Khvorostishin’s granddaughter, who married B.A. Golitsyn. In 1747, Ya.A. Golitsyn ceded his share to his brother, whose children, having inherited the courtyard, sold it in 1776 to Lieutenant-General S.M. Rzhevsky, who immediately began construction of two-story stone buildings flanking the street. In 1772 the Rzhevskys gave their yard as a mortgage, and in 1788 it was bought by the Moscow merchant of the 1st guild, T.D. Shevaldyshev, by whose name the name “Shevaldyshevskoe courtyard” was assigned to the property and survived regardless the sale of the site in the middle of the nineteenth century to another owner.

Building up the property purchased from the Rzhevskys around the perimeter, Shevaldyshev was guided by profitable goals. Thus, the period of functional evolution of home ownership was marked by the fact that the basements and first floors of all buildings were given to trade (shops, warehouses), and the upper ones were residential and rented out. In 1846, this object was acquired by the merchant I.V. Alekseev, whose heirs it belongs to until 1917.

The development complex of the property, which is one building, took shape over more than 100 years and included parts of buildings of different times. The currently existing building, with the boundaries of the property along the entire perimeter, acquired its final shape in 1870–75, after reconstruction was carried out in the possession of Alekseev. In terms of the structure, it has the rectangular shape typical of that time, with a division into three inner buildings (Fig. 5).

The restoration of the object is carried out according to the methodology described above. At the first stage, using a UAV, a model of an object in the form of a point cloud was created (Fig. 6).

Based on this model, an information model of the object was created, combining into a single whole the preliminary design of the restoration and the design of the adaptation. Object visualization is shown in Fig. 7.

At present, all the work preceding the implementation of the restoration work has been completed.

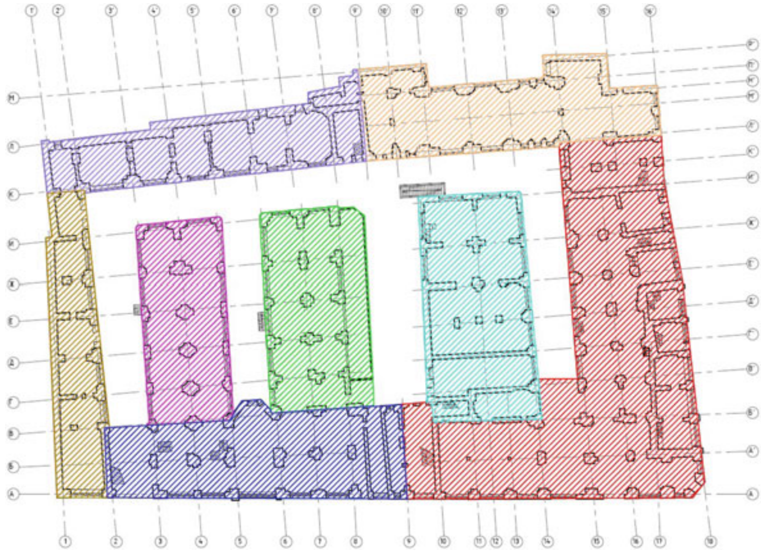

Fig. 5 Plan of the structure of the Shevaldyshevsky courtyard (*Source*: materials of the restoration project of JSC "Guta-Development")

Fig. 6 An example of a digital model of CHO in the form of a point cloud (*Source*: materials of the restoration project of JSC "Guta-Development")

Fig. 7 Object visualization (Source: materials of the restoration project of JSC "Guta-Development")

a b

Fig. 8 Facade of the object "Dwelling house of the Abrikosovs" before **a** and after **b** restoration work. Address: Moscow, st. Malaya Krasnoselskaya, 7, bldg. 31. (*Source*: materials of the restoration project of JSC "Guta-Development")

Another example of the applied methodology is an object of cultural heritage of regional significance "The Abrikosovs' dwelling house with the administrative premises of the Partnership "A.I. Abrikosov Synovaya "(since 1922 - confectionery factory named after P.A. Babaev), 1900s, engineer B.N. Schnaubert ", whereas the restoration of the facades was completed in 2020. Figure 8 shows the photographs of the CHO before and after restoration.

4 Conclusion

The use of Industry 4.0 technologies, for example, UAVs, during restoration work can significantly reduce the time for creating an information model of CHO or HVTFO, while transferring the exact shape of an object. The use of information modeling technology makes it possible to carry out quality control of work during the development of design documentation for CHO or HVTFO, thus avoidig collisions during design and significantly reduces the time required for the development and release of scientific and project documentation for the facility.

A promising direction is the creation of 3D casts of fragments of the de-cortex of historical objects for their further use in the restoration of CHO. All this testifies to the fact that the integration of information technology into the construction industry expands the capabilities of builders, designers, restorers, reduces the time required to complete the work, and allows solving problems that were previously unsolvable.

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Management of the Implementation of a Construction Project Based on Integrated Digital Models

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Abstract Issues related to the organization of production in the implementation of investment construction projects are particularly acute. Problems arise related to efficiently managing the timing, quality and cost of construction work.

The use of digital tools helps ensure effective construction management both during the design phase and during the construction phase.

The article explores the issues of using integrated digital modeling, including virtual, augmented, mixed reality.

Approaches to optimization of construction at the design stage based on scheduling and simulation tools are considered. As an alternative method, the authors propose the use of the network method of the formed representation of control systems, the essence of which is the construction of a dynamic network model using BIM technologies.

When managing the construction phase, it is proposed to create a project management center, whose task is to monitor the progress of construction based on modern digital technologies.

Its activity should be based on the collection of operational information from the construction site.

The result of the work is a number of documents, which include a balanced work schedule, taking into account the delivery and installation time of technological equipment, a balanced schedule of the needs of materials, people, machines and mechanisms. The proposed tools provide, in the event of deviations in the course of the project, the adoption of effective operational organizational and technological decisions throughout the project.

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Keywords Information modeling · Digital model · BIM-technology · Construction · Design · Augmented reality · Mixed reality

1 Introduction

Modern conditions for the development of the construction industry require new approaches to the organization of production in the implementation of investment construction projects. In particular, the issue of increasing the efficiency of designing deadlines and budgets while maintaining the quality of work is especially acute. According to a study by the 8th Global Project Management Survey, 2016, [1], more than 47% of projects exceed budget, 51% of projects do not meet deadlines, 38% of projects do not reach their goals, and 16% fail completely.

According to research conducted by Independent Project Analysis on 173 large projects (>690 million USD) carried out between 2010 and 2020 [2], the main causes of problems in the construction industry include: lack of project management skills - 11%, ineffective control and communication - 15%, design collisions and alterations - 15%, planning errors - 25%, delayed deliveries of MRI - 19%.

The solution to these problems can be an increase in efficiency at the stages of construction design and construction production using digital technologies.

2 Materials and Methods

Issues related to ensuring the quality of construction work at the planned time and price can be resolved at the design and implementation stages of construction work using digital construction control tools.

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

The main idea presented in the publications is the introduction of augmented and virtual reality tools, TIM-modeling in construction design and construction work.

Virtual reality is a computer-generated, interactive three-dimensional image.

Augmented reality (AR) is the imposition of virtual reality on a real environment. Mixed reality, defined by Milgram and Colquhone [3], is a combination of virtual and real environments. Thus, the image of the real scene is improved for the user's perception of the real environment, providing access to information that the user cannot directly perceive without assistance. J. Kumaran [4] argues that augmented reality deployed in the commercial market will significantly reduce labor costs, time and resources.

Examples of different types of reality are presented in Fig. 1.

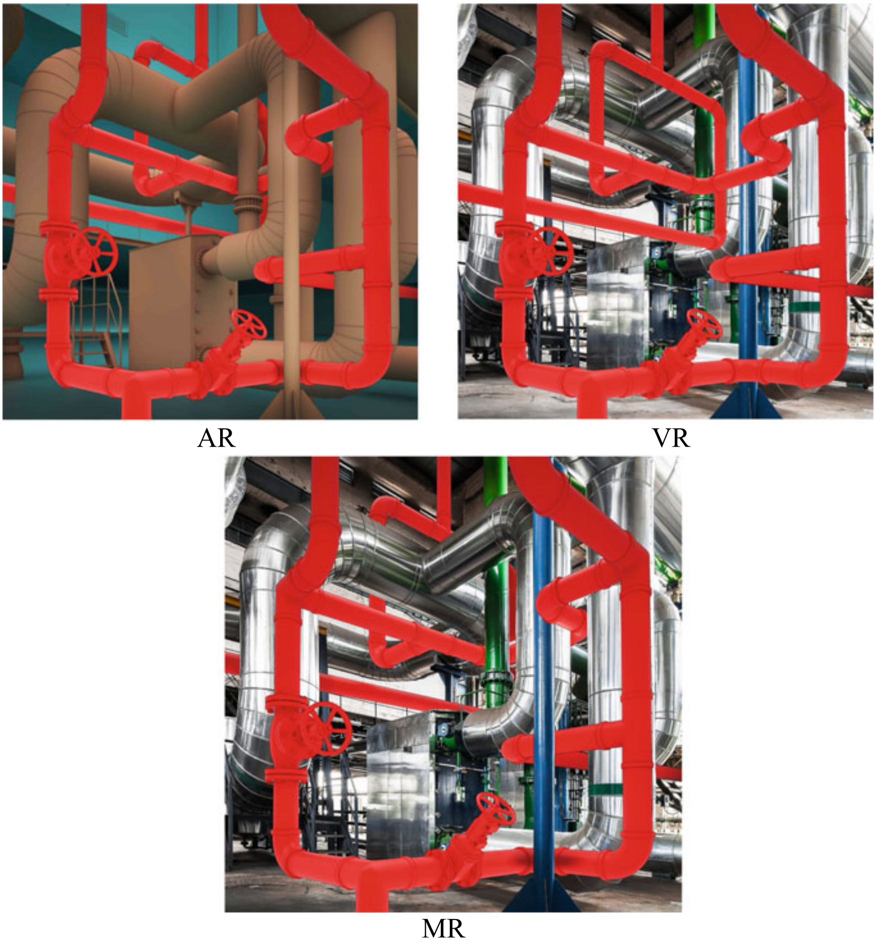

Fig. 1 Examples of different types of reality

According to a study by R. Machado and S. Vilela [5], in the process of construction at the stage of installation of subassemblies and infrastructure, integrated modeling of AR and BIM technologies has a high applicability potential, which makes it possible to form a system that is intuitive to the user and expands BIM - model in such a way as to shorten the response time to possible conversion solutions at the construction site.

The potential for using integrated technologies is increasing due to the evolution of portable computers, the introduction of mobile devices, and the development of a virtual environment. Liu Yang and Jack Cheng [6] prove the effectiveness of using digital models to optimize construction using certain types of structures, in particular, metal structures. Pointing to the low quality of 3D modeling, M. Basier [7] and S. Winke, Z. Puchko [8] propose new approaches to metric quality control of construction sites based on a point-check cloud, as well as the use of cameras on helmets, designed to improve the quality 3D models obtained as a result of scanning of building structures.

The prospects and specificity of the use of digital technologies based on BIM, AR and other modeling tools are of interest to Russian authors as well. In particular, V.Yu. Gulik [9] examines the technology of using BIM-modeling in construction and points to the multivariance and effectiveness of this tool.

The study of foreign experience in the use of BIM-technologies by V. Ilyinova and V. Mitsevich [10] shows that Russia lags behind in this matter, whereas these mechanisms are used by no more than 10% of companies. As the result, the low number of objects that are difficult to design experience the urgent need for digital technologies and high implementation costs, and unavailability of management for innovations.

BIM technologies can be used to improve the energy efficiency of buildings, which requires the integration of information models with building service systems [11, 16]. Their use is also possible when examining buildings. Here it is important to determine in advance the requirements for the designed information model, considering the specifics of the building [12, 17].

Information modeling can also be used in the construction of infrastructure facilities, for example, subways, railways, etc. [13, 18–20]. This will optimize the passenger traffic system, reduce the need for personal vehicles, and increase the city's economic competitiveness.

Thus, digital technologies such as information modeling BIM, augmented reality, actively developing abroad, are beginning to be applied in Russia. There is a need for methods of their complex implementation based on the principles of accuracy, availability and cost-effectiveness. This will increase the efficiency of production of construction products at different stages of their life cycle.

When implementing investment projects, the BIM-modeling technology proved to be the most effective. This technology at the stage of development of documentation allows eliminating a large number of collisions. The information model is usually divided into levels - 3D, 4D, 5D, 6D.

3D is a three-dimensional parametric design, the fundamental distinction from classical CAD systems is that any line in the drawing should now have properties.

4D - Time Management. In the modern world, time has become decisive in the formation of an investment object, since the investor pays% for the use of credit money. The sooner an investor will hand over an object, the faster he will make a profit, especially this became clearly visible when introducing escrow accounts in Russia for the construction of residential buildings. It is also worth noting that a reduction in construction time leads to a reduction in overhead costs associated with the maintenance of the directorate of the customer and the contractor, the maintenance of the construction site (security, payment of utility bills, crane rental, etc.). The use of a 4D information model makes it easier to visualize the sequence of future work performed.

5D - money management. In addition to 4D, forecasting of financial flows is carried out; unloading volumes of materials/works/equipment for cost modeling, as well as control of the project cost.

6D - Facility Operation. Condition monitoring is carried out, an electronic passport is formed, repairs and maintenance are carried out, energy efficiency and reconstruction are managed.

3 Discussion

3.1 Optimization at the Design Stage

In the process of designing the timing and cost of work, several tools can be distinguished:

- scheduling;
- building a gantt chart;
- application of simulation modeling;
- building an integrated information model.

The task of scheduling investment projects in the field of construction is to determine the optimal time for the completion of construction work and involves identifying the stages of development and implementation of the schedule with different levels of detail.

Detailing the stages of the schedule allows you to optimize the start and end dates, the duration and cost of work, as well as provide an opportunity for their high-quality performance based on ensuring the control of construction work, choosing a contractor who can provide such quality.

Depending on the degree of detail, multilevel graphics can be used (Fig. 2).

Level 1 Schedule or Project Master Schedule (PMS).

Determines the main stages of the project and the activities included in them, in the context of the timing of implementation and the duration of the main groups of work. Serves as the basis for the development of more detailed schedules and is, as a rule, an annex to the construction contract.

Level 2 Schedule or Summary Master Schedule (SMS).

Refines the information of the 1st level schedule and summarizes the activities and stages of the 3rd level schedule. It is supposed to be used in large projects where it is difficult to control the entire project at once. It can be in demand as a type of reporting for the Customer, in which there is no need for detailing. It is also the basis for coordinating the work of individual subcontractors.

The Level 3 Scheduling or Project Coordination Schedule (PCS) is an integrated critical path view (CPM) of a project. It is used as a reporting one for project management and the Customer (on demand) and is an integrated level 4 schedule. At the

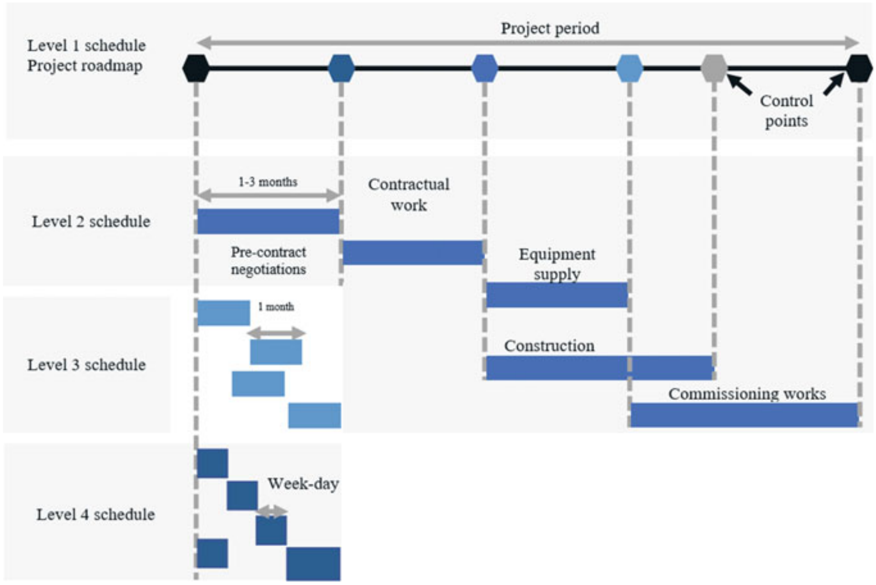

Fig. 2 Investment construction project calendar charts

stage of project implementation, it determines the duration and stages of the overall critical path and is the main tool for coordinating the project as a whole.

A Level 4 Schedule or Working Schedule (WS) details the steps and activities represented in a Level 3 timeline. Used as the main work schedule for the project. It imposes on the stages and work the costs of resources: labor, material, etc. This graph uses a level of detail from a week to a day.

When planning the timing of work, it should be borne in mind that an increase in the level of detail of the schedule leads to a decrease in the controllability of its implementation.

Based on the Work Schedule, the status of the project and its terms are tracked. The search for the critical path is carried out on a level 3 chart, while the works on the critical path are embroidered to level 4 to optimize and control their execution. This allows you to optimize the complexity of the work.

Gantt chart and critical path method are used to build network diagrams. Their significant drawback is the lack of a scenario approach and, as a consequence, the impossibility of taking into account the options for the development of construction processes.

A Gantt chart is a complex of actions to maintain a complex network of hierarchical relationships and subtasks. The construction of large-scale facilities leads to the emergence of complex sequential tasks, which leads to an increase in the complexity of management and control over the Gantt chart. There is also a high dependence on the human factor. And since the collection of data on actually completed work becomes decisive in the implementation of investment projects, then the use of this tool for modeling the result when any initial data changes, it is advisable to limit in favor of other tools.

As an alternative method, the authors propose the use of the network method of the formed representation of control systems, the essence of which is the construction of a dynamic network model using BIM technologies. In this model, the entire process is divided into separate operations, located in a strict technological sequence of their implementation. Work performance parameters are set at the stage of BIM model development based on flow charts or experience in performing these works. They determine such parameters as labor, material resources, cost.

When building a BIM model, a link is formed with a network dynamic graph (structure of dependent and sequential links). Further, using the Monte Carlo method, the causal relationships of the elements of the BIM model and the dynamics of change of each element are displayed.

According to the Monte Carlo method, a random number generator assigns an instant numerical value to each initial calculation parameter, one of the possible values from its interval estimate [14]. Further, using the interaction functions, instantaneous values of intermediate and final parameters are obtained, which characterize the state of a structure, a floor of a structure, an element of a structure or a united group of structures, united by common features: belonging to the same series or to one territory. Instantaneous values can change or be constant over time.

When developing a simulation study, the main scenarios are being worked out, which become the basis for the formation of an integrated model formed on the basis of various types of modeling [15], presented in Table 1 (Fig. 3).

At the beginning of construction, this model is optimized for a specific contractor, depending on its technical equipment, the qualifications of the engineering and working staff.

3.2 Optimization During the Construction Phase

Currently, the information model is rarely used in construction. Developed by design organizations, it is not used in practice by construction organizations. Information about the actually completed scope of work often does not correspond to the fact. For example, there is a term such as "mounted but not accepted". This means that the structures have been assembled, but the construction control has remarks on the quality. "Assembled, but not delivered" means that the structures have been installed, accepted by the construction control, but there is no executive documentation.

As a construction management tool, it can be the creation of a project management center (PMC), whose task is to monitor the progress of construction based on modern digital technologies.

Table 1 Types of modeling

Modeling type	Modeling method
Resource and technological modeling (RTM)	Modeling is carried out in order to estimate the cost of the project, depending on the factors of pricing The resulting model consists of two blocks: resource, based on the physical measurement of materials, construction volumes, labor costs, and cost, which estimates the cost of a unit of resource volume and a unit of volume of construction products
Logical modeling (LM)	Modeling of organizational work required to ensure the supply of material and technical resources. Considers the order of material and technical support adopted in the organization Describes all stages of procurement for each assembly/procurement package/lot Contains information about the timing of each of the stages
Organizational and technical modeling (OTM)	Generated by reverse calculation from the construction and installation schedule Represented as a graph included in the complex project model Takes into account 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 the estimated time frame for each of the stages Allows you to issue weekly and daily tasks to designers, buyers and other departments, ensuring their well-coordinated work
Organizational Modeling (OM)	Modeling the organizational structure and personnel mobilization plan The number of AUP and the organizational structure is calculated and formed on the principles of manageability. The number of support personnel and the final overhead costs are determined by calculation from the number of AUP and production personnel on the basis of provision rates A bunch of OM with RTM allows you to form an optimal mobilization plan
Risk Model (RM)	Calculated through the inflation model and in conjunction with selected market solutions in the field of risk management

(continued)

Table 1 (continued)

Modeling type	Modeling method
Financial and economic model (FEM)	Calculated by the direct resource method. It is formed from the totality of financial and economic data of all previous models (BIM, RTM, LM, OTM, etc.) It is dynamically linked to the above models, which makes it possible to take into account the impact of these changes on all financial and economic indicators of the project when changing any data in them. At the beginning of construction, this model is optimized for a specific contractor, depending on its technical equipment, the qualifications of the staff

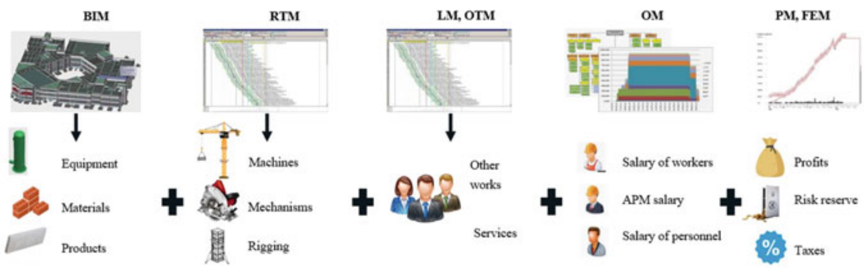

Fig. 3 Modeling of the construction process

The activities of the PMU should be based on the collection of operational information from the construction site.

Currently, two technologies are most widely used: the use of optical scanners on an unmanned aerial vehicle (UAV) and the BRIO MRS tablet with mixed and advanced mixed reality technology. The fundamental difference of this technology lies in the use of mixed reality MR, which allows you to see the interaction of real and virtual objects. A person can already appreciate the foreground and background, how objects are located relative to each other. A point of contact between real and virtual objects appears (Fig. 4).

The information model used on the site allows the construction control engineer to receive all the information contained in the model, indicate the current status of the mounted element and transfer to the manager's desktop a 3D graph of the object, where the colors indicate: yellow - the element is being mounted, red - the element is expired time and green - the element is installed and accepted by the customer (Fig. 5).

During the processing of technical information model, the customer is obliged to collect the executive information model "as built", i.e. is obliged to align the graphic representation of the information model. For example, if the air duct was displaced by the builder from the design position, the technical customer must agree on this change

Fig. 4 Tablet BRIO MRS

a b

Fig. 5 Example of BRIO MRS tablet operation

with the design organization and, if he has no comments, make an adjustment in the information model, in fact, indicate “how it was built.” In addition to the graphic display, he is obliged to enter all the information in the information model about the materials used, equipment passports, certificates and other documents provided for by the current legislation.

The structure of the integrated information model is shown in Fig. 6.

A feature of the proposed concept is the absence of an additional need for additional personnel at the construction site and an increase in the labor intensity of construction management processes.

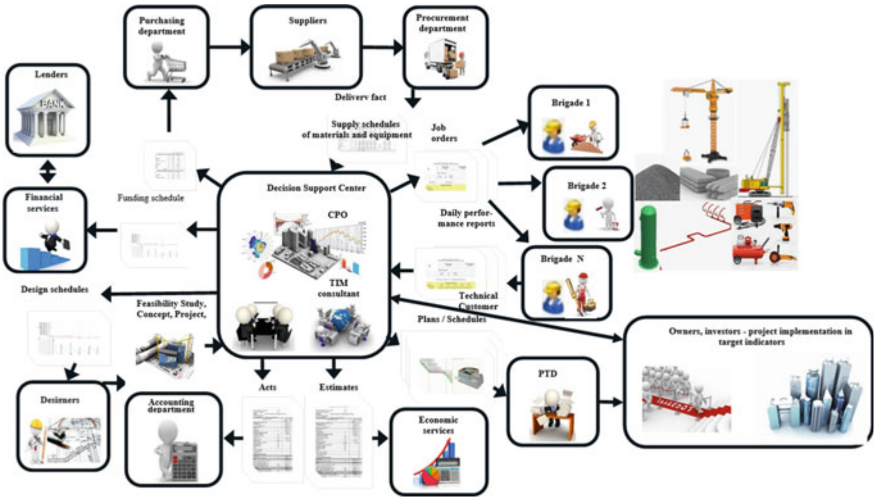

Fig. 6 Project progress management using a comprehensive information model

4 Results

The result of the work is a number of documents, which include a balanced work schedule, with due account to the delivery and installation time of technological equipment, a balanced schedule of the need for materials, people, machines and mechanisms.

On-site construction support, ensuring, in the event of deviations during the Project implementation, the adoption of effective operational organizational and technological solutions, allows you to keep the Project in the target indicators specified by the Customer.

Implementation of the concept allows to ensure reduction of non-production losses, which can be achieved due to:

- increasing the accuracy of calculating physical volumes (using verified/validated BIM models) of work;
- transition from empirical top-down planning to accurate bottom-up modeling;
- justified by calculations of the choice of the best (with minimal costs) way of implementing the project among the available opportunities and limitations (time, cost, resource, logistics and climatic);
- modeling to work processes and, as a result, the transition from standards for large-scale types of work to technologically sound standards;
- ensuring balance, taking into account the interchangeability and qualifications of resources, enabling to reduce rush jobs and equipment downtime;
- making optimal, accurate, grounded and coordinated organizational and technological decisions during the entire project;
- operational control from the "field" with minimal human involvement.

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Regression Analysis as a Method of Telemetry Data Verification

Elena Kitaytseva

Abstract The **Purpose.** The aim of the research is to use regression analysis for telemetry data verification. **Methods.** The article discusses 3 models that approximate telemetry data. To check the adequacy of the models to the physical process, the analysis of the frequency distribution of the deviations of the predicted values from the measurement results was used. An algorithm for eliminating outliers is proposed. The significance of the coefficients included in the approximating functions is estimated. **Results.** Regression analysis was used to obtain the coefficients of 3 models for each of the 7 objects. Pearson's criterion confirmed the consistency of the distribution of the residuals of the models that take into account the influence of the flow rate, with the normal distribution for all objects. The significance of the coefficients included in all models is confirmed using the Student's t-distribution. The coefficient of determinism R^2 is practically the same for different models for all objects. **Discussions.** The obtained approximating dependences, taking into account the flow rate, adequately and fairly accurately describe the physical process in the range of parameter changes recorded in the archive. When leaving this area with increasing flow rate for model (2), there is no adequacy to the physical process. **Conclusions.** Regression analysis revealed abnormal measurements. When choosing the appropriate dependencies, it is necessary to rely on physical laws.

Keywords Telemetry data verification · Regression analysis · Heat supply systems

1 Introduction

The longest period in the life cycle of engineering systems, including heat supply systems, is the period of the system's operation. With the centralized heat supply of large settlements adopted in a number of countries, the heat supply system becomes a life support system. Systems for automatic regulation of heat supply, without which it is already impossible to imagine the operation of heat supply systems, include

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modules that perform the functions of monitoring processes [1–5]. The monitoring system not only transmits the current parameters of the system, but also archives them, which allows for a retrospective analysis of the heat supply process. Automatic control systems require constant monitoring their performance is assessed by verification of the transmitted data. One of the verification methods is regression analysis [5].

As a parameter, the dynamics of which reflects the process of heat supply and heat consumption of objects, it is recommended to choose the temperature t_2 at the exit from the heating systems or the temperature at the entrance to the central heating point.

In [2–4], regression analysis is used to plot the dependence of the coolant temperature t_2 on the temperature t_1 at the outlet from the central heating station and on the flow rate M. The obtained approximating dependences are taken as a reference and used to assess the efficiency of heat supply control for heating needs.

When constructing and selecting models approximating the measurement results, the following criteria should be used separately or in some combination:

- the minimum number of independent variables that significantly affect the accuracy of the approximation;
- the simplest form compatible with reasonable error;
- reasonable physical grounds ("follows from some law");
- the minimum sum of squared deviations between the predicted values and the measurement results.

Of the criteria listed, criterion 3 is not used in [1–5], only a verbal description is given – as the flow rate M increases, the temperature t_2 increases. As an approximating dependence, it is proposed to use a linear model in terms of coefficients and parameters $t_2 = f(t_1; M)$.

2 Methods

The temperature t_2 is primarily affected by the temperature at the outlet of the t_1 source.

The dependence of the heat flow on the temperature difference t_1 and t_2

$$Q = c(t_1 - t_2)M \tag{1}$$

suggests a linear relationship between temperatures:

$$t_2 = b_{I0} + b_{I1}t_1, \tag{2}$$

where b_{I0}, b_{I1} are the coefficients of the approximating function Eq. (2), hereinafter referred to as model I.

The temperature t_2 depends on the mass flow rate M – the greater the flow rate, the higher the temperature. The dependence is taken into account by an additional term [2–4]:

$$t_2 = b_{II0} + b_{II1}t_1 + b_{II2}M, \tag{3}$$

where b_{II0}, b_{II1}, b_{II2} are the coefficients of the approximating function Eq. (3), hereinafter referred to as model *II*. It should be noted that the coefficient b_{II2} must be positive, otherwise the physical meaning of the dependence is lost – with an increase in the flow rate M, the temperature t_2 will decrease. However, with a positive coefficient b_{II2}, another distortion of the physical process is possible – at high flow rate, the temperature t_2 will exceed the temperature t_1.

An alternative to model *II* is the model:

$$t_2 = b_{III0} + b_{III1}t_1 + \frac{b_{III2}}{M}, \tag{4}$$

where $b_{III0,}$ $b_{III1,}$ b_{III2} are the coefficients of the approximating function Eq. (4), hereinafter referred to as model *III*. With a negative coefficient *bIII2*, model *III* adequately describes the physical process - an increase in temperature t_2 with an increase in flow rate M, while no increase in flow rate will allow to obtain a temperature t_2 above temperature t_1.

Models I – III described by dependencies Eqs. (2, 3, 4). They are linear in coefficients, so linear regression analysis is applicable to them [6]. The least squares method is used as a method for finding linear regression coefficients. Estimates of coefficients **b** are found as a result of solving a system of linear equations:

$$x^T x b = x^T Y, \tag{5}$$

where

$$x = \begin{bmatrix} 1 & x_{11} - \overline{x_1} & \ldots & x_{q1} - \overline{x_1} \\ 1 & x_{21} - \overline{x_1} & \ldots & x_{q2} - \overline{x_1} \\ \ldots & \ldots & \ldots & \ldots \\ 1 & x_{n1} - \overline{x_1} & \ldots & x_{qn} - \overline{x_1} \end{bmatrix};\ Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \ldots \\ Y_n \end{bmatrix};\ b = \begin{bmatrix} b_0 \\ b_1 \\ \ldots \\ b_q \end{bmatrix};$$ n is the sample size; q is the number of model parameters. For model I $q = 2$, for model II and $III - q = 3$.

In all models, the first independent variable x_1 is the temperature t_1, the second independent variable x_2 is the mass flow rate M for model *II* or *1/M* for model *III*. The dependent variable Y is the temperature t_2.

The accuracy of data approximation is estimated using the determinism coefficient calculated by the formula:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_i - \widehat{Y}_i\right)^2}{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2}, \quad (6)$$

where $\widehat{Y}_i$ is the predicted value; $\overline{Y}$ - is the average value for the entire sample.

One of the assumptions underlying the least squares method is the assumption of a normal distribution of residuals $\varepsilon_i = Y_i - \widehat{Y}_i$. To check the consistency of the distribution with the normal distribution, the Pearson criterion is used [7].

Estimates of model parameters were calculated iteratively. At the first iteration, the entire sample was considered, and the residuals were analyzed. All residues ε_i that do not fall within the range:

$$Q_1 - k(Q_3 - Q_1) < \varepsilon_i < Q_1 + k(Q_3 - Q_1), \quad (7)$$

where Q_1, Q_3 are the first and third quartiles of the sample, respectively; the coefficient $k = 3$ (for explicit outliers [8]), were removed from the sample and the process was repeated.

To test the hypothesis that the parameter k-th is not significant (coefficient $b_k = 0$), statistics were calculated;

$$t_k = \frac{|b_k|}{s_{\overline{Y}i}\sqrt{c_{kk}}}, \quad (8)$$

where c_{kk} is the kth diagonal element of the matrix $c = \left(x^T x\right)^{-1}$;

$$s_{\overline{Y}i} = \sqrt{\frac{\sum_{i=1}^{n}\left(Y_i - \widehat{Y}_i\right)^2}{n - q - 1}}. \quad (9)$$

When the condition $t_k > t_{1-\alpha/2}$ for n-q-1 degrees of freedom was met, the hypothesis about the non-significance of the parameter was rejected.

3 Results

Models *I-III* were used to verify the measurement results of the parameters of the heat network. The sample covered measurements in the period from 1.01.2018 to 25.03.2019. The summer period of operation of the heating network was not explicitly set, so it was calculated from the average daily outdoor temperature. As a result, the data of measurements carried out from 18.06.2018 to 29.09.2018 were removed from the initial sample. The frequency of data collection is a day. The initial sample size is $n = 340$. The information was collected at 7 central heating points connected to one heat supply source.

The archived telemetry data concerning the parameters of the secondary heat carrier intended for the heating of buildings was used to solve the task:

- the temperature of the coolant, °C, at the outlet of the central heating point t_1 and at the entrance to it t_2;
- volume flow rates, m^3/day, in the supply pipeline at the outlet of the central heating point V_1 and in the return pipeline at the entrance to it V_2.

The mass flow rate, M, t/day, used in the simulation, was determined by the formula:

$$M = 0,5[\rho(t_1)V_1 + \rho(t_2)V_2], \tag{10}$$

where $\rho(t_1)$, $\rho(t_2)$ is the density of the coolant, respectively, at temperature t_1 and t_2 was found using a formula approximating the tabular data:

$$\begin{aligned}\rho(t) = 1000 - 3,8718 \cdot 10^{-2}(t-4) - 5,38 \cdot 10^{-3}(t-4)^2 \\ + 2,008 \cdot 10^{-5}(t-4)^3 + 4,2896 \cdot 10^{-8}(t-4)^4\end{aligned}. \tag{11}$$

The ranges of changes in the parameters M, t_1 and t_2 involved in the calculation are shown in Table 1.

Absolute values of rate flow M (columns 3–5) and ranges of changes M (column 6) depend on the object, which is explained by the difference in the connected load of heating systems (column 2). When constructing models *II–III*, a scale factor of 0.001 was used for the flow rate M.

Absolute values of temperature t_1 and its average values (columns 7–9) practically do not depend on the object. At the same time, the difference in the temperature of

Table 1 Ranges of change of parameters of objects

Ob	Q_n Gcal/h	M, t/day			$(M_{\max}\text{-}M_{\min})/M_{\mathrm{m}}$ %	t_1, °C			t_2, °C		
		Min	Max	Mid		Min	Max	Mid	Min	Max	Mid
1	2	3	4	5	6	7	8	9	10	11	12
1	8.735	6541	9687	8233	38.2	44.6	75.8	64.1	39.6	61.9	53.1
2	4.380	3956	5394	5215	27.6	44.6	75.6	63.8	40.5	63.9	54.9
3	1.635	596	1776	1565	75.4	44.7	75.7	63.9	38.5	61.3	52.7
4	1.259	1537	2728	2389	49.9	44.4	75.6	63.9	40.6	67.7	57.7
5	1.095	934	1277	1137	30.2	44.8	75.8	64.4	39.6	61.0	52.5
6	0.574	456	705	514	48.4	43.3	75.7	63.7	39.5	63.7	54.8
7	0.470	482	735	586	43.2	44.0	75.3	63.4	40.0	65.3	54.8

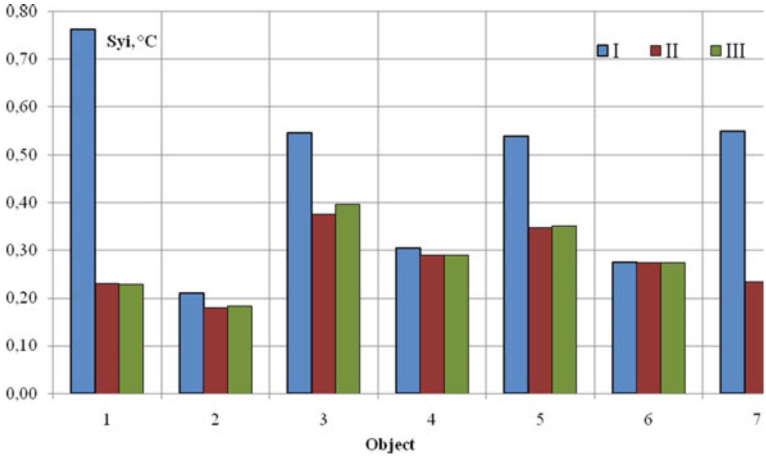

Fig. 1 Mean square deviations $s_{\overline{Y}i}$

water (columns 10–12) t_2 returned to different central heating points from heating systems is more significant.

Figure 1 shows the values of the mean square deviations $s_{\overline{Y}i}$ of the values predicted by different models from the measurement results for all objects.

The maximum value $s_{\overline{Y}i}$ does not exceed 0.8 °C (model *I*, object 1), which indicates a high accuracy of approximation.

Regardless of the object, the lowest approximation accuracy (high value $s_{\overline{Y}i}$) has a model *I*. This result suggests that it is not enough to consider only temperature t_1 as an independent variable. However, with a small absolute range of flow variation *M* (object 6), the value $s_{\overline{Y}i}$ for model *I* is the same $s_{\overline{Y}i}$ as for models *II* and *III* (see Table 1 column 6, row 6). The slight decrease $s_{\overline{Y}i}$ in the transition from model *I* to model *II* or *III* for object 2 is explained by a small relative change in flow rate $(M_{max}-M_{min})/M_m$ (see Table 1 column 6, row 2).

Regardless of the object, the accuracy of data approximation using models *II* and *III* practically coincides.

The determinism coefficient R^2 for all models of all objects did not fall below 0.986 (Model Object 4). The average value for all models and for all objects $R^2 =$ 0.997.

Due to the absence of repeated measurements, the adequacy of the model to the real process was checked by checking the consistency of the frequency distribution of residues to the normal distribution law. The frequency distribution of residuals for models *I*, *II* and *III* for object 1 is shown in Fig. 2.

As can be seen from the Fig. 2, the frequency distribution of residuals for model *I* does not agree with the normal distribution law. The Pearson criterion confirms the consistency of the frequency distribution of the residuals of models *II* and *III* with the normal distribution law. A similar check showed that the residuals are distributed according to the normal law for model *I* (objects 2, 4, 6) and for models *II*, *III* (all objects).

Figure 3 for object 1 shows the residuals $\varepsilon_{ij} = Y_i - \widehat{Y}_{ij}$ obtained for different models j. The average value of residuals for any model is 0.0. For model *I* (blue markers), the spread of residuals is significantly greater than for other models.

The coefficients of models *I–III* obtained by the least squares method based on telemetry data for 7 objects are shown in Fig. 4.

Analyzing the obtained results, the following conclusions can be drawn:

- Trends of all coefficients are the same for different objects;

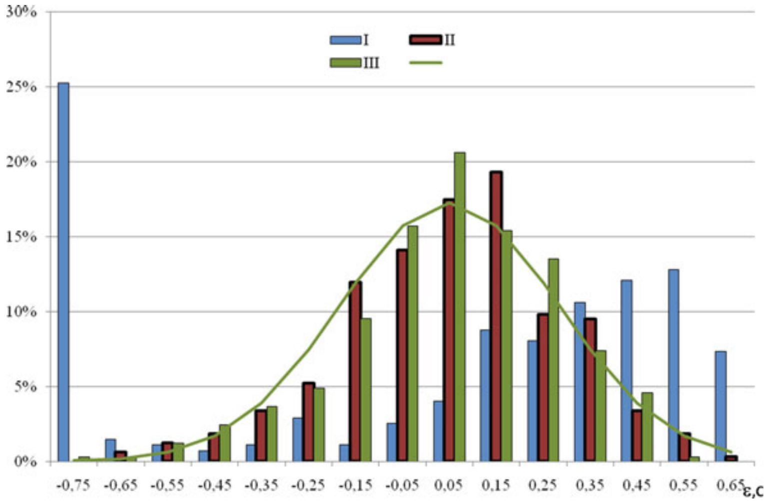

Fig. 2 Frequency distribution of residuals of models *I*, *II* and *III* for object 1

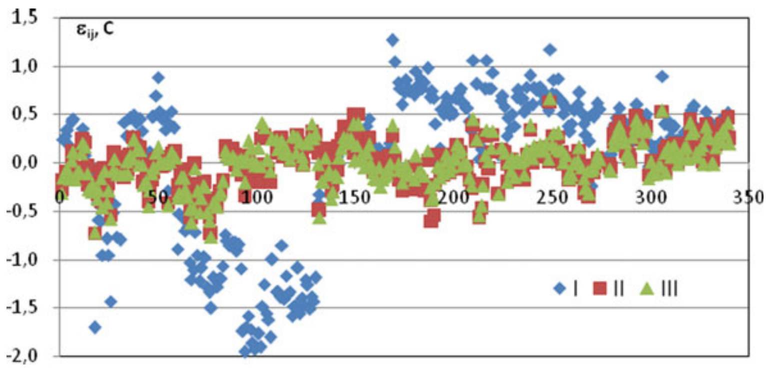

Fig. 3 Distribution of residuals for object 1

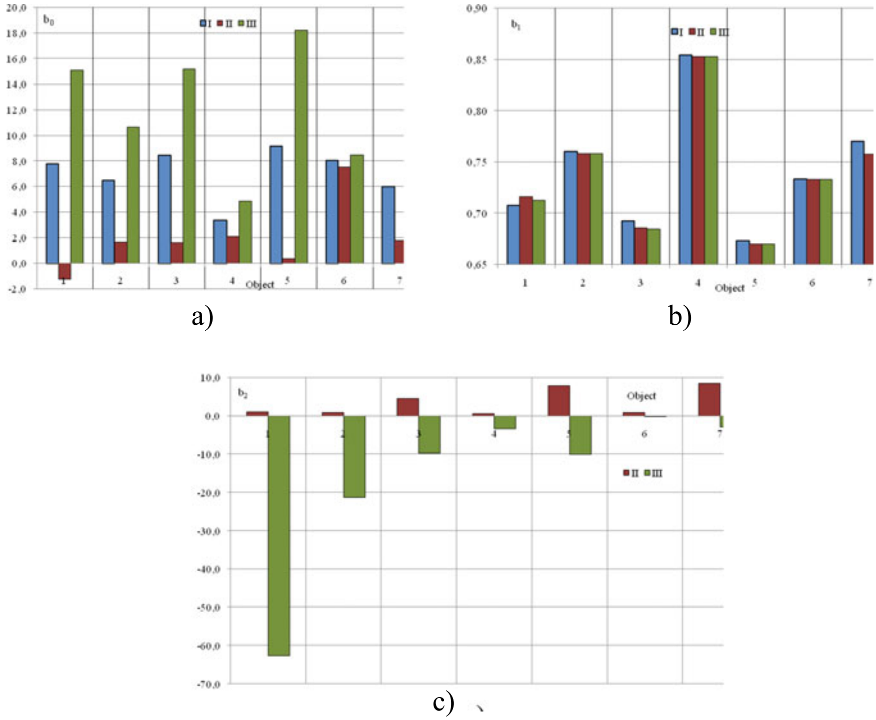

Fig. 4 Coefficients of models *I*, *II*, *III* **a** - coefficient b_0; **b** - coefficient b_1; **c** - coefficient b_2

- The coefficient b_0 for model *I* is less than for model *III*. In both models, it is always positive. The coefficient b_0 obtained for model *II* has the smallest, including negative values.
- The coefficient b_1 lies in the range from 0.67 to 0.85.
- Coefficient b_2 has negative values for model *II* and positive values for model *III*, which corresponds to the physics of the phenomenon - an increase in flow contributes to an increase in temperature. Flow *M* is not included in model *I*.

Checking the significance of the coefficients showed that all the coefficients of all models based on the data of different objects are significant. The exception is the coefficient b_2 with the parameter *M*, which for all models built for object 6 was not significant, which is explained by a small range of variation (see Table 1 column 6, row 6).

4 Discussion

The analysis of the residues made it possible to detect outliers in samples of different objects. The ejection could correspond to both a single measurement and a certain sequence of measurements.

For each object, the location of the emissions coincided for different models. Such a coincidence may indicate a change in the operating mode of the system. “Faulty measurements” were removed from the sample.

The analysis of the residuals did not reveal a trend, a sharp shift in the level and changes in the variance (see Fig. 3).

Models *II* Eq. (3) and *III* Eq. (4) have the same independent variables - temperature t_1 and flow M. The difference is that model *II* contains the expense in the numerator, and model *III* in the denominator. Positive coefficients b_{II2} and negative coefficients b_{III2} are obtained for all objects, which corresponds to the physics of the phenomenon.

The predicted values of t_2 should fall within the range $t_i < t_2 < t_1$. The indoor air temperature t_i was not included in the models considered, and therefore only part of the restriction was considered, namely $t_2 < t_1$.

According to model *II*, with an increase in the flow rate M, the temperature t_2 will increase. If the conditions

$$\begin{cases} t_1 > \dfrac{b_{II0}}{(1 - b_{II1})} \\ M \geq \dfrac{t_1(1 - b_{II1}) - b_{II0}}{b_{II2}} \end{cases} \tag{12}$$

are met, the temperature t_2 will exceed the temperature t_1, which is contrary to the physical process. For the coefficients obtained for model *II*, the first inequality from system Eq. (12) is always satisfied (see Fig. 4 a–b). The maximum increase in the average flow rate M depends on the object: from 1.6 times for object 1 and up to 7.9 for object 6.

According to model *III*, with an increase in the flow rate M, the temperature t_2 will increase. If the conditions

$$\begin{cases} t_1 < \dfrac{b_{III0}}{1 - b_{III1}} \\ M \geq \dfrac{b_{III2}}{t_1(1 - b_{III1}) - b_{III1}} \end{cases} \tag{13}$$

are met, the temperature t_2 will exceed the temperature t_1, which is contrary to the physical process. For the coefficients obtained for objects 2 and 6, the first inequality from system Eq. (13) is never satisfied. For these objects, no increase in consumption will lead to a violation of the physical essence of the process.

For other objects, there is a temperature range for which the first inequality Eq. (13) holds. In this temperature range, the critical increase in the average flow rate M will always be greater than the increase in the average flow rate according to model II - from 1.7 times for object 4 to 5.1 for object 3.

5 Conclusions

The coincidence of emissions for the considered models allowed us to identify abnormal values in the sample of parameter measurements.

A high coefficient of determinism is not a guarantee of the adequacy of functional dependence to the physical process.

When choosing a functional dependence, it is necessary to rely on physical laws.

The range of parameter changes at which the predicted values of temperature t_2 will not contradict the physics of the process is wider in model III. Therefore, preference should be given to her.

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Visual Programming Systems for Assessing the Survivability of Reinforced Concrete Buildings

Korenkov Pavel, Fedorov Sergey, Rodin Stanislav, and Kovalchuk Aleksandr

Abstract The development of digital technologies serves as an important tool for solving urgent problems in the field of construction of new and reconstruction of existing real estate objects.

The widespread introduction into practice of modern software systems that imply BIM technologies allows to avoid errors in the creation of design models of buildings and structures for the analysis of resistance to progressive collapse. This article examines the influence of the method of forming the design model on the qualitative and quantitative indicators of the parameters of the stress–strain state of the bearing system.

The research methods are based on comparing the analysis results and the established parameters of the stress–strain state of the design model of a multi-storey building made of monolithic reinforced concrete when comparing them with the results of experimental studies.

It was found that the use of BIM-technologies, in particular, the system of the graphic editor of algorithms for constructing the design scheme of the building using the SAPFIR-3D software complex, when analyzing the resistance to the phenomena of progressive collapse, does not reduce the quality of the executed design model. Together with a decrease in labor intensity and the number of possible errors, the use of the described technology for the formation of a computational model will reduce the time required for the design work, which will reduce the time required to prepare the necessary documentation.

Keywords Survivability · BIM · Information model of object · Analytical model · Calculation scheme

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1 Introduction

According to analysts [1], the construction industry is behind the leaders of digital transformation such as the information technology and software development sector, as well as the banking sector. The modern reality presents new, previously not imposed requirements for the design of construction projects. In particular, since January 2022, when concluding an agreement on the preparation of project documentation for the construction, reconstruction, overhaul of an object financed with the involvement of budgetary funds, the formation and maintenance of an information model of the object becomes mandatory for the customer, developer, technical customer and the operating organization [2].

In the course of the study [3], it was revealed that the use of BIM technology contributes to an increase in the economic efficiency of investment and construction projects, including a reduction in the payback period of an investment and construction project to 17%, a decrease in the cost of the project associated with a reduction in costs for construction stage up to 30%. The introduction of BIM technologies into project activities is an integral part of the effective functioning of a project organization, while the total costs from the introduction of BIM technologies decrease over time, and the efficiency and profitability of activities increase up to 50% [4].

Modern computational software packages such as STARK ES [5], LIRA SAPR [6, 7] and SAPFIR-3D [8, 9], Tekla Struktures [10], Autodesk Robot and Autodesk Revit [11] and LS -DYNA [12], ANSYS Mechanical [13] allow to accurately form a design model with its physical and geometric properties for various design situations that arise during the entire life cycle of a structure, including emergency impact, using the analytical model of the building.

The purpose of this work is to demonstrate the advantages and verification of the computational model built by means of the SAPFIR-3D graphical editor system for analyzing the danger of progressive collapse of a multi-storey building made of monolithic reinforced concrete.

2 Methods

To demonstrate the methodology for assessing the survivability of the supporting system of a building, both at the design and reconstruction stages, we will create and calculate the danger of progressive collapse using the example of a fragment of a multi-storey building made of monolithic reinforced concrete.

For the reliability of the correctness of the proposed approach to modeling, the analysis of the parameters of the stress–strain state will be compared with the results of experimental studies carried out by the authors, published in [14, 15].

The system under consideration is made in the form of a two-span three-story frame made of concrete of class B15. The crossbars of the frames are reinforced in the upper and lower zones with symmetrical reinforcement along the section height

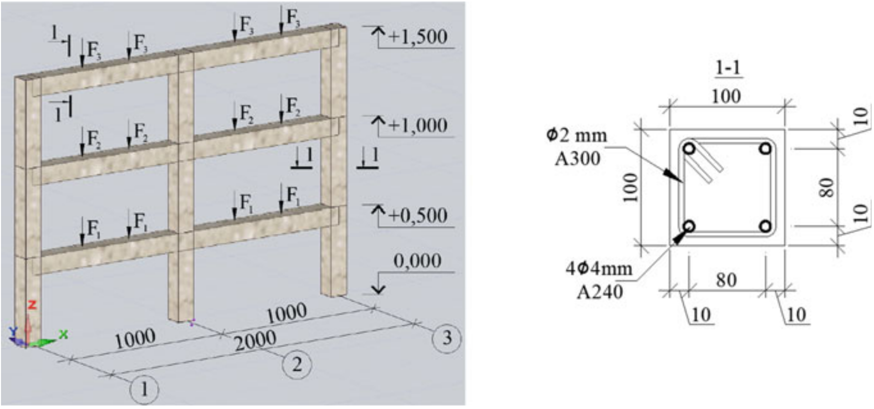

Fig. 1 Parameters of the computational model imported for computational analysis into the LIRA SAPR software package

with working reinforcement in the form of two rods with a diameter of 6 mm of class A240 as shown in Fig. 1.

The transverse reinforcement of the girders is made of wire with a diameter of 2 mm with a pitch of 50 and 100 mm at the supports and in the span, respectively. Such reinforcement was assigned according to the results of the calculation of the experimental frame structures for a given design load in the form of concentrated forces Fi applied in pairs to each crossbar symmetrically at a distance of 1/3 of the design span. The load on the girders of the first, second and third level before the emergency impact was $F_1 = 3.28$ kN, F2 = 2.13 kN and $F_3 = 1.48$ kN.

To transfer the design load, there was used a mechanical gravitational lever arrangement [16, 17] that consists of a lever and a set of rods and distribution beams, transmitting to the frame the load from the platform with piece weights. The tests were carried out according to the methodology [18, 19] measuring and recording deflections, displacements, deformations of concrete and reinforcement, recording the nature of formation, development and opening and closing of cracks at different stages of loading. The considered high impact scenarios were the removal of the middle and outer columns of the first floor.

3 Results

Let us consider the solution of the problem of protecting the bearing system of a renovated building, when information modeling is carried out based on the results of determining the existing topological parameters (such as overall dimensions of sections, strength characteristics of materials, type and nature of reinforcement) of the structural system of the building identified as a result of the work on the survey.

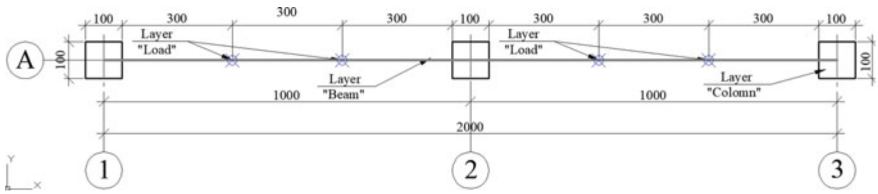

Fig. 2 Background of a fragment of a building in the format *.dxf

For the most part, existing buildings do not have an information model (BIM) [20], therefore, work begins with the study of design documentation and clarification of the reality of its compliance with the actual implementation. Building of an information model of a building will simplify the use of the tool built into the SAPFIR-3D PC - a visual programming system with which you can perform parametric modeling of buildings and structures of arbitrary shape. This system is a graphical algorithm editor that uses the modeling tools of the indicated software package.

The result of the Generator's work is a 3D model consisting of basic objects: columns, beams, walls, slabs, piles, trusses, surfaces, loads, boundary conditions and other objects. When working together, the Generator and the SAPFIR-3D software make it possible to use precise parametric control over the model with its subsequent export to the LIRA-SAPR software for further computational analysis.

At the first stage, it is necessary to prepare a geometric model in the form of surfaces (for geometrically complex shapes) in the *.obj format, or geometric primitives in the *.dxf format (points, lines, polylines, contours), the substrate scheme is shown in Fig. 2. If the building is multi-storey, it is important that the plans have a common reference relative to the origin of coordinates (0; 0; 0).

For the correct display of each of the created elements of the structural system, they are each tied to their own layers in the drawing. Columns in the Column layer, beams in the Beam layer, design loads applied to the frame in the Load layer.

When you change the original data in other CAD systems (editing the shape of the surface or adjusting the *.dxf file), the model is automatically updated in the "Generator".

The graphical algorithm for creating a model of the system under study is shown in Fig. 3, in which NOD 1 - "Advanced creation of floors" is set to describe the height characteristics, where the number of floors and their geometrical parameters are indicated using NOD 2 - "Real number". Since in the example under consideration, the load-bearing structural of all floors is the same, then to create a design model of a building, you can limit yourself to one group of NOD, applying the specified parameters for all floors. For the convenience of the user, it is possible to group NODs into groups.

Creation begins by setting the activity of the current floor. Then, using NOD 3 ¬ "Import background from file", a file is selected, on the basis of which, using NOD 4 ¬ "Filter elements of a given layer", the parameters of the building's supporting structures are generated: 5¬ "Column", 6 ¬ "Beam" and load parameters 7 ¬ "Loads"

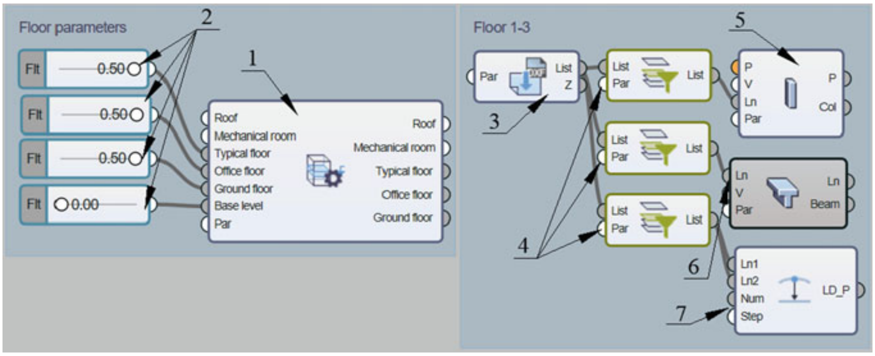

Fig. 3 A graphical algorithm editor system used to form a computational model of the bearing reinforced concrete frame of a multi-storey building

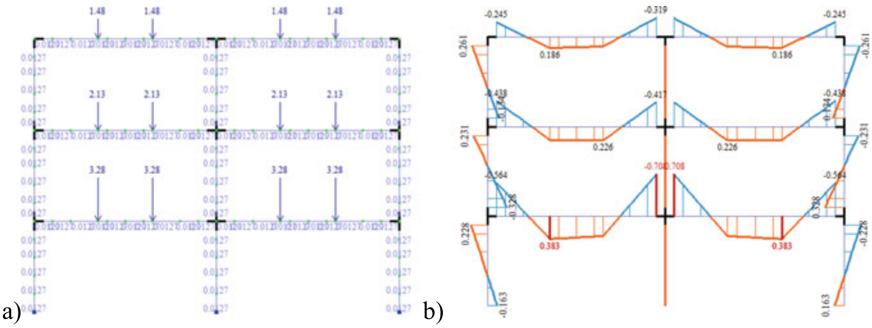

Fig. 4 Design model **a** and diagram of bending moments **b** under operational loads (kN *m)

with their geometrical reference. The result of the operations performed will be the formed physical model of the building, with the given characteristics of the work of structural materials and the established boundary conditions for interaction with the soil foundation.

After checking the physical model for errors and, if necessary, correcting them, the calculated FEM is formed, shown in Fig. 4 - the model with a given triangulation step and transfer to the LIRA SAPR software package for further quasi-static or dynamic analysis of the danger of progressive collapse of the investigated carrier system (Fig. 4b).

To take into account the nonlinear nature of the work of the material, it is possible to set the parameters of the diagrams of the state of materials: reinforcement and concrete with various types of analytical description of the "stress–strain" dependence.

4 Discussion

Based on the performed procedure of automatic frame creation of a multi-storey building to assess the survivability of its supporting system, it is possible to note the high accuracy and fast timing of the formation of the design model using the graphical algorithm editor, which allows to reduce the labor intensity and timing of design work.

The results of the computational analysis in the form of qualitative and quantitative values of the parameters of the stress–strain state convincingly agree with the results of experimental studies performed for the considered structural system.

5 Conclusions

The use of BIM-technologies, in particular, the system of the graphical editor of algorithms for constructing the design scheme of the building using the SAPFIR-3D software package, does not reduce the quality of the computational model when analyzing the resistance to the phenomena of progressive collapse.

In combination with a decrease in labor intensity and the number of possible errors, the use of the described technology for the formation of a computational model will reduce the time required for the design work, which will reduce the time required for the preparation of the necessary documentation.

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Labor Costs for Major and Current Repairs During the Operation of Buildings

Oleg Korol

Abstract When evaluating design solutions for apartment buildings, it is necessary to take into account the labor costs for their repair during the entire service life. The service life of individual structural elements is generally shorter than the service life of the building. During the operational period, during the overhaul of buildings, worn structures are replaced or repaired, and in the period between overhauls, current repairs of buildings are carried out, which consists in carrying out preventive work to preserve parts of the building from premature wear and work to eliminate minor damage and malfunctions. Arising during the operation of buildings. When determining labor costs, the volumes of work performed during major and current repairs are formed taking into account the specifics of the considered options for technical solutions.

Keywords Capital repair · Service life · Maintenance of individual structural elements · Labor costs · Technical inspections

1 Introduction

The service life of individual structural elements of buildings and structures, as a rule, is shorter than the service life of the building, in general. After the expiration of the service life of individual structural elements, the worn out structures are replaced or repaired during the overhaul of the building. In the period between major repairs, current repairs of buildings are carried out, which consists in carrying out planned preventive work to preserve parts of buildings from previously temporary wear and tear and work to eliminate minor damage and malfunctions that have arisen during the operation of the housing stock.

In most of the studies carried out, when determining the organizational and technological parameters of repair and construction work, only labor costs of workers

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employed in the main technological processes are taken into account [1–7]. They establish the dependences of the influence of the quantitative composition of workers and qualifications on the intensification of production processes, their duration and the cost of the work itself [3, 5, 6]. For this, various tools are used, including organizational-technological and information modeling [8–13]. They allow you to optimize both the technological processes themselves and their complexes [14, 15]. However, the total labor costs also include the costs of materialized labor embedded in the objects of labor (materials, products, structures) and means of labor (machines and mechanisms) used in the implementation of repair and construction work, which affect the organizational and technological parameters of the complex of repair and construction works [16].

2 Materials and Methods

The total labor costs for repairs and technical inspections of labor intensity (Li) buildings are measured in man-hours (man-h) and are made up of labor costs for major (Lm.r.) and current repairs and technical inspections (Lcur.r.) throughout the entire service life of the building and are determined by the formula

$$L_i = L_{m.r.} + L_{cur.r.} \tag{1}$$

Labor costs for building repairs, both major $L_{m.r.}$ and current $L_{cur.r.}$, are composed of the labor costs of workers engaged in repairs, the costs of materialized labor inherent in objects of labor (materials, products, structures) and means of labor (machines and mechanisms) used when performing repairs, that is:

$$L_{m.r} = L_{m.r}^{1.1} + L_{m.r}^{0.1} + L_{m.r}^{m.1} \tag{2}$$

$$L_{cur.r} = L_{cur.r}^{1.1} + L_{cur.r}^{0.1} + L_{cur.r}^{m.1} \tag{3}$$

$L_{m.r.}^{l.l.}$ - labor costs for major repairs throughout the entire service life of the building or its part;

$L_{cur.r.}^{l.l.}$ - the same for current repairs;

$L_{m.r.}^{o.l.}$ - the costs of materialized labor transferred to the products of construction production during major repairs from objects of labor;

$L_{cur.r.}^{o.l.}$ - the same for current repairs;

$L_{m.r.}^{m.l.}$ - the costs of materialized labor transferred to the products of construction production during major repairs from the means of labor;

$L_{cur.r.}^{m.l.}$ - the same for current repairs;

The labor costs of workers for major repairs during the entire service life of the building $L_{m.r.}^{l.l.}$ can be determined by the formula

$$L^{l.l.}_{m.r.} = \sum_{1}^{n} L^{m.r.}_{l.c.p.i} \cdot Q_i \cdot r \,, \tag{4}$$

where $L^{l.l.}_{m.r.}$ - specific total labor costs for one overhaul of the unit of measurement of an element or its replacement, including labor costs of all categories of construction and production personnel, man-h;

n – the number of elements to be overhauled;

Q_i – the number of units of the overhauled i^{th} element;

r – coefficient that takes into account the increase in labor productivity due to the development of scientific and technological progress during the operation of the building.

The values of the coefficient *r* are determined empirically, taking into account the fact that most residential buildings in high-rise urban construction have a service life of 125−150 years, depending on their design solutions. The average service life of individual structural elements of residential buildings is much shorter.

Indicators of the specific total labor costs for one major repair for the main elements of residential buildings $L^{m.l.}_{m.r.i}$ are determined on the basis of experimental data.

The costs of materialized labor in objects of labor used in major repairs during the entire service life of residential buildings $L^{o.l.}_{m.r.}$ are determined by the formula

$$L^{o.l.}_{m.r.} = \sum_{1}^{n,m} L_{yaj} \cdot P_{ji} \cdot r, \tag{5}$$

where m – the number of objects of labor consumed during major repairs of the i^{th} elements of the building;

P_{ji} – consumption of the j^{th} object of labor in one major overhaul of the i^{th} element of the building;

L_{yaj} – the specific indicator of labor costs embodied in the units of measurement of the j^{th} objects of labor, man-h/unit. rev.

The consumption of the main objects of labor during major repairs P_{ji} is determined on the basis of reference data compiled from experimental data. Specific indicators of labor costs embodied in objects of labor L_{yaj} are determined by calculation.

The cost of materialized labor in the means of labor $L^{m.l.}_{m.r.}$ used in major repairs is determined by the formula

$$L^{m.l.}_{m.r.} = \sum_{1}^{n} L^{m.r.}_{l.c.p.i} \cdot Q_i \cdot r \tag{6}$$

where $L^{m.r.}_{l.c.p.\boldsymbol{i}}$ – the costs of materialized labor transferred from the means of labor during one overhaul of a unit of the i^{th} structural element.

The indicator $L^{m.r.}_{l.c.p.\boldsymbol{i}}$ – is determined by calculation with a coefficient of 2.5, taking into account dismantling work.

Labor costs for current repairs of the building and technical inspections $L^{total}_{cur.r.}$ during the entire service life, are calculated depending on the established duration of the building's operation according to empirical formulas:

for buildings with an established service life of 150 years:

$$L^{total}_{cur.r.\boldsymbol{I}} = \left[0.003 \times \boldsymbol{r'} + 0.278 \times \boldsymbol{r''} + 0.359 \times \boldsymbol{r''}'\right] \times 1.2 \times 1.15 \quad (7)$$

For buildings with an established service life of 125 years:

$$L^{total}_{cur.r.\boldsymbol{II}} = \left[0.003 \times \boldsymbol{r'} + 0.248 \times \boldsymbol{r''}0.298 \times \boldsymbol{r''}'\right] \times 1.2 \times 1.15 \quad (8)$$

where D_{bsl} - building service life, years;

0.03 - annual labor costs for technical inspections per 1 m^2 of the total area of the building, person-h/m^2 * year;

0.278 - is the specific indicator of annual labor costs for current repairs in residential buildings with an established operating life of 150 years in the first 10 years per 1 m^2 of the total area, man-h/m^2;

0.359 - also, in subsequent years, man-h/m^2;

0.248 - is the specific indicator of annual labor costs for current repairs of residential buildings with an established operating life of 125 years in the first 10 years per 1 m^2 of the total area, man-h/m^2;

0.298 - the same, in subsequent years, man-h/m^2;

1.2 - coefficient taking into account unscheduled repairs;

1.15 - coefficient for unaccounted costs;

r', r'', r''' - coefficients that take into account changes in labor productivity caused by the development of scientific and technological progress.

Considering that during the current repairs of items and means of labor, relatively little is spent, and the main part of labor costs falls on the labor costs of workers, the total labor costs for the operation of residential buildings can be determined by the formula

$$L_{cur.r} = 1.25 \cdot L^{l.l.}_{cur.r.}, \quad (9)$$

3 Results and Discussion

The coefficients taking into account the increase in labor productivity due to the development of scientific and technological progress during the operation of the building are intended in order to assess the possible reduction in labor costs in the repair and construction industry during the long-term operation of buildings, up to 100 years or more.

The coefficient r can be determined by one of the forecasting methods - the method of calculating prospective indicators using the growth rate coefficients. The method is based on the assumption that the series of economic indicators characterizing the development of indicators over time represent a decreasing geometric progression, that is:

$$r = d^{qi} + d^{2qi} + d^{3qi} + \ldots d^{uqi}, \tag{10}$$

where d – is the average annual coefficient of reduction of labor costs (in fractions of a unit), due to an increase in labor productivity as technical progress develops (for practical calculations, it is approximately equal to 0.97);

qi – power of raising the number d, applicable equal to the number of years of the established service life of the i-th element;

u – is the number of major overhauls of a structural element during the service life of the building;

$$u = \frac{\mathrm{D_{bsl}}}{\mathrm{D_{qi}}} - 1, \tag{11}$$

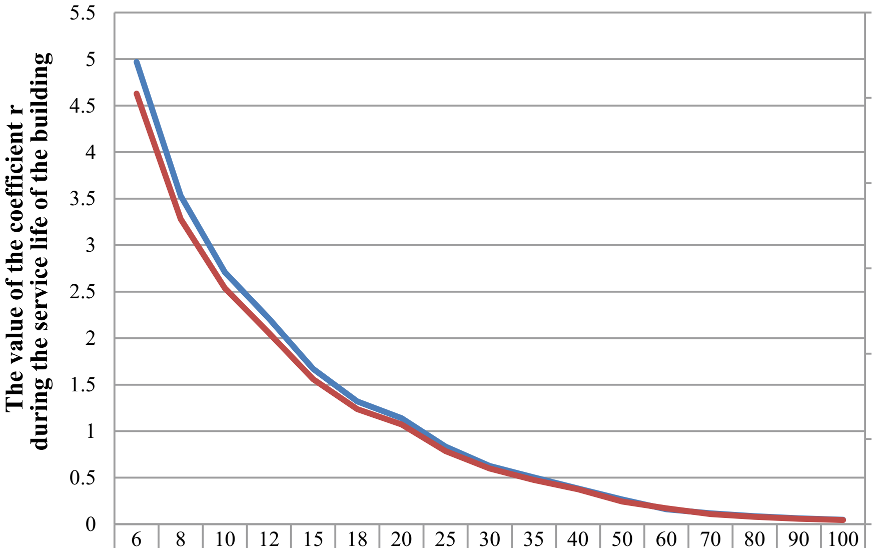
The values of the coefficient r are determined empirically (Fig. 1, Fig. 2). They take into account that most residential buildings in high-rise urban construction have a service life of 125−150 years, depending on their design solutions. The average service life of individual structural elements of residential buildings is much shorter.

Coefficients that take into account changes in labor productivity during the production of current repairs of the building for the first 10 years of operation $\boldsymbol{r}^{'''}$', for subsequent years until the end of the building's service life $\boldsymbol{r}^{'}$, and for the entire service life of the building $r^{'}$, can be calculated by empirical formulas:

$$r^{'} = \frac{\left(1 - d^{Dbsl}\right)}{1 - \mathrm{d}} \tag{12}$$

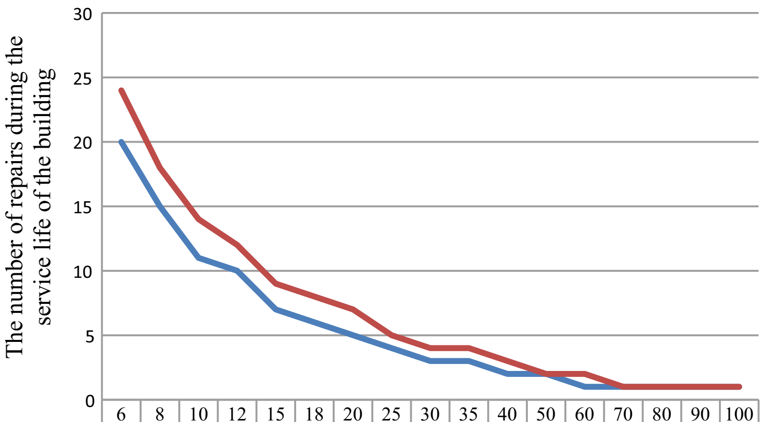
$$r^{''} = \frac{\left(1 - d^{11}\right)}{1 - \mathrm{d}} \tag{13}$$

$$r^{'''} = \frac{\left(d^{11} - d^{Dbsl}\right)}{1 - \mathrm{d}} \tag{14}$$



	6	8	10	12	15	18	20	25	30	35	40	50	60	70	80	90	100
125	4.97	3.53	2.71	2.21	1.67	1.32	1.14	0.83	0.63	0.5	0.38	0.27	0.16	0.12	0.09	0.06	0.05
150	5.05	3.58	2.77	2.24	1.7	1.35	1.17	0.86	0.65	0.52	0.41	0.27	0.19	0.12	0.09	0.06	0.05

Fig. 1 The change in value of the coefficient r for structural elements of different service life



	6	8	10	12	15	18	20	25	30	35	40	50	60	70	80	90	100
125	20	15	11	10	7	6	5	4	3	3	2	2	1	1	1	1	1
150	24	18	14	12	9	8	7	5	4	4	3	2	2	1	1	1	1

Fig. 2 The number of repairs to structural elements of various durability with a building service life of 125 and 150 years

The operational stage of the life cycle of buildings is the longest and for buildings of various capital capacities is up to 100 years or more. Over such a long period, physical deterioration of its individual structural elements occurs. The frequency of major and current repairs is determined, first of all, by the durability of individual structural elements [4].

It is not possible to make a correct integral assessment of labor costs for major and current repairs, prolonged in time, if we do not take into account that over the real life of buildings, there is a development of equipment and technologies aimed at reducing labor costs in the production of work, and, accordingly, increasing labor productivity. An integrated systematic approach to this problem was also used in the studies carried out by other authors [15, 16].

To solve this problem, predictive values of empirical coefficients can be used, which, as experimental data accumulate, are refined and adjusted in mathematical models describing the calculation of labor costs.

4 Conclusion

When determining the integral labor intensity of work in repair and construction production, it is necessary to take into account the entire list of works and the corresponding labor costs carried out not only by workers employed directly in the production process, but also the costs of materialized labor inherent in objects of labor (materials, products, structures) and means labor (machines and mechanisms) used in the performance of repair and construction work. This makes it possible to perform a correct calculation of the unit labor costs per unit of finished product and, accordingly, the necessary financial costs for the production of major and current repairs of buildings. In addition, this approach allows the selection of the most rational technical and technological solutions when comparing several options for the production of work using alternative materials and means of mechanization.

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Facility Management Based on Integrated Information and Resource Modeling

M. M. Kozhevnikov, A. V. Ginzburg, and S. T. Kozhevnikova

Abstract A significant part of the document flow during construction is production and executive documentation. The compilation and processing of the documentation sets under consideration is a labor-intensive process. In order to optimize it and reduce labor costs, it is necessary to use automated means.

This article deals with the possibilities of converting data into a digital format at a construction site. The authors have analyzed the problems arising when working with production and execution documentation and suggested ways to solve them. The article deals with a method, which, due to the introduction of information modeling technology, allows increasing the efficiency of the management of document flow process, which directly affects the duration of construction.

The information-resource model brings together disparate information about the site and participants involved in a single information environment. The approach allows minimizing organizational, functional, informational and financial gaps, to ensure effective management.

For full use of information technologies, it is important to understand that the information model, as well as the object itself, should be modified due to actualization of geometry and attributes, as well as due to filling with information appearing at appropriate stages of object existence. An important feature is the uploading of documents reflecting the quality and quantity of supplied materials and equipment, which are electronically confirmed by the factory or supplier, into the model.

The final result of using the model is to ensure safety and optimize the time and material costs throughout the life cycle of the facility.

Keywords Executive documentation · Object · Construction · Information model · Life cycle · Control · Technology

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1 Introduction

The modern construction industry is gradually moving towards automation of processes at all stages of the life cycle of objects and currently possess an impressive variety of mathematical and information processes [1].

The development in this direction is gradually gaining momentum [2, 3], but the lack of proper regulation of information technology makes it difficult to fully transition to a full-fledged informatization of the direction.

The existing economic situation and the current system of interaction with the construction object at various stages of the life cycle determine a number of problems and cause an urgent need for activities aimed at reducing the design and construction time, reducing the cost of erecting the object, increasing the efficiency of labor resources in designing, erecting and operating the object, as well as reducing costs when owning the object during the entire life cycle [4].

Widespread use of information modeling technology in construction combines architectural, structural and engineering solutions with error detection at various stages [5]. Visual calculations of building structures using libraries of typical assemblies, automated download in electronic form of information on the construction object, visualization for users (including at the stage of operation), based on the creation of an information model, are actively introduced in investment and construction projects [6, 7].

Despite the rapid development of construction technologies, including different software complexes used at its individual stages, process modeling, automation of calculations [8–10], one of the global problems unresolved at the universal level is the preparation of executive documentation and evaluation of the quality and volume of used materials.

Currently, it is possible to observe the release of separate normative documents, the purpose of which is to systematize and streamline the general requirements for the executive documentation, including formation on the capital construction objects, the projects of which are developed in BIM [11–13]. Due to the diversity of organizational, design and technical features, this approach does not bring the construction community closer to the solution of the necessary tasks, but only introduces additional differences in the regulatory field.

2 Methods

The research in this direction is carried out within the concept of information model formation, which implies virtual representation of physical and functional characteristics of the object from the design stage to the stage of operation, taking into account the expanded functionality of information modeling with the possibilities of joint work of participants, process processing and systematization of information flows and data on the state of the object. A prerequisite for the study is also the development and implementation of regulatory documentation in the use of information technology, expanded functionality of the information model in the construction, various regulations for their use in the organization of construction work [14].

During the study, the system and information approaches were used, the provisions of the theory of computer-aided design systems construction, Building Information Modeling (BIM) approach, methods of integration of software products and information systems, theory and methodology of construction object management at various stages were used as methods [15].

Formalizing the problem of maximizing the effectiveness of the investment project in the framework of the study established the following criteria:

– increasing the accuracy, reliability and quality of decisions made in the design, construction and operation;
– increasing the validity of the declared economic indicators and reducing the likelihood of unplanned cost increases;
– reduction of financing risks due to detection of discrepancies and collisions;
– reduction of work completion time at different stages of the facility's life cycle;
– improving the quality and efficiency of construction monitoring, exchange, preparation and accumulation of documentation;
– increase in labor productivity and simplification of work in preparation of executive documentation and interaction with suppliers of materials used in construction.

Tools to implement the concept of creating an integrated information and resource model are software products (Allplan, Revit, Autodesk, and others) that enable the use of dynamic information in intelligent models.

3 Results

Work on the formation of sets of executive documentation for the object is multi-detailed and associated with the linkage of the requirements of the legal framework, the theoretical characteristics of the project, the actual work and indicators [16]. Certain difficulties arise at each stage of the work, both with the primary and with the final documentation [17].

Using a representative sampling of transport construction sites, the authors analyzed conformity of deadlines for certification of hidden work, intermediate acceptance of erected structures and preparation of documentation sets; as a result, 86% of cases were found to fall behind and 97% lacked planning of preparation of executive documentation when performing work.

Lack of systematized approach to preparation of turnkey documentation during construction of objects of various purposes causes difficulties to work producers and requires considerable time for its execution [18, 19].

According to the results of systematization of elements and experiential analysis it was revealed that often ready documentation on the construction object can be seen months after the actual performance and acceptance of construction and installation works. Often at the stage of preparation of the executive documentation the absence of documents (passports, certificates, quality documents, test reports, etc.) or their inconsistency with the design requirements is revealed. In such cases, the search for documents occurs at the final stage of formation of the executive documentation, which directly affects its quality.

These facts form a significant time lag in financing and consequently in the production process which in its turn increases the time of material delivery to the site, causes the risk of failure to meet the approved construction deadlines up to complete termination of the works and makes it impossible to timely hand over the site and transfer it to the operator.

Improvement of work quality is possible on condition of timely and correct execution of executive documentation fixing the process of civil and erection works and state of the object. The afore-said points out the necessity of optimization of the process of keeping, filling and control of the executive documentation at the stage of acceptance and intermediate control.

One of the solutions which allow solving system problems in the building branch is the introduction of the concept of complex information and resource modeling.

Under complex information-resource model it is offered to understand collectively created unique information environment for dynamic object modeling in real time for the purpose of decision-making and verification during the object life cycle with a possibility of calendar planning, resources accounting and executive documentation fomation (Fig. 1).

The application of comprehensive information and resource model consolidates accurate data for facility management, ensures compliance of documentation, works, facility, and applied materials with established requirements, and makes it possible to manage the facility from a process-oriented approach.

As one of the solutions we have considered is the detailing of the project of works in terms of the schedule of works and planned volumes. The peculiarity of this approach is to plan not only technically realizable construction processes, but also their division into sub-stages according to cost estimates and/or bill of quantities. One of the main tasks of the developer of the project should be the compilation of the register of necessary and sufficient documents for a particular object, taking into account its characteristics with a breakdown into sections or segments with an estimated number of works on them. The register proposed for the development should be accompanied by a graphic part, reflecting the specific work according to the project documentation. The drawings of the graphic part will serve as layouts for further registration of the executive geodetic schemes. It is proposed to form this information into a separate section and agree with the customer as part of the project of works.

Taking into account peculiarities of construction works to essentially decrease labor costs for preparation and control of documentation the program module was designed. It makes it possible to take into account initial permissive and

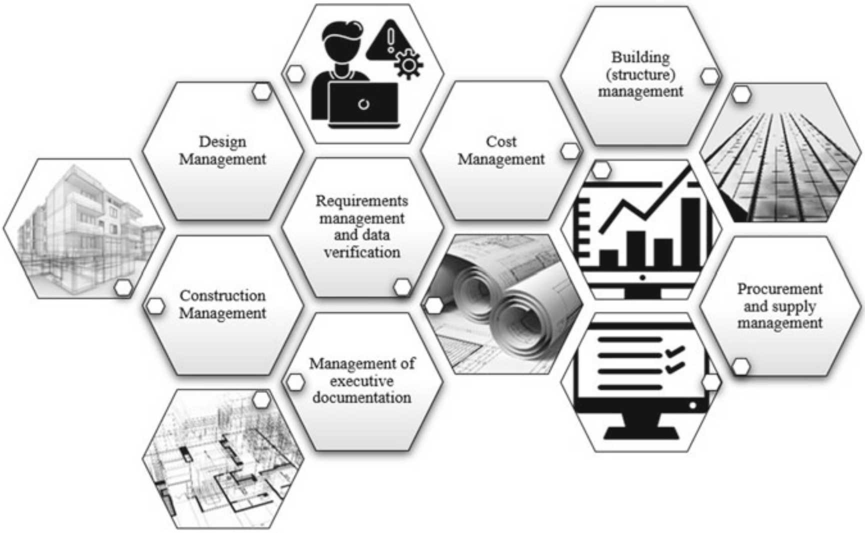

Fig. 1 The structure of an integrated information resource model

design documentation and also automates registration and preparation of executive documentation on its basis.

The implementation at the construction site (Fig. 2) of the proposed concept has achieved the following advantages and results:

– reduction of the number of inaccuracies and errors when compiling the executive documentation;
– automatic identification of the lack of executive documentation for a specific structure (stage of work);
– automatic control of deadlines in which the executive documentation must be executed;
– ability to work in the unified information space and mass corrections;
– collision checking for compliance of the data in the work logs and for compliance with the working documentation;
– registration of the executive documentation by type of work, based on the actually performed scope of work and in accordance with the approved list of acceptance documents;
– registration of scanned copies of the executive documents and formation of registers of the executive documents.

One of the most important quality criteria of the executive documentation is the adequacy and reliability of the data reflected in it [20]. To increase the reliability of the data received from the construction site, the design, procurement and construction processes were integrated; information support of the purchases and deliveries was provided, in the course of which a 5D object model was developed by uploading the

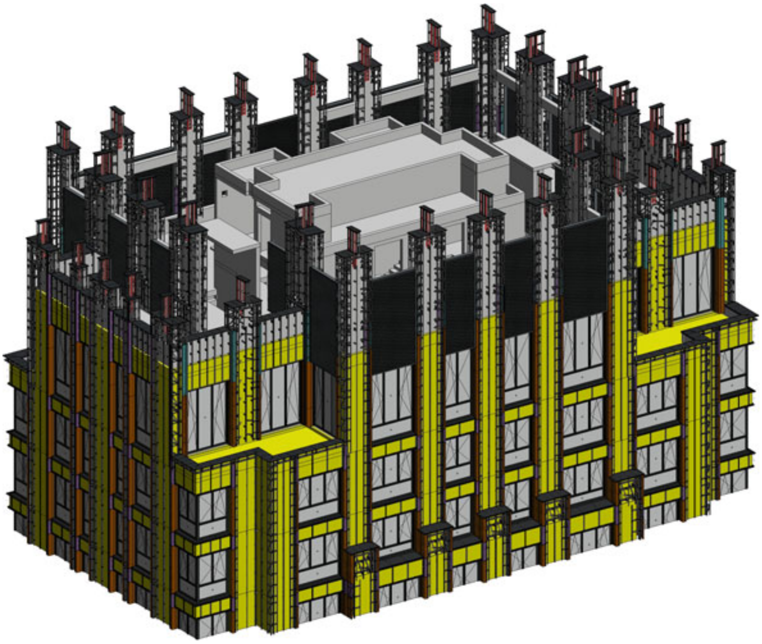

Fig. 2 Business class residential complex «Paveletskaya City» (Moscow, Dubininskaya st., 65, b. 1)

documents confirming the quality and quantity of the materials, products, structures and equipment supplied to the site into the information and resource model. The reliability of the data was in turn confirmed by the manufacturing plants and suppliers of the products in electronic form.

Related tasks of this work were: identifying discrepancies between the design and real needs for material resources; operational analysis of the quality of procurement by quantity, types and types of materials; minimizing information gaps in the design, procurement and supply due to the synchronization of schedules of design, procurement and construction.

4 Discussion

The proposed concept of formation of an integrated information and resource model does not involve a change of software products, but the need to change the process of design, organization of construction production, interaction between participants, filling and resource model.

As the basic directions of development of the developed concept at realization of investment and construction projects are allocated:

- fixing at the legislative level of the necessity of stage-by-stage implementation, with the participation of designers, customers, construction control, producers of works, suppliers of raw materials and products, representatives of operating organizations;
- formation of the unified system of classification and coding of elements;
- training of users to work with the object model, associated with the schedule, detailing of the project cost, systematization and unloading of information and documentation;
- development of industry standards for information modeling, taking into account the specifics of the direction, requirements and designs.

5 Conclusion

The proposed approach makes it possible to analyze the project in more detail, plan the financing schedule more thoroughly, justify as many positions of the contract list as possible, avoid most of the adjustments of the executive documentation and reduce the load on the production and technical department in the course of construction.

Automation of typical operations, namely, accounting and registration of acts of certification of hidden works, critical structures, etc., loading documents, including executive schemes, and the formation of the final sets of executive documentation is one of the main features of the integrated information and resource model, allowing to achieve maximum effect from the production process, as well as when putting the object into operation.

Implementation of the integrated information-resources model concept allows to combine a 3D model with its planned and actual version into an integrated model, which consolidates the information about the used materials and products, the results of laboratory and acceptance tests, terms and duration of work for each construction unit, documentation from suppliers about quality and volumes for each element and stage of work.

The result of this approach implementation is improvement of competitiveness of the information modeling technology at different stages of the object life cycle on the basis of quality improvement, cost reduction and collision risk reduction and reduction of construction terms.

Integrated information resource model created by collecting and comprehensively evaluating information from various sources is designed to support decision-making during the life cycle of the object and serves as a fundamental way out of the existing problems of information metabolism.

Information presented in this article can be used to continue research in expanding the directions and ways of application of information modeling technology in conditions of management of construction objects. Further research in this area may include an assessment of minimizing the total cost of the object using a comprehensive information-resource model and various types of software and tools needed to implement the proposed approach.

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Conceptual Digital Organizational and Technological Model Scenarios at the Construction Organization Project

Olga Kuzina

Abstract The article is devoted to the issues of management processes in construction with functional information modelling based on the construction organization project, which includes the construction process's resource support, calendar planning (scheduling) and distribution of financial costs. Based on the described information modelling scenarios upon the construction organization project, the purposefulness of the organizational, technical and technological solutions ensured to achieve the goals of putting the object into operation. An important result is the demonstration of the digital construction organization project concept consisting of certain basic processes that form the sequence of the implementation scenario in digital databases, software algorithms for the industrialization of the structure and, in general, to increase the constructability of construction production, which will optimize production processes, further maintainability and operational qualities. As a whole the scenario approach in information modelling forms the basis of the methodology for the transition to machine-readable forms of normative values and codes features for all types of resources for the implementation automated variant design, including the cost of construction. The adaptation and development of the progressive work packaging method based on the construction of scenario-parametric rules for unambiguous linking of operational processes and model elements.

Keywords Digital technologies · Life cycle · Information modelling · BIM · Big data · Data analyses · Construction organization · Project data management

1 Introduction

The construction sector plays a significant role in the country's economy. Construction ensures the reproduction of fixed assets in all sectors of the economy, has complex intersectoral relationships and high level of multiplier effect. It shows the measure

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of the multiplying effect of positive feedback on the output value of the managed system – the ratio between investments in basic processes and the income of organizations [1]. The basic processes for the construction industry can be generalized to three main ones: design, capital construction and real estate object operation. The main criteria for evaluating the work performed in each basic process are quality, term, cost, and productivity. And for improving that KPI is used different tools like data management based on end-to-end digital technologies. In their turn, end-to-end digital technologies considered allocation that tools among tasks and decision in construction area and users can describe tools integration in project lifecycle. For instance, we have smart-contracts [2, 3], Robotic technologies [4], BIM data analyses [5], artificial intelligence [6] – and all of this for now considered as duty practice in designing, construction and facility management.

The hierarchical structure of the elements of the organizational and technological model is a sequence formed according to the principle from the maximum level of enlargement to the minimum: Construction phase -> Start-up complex -> Node complex -> Building/construction -> Production cycles -> Organizational and spatial module/capture/tier -> structural element.

In the era of transition to digital technologies in various industries, data and metadata are becoming a factor of production, and the economy's competition on the world stage can be provided by system for managing this data, implementing the principle of the relationship between man-technology-environment. Responding to the challenges that the construction industry is currently facing, it is important to develop tools that allows the use of data in different forms, in different systems with set access levels, at different calendar stages of the project life, by different participants in the construction process, in order to quickly resolve issues related to the safe conduct of work, the performance of work on time according schedule with set level of cost, or to be able to predict (based on existing data and trends) changes in terms of time and cost, and also predict the risks of each participant in the implementation in each stage during object's life cycle [7].

One of the challenges faced by the industry is the poor quality of project documentation, errors in the examination of the project, errors in the calculation of the cost at the design stage. To solve these problems, platform solutions, shared data environments, data transmission formats, n-d modelling, systems for verifying design solutions, verifying project costs, and predicting risk situations are being developed [8, 9].

To make a decision on how to transform the basic processes of organizations in the construction industry, it is important to identify the main process that connects the others in each basic process. If we talk about design, then such a connecting part of the two stages - design and construction - is the construction organization project (COP), which describes the resources support of the project and its technical and economic indicators. But currently there are no tools for modelling organizational and technological solutions in the unified form. The development strategy of the entire project based on the solutions specified in the COP. The organization of construction should ensure the purposefulness of all organizational, technical and technological solutions to achieve the result—the commissioning of the object with the planned project quality and within the established time frame [10].

2 Methods

Digital COP is developing by the methodology of system analysis, in which the influence of all factors in each specific situation is considered: technical, economic, socio-psychological. Logical system analysis in this case supplemented by forecasting tools based on mathematical methods of statistics, determining economic indicators of the multiplicative effect from end-to-end digital technologies in the production inception [11].

Data is accumulated from the moment of the idea of the object when using digital technologies sequentially over the life cycle:

– at the pre-project stage, predictive models are used to calculate the cost of designing and building an object, at this stage, the main design solutions, materials and technologies for the construction of the object, and related processes are also predicted;
– at the design stage, data is accumulated into multidimensional model for design solutions, building elements, their properties, attributes, each element and technology in this case, a classifier code is assigned, which will allow you to use data on such solutions in the future, to calculate the cost of the construction of the object.

COP is a part of the design and estimate documentation, the data reflected in the COP allows you to take into account the resources and specific conditions of work to determine the reliable cost of construction. The COP passes the examination together with the rest of the project, that is, it is formed by the project organization. In this regard, it is quite obvious that for the construction phase, the COP solutions may not be applicable by the general contractor developer. However, the control of the deadlines' execution, the volume of work, the used equipment, and labour costs are carried out exactly according to the COP, that is, the controlling body can stop construction if there are discrepancies with the COP. It is also extremely difficult to make changes to the COP, because such changes are most often associated with changes in the conditions for safe work and require additional expertise, which means financial and time costs [12].

The choice of solutions for the organization of construction should be carried out on the basis of alternative study with wide application of multi-criteria assessment methods, modelling methods and modern CAD systems.

COP is a document that describes the entire "Construction" stage, but is developed before it begins. If we consider the COP within the framework of the information modelling methodology (BIM,) then it is the basis for planning, forming organizational, contractual and financial relations at the "Construction" stage. The COP as part of the information model is also a technological model of construction. For example, in the COP, the main construction machine is selected – a crane that meets the needs of this construction site in terms of load capacity, boom reach and lifting height, and the spatial limitations of the site, but at the same time they are not too expensive. Besides, when choosing a crane, the possibility of renting or purchasing it in the construction region or in the neighbouring region is taken into account. Further, for the entire period of construction, temporary buildings and structures are defined in the COP, their nomenclature diversity also leaves the possibility of a long choice not only in type and size, but also in spatial location. And all this affects the cost of the construction project [13].

Having the necessary set of data presented in real time, the customer has the opportunity to choose the optimal models for the production of works, minimizing the duration of these works and the cost of all types of resources.

Follow customer restrictions and tasks the cost of the project depends on the applied decisions by different groups of factors:

$$F(x_i) = F(x_1, x_2 \ldots x_n) \to \begin{cases} a_1 \ldots a_n \\ b_1 \ldots b_n \\ c_1 \ldots c_n \end{cases} \quad (1)$$

Factors influencing the choice of a design solution are formed by levels - functional needs, design features, organizational and technological requirements for the implementation of the project [14].

This factors for determining the most effective design solution concern: type of the object location, tightness of buildings, geological features, functional purpose, the category of object complexity, the class of responsibility, the number of floors, its functional purpose and capacity, terms of the beginning and construction end, funding source, compliance with fire safety requirements (security, fire alarm and fire extinguishing systems).

Another group of decision-making factors refers to the basic architectural and structural requirements: requirements for the organization of landscaping, bearing and enclosing or special support structures, elevator equipment, technological equipment, net of engineering systems including external [14].

Third group of factors provides ecological vision of project: sanitary requirements, waste dispose, demolition, structures energy efficiency, additional or special lighting [14].

And additional group of factors take into account the digital economy requirements:

– "smart city" infrastructure, designing databases, requirements for information systems, document management and monitoring during the operational phase of the object, requirements to information security systems [15, 16].

Thus, organizational limitations of the project should be included into COP: objects mutual placement on the general site plan; materials and equipment suppliers, terms of delivery, mechanization level, labour organization rules, temporary engineering systems etc. [14].

Taking into account a large number of factors makes it possible to choose the most optimal solutions, as well as to predict possible changes over time [17]. It is important to note that the implementation of the optimal solution choice is based on the observance the certain sequence. For example, the choice of an architectural solution is complementary to the choice of a design solution, and sometimes the possibility of implementing a design solution changes the choice of an architectural solution. Thus, depending on the goal, restrictions and conditions are determined, on the basis of which the criteria for choosing alternatives are developed, and then the resulting alternatives are considered [13].

The assessment of organizational reliability (2) is based on the ability of organizational decisions to link the implementation of construction processes, so that in the event of deviations, their functioning is ensured.

$$P(\Pi_i) = P(\Pi_{i\ cp} \geq P_{xi}) \tag{2}$$

where $\Pi_{i\ cp}$ – the mathematical expectation of the value of an estimated indicator of the preparation of the construction site;

$P_{xi} = \frac{n}{N}$ – probability of providing each estimate from the sample size (N).

Reliability, estimated by the entropy of the implementation of each organizational and technological decision, is determined by the formula 3.

$$H_j = -\sum_{i=1}^{n} P(x_i) \log_2 P(x_i) \tag{3}$$

At the same time, the total terms of work should not exceed the calculated values. Organizational reliability is based on technological reliability, which should ensure an uninterrupted sequence of organizational and technological stages and, when exposed to random factors, not go beyond certain limits.

3 Results

The purpose of data management model is to create shared data environment (SDE) for project participants to provide optimal level of information support in the chain of construction processes: at the pre-project stage in helps to plan every decision for construction stage with it suppling with all types of resources, at the construction stage SDE accounting delays for executing processes and project changes, completing sufficient information base for subsequent operation of the object and monitoring of engineering systems and structures of the object. All participants in SDE follow requirements and restrictions to provide selection of solutions, generate changes in the model and generate technical and economic indicators in the selected model elements using end-to-end digital technologies, understanding possible risks of adverse circumstances or threats to the security of the object and its infrastructure [11, 18].

The conceptual digital organizational and technological model contains 3 types of data models: the Project Model, the Resource and Technological Model (RTM), and the organizational and technological model (OTM). Figure 1 shows BIM automated selection scenarios that will allow project teams (PT) to combine data in such a way as to develop industrialization schemes, technology maps, resource-based organizational and spatial modules, and object-based resource databases in a single model.

The construction of scenario-parametric rules for unambiguous linking of simple workflows and model elements is advisable to form within the framework of 2 models: organizational-technological (Table 1) and resource-technological (Table 2) [19]. Data management in the process of forming the TSOTM and TSRTM is carried out within the sequence established by the specific selected scenario for the formation of this model. Table 1 and 2 show the options for such scenarios at the stage of organizational and technological design.

Scenarios are datasets for certain operations, consisting of a sequence that describes digital behaviour. When the script is executed, a dataset is generated, which is then extracted (partially or completely). When checking action datasets, any output data/detected data should be compared with the actions performed during the data set construction process, with a reference to the digital scenario, which should have been simultaneously supported and provided by the data set creator [19].

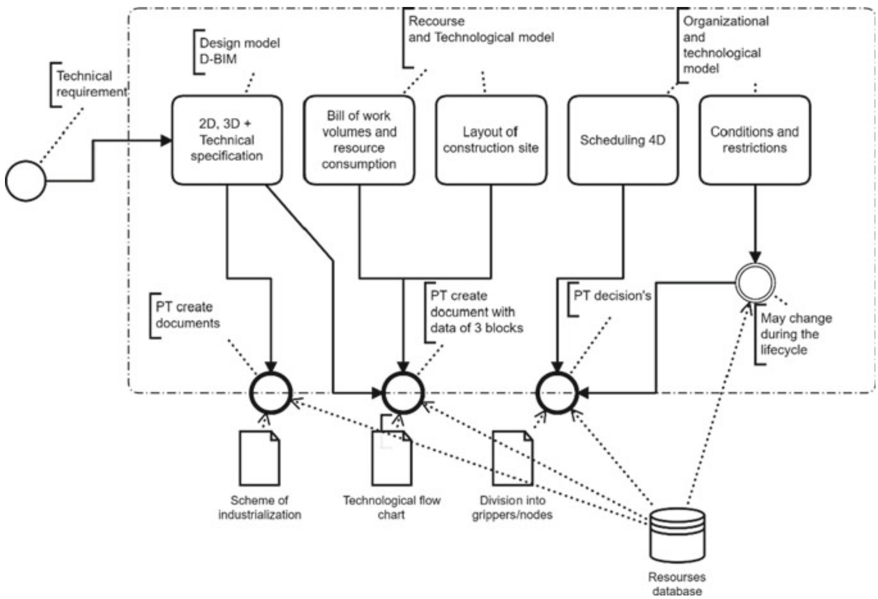

Fig. 1 Conceptual digital organizational and technological model

Table 1 Model DOTM scenarios

Digital scenario	Model DOTM scenarios			
	I	II	III	IV
	Organizational and spatial modules	Resource databases	Modelling labour organization	Economic modelling
Resulted models	Filling with technological parameters dedicated modules	Database modelling (materials, structures, equipment, workers, machines and mechanisms)	Modelling of work production schedules and their resource support	Formation of estimated documentation, schedule of distribution by nodes and stages

Table 2 Model DRTM scenarios

Digital scenario	DRTM scenarios			
	I	II	III	IV
	Scheme of industrialization	Technological flow chart	Modelling of the object resource support system	Construction site simulation
Resulted models	Modelling of mechanization schemes	Formation of assembly models of selected nodes	Materials and equipment specifications formation	Modelling of the main objects layout at the construction site
	Modelling of options for industrialization, prefabrication by dedicated nodes	Modelling a sequence of operations	Bill of work volume, labour costs and machine time	Modelling of on-site roads
				Modelling of storage sites
				Modelling of temporary buildings and structures

The application of the described approach has been tested at the construction site of dormitories complex with reconstruction of existing buildings in Moscow (Table 3).

Even in the presence of imperfect software tools, when using the approach of detailed study of organizational, technological and resource-technological solutions at the planning stage for buildings 3,4,5, optimal labour and material costs were predicted, which led to reduction in the cost of the project and time for work due to the use of industrial methods of structure production. But at the same time for building 2 this approach showed the increase of cost because of more sophisticated designing decisions analytics and choices.

Table 3 Result of DOTM and DRTM scenarios implementation

№	Name of works and costs	Objects cost			Total cost
		Building 2	Building 3	Building 4, 5	
1	Structural solutions LOD 300	12 586 716	13 369 660	25 306 807	51 263 183
2	Structural solutions LOD 400	13 298 945	11 512 878	22 981 540	47 793 364

4 Discussion

To build scenario-parametric rules for unambiguous linking of simple workflows and elements of a specific object into a single digital model, it is necessary to translate requirements and norms into databases for automatic search, selection of resources in the model [7].

Creating a digital organizational and technological model will allow you to:

– increase the efficiency of design, construction, and operation based on predicting the behaviour of the building system and its infrastructure;
– organize the rational management of the project implementation by increasing the level of planning;
– build a predictable system of financing the object throughout the entire life cycle of the building, simulate changes in infrastructure projects;
– reduce the time for preparation and execution of work, labour costs for operations for searching and processing data for decision-making [20].

5 Conclusion

Resource data management affects labor productivity at the construction stage due to preliminary and careful planning at the design stage. The development of digital construction technologies affects the efficiency of data management and is necessary for forecasting risks at the planning stage. The current goal of improving the quality of organizational and technological solutions is determined by an unambiguous trend to increase the level of COP development, mixing it with the project of work production by a specific construction organization [21].

To develop the digital COP, the following elements need to be worked out:

- formation of standard node schemes for various types of objects,
- adaptation and development of the method of progressive packaging of works,
- risk management in construction,
- managing the technological parameters and, as a result, increasing industrialization [22].

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Application Programming Interface Features of a Building Information Modeling at the Design Stage Within Life Cycle

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Abstract The article studies some application programming interface features for building information modeling at the design stage within its life cycle. The task of automating information processing previously performed with a high proportion of so-called "paper" technologies concerns, in particular, the task of traditional filling in lists of materials for creating design and estimate documentation before passing the state expertise are the domain area of the study analysis. The most dynamic and structured domestic building information modeling system has been used as a platform to analyze its ability to solve such routine task. Currently, buildings and structures life cycle information support is largely based on the application programming interface (API) implementation in the relevant software products. The object of analysis is the software API library. The API model structure of classes has been analyzed in terms of the task. It has been found that the presence of the API library does not guarantee a software can automate routine information modeling tasks. It is shown that one of the main reasons for this is the features of the API library classes structure development which does not allow adding parameters to object type styles and making any changes to the list of building materials, therefore, creating a consolidated list of own building materials. Revised structure of classes and additional API methods are needed to automate the routine work with building materials, change and create own elements in the list of building materials at the design stage within building life cycle.

Keywords Application programming interface · Information modeling · Design stage · Life cycle · Life cycle management · Information model · Model structure · Building material list

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1 Introduction

The concept of a building *life cycle management* requires design values and estimation control in Russia, which is evidenced by the Federal Law No. 384, adopted more than 10 years ago (3.2, 5.1, 15.10). The law is also known as the Technical Regulation on the safety of buildings and structures.

Nowadays, the most developed stage within a building life cycle is a *design stage* in the terms of *information modeling* technologies [1–3]. Besides the other things, this is manifested in the fact that the process of "Architectural and Construction Design" is increasingly being replaced by the term "Information Modeling" or "Building Information Modeling" in domestic practice. But in order to carry out effective activities in the field of modeling, it is necessary to perform the task of automating information processing, which was previously performed manually or with a high proportion of so-called "paper" technologies. In particular, this concerns the processes of traditional filling in lists of materials for creating design and estimate documentation before passing the state expertise, which is the domain area of analysis in this work.

Among the four main domestic information modeling systems, the most dynamic is the Renga system in terms of its complex structure and updates frequency [4–6]. There are various tasks to in any building design, based on national or corporative standards including requirements to design documentation, estimations and integration dealing with estimation, structural engineering and workflow software, specific calculation, visualization, and others. These tasks lead to the specialized functionality and plug-ins creating that extends the functionality of the system. The main way to functionality extension is using of *application programming interface* (API) [7–10]. However, the flexibility and complexity of such API solutions depend on the API *information model* (IM) structure for each particular software [11–13]. The API model on the base of the Renga API library is the subject of analysis in this work [14, 15].

2 Method

Applying analytical methods to the problem, it becomes obvious, IM of the software (release 4.8.36912.0) is based on an object-orientated paradigm and described by the loadbearing, non-loadbearing parts of the building, engineering networks, their components and elements of drawings and specifications, which could be defined as object types [16].

2.1 Structure of Software IM

Various object types are also linked at the software level to one or more lists of styles and materials that can be combined into a public group called "*style types*". This relationship determines which types of styles can be assigned to certain object types. For example, an object of the "Column" type is bound to the style type "Column Styles". It is also worth noting that some types of styles may depend on others. For example, the "Multi-layer Material" style type refers to the "Material" style type, it means, each multi-layer material consists of a set of single-layer materials.

Figure 1 shows the general structure of Renga information regarding the graphical user interface (GUI) [17]. In this drawing, any element placed in the model is an object, and a variety of this object can determine a style.

The objects in the model are divided by types, which define a set of *properties* and *parameters* for the corresponding object. In addition, a designer or developer can select a style for an object (the possible set of styles is determined by the type of an object). A designer is allowed to add, delete and change the set of available styles and properties associated with object types. The set of parameters of object types is fixed, and a specialist can only set their values. Either changes in styles and a set of properties are stored within the corresponding project file or template.

There is a set of two groups of information defining for each object type, as well as for the most style types:

- properties (semantic attributes);
- parameters (geometric attributes).

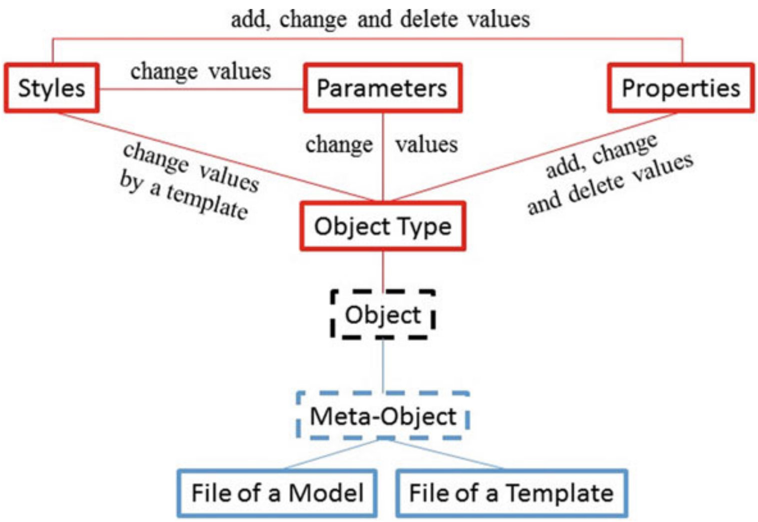

Fig. 1 The principal structure of Renga software information model regarding to the graphical user interface (GUI)

These sets define the data structure of the subordinate elements.

Properties are understood as information defines the so-called LOI (Level of Information) [18]. LOI also includes user properties that a specialist can create and edit if necessary. These properties can be used, for example, in the automated formation of specifications. When creating a new project, the set of such properties is automatically formed, for instance: “Note”, “Heat transfer resistance”, “Fire resistance limit”.

Parameters are understood as information defines the so-called LoD/LoG (Level of Details/Level of Geometry) – the depth of IM details [19]. The level determines IM objects geometric characteristics, which are used by Renga during its virtual (information) modeling, parametric calculations, as well as for visualization of IM. Examples of parameters can be “Wall height”, “Level”, “Multilayer material”.

Some parameters in styles contain references to the particular parameter in the corresponding list. In this work, the list is understood as a reference of templates: materials, styles of various elements, etc.

When commercial software functionality expanding tasks have to be solved by the efforts of local specialists without the resources of software developers, these tasks are mainly solved today with the help of API libraries as a part of software development packages SDK (Software Development Kit). Commercial developers accompany the distribution of their software products with SDK.

2.2 *Task for Testing API Flexibility*

The main opportunity for local specialists to remove additional routine load from designers within a building life cycle is their ability to work with reference manuals through the software API, which should open up the possibility to automate information modeling process. There is one process considering in order to test Renga API flexibility - the task of filling in own material lists for creating design and estimate documentation in application to consolidated lists of materials.

It is worth to note that materials in Renga are divided into two types and each one can be linked to certain types of structural elements:

- single-layer materials, for example, concrete, aluminum, wood. Materials of this type can be specified for, as an example, columns, doors and foundations. In the list of materials, each of them is described by such properties as name, color, density, etc.;
- multilayer materials. Materials of this type can be selected for walls, ceilings and roofs. These materials are a set of layers, and its layer thickness as well as the visualization parameters are specified for each layer of the material from the list of single-layer materials.

Figure 2 shows a diagram of the Renga API classes that allow designer to access both the list and the binding of materials to the structural elements of IM.

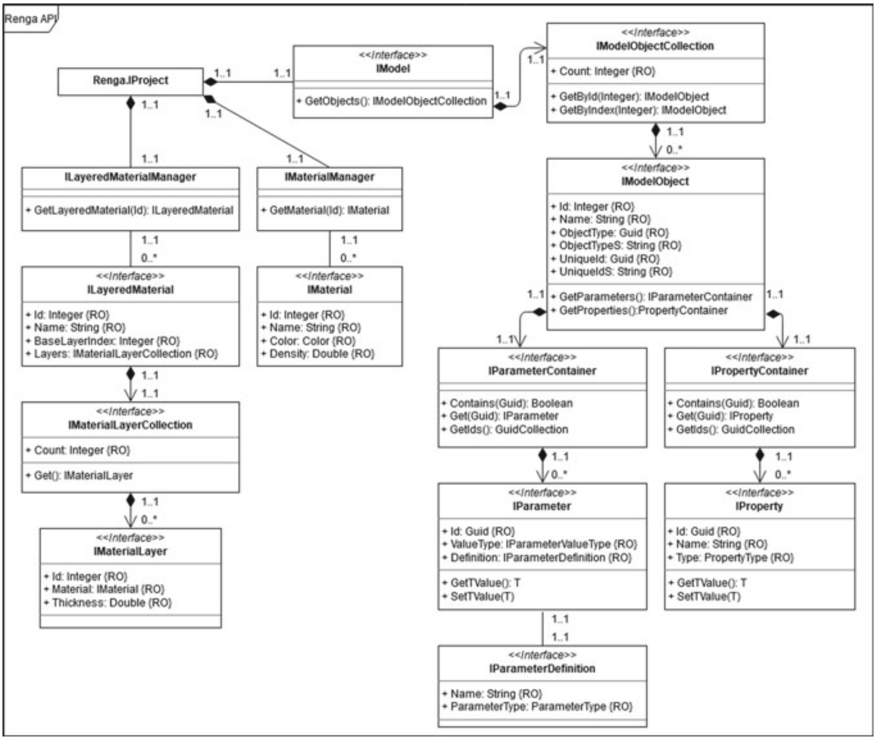

Fig. 2 UML Class Diagram for Renga API classes related to modeling using construction material information

The read-only properties are indicated by the "{RO}" label (Fig. 2). In addition, the *IParameter* and *iProperty* interfaces provide a set of methods for obtaining and changing the parameter or property value by data type. For the sake of brevity, these methods are grouped in the diagram, and "T" label is specified instead of a specific data type.

Since most of the elements of this diagram are interfaces, for the sake of readability, instead of writing the form as "an instance of a class implementing the *IModel* interface", an "*IModel Object*" is used.

The diagram shows there are three "branches" originating from the *Renga.IProject* object:

- the branch goes into the *IMaterialManager* object opens access to the list of common materials;
- the branch goes into the *ILayeredMaterialManager* object opens access to the list of multilayer materials;
- the branch goes into the *IModel* object allows to get a list of all the elements of IM, as well as read and change the values of their properties and parameters.

However, as a result of the Renga API study [16] it has become obvious the inability to make any changes to the list of materials, because the list itself, as well as the values of the properties and parameters of its elements, are read–only.

The only possibility to make changes is related to materials found. It is the procedure of linking the existing material to the element placed in IM.

The lack of the possibility to program editing the list of materials leads to the conclusion that it is impossible to perform the task of automating the filling of this list. It illustrates the current constraints of APIs and shows the evidence to which developers shall pay attention to API directives to correctly programming information support for routine building modeling tasks with APIs [20]. That is why the studied task of filling in lists for creating design and estimate documentation in application to lists of materials could not be solved by the given software API at the moment.

On the other hand, when working with properties, the Renga API provides the ability not only to programmatically read and edit the property value of a specific object, but also allows registering new properties and binding them to specific types of model objects. This feature allows not only increasing the LOI of the model and expanding the possibilities for automated calculations and filling in specifications, but also allows a specialist to use these properties for the needs of expansion modules and increase its complexity and flexibility [21, 22]. In particular, this feature was used in the development of an extension module that gives the possibility of combining model elements into groups [23].

3 Results

The study of opportunities to solve a building life cycle API-task with the help of the Renga APIs has given the results as follows:

1. The analyzed software structure of classes makes it possible to create and define properties of object types.
2. The analyzed software structure of classes makes it possible to create styles for object types according to the samples set by the developers, but it does not allow adding parameters to such styles.
3. The analyzed APIs do not allow making any changes to the list of building materials (which are, in fact, a list of styles of object types "Materials" and "Multilayer materials"). The list items are read-only.
4. When using the API library of the analyzed software, it is impossible to automate the process of filling in lists and, accordingly, creating a summary list of building materials.

At the same time, it is possible:

- to expand the information level of the model and automate analysis and calculations based on additional data;

- to implement complex logic based on registering, writing and reading additional properties of objects.

Summarizing the research results, it obvious that it is impossible to automate the process of filling in the lists of materials. It requires an additional routine load from the designer side and has been performing with a high proportion of so-called "paper" technologies.

4 Conclusions

Currently, life cycle information support of buildings and structures is largely based on the API implementation in the relevant software products.

This study shows that the presence of the APIs library does not guarantee a software can solve routine information modeling tasks.

It is shown that one of the main reasons for this is the features of the API library classes structure development.

To automate routine information modeling tasks such as the work with building materials through the software GUI, the revised structure of classes and additional API methods are needed. It would allow local specialists to change, and in the future create own elements in the list of building materials.

Hopefully the Renga API library of future releases would get benefits if it became possible to programmatically add and edit elements in lists.

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The Role of Augmented Reality in the Development of BIM for Construction Visualization

Hassan A. Mohamed and Venera Garaeva

Abstract The notion of augmented reality (AR) has been around for a long time, and the widespread availability of new mobile technology, such as Smartphone and portable devices, has aided in the realization of the concept. Various industries, including the Architecture, Engineering, and Construction (AEC) business, are taking use of the expanding possibilities that the notion of AR may provide. The use of augmented reality in civil infrastructure can help to avoid costly mistakes, increase efficiency, and save money. Building-Information-Models (BIMs) are also used in AR to provide precise 3D information about the structure for display. AR has also been investigated for Structural-Health-Monitoring (SHM), regular and problem identification, energy effectiveness evaluation, cracks examination, digging, and subterranean utility servicing. The goal of this article is to make the operation of supervising infrastructure projects a little easier. The traditional method of measuring building progress is to use paper reports, which requires a significant amount of human data collecting as well as the effort of visualizing the real progress from the paperwork. This research highlights a novel approach for utilizing Smartphones to track building progress. This is accomplished by offering a new system that includes a newly created application known as "AEC-AR". "AEC-AR" is an Android application that is utilized throughout the building phase by integrating a 4D "as-planned" phased layout including an augmented video that shows actual or projected development. The project's outcomes are then analyzed and evaluated in order to predict the potential of these and other time and cost tracking approaches in building activities.

Keywords Augmented reality (AR) · Building information modeling (BIM) · AEC industry · Construction projects tracking · Unity · Smartphone app

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1 Introduction

Portable smart phones are now being utilized for a broad array of purposes. That contains Augmented-Reality (AR) in the building environment, and the mobility and convenience of portable smart phones has encouraged academics to look into their possibilities for automated building site supervision. Simultaneously, the advantages of using building data modeling (BIM) for the architecture, development, and implementation of built assets have been widely publicized. BIM provides coordinated and consistent views and representations of the 3D model, including reliable "4D" (time) and "5D" (cost) data. Several of these advantages are related to the possibility for increased onsite operations throughput. As per Kim et al., this comprises project monitoring capabilities as well as the capacity to allow real-time communication and information sharing amongst construction stakeholders [1].

1.1 Augmented-Reality Overview

Computer-generated data like images, audio, movies, or electronic data are overlaid on actual components in Augmented-Reality. From Ivan Sutherland's first see-through head-mounted AR display in the 1960s [2] to Golparvar et al. enhanced. 's HD4AR and Mobile Augmented Reality System (MARS) [3], Augmented-Reality innovations have been utilized in a wide range of subjects and arenas, including engineering, recreation, aviation, pharmaceutics, armed services, and the automobile industries [4].

1.2 Augmented Reality (AR)

In addition, the AEC sector is embracing more AR technology to improve different phases of building projects. This powerful computer innovation offers substantial benefits to the construction projects through modeling and visualization, such as allowing the analyst to communicate directly with both real and virtual objects and monitoring construction activities by comparing the development's as-planned and as-built condition [5].

At least three layers of AR technology can assist the AEC/FM industry: visualization, extraction of data, and collaboration. [6]. Different studies have proposed various AR applications for the AEC/FM sector. Dunston and Wang suggested AR solutions for the AEC sector to support all phases of the project life cycle for built facilities [7]. Wang et al. look at the use of augmented reality in heavy machinery operation learning [8]. Golparvar-Fard et al. created a four-dimensional AR model to automate work progress tracking, data gathering, processing, and transmission during the project's building phase. [9].

To effectively deploy Augmented reality technology in AEC developments and to realize their full capacity in this sector, it is necessary to determine areas of application where AR may be utilized to improve productivity. The following questions are addressed in this study paper: Based on the applicability of AR technologies, what are the major AR application areas in the AEC industry? What are the gaps in this sector that AR technology might potentially fill? Predict how AR technology might be enhanced for future applications based on future trends.

This article provides a comprehensive overview of augmented reality technology in the construction industry. The goal of this study was to look at the benefits of employing portable smart phones on infrastructure projects by combining BIM and AR in a platform that provides customers to track, amend, and visualize development cost and time progress. The premise of the study is that when portable mobile devices are coupled with other technologies, they provide a strong system for BIM construction progress monitoring. Monitoring and evaluation, according to Iyer and Jha, is a crucial component in completing construction projects on schedule and on budget [10]. As a first approach towards better building progress assessment on the job site, a system is presented that allows project managers to spot performance discrepancies, which will help them make better decisions. The hypothesis is evaluated by constructing, analyzing, and evaluating the current plan of the highlighted apps on a real construction project with qualitative input from interviews. To learn more about the participants' views and opinions, a semi-structured interview approach was employed.

2 Methods

2.1 Methodology

This feature article emphasizes on innovative augmented reality solutions to assist bridge the gap between online and physical world information (AR). AR is a method of displaying cyber information over physical images and altering it through interactions with real-world items. Sensors, like as the camera on a mobile device, are utilized in AR systems to derive information about user interactions with the actual environment. Such derived data can then be used on connected devices like Smartphone or tablets to help visualize information about real-world shapes, like outlined areas of a construction project image, or infer interactions with virtual information, such as inferring the shape change of a virtual 3-D model created by cutting it around the customer with something like a knife. In a variety of areas, such as health, building, entertainment, engineering, and computing, AR has showed great potential in addressing cyber physical system visualization and interaction problems. While AR's potential and widespread use, substantial research hurdles remain, including sensor-noise, accurate location, interruption, data acquisition, complicated information presentation, and computing complexity. This feature article examines

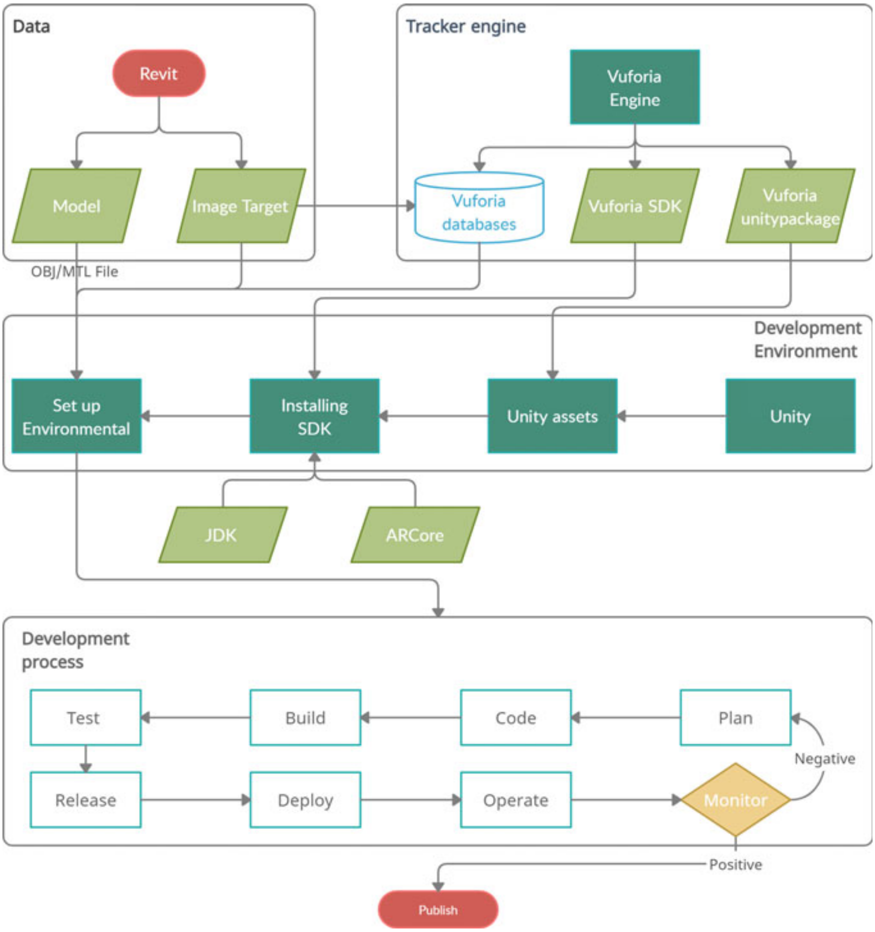

Fig. 1 Methodology flowchart

AR research applications and advancements in the underlying computer vision, indoor/outdoor mapping, and interpersonal communication technologies that enable these implementations.

2.2 Development of App and Experimentation

The hunt for a framework through which to build a viable augmented reality app took a long time. A variety of Smartphone and Tablet-based solutions, applications, and methodologies were tested to see how effective they might be in providing a usable design visualization solution. After some searching, a suitable application named "AEC-AR" was discovered that met the majority of the research's needs. AEC-AR is primarily intended for construction and engineering visualization in the AEC sector. When compared to other programs created for the same purpose, AEC-AR is easier to use and set up. As AR data, it enables 2D pictures, 3D models, audio, and video that are given a location-specific position. During early testing, it was discovered that while the process of generating and deploying bespoke AR content remained a rather complicated effort, it was still much simpler than some of the other apps examined. The way the app is developed using different techniques and coding is explained in the following Fig. 1.

The above figure shows that the Revit file or model has been exported to unity, which modifies the materials of the model and files. With the use of these, the Vuforia has been used in the coding of the app to detect the images which are uploaded using a Smartphone or handheld device app like tablet. This Vuforia connect the model to the image in unity to put the model on the image whenever detecting in reality. The Revit, Unity, Vuforia, ARCore SDK and Microsoft Visual Studio has been used to write the coding of the app in C# format. Furthermore, to build the app for Android devices support Android Studio has been utilized.

3 Results

The AEC AR Smartphone app was created utilizing unity methods in accordance with the project implementation approach. With the aid of some extra software from the Unity Asset Store, this app was created utilizing the Unity platform's application. It makes it easier for beneficiaries to communicate with one another. The project's many experts can utilize augmented reality to exchange project information. To make the execution sound, some supply information (technicians) while others receive it (workers/builders/city councils). Manuals, assembly instructions, and other materials might be supplied to guarantee that the design is followed. The following Fig. 2, represent the layout of the screen which shows how it look.

The buttons on the right side allow the user to control whatever parts of the building they wish to see (architectural, structural, and MEP). The program allows you to demonstrate a piece of a structure using Cut Plan, and you may change its placement and angle from the left side of the app.

After finishing the creation of the augmented reality AR application and testing it on many devices to ensure that it works properly and that it does not clash with any other applications, as shown in Fig. 3.

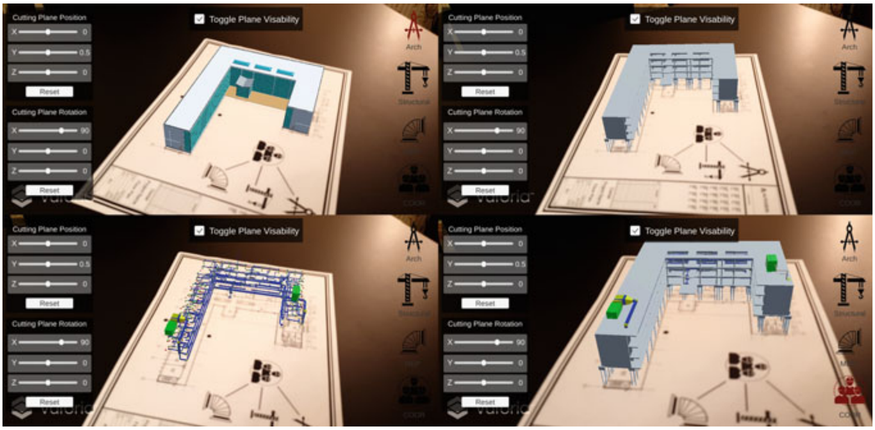

Fig. 2 Screenshots of using the app

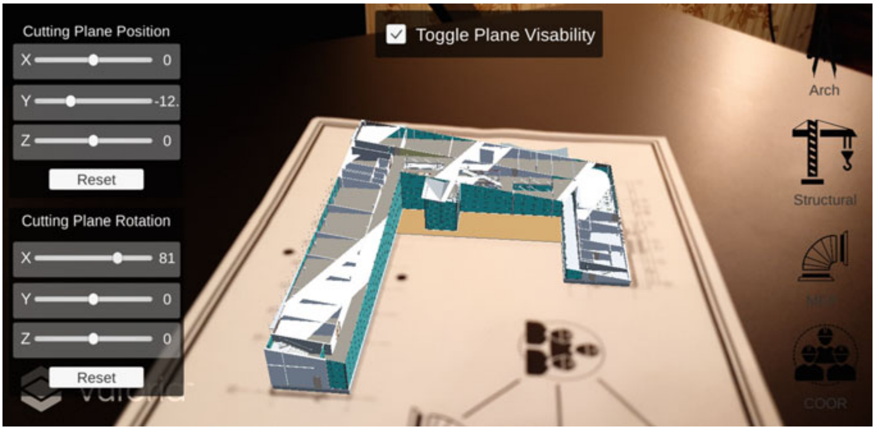

Fig. 3 UI of application

4 Discussion and Conclusions

The potential for AR technology to completely transform how we design, build, run, and monitor the AEC sector has been demonstrated. However, data generation, storage, administration, interchange, and sharing must all be integrated effectively. The loss of enthusiasm in Augmented Reality technology and the process of designing and translating complicated solutions into augmented reality in the literature prompted this study. This article covers the whole process of creating an AR app, as well as the software required for the development process that is suited for each project and organization. The combination of BIM and AR may enhance the performance of AEC projects in terms of time, cost, quality, and safety, as well as affect the sales and advertising of building materials and complicated solutions in the construction industry. This integration is helpful for both the entire origin and particular sections of the origin.

The sample project implementation and development approach provided in this article offers a feasible, simpler, and more transparent alternative. Recent academic articles, results of discussions with academic and experienced specialists, and experiences of professors in the field were used in a case study project demonstrating complex solutions in construction using AR technology to identify the strengths and weaknesses of the proposed system. It makes it easier for beneficiaries to communicate with one another. The project's many experts can utilize augmented reality to exchange project information. To make the execution sound, some supply information (technicians) while others receive it (workers/builders/city councils). Manuals, assembly instructions, and other materials might be supplied to guarantee that the design is followed. Enhancing quality assurance in the on-site inspection phase, augmented reality offers several advantages, since people in charge can foresee possible discrepancies and make choices accordingly.

Housing is on display before you buy it. The advantages of augmented reality for potential buyers and investors are unrivalled. From visiting a home before to purchase and imagining what life may be like in the future to being able to adopt reforms and finish options for future improvements, we've got you covered. During the building period, there is a higher level of safety awareness. Better judgments may be made while executing the occupational health and safety risk prevention strategy before construction using augmented reality visualization. As a result, users may see how the various essential safety aspects should be positioned in the individual project ahead of time. See it before you create it. Augmented reality (AR) lets you avoid mistakes by seeing 3D BIM/VDC information before you construct it in reality. Track progress, AR makes it simple and easy to keep track of the building progress. Show progress, AR allows you to see phases of your building process in Autodesk Revit® using data from your BIM/VDC model. Mix and match models. In one view, you may merge different 3D BIM models. Presentation on a tabletop Place a scaled model on a table for a clear viewpoint, such as during design reviews. Projects are completed on time and on budget. BIM has already been shown to reduce project delivery time and keep projects under budget. This will be made much easier by combining AR and BIM. You might use augmented reality to walk around a full-scale BIM model to build the most efficient construction timetable and develop a site logistics plan for staging spaces, material and supply delivery, and equipment storage.

The amount of stakeholder acceptability, their knowledge of the relevance of AR, the usability of the software, and the acceptance of paying additional expenditures for hardware, software, and training are all obstacles from the users' perspective. Each of these categories poses a barrier for AR understanding and acceptability in the future, which is critical to increasing the efficiency of AR use in the AEC sector.

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Information Model of Intelligent Support for Effective Decisions

Andrey I. Mokhov, Nikolai M. Komarov, and Ivanna A. Abrosimova

Abstract The article aims to reveal the patterns in the formation of entrepreneurial activity in the construction complex on the basis of modeling high humanitarian and social technologies used at its stages. In turn, the found patterns will become an important aid in the rationalization and efficiency of the decision-making process.

The methods used in the study included infographic modeling and complex engineering of the building complex. Infographic modeling is used to visualize the processes of creating managers of construction enterprises for products in demand by the consumer and to distinguish between approaches to the formation of high humanitarian and social technologies. The complex technique of making effective decisions is proposed by the authors as a generalized method for constructing high technical and humanitarian technologies for entrepreneurial activity based on the use of data processing and documentation models. The results of the study were visual representations of the mechanisms for transforming the parameters and characteristics of the source material by high humanitarian and social technologies of entrepreneurial activity into the final product. The conclusions to this article were the substantiation of active growth and the identification of the prospects for the development of communities of business coaches, management consultants, interims, moderators and other specialists who own similar technologies and carry out its methodological support.

Keywords Effective solutions · Information model · Complex engineering of the construction complex · Technology modeling · Intellectual support

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1 Introduction

The authors of the article believe that the conscious use of high humanitarian and social technologies will make it possible to introduce an organizational component in business activity which can focus the result of entrepreneurial activity on a particular consumer, even in new markets.

The topicality of the issue considered in the article consists in developing entrepreneurial activity, identifying and modeling the patterns of entrepreneurship that ensure its success. The aim of the article is modeling high humanitarian and social technologies of entrepreneurial activity for visual representation in the process of product creation. The goals of the study include the logic analysis of the sequence of stages in entrepreneurial activity, the identification of the features of combining high humanitarian and social technologies in entrepreneurial activities, the construction of infographic models of both traditional and high technology entrepreneurship.

Let us consider the aspects of both technical and humanitarian technologies, allowing to classify these technologies as “high” ones. It should be noted that while high technical technologies had been actively analyzed by the authors [2–4], the aspects of humanitarian high technologies became the objects of research quite recently. Such studies include the works [5–7], where the methodological scheme of practical activity, shown in Fig. 1 [8], is presented in the form of the cybernetic model (Fig. 2) [9].

The given scheme consists of two parts. The right lower part shows the “objective” part of this activity: the source material of the objective transformation (the dotted circle), its product (the dot-and-dash circle), the transformation tools (full circle), and the actions (D1…Dk) performed by a person (taken together with the tools, they form the procedures of activity). The left upper part of the diagram shows the “subjective” part of the activity: a person himself, his goal, means (Δ) and

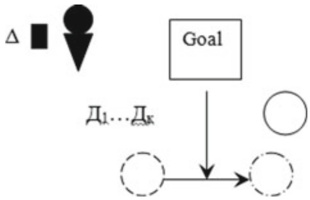

Fig. 1 Practical activity diagram

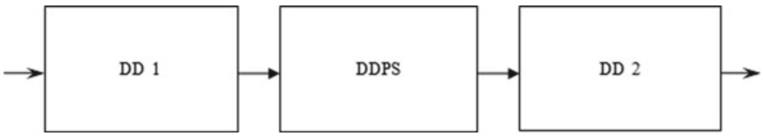

Fig. 2 Generalized cybernetic scheme of DDPS [9]

abilities ([redacted]), necessary for using the means, performing actions and constructing the corresponding procedures that convert the source material into a product.

Using the graphical representations of [9], we consider the source material and the product, respectively, the object and the result of data and documentation (DD) processing, i.e. we will describe the scheme of practical entrepreneurial activity by a set of procedures for a data and documentation processing system (DDPS).

The presented model reflects that each parameter of the object changes its value as a result of processing, under the influence of the corresponding characteristics of the processing subject. This trace left by the processing system on the object and characterized by a change in its parameters determines the characteristics of this system. The trace is fixed in the changed parameters of the source material, and further becomes the basis for analyzing the characteristics of the means of activity of the subject involved in the processing [10].

The generalized cybernetic scheme of DDPS [9] is shown in Fig. 2.

2 Materials and Methods

The main model of the study is the infographic model of processing technology, obtained by combining the scheme of practical activity and the generalized cybernetic scheme of DDPS. The source material of the activity will be the parameters of the object of processing, carried out by the processing subject with the corresponding performance characteristics in the data and documentation processing procedures.

The methods used in the study included infographic modeling and complex engineering in business. Infographic modeling is used to illustrate the processes of creating products by entrepreneurs and differentiate between the approaches of the formation of high humanitarian and social technologies.

Complex engineering of entrepreneurship is proposed by the authors as a generalized method of constructing high technical and humanitarian technologies of entrepreneurial activity on the basis of application of data and documentation processing models. Complex engineering [15], in contrast to system engineering [16], has been developed quite recently, but proved its necessity in modeling practical processes in a number of areas, such as construction, sociology, automation, education, economics, etc. [17–20]. The complex approach, which is the basis of complex engineering, allows us to unite systems with opposite goals of functioning in a well-coordinated mode of interaction.

Let us consider sequential transformation of the source material into the parameters of the product (item) according to the sequence of the procedures of the data and documentation processing system (DDPS). Figure 3 shows a model for the sequential transmitting of the results of processing from one stage to another in the DDPS [9].

The abovementioned analysis, synthesis and practical synthesis problems are solved in the data and documentation processing system by implementing the stages of "RECOGNITION", "FORMATION", and "STORAGE" of data and documentation (DD). The sequence of transformation of the data and documentation parameters

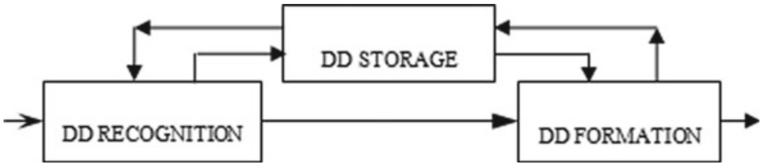

Fig. 3 Model of transmitting the results of processing from one stage to another through DDPS

in the processing procedures “RECOGNITION” (analysis) and “FORMATION” (“synthesis”) is implemented in the model by the direct transfer of DD from one processing stage to another. Conversion of DD parameters through “practical synthesis” is fulfilled in the model by the reverse scheme of the stages “FORMATION”” and “RECOGNITION” through “STORAGE”. The application of such a scheme ensures the activity of an entrepreneur to use available successful business solutions prepared by predecessors and transmitted in the form of methodological recommendations. At the same time, an entrepreneur can independently organize his activities based on the application of standard business projects, analyzed, stored and used in simple combinations.

In the considered case, a complex approach is used since it skips the stage of diving in the immediate experience but forms the competence of the expert in entrepreneurial activities. Competencies are created on the basis of identifying aspects of holistic skills, by consistently focusing on the levels of application of the tools of transformation [7].

The implemented changes included in entrepreneurial activity raise the entrepreneur up to an expert level. This means “an expert in entrepreneurship”, where a person focuses on the development of his own means and abilities.

For the methodologist, presented as ▽ the entrepreneur ▼ becomes an object that is transformed into a subject.

The methodologist deals with the development of the “subjectivity” of the object, by putting him into a state indicated by a figure fixing the change (synthesis) of the vision of the entrepreneur corresponding to the given methodological competencies.

In the article [7], the optionality of parameters of an object for choosing a solution in entrepreneurial activity is defined as a process of putting an entrepreneur into a reflective position which sets him apart from his traditional decision-making process of a sample product creation. Such a situation is required for the entrepreneur to develop an independent skill in conducting an alternative analysis. In [9], this processing stage is the “RECOGNITION” procedure and the result of it, according to the scheme shown in Fig. 4, is transferred for further processing to the “STORAGE” and the “FORMATION” stages for implementing alternative synthesis. An alternative synthesis is defined as a creative process of transferring an object from the “past” to the “future”, with the record of the obtained data.

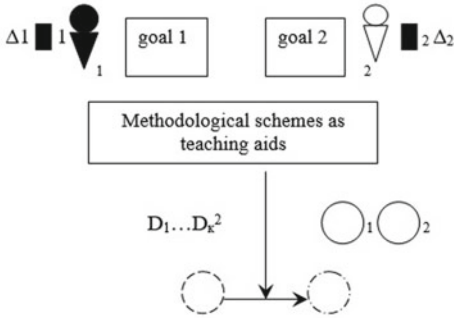

Fig. 4 Model of teaching entrepreneurs to apply methodological schemes [7]

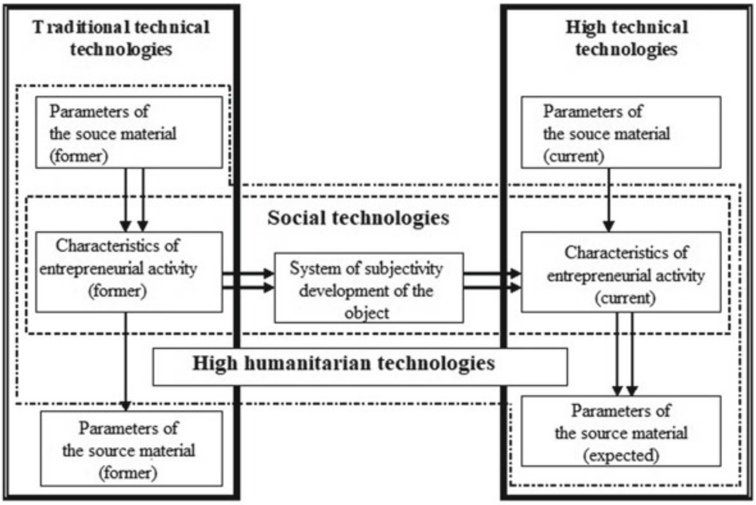

Fig. 5 Combined cybernetic model of entrepreneurial activity technologies

3 Results

The model analysis shown in Fig. 5 confirmed and showed that the key process of entrepreneurial activity is the management of its characteristics. A separate block of the cybernetic model of entrepreneurial activity, the "system of subjectivity development of the object" is responsible for developing this activity by organizing its progress. The system of subjectivity development aims at adjusting the modes of fulfilling the "technical" and "humanitarian" components of activities, thereby forming the logic of stages of entrepreneurial activity and coordinating the production and consumption processes. The content of the considered block includes an intelligent organizational mechanism which forms the high humanitarian and social

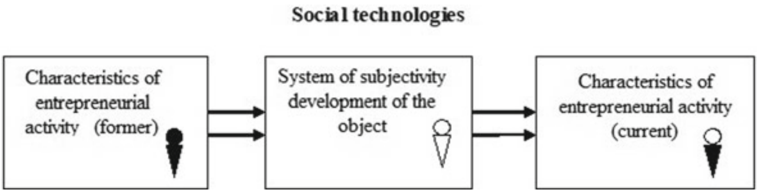

Fig. 6 Infographic model of social technology implementation (obtained by the authors)

technologies in order to advance the business environment; the mechanism is implemented by business coaches serving the communities, management consultants, interims, moderators and other professionals engaged in methodological support of entrepreneurship.

4 Discussion

Below, the article considers each element of entrepreneurial activity. Figure 6 shows an infographic model of the implementation of social technologies in the process of entrepreneurial activity, where the elements of the methodological approach are added.

Such an addition does not violate the modeling conditions, since the methods of management consulting nowadays make it possible to neglect (record, objectify) the main characteristics of a particular entrepreneur for the subsequent identification of inconsistencies which may appear in a particular situation where the entrepreneur performs his activities. The study may serve as an example [15]. On the other hand, the mechanism of the system of subjectivity development of the object also becomes "objectified" in connection with the development of relevant professional standards conducted by business coach communities. Publishing can be an example of the study aimed at identifying the laws of professional methodological activity [19].

5 Conclusion

The results of the study are the following:

1. It was confirmed that entrepreneurs use advanced humanitarian and social technologies to solve development problems of their activities which serves as organizational support of high technical production technologies. The formation of an infographic model of entrepreneurial activity is carried out by combining the cybernetic and methodological schemes of practical activity.
2. The introduction of the models of the data and documentation processing system to the entrepreneurial activity made it possible to logically link the stages of

analysis, synthesis, alternative analysis and alternative synthesis of parameters and characteristics of objects in the cycle of implementing high humanitarian and social technologies.
3. The introduction of the term “complex technology of entrepreneurship” will make it possible to introduce this scientific direction into the humanitarian sphere since it was based on the integrated approach that appeared and was firstly applied in the technical sphere.
4. The clear mechanism of transforming the parameters and characteristics of the source material for the realization of the final product by high humanitarian and social technologies of entrepreneurial activity was developed.
5. The development of social technologies defines the prospects for the development of communities of business coaches, management consultants, interims, moderators and other professionals, who master these technologies and implement methodological support for entrepreneurial activities for its activation.

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Time Reserve Determination During the Large Industrial Construction

Aleksandr S. Pavlov and Elena A. Gusakova

Abstract Duration of construction is one of the most important indicators of construction, along with cost, quality, safety. In many power plants, the actual construction period is significantly longer than the originally planned construction period. The progress of construction of several power units of power plants with a capacity of 1000 MW and more is considered. A set of factors influencing the overall duration of the investment cycle is proposed. These include: the capacity and seriality of the power unit, the number of workers at the construction site, the experience of contractors in the construction of similar facilities, the presence of state regulation. Regression analysis was chosen as the method of factor analysis. As a result of the research, a formula was obtained for predicting the duration of the construction of a power unit. The best results are shown by construction sites where there are a sufficient number of workers; there is experience in construction and government support. These are mainly construction sites in China. Depending on the forecast of the factors considered, a general reserve of time on the critical path of construction should be established. It will reduce the risks of economic losses for the investor.

Keywords Construction duration · Construction projects · Time reserve · Scheduling delays · Power plant · Factor analysis

1 Introduction

Construction duration of is one of the most important indicators of construction, along with cost, quality, safety [1]. A large number of studies are devoted to the problems and methods of determining the exact duration of the construction of an object. [2, 3]. This is an especially important indicator for the construction of large

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industrial complexes. And this fully applies to the construction of power plants. Due to the greenhouse effect threatening the planet's ecology, the share of power plants burning hydrocarbon fuels is decreasing. At the same time, the importance of power plants using renewable energy sources and powerful nuclear power plants is growing. However, the duration of the construction of modern nuclear power plants is at least 5–8 years. At the same time, capital investments of about US $ 10 billion and more are "frozen" [4].

Experience shows that in rare cases, builders manage to meet the originally planned deadlines. In case of any delays in construction, the investor incurs significant losses, since it is impossible to put into operation an industrial production or a power plant, if the construction of absolutely all facilities provided in the project is not completed [5–8]. With the delay in construction, inflation has an increasing influence, affecting the prices for construction materials, equipment, and labor. Such objects are often built with borrowed money, and with an increase in the duration of construction, the payment of interest on a loan also goes up. In addition, with each missed year, the power plant becomes obsolete, ceases to comply with environmental requirements, which often leads to rework of the project.

Lessons learned show that the key events of the critical path for the construction of facilities such as PWR nuclear power plants are usually: start of concrete work on the foundation of the main building ("first concrete"); completion of the main concrete work; installation of a maintenance overhead crane; construction of the containment; installation of the equipment case; completion of pipeline welding; "cold" hydraulic tests; "hot" hydraulic tests; start-up, comprehensive testing and commissioning [9].

Directly for the period of construction and installation work, you can specify other events, which can be used to analyze the progress of work from the "first concrete". For example, for the second unit of the Sanmen NPP (China), key events

Table 1 Some key events in the construction of the Sanmen-2 power plant

Key event	Date from "first concrete", month
Start of installation of containment structures	6
Installing the enclosure	57
Start of installation of steam generators	64
Completion of installation of steam generators	66
Installation of the dome of the inner containment	67
Completion of the outer containment	73
Completion of the installation of the main circulation pumps	85

are monitored, counting the date from the start of placing concrete in the foundation slab of the reactor building, indicated in Table 1 [10].

If we bear in mind that the planned dates of key events indicate a certain planned percentage of work performed, then the dependence of the actual dates on the planned ones symbolizes the dependence of the duration of construction on the volume of work performed. In many cases described below, this dependence has a character close to linear, and the slope of this function, as a rule, is greater than unity. This suggests that the lag behind the schedule usually grows gradually, and few people manage to compensate for this lag.

2 Methods

The duration of the main construction period for the power plant is traditionally counted from the start of concrete work on the foundation of the main building ("first concrete") to start-up. However, the investment cycle for the construction of the power plant begins several years before this event. In many power plants, the actual construction period is significantly longer than the originally planned construction period. Examples are the completed projects of power plants in the Russian Federation and in other countries. Russia (then the USSR) is a pioneer in the peaceful use of atomic energy; the first nuclear power plant was launched in 1954. Currently, Russia has 11 nuclear power plants, more than 1,500 thermal power plants and more than 100 large hydroelectric power plants.

At the Novovoronezh NPP (NVNPP), two new power units with a VVER-1200 reactor (AES-2006 project) with a capacity of 1180 MW each were built [11]. The start of construction of power units No. 6 and No. 7 took place in June 2008 and July 2009, the physical start-up - in May 2016 and March 2019, respectively. Thus, the duration of construction from the "first concrete" to the physical start-up was 95 and 116 months. The initial completion of construction was expected in 2012–2013, the cost was estimated at US $ 5 billion [12]. It should be noted that the prototype of a power unit is always built a little longer (according to the experience of thermal power plants, it is 20–30% longer). The delay in construction was also caused by modifications to the power unit electrical equipment.

The same power units were built at the Leningrad NPP (LNPP-2). The state contract was signed in 2008, the commissioning of the first power unit was scheduled for 2015. The start of construction of power units took place in October 2008 and April 2010, start-up - in February 2018 and August 2020, respectively. [13].

Nuclear power plants are of great importance to China's energy sector. At one of the largest power plants in the world, Tianwan (田灣 核電站) on the shore of the Yellow Sea, reactors made in Russia and China are installed. For the first two power units, VVER-1000 reactors (model V-428 with a design capacity of 1060 MW) were supplied. An intergovernmental agreement was signed in 1992, the construction of the first power unit began in October 1999, and the physical start-up took place in December 2005. Construction of the second power unit began in September 2000 and ended in May 2007 [14]. Thus, the main construction period lasted 74 and 80 months, respectively.

The contract for the construction of the 3rd and 4th power units of the Tianwan NPP was signed in 2010. The first concrete was laid in the foundations of the reactor buildings in December 2012 and in September 2013. The physical start-up took place in September 2017 and September 2018. Thus, the main period lasted 58 and 60 months, respectively [15]. At the 5th and 6th power units, the Chinese ACPR-1000 reactors with a capacity of 1000 MW each were installed. Construction lasted 55 and 56 months. Construction of facilities in China is distinguished by a large number of employees and high labor discipline. As a rule, Chinese power units built according to the mastered technology are built in no more than 5–6 years. In mid-2021, the total capacity of operating nuclear power plants in China exceeded 49 GW, 17 GW – under construction [16].

Nuclear power plants are widespread in France. In 2004, Électricité de France (EdF) presented for public comment a project for the construction of a 1630 MW EPR power unit at Flamanville station on the shores of the English Channel. The contract for the supply of the reactor plant was signed in April 2007.The first concrete was poured on December 3, 2007. The power unit was originally supposed to be commissioned in 2012 [17]. However, due to the identified defects, the deadline was repeatedly shifted. At the beginning of 2014, the reactor vessel was installed, and it was only in February 2020 that the cold and hot tests of the reactor plant were completed. The power start-up of the reactor is expected no earlier than 2023. The expected cost of the power unit during this time increased from 3.6 billion euros to 19.1 billion euros. The number of workers reached 2850 people, of which 19% were hired foreign workers [18].

A power unit with a similar reactor is to be launched at the Olkiluoto power plant on the Finnish Baltic Sea coast. The decision to build was made in 2002, the contract with the European consortium, which included Areva NP (France) and Siemens (Germany), was signed in December 2003. Siemens subsequently left the consortium. Construction began in September 2005. The commissioning date was originally planned for 2010, then was repeatedly postponed. Many delays were caused by contractors' conflicts with the Finnish Radiation Safety Authority (STUK) over manufacturing and installation defects [19]. Now, commissioning is expected no earlier than 2022. At the same time, the construction cost has tripled compared to the contract price of 3 billion euros [20]. The construction employed 4,000 people, of whom 2/3 were foreign workers, including Poles and Slovaks. [21]. A feature of construction is also the presence of a large number of contractors and suppliers (up to 1,500 companies), which complicated the organization of construction.

In 2008, for the first time in many years, a contract was signed in the United States for the construction of two new AP-1000 power units with a capacity of 1215 MW each according to the Westinghouse Electric Company project. Construction, which began in 2013 at the Vogtle power plant in Georgia, was scheduled for completion in 2016–2017. However, construction experienced numerous delays, including the bankruptcy of contractors and suppliers. In 2021, NPP equipment was "hot" tested;

commissioning of power units is expected in 2022. The cost during construction increased from an initial $ 14 billion (for two units) to $ 27 billion [22].

Similar power units with two AP-1000 reactors were planned for installation at the Chinese power plant Sanmen (三门 核电站) on the coast of the East China Sea. The start of construction was recorded in April and December 2009. The completion of construction was originally scheduled for 2013 and 2014, but the actual physical start-up took place in June and August 2018, 106 and 104 months after the "first concrete". In the same year, the power plant was put into commercial operation. The delay was caused by quality problems of the main circulating pumps, which could not be replaced according to the project. Some of the equipment was manufactured in Chinese factories. The cost of the station has risen, according to Western estimates, from 32.4 billion Yuan to about 50 billion Yuan [23].

Haiyan NPP (海阳 核电站) is the second NPP in China with the same AP-1000 power units, located on the coast of the Yellow Sea. The construction of the reactor buildings of the power units began in September 2009 and June 2010, the physical start-up took place in 106 and 99 months, respectively, and the commissioning took place in 2018 and 2019.

The Taishan NPP (台山 核电站) is located on the shores of the South China Sea. Both power units of the plant are equipped with European-made EPR-1750 reactors. The duration of construction from the "first concrete" to the physical start-up of the reactor was planned at 46 months. The construction of power units started in the middle of 2008. The first concrete was laid in the foundations of the power units in November 2009 and April 2010, the physical start-up took place in 103 and 107 months, respectively, and the commissioning took place in December 2018 and September 2019. Although major work was completed by 2015, fuel loading was delayed due to concerns about problems with similar reactors at the Flamenville nuclear power plant (see above). Value increased from RMB 50 billion to RMB 77–80 billion [24].

All the described power units have the same type of reactor: pressurized water-cooled thermal neutron reactor (PWR). These power units have a two-circuit thermal scheme, similar steam parameters, one steam turbine per power unit, a double containment shell, reinforced concrete structures of most buildings and structures, and similar security systems. Reactor plants belong to generation III or III+ for safety requirements. However, construction times vary from 4.5 to 16 years. Having considered the progress of the construction of power plants in different countries, it is possible to propose a set of factors influencing the forecast of the total duration of the investment cycle, including the main construction period. These include the following factors:

- The electric power of the power unit, for the considered units, varies from 1.0 to 1.75 GW. Indirectly, the capacity determines the main volume of construction and installation work;
- The number of the power unit at the power plant, characterizes the "learning effect" of construction and installation personnel;

- the number in the series of the main power equipment produced, characterizes the "learning effect" of the plant personnel;
- The maximum number of workers at the construction site. Along with the availability of construction equipment, it determines the possible intensity of work. It should be borne in mind that at work on the installation of equipment and on special construction work, the number of qualified workers is important, and not all in general;
- The complexity of the construction of the facility. Complexity is conditionally equated to the number of "safety generation", adjusted for technical solutions. For example, for the AP-1000 reactor plant of the "III+" generation, the complexity is 3.5, but taking into account the simplification of the building structures, 3.0 is taken;
- Experience of the main contractors in the construction of similar facilities. It can be determined (in a negative sense) by the number of years that have passed since the end of the construction of a similar object. If such an object has not been built at all before, the maximum period should be taken after which the experience of the organization disappears, for example, 10 years;
- The factor of state participation was estimated by the authors with a conditional score, giving a total of up to 1.0. The minimum score can be 0.2, which means government licensing and supervision; state budget financing and state guarantees of long-term loans were assessed with an additional score of up to 0.5; participation of state and parastatal contractors, technical customers add up to an additional 0.3.

Besides, additional influencing factors can be taken into account: climatic, economic, technological. For example, the organization of construction management must be optimal. It is difficult to manage construction with thousands of contractors and suppliers, but it is also not always rational to give all the work under the general contract to one company. However, this factor is difficult to quantify; it is only possible to assess it with a conditional score. On the other hand, hardly anyone will say before the start of construction that the organization of construction will not be optimal. Therefore, this factor was not considered, and such an analysis can be carried out in the future.

The method of analyzing the degree of influence of factors is a regression analysis on the assumption that the resulting feature (duration of construction) can be expressed by a production multiplicative function (by analogy with the Cobb-Douglas function), since an additive linear function of several summands is usually valid only over a short interval of factor values. Some drawback of research using multiplicative functions is that the argument cannot take non-positive values.

3 Results

The approximate values of the initial factors and the effective indicator are given for some foreign power plants in Table 2. The effective indicator (the main period of the duration of the construction of the power unit from the "first concrete" to the start-up) is determined according to the IAEA data.

For Chinese construction projects, the value of the maximum number of workers is usually not published, however, it is clear that the country does not experience restrictions on this factor. Therefore, in Table 2, a conditional maximum value is accepted for them, which can be imagined based on the front of work at the power unit. State participation in Russia, Belarus and especially in China was expressed in budget financing and lending to construction sites, in the participation of state and parastatal organizations in construction as customers and contractors.

The results of the regression analysis are presented in Table 3. According to the results of the calculation, the power was estimated with a low correlation coefficient, and therefore was excluded from the set of factors As a result of factor analysis, partial correlation coefficients were obtained, which indicate that the serial production of a power unit, as well as the experience of contractors, can have the greatest impact

Table 2 Factor analysis of the construction duration of power units

Power unit	Factor values					Duration of construction, months
	Power, GW	Reactor number in series	Unit number at the station	Number of workers, thousand people	State participation	
Tianwan	1.06	32	1	8	0.9	74
Tianwan	1.06	33	2	8	0.9	80
Tianwan	1.126	36	3	8	0.9	58
Tianwan	1.126	37	4	8	0.9	60
Tianwan	1.118	2	5	8	0.9	55
Tianwan	1.118	3	6	8	0.9	56
Sanmen	1.25	1	1	7	0.6	106
Sanmen	1.25	2	2	7	0.6	104
Haiyang	1.25	3	1	7	0.6	106
Haiyang	1.25	4	2	7	0.6	99
Vogtle	1.25	5	3	4	0.3	110
Vogtle	1.25	6	4	4	0.3	100
Flamanville	1.63	1	3	2,9	0.2	180
Olkiluoto	1.60	2	3	4,0	0.2	195
Taishan	1.75	1	1	8	0.6	103
Taishan	1.75	2	2	8	0.6	107

Table 3 Results of regression analysis of the construction duration

Factor name	Correlation coefficients	Regression coefficients
Normalizing factor *A*, мес.		«60.13»
Equipment series number *N*	−0.113648	−0.01445
Station number *M*	−0.559628	−0.11845
Complexity *C*	0.467326	0.40247
Maximum number of workers *W*, thousand people	−0.157761	−0.07899
Years since last construction *L*	0.505206	0.18206
Government participation index *G*	−0.474996	−0.26825

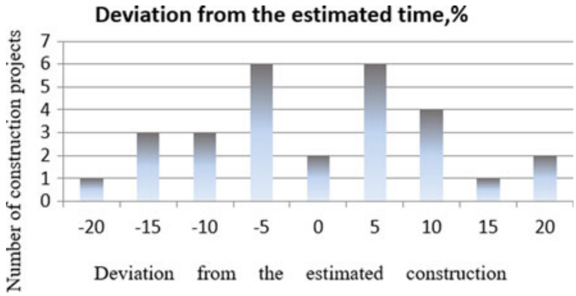

Fig. 1 Deviations of the actual duration from the calculated one, in percent

on the duration of construction. The degree of government participation and the available labor force have a lesser effect on the duration of construction.

The multiple correlation coefficient was 0.9497, which indicates a fairly complete result of factor analysis. Thus, the forecast duration of the main period T, in months, can be estimated by the formula: $T = \frac{A \cdot C^{0.4025} L^{0.182}}{N^{0.0145} M^{0.1185} G^{0.2683}}$

The calculated data indicate that only at the power units that have been mastered for a long time and with a large number of available qualified labor resources, a relatively short construction period can be expected, about 60 months. In other cases, the term can be 2–3 times longer, which leads to multi-billion dollar economic losses.

Despite the high coefficient of multiple correlation, the residual uncertainty remains quite high. Analysis of deviations of the actual duration from the calculated one showed that the standard deviation is about 10% of the estimated period. Such a period should be considered the minimum necessary reserve of time, by analogy with the reserve of cost in estimates. The histogram of deviations of the actual duration from the calculated one is shown in Fig. 1.

If we count the deviation not from the calculated value, but from the design duration, then the average deviation will be simply huge - over 50%. This gap is caused by various reasons, and it, of course, cannot be included in the contractual terms. The authors believe that for a more reliable execution of the work schedule, it is advisable to set a time margin within 15–20% of the estimated period.

4 Discussion

It should be noted that the main construction and partly installation work at many lagging power plants was nevertheless completed on time or with a slight delay. Serious backlog, on the contrary, is often caused by reasons beyond the control of contractors: the supply of defective equipment, additional customer requirements, economic conditions, etc. In this regard, it is unreasonable to set the planned period much longer than the technology of construction and installation works allows. At the same time, it has long been known that the construction of an object is a complex open dynamic system, which is influenced by many factors that cannot be foreseen in advance. This set causes a similar set of risks, the implementation of which leads to the results discussed above.

To deal with risks, more precisely, with their consequences, there are two main methods: insurance and reservation. Both methods require certain costs, but they cannot be completely avoided. In the practice of the Russian Federation, both methods are used: to neutralize financial risks, insurance is mainly used, for contract risks – reservation. In particular, power plant projects include up to 10% of the cost reserve, excluding adjustments for inflationary expectations. However, such time reserves are not provided for when determining the duration of construction. Therefore, any lag in the course of construction requires the acceleration of subsequent work, which is not always possible for technological and organizational reasons. And time is the same management resource as money, and perhaps even more valuable: it is far from always possible to correct the time lag with additional funding.

5 Conclusions

Therefore, the authors propose, when concluding contracts for the construction of large objects, such as power plants and factories, to provide for a “general” time reserve for the general contractor or EPC contractor in the amount of 15–20% of the planned period. Such a reserve should be taken into account when determining the effectiveness of capital investments for the investor. However, when planning, this reserve is not distributed among the performers, that is, key events on the construction schedule (milestones) should be placed without taking into account this reserve. Accordingly, the economic sanctions for the contractors should remain the same as in the case of a schedule without a reserve. General reserve of time can be wasted only as a last resort, if there are compelling reasons - mostly external.

In the future, it is necessary to clarify the appropriate size of such a reserve and, possibly, create a hierarchy of reserves of time in accordance with the structure of contractual relations.

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Development of an Integrated Information Model Based on Standard Modular Elements of the Maximum Readiness Basis

Angelina Rybakova

Abstract Building information modeling and modular construction are important promising technologies for the development of the construction industry. The combination of these techniques will provide a completely new approach to design and construction. In view of the continuous development of software systems for information modeling, as well as the trend of the spread of the modular principle in construction, a hypothesis arises of increasing the efficiency of work due to the integration of these approaches. However, as of today, there is little data on this. The purpose of this study is to form the theoretical and practical foundations for the development of an integrated information model based on typical modular elements of maximum readiness. To achieve this goal, it is necessary to solve the following tasks: to determine the features of modular design, to form a classification system for autonomous sections (modules), to highlight the fundamental components of the module, to assess the functionality of the information modeling software complex, to formulate the concept of developing the final model. As a result, a two-stage conceptual algorithm for the development of a complex model based on modular elements is presented, and the features of its functioning and development directions are formulated.

Keywords BIM · Complete modular units · Prefabrication · Design automation · Construction management · Modular structure

1 Introduction

Modular construction is the process of erecting a building from special autonomous sections (modules). Manufacturing these modules and their elements at the factory is called prefabrication. The materials for the modules, as a rule, are used the same as for any other type of construction. Finished parts with built-in windows, doors and communications, if required, furniture, equipment and smart home systems are

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transported to the construction site where their installation is completed. Modular buildings can be either stationary or mobile [1, 2]. In comparison with foreign countries, the popularity of modular construction in Russia is much lower [2–4]. To spread and improve the quality of modularity, it is necessary to integrate with other modern technologies and directions. Information modeling (BIM) technologies are one of the promising tools for the development of modular construction.

Modular construction and information modeling technologies are fundamental ways to implement design and construction and installation work [5, 11]. These directions are closely interrelated and can be used together to maximize profits for the construction industry [6, 7]. Consequently, it is advisable to jointly use them in the construction of certain construction objects [8].

Through off-site construction, the modular design concept can eliminate the time, cost and material inefficiencies of the standard construction approach by completing 60 to 80% of the work [9]. In Western and Asian countries, modular construction is used to implement projects such as small and medium-sized residential buildings, schools, kindergartens, clinics. However, today there is a tendency to extend the method to high-rise and industrial buildings [9].

To date, the analysis of the integration of modular construction and information modeling technologies is not presented in sufficient volume. Therefore, it is necessary to study the possibility and feasibility of combining the two concepts from the point of view of practical implementation.

Accordingly, the purpose of this study is to conduct a practical analysis of the information modeling functionality for the main tasks at the stages of the life cycle of modular construction. It is advisable to consider the concept of modularity based on information modeling technologies on the basis of the relationship between the elements of modules and BIM tools.

2 Methods

2.1 Classification of Modular Elements of Maximum Availability

For a full consideration of the implementation of a BIM module, it is necessary to form a theoretical basis for further practical activity: concepts, relationship and classification.

A modular element of maximum readiness in construction (MEMR) is a full-fledged element of construction, pre-made from various materials, which has the highest degree of readiness for installation. The module includes the necessary architectural and design characteristics, engineering solutions, equipment and, if necessary, options for interior and exterior decoration (Fig. 1) [10].

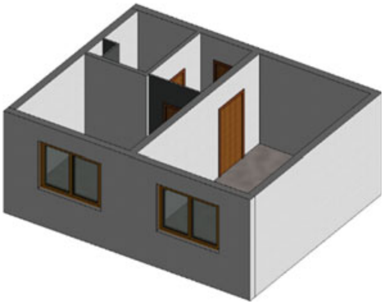

Fig. 1 Example of a complete modular unit

To classify modular elements of maximum readiness, it is necessary to identify the directions of grouping properties for systematization [12, 13]. The main characteristics of the analysis are the following categories:

– purpose of the object;
– technological affiliation;
– geometric characteristics;
– composition of sub-elements;

From the point of implementation of a modular element of maximum readiness by means of information modeling tools, it is advisable to continue the classification of potential blocks according to the totality of geometric and qualitative characteristics of the module and its sub-elements [14]. The development of a particular block does not depend on its technological affiliation and the purpose of the future object (Table 1).

The classification by the type of MEMR location is based on the number of external walls in one block. Depending on the location of a particular MEMR in the system of a complex building, it includes from 1 to 3 external walls. MEMRs that are absolutely identical in other characteristics can differ only in the number of external structures; in the absence of one or several faces, the bordering side is considered as imaginary [15].

With respect to the number of available faces, the reference is a fully closed MEMR, which includes all six faces. However, in some MEMRs there is no need for all faces from the point of view of block matching. Therefore, MEMR can consist of 3, 4, 5 or 6 faces [16–18].

Table 1 Classification of modular elements of maximum availability

External	Internal	Volume	Detailed
1 side	6 faces	Cube	Space-planning and design new solutions
2 sides	5 faces	Parallelepiped	Engineering and technological support
3 sides	4 faces	Capsule	Interior decoration
	3 faces		Furniture and equipment

Taking into account the geometric features of standard construction objects, the MEMR shape can be of three types: a cube, a parallelepiped and a capsule (for self-standing MEMRs). The use of a rounded shape is impractical due to the specifics of construction [19]. Complex geometric shapes can be applied to unique buildings and structures, but it is not rational to implement and type them.

The level of detail can be formed by a more frequent gradation, depending on the purpose of the object and the requirements of the technical task. From the point of view of the development and implementation of MEMR, 4 levels are generally distinguished: from the minimum filling in the form of space-planning solutions to the maximum, ready for operation [20].

If necessary, it is possible to make adjustments to one or another MEMR, but reuse and typing is irrational. Any potential SEMG can be represented in the system for each group of properties. Based on this classification, you can drill down further into components and evaluate the correlation with information modeling tools.

2.2 Components of Modular Elements of Maximum Availability

Regardless of the classification, each MEMR has a standard set of components. The totality of all components is an autonomous unit system. Component properties may differ in different MEMRs, may have a limited set of options, or may be unchanged.

Standard components of a single MEMR are formed according to the main components of any building: architectural part, constructive, engineering and technological support, and also elements of fastening and block joining are added (Table 2).

In connection with the fact, some architectural elements can be at the same time design, and the composition of the elements of engineering systems can vary depending on the type and purpose of the construction object. Thus, each MEMR is a certain sample of elements from a set of components, the totality of which represents a full-fledged autonomous system. The criterion for the functionality of this system is complex performance, regardless of the presence and functionality of other systems (MEMR).

When unifying MEMR and its constituent components, the issue of grouping and combining several sub-elements is important. From a conceptual point of view, the grouping is irrelevant, since it does not affect the stability of the structures. However, from the point of view of the development and use of an element in a particular software package, the issue of unification is an important strategic point.

Thus, it is necessary to analyze not only the transfer of physical components to the digital environment, but the ways of combining them. Information modeling technologies have sufficient functionality, both in terms of the number of primitives and tools. However, it is necessary to find out how they correlate with the base of modular elements.

Table 2 Comparison of functional and information modeling objects MEMR he system of components of the modular element of maximum readiness

Group	Component	Functions and primitives
Architectural part	External and internal walls, Overlaps, Partitions, Roof and roofing, Stairs, Windows and Doors	Architectural tools, The conceptual modeling tools, Setting materials Import objects
Constructive	Plates, Beams, Supports, Frame, Foundation Mounting elements of blocks	Tools of constructive, Architectural tools, Import objects, Tools collections of objects
Engineering ant technological support	Communication, Openings for communications, Pipes Air Ducts, Trays and busbars	Tools engineering systems, The add-in and the base from the manufacturer, Tools collections or objects with the addition of sizes
Furniture and equipment	Depending on the specifics technical task	Import the Database, From the manufacturer, Tools collections
Fastener and convergence of the elements		Tools of constructive, Architectural tools, Import objects, Tools collections or objects
Grouping and combining		Group model, Tools collections
Observation tasks		Editing tools, Visualization, Tools documentation tools, Import and export

2.3 Information Modeling Functionality for the Development of Modular Elements of Maximum Availability

Traditionally, software systems for information modeling include groups of commands and primitives for architecture, constructive, engineering systems, master plan, documentation, collaboration and creation of non-standard elements. It is necessary to adapt the approach of using the available tools for work within the framework of the modular method.

Therefore, it is advisable to define an appropriate information modeling tool for each MEMR component. Compliance with the example of the functionality of the Autodesk Revit software package is presented on Table 2.

As a result of the analysis of the comparison of the Autodesk Revit toolkit, it can be concluded that through the information modeling functionality it is possible to perform a full-fledged construction of not only any MEMR, but also a complex information model based on MEMR. The difference from the traditional development approach lies in the vector for constructing the main components: the order and volume of modeling changes according to the MEMR division. In addition to standard commands and elements, when developing MEMR, it is important to combine all the components into an information block. This operation in Autodesk Revit can be implemented in two ways: by creating a model group or by developing a family.

The selected objects are grouped by the corresponding command after all the MEMR components have been fully modeled. Each group is assigned a unique name. If necessary, the group can be edited, ungrouped or unloaded to another project. Storing groups is carried out exclusively within the project file. The group is a complicated analogue of the Autodesk AutoCAD block.

Family development usually begins with a full-fledged modeling of all components. Due to the peculiarities of the interface of the family editor, it is advisable to work with nested families, since a standard family includes only one group of objects according to its purpose. The hierarchy of families of components together represents MEMR. When you adjust a component, its family is edited. MEMR families are stored as separate files.

Each approach to combining MEMR components has its own characteristics and orientation. The choice of one or another approach is based on the specifics of the object, its complexity and previous experience in MEMR design. If necessary, both methods can be used simultaneously with partial integration.

Based on the data on the methods and tools for modeling a single MEMR, it is possible to form a universal approach for integrated information modeling of a construction object. Taking into account the proposed classification of MEMR (Table 1), single informational models of MEMR are also systematized.

3 Results

As a result of the study, it can be concluded that the design of an integrated information model is conventionally divided into two stages: the development of typical MEMR models and the formation of the final model. The stage of MEMR modeling for different complex models may overlap, since the same MEMR can be reused in other final models.

In the process of modeling single MEMRs for a large number of information models of objects, a library of typical MEMR elements is gradually formed according to their classification (Table 1). If necessary, the MEMR components are developed or adjusted first. The development of a new MEMR is carried out provided that there is no analogue in the library. Consequently, with the implementation of each new object, the volume of the library increases, and the cost of modeling MEMR decreases (Fig. 2).

At the second stage, a consolidated model is formed, which is a certain combination of MEMR from the library. The number, dimensions and name are determined by specialists, taking into account the specifics of the object on the basis of the requirements of the technical task (Fig. 3).

Completion of the final building model is implemented by compiling an object from a set of MEMRs, adjusting or detailing a universal MEMR, developing one

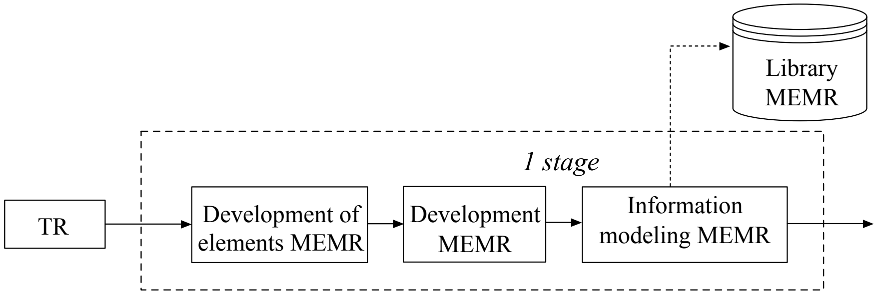

Fig. 2 MEMR simulation

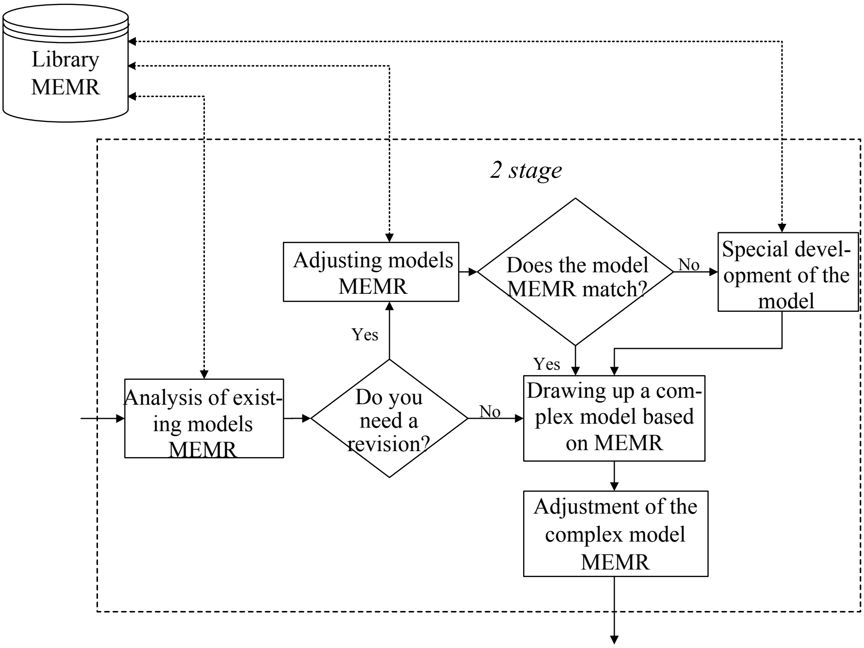

Fig. 3 Complete set of the final building model

or several BKUs specifically for the project. For maximum versatility of this design approach, it is rational to use all methods simultaneously.

Aggregating the features of information modeling and the fundamental foundations of modular design, a new design algorithm has been formed: on the basis of modular elements of maximum readiness. The algorithm is versatile due to adaptation for any construction object due to the basic classification, which takes into account the comprehensive characteristics of the model, and the use of information modeling functionality from the point of view of modular work. Based on the concept of this algorithm, new research directions are formed for the future rationalization of the approach, as well as for the search for new implementation tools.

4 Discussion and Conclusions

The application of a two-stage design approach is adapted for objects of any complexity and any construction volume. If the most suitable MEMR models are available, some of the tasks will be skipped or completed in the shortest possible time. With each new design object, the library of MEMR models increases, due to this, the design time for future objects is reduced.

When forming architectural, structural and engineering-technological components, no additional tools for developing an information model are required, with the exception of creating families or importing objects. In each software package, in addition to specific design tools, there is a general geometric one, which allows you to simulate any geometric shapes. Thus, when developing a complex model, it is possible to create not only construction objects. Design based on modular elements of maximum readiness includes a number of upgrades, which ultimately give a positive effect to both design and construction.

Thus, the development of an integrated information model based on typical modular elements of maximum readiness is carried out on the basis of a new algorithm that accumulates the fundamental aspects of the modular construction method and information modeling technologies. The newest approach to design forms new methods of performing all types of work, opens up development paths for specialists of all levels involved in construction.

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Modelling and Experiment to Identify the Urban Development in an African Country – Burundi

N. A. Samoylova, V. E. Emelanov, and I. R. Havyarimana

Abstract Information modeling technologies in building life-cycle management is used to regulate urban problems. This computer-aided model is based on the use of the World Atlas of the zenith artificial night sky brightness and zones of urban development impact of settlements (urban planning zones) for measuring urban planning boundaries stemming from the various ranks settlements area of influence. This article puts in the graphic scheme of urban modeling as in the experiment case of the territory of Burundi. The rates of urbanization in the African country of Burundi have still remained one of the lowest in the world. Housing development is expected to increase considerably within the country due to the massive natural population growth in the nearest future. It will require the use of technologies in building life-cycle management. The represented computer-aided modeling is multifunctional and can be applied in different countries and parts of the world. Comparison of the relationship of various types of buildings within the settlement there has been made with regard the Atlas for Bujumbura, Gitega and Ngozi. The basic graphic scheme of urban modeling is applicable to any territories and enables to get the latest and reliable data for urban planners, as well as to model the urban development of the settlements through the parameters; it also helps to draft proposals on choosing territory practice: either intensive or extensive settlements' growth; to justify the urban planning policy operating on densifying within the territory or vice versa and many other things.

Keywords Information modeling technologies · Urban development · World Atlas of the zenith artificial night sky brightness · Zones of urban development impact of settlements · Urban planning zones

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1 Introduction

The web-cartographical site (henceforth Atlas) [1] shows that about two-thirds of the world lives under a definite brightness sky, in the areas with high above average amounts of the fixed threshold. This Atlas is made on the basis of investigations of the zenith artificial night sky brightness at sea level. The Atlas provides almost a bird's-eye view of the process where the mankind has continued to cover him with the luminous mist through gauged emission satellite DMSP HD data and an accurate atmospheric propagation of light modeling.

In 2001 the world's leading scientific journal Monthly Notices of the Royal Astronomical Society (MNRAS) published a piece [2] which revealed a comparison of the Atlas graphic data and population density database, as well as the specified brightness sky proportion of the population. About two-thirds of the world's population and 99% of both American and European population (other than Alaska and Hawaii) live in the area with the exceeded threshold night sky amount, set for the contaminated status. However, in such continents, as Africa, Australia, Latin America as well as the much area of Asia in Russia, the night sky does not exceed the threshold amount which indicates the low urbanization within the territory (see Fig. 1).

In 2016 in MGSU there has been defended a thesis [3] with reference to the scientific research [4] which also sets forth the use of the Atlas for urban analysis. Within the educational process of the urban department of MGSU there are tried out the investigation inside the territory of different zones of the urban development impact of settlements [5–7].

This article outlines the methodology of carrying out urban investigation with computer-aided modeling. Atlas Artificial night sky brightness at sea level in the World is presented in Fig. 1.

Moreover, the article shows the result of the project computer-aided modeling experiment on the basis of an accurate atmospheric propagation of light modeling

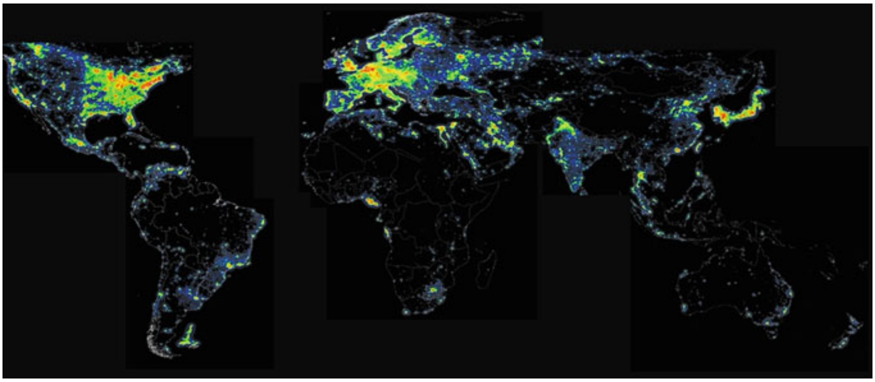


Fig. 1 Atlas Artificial night sky brightness at sea level in the World. The map has been computed for the photometric [2]

(that is the Atlas) through satellite DMSP HD data within the smallest country of Africa -Burundi.

2 Urban Characteristics of the Research Area

Burundi is a small state (its surface is 27,834 km^2 at the intersection of central and eastern Africa, population is 12.9 mln as for 2020). The country has a high density of the population, that is 422.50 people per a square kilometer, at the same time the population growth is 2.40% a year that is equal to the latter in a Moscow region of Russia.

If compared, the territory of Burundi is 10 times larger than of Moscow (the density of the population is 4880 people per square kilometer) and 1.5 times less than of Moscow region (the density of the population is 173.89 people per square kilometer). Bujumbura is the economic capital of the country, whereas Gitega is the political capital of Burundi.

Burundi urbanization rates have still remained the lowest in the world. The premise of the development is the fact that just since 1850 in Bujumbura have appeared several group residential areas [9].

Since 1930 of the twentieth century, Bujumbura has been the most inhabited city of Burundi. The Colonial structures of European type had been erected till the Independence of the country in 1962 and some of them still exist while the ordinary structures have been disappearing. Since 1987, there have been erected high-storey houses for servants. There are just several dozens of nine-storey houses by now and in 2020 the construction of the first 12-storey house in the country began. Low-storey houses were prevailing in Burundi. The types of buildings are as follows: medium-rise buildings, two-storey houses, single-storey houses, simple houses, and traditional houses.

The types of buildings in Burundi are as follows: 50.1% is in the ownership, 42.9% is on loan, 1.7% is for free (within the urban area), 96.6% is in the ownership, 2.0% is on loan, 1% is for free (within the rural area) [10].

3 Materials and Methods

The map within the atlas has two base layers (communication and hybrid maps), overlapping VIIRS/World Atlas'Clouds and dotted objects overlapping (SQM, SQC and Observatories). The data in the Atlas are within 2012–2021. Legend from World Atlas of the zenith artificial night sky brightness. Google maps has the borders of the country and provinces. The data of Google maps are 2020. OpenStreetMap data has the main and other roads of the country. The data of OpenStreetMap are 2021.

For modeling there has been used the graphic comparative analysis, urban planning approach for measuring urban planning boundaries stemming from the various ranks settlements area of influence [3–5]. These ranks reflect the number of population as well as the relationship of such areas (types and subtypes), characterizing parameters of relationship of such areas [5].

4 Results and Discussion

There has been developed the procedure of an urban planning investigation with Information modeling technologies in building life-cycle management based at the accurate atmospheric propagation of light modeling (Atlas) through satellite DMSP HD data and zones of urban development impact of settlements (see Fig. 3) and urban planning zones (see Fig. 2).

The developed procedure of an urban planning investigation with computer-aided modeling (based at the accurate atmospheric propagation of light modeling (Atlas) through satellite DMSP HD data and the zones of urban development impact of settlements) has made it possible to prepare graphic work material for the settlement relationship analysis within the territory. Technical modeling is tested zones of urban development impact of settlements within the territory of Burundi and the adjacent large settlements as well as within Burundi.

The modeling of zones of urban development impact of settlements as well as urban planning zones can be made from a relative geographical center [7] (see Fig. 2, 3) or from the actual (formal) settlement boundaries [5, 8] taking into consideration the required accuracy of the urban planning analysis.

Comparison of the relationship of various types of buildings within the settlement there has been made with regard the Atlas for the three main cities (Bujumbura, Gitega and Ngozi) of Burundi (see Fig. 4).

5 Conclusion

In comparison with other available information-retrieval maps (Google, Wikimapia, Yandex and tec.) as well as its GIS processing programs the resulted graphic work materials (see Fig. 2–4) are easy to receive, moreover they are visual, objective, actual, authentic and allow to shape analytical reports neglecting the official statistic areas of data-collecting as well as officially established boundaries of the settlements and countries.

Zones of urban development impact of settlements and urban planning zones within the experiment are modeled based on the actual settlement population data. These zones can be modeled on the basis of population projection data.

The alignment of SEG zones and the Atlas lighting zones levels its specified drawbacks by the author of the Atlas, such as (1) the apparent proportionality between population and sky glow breaks down going from large scales to smaller ones and concretizing, owing to the atmospheric propagation of light pollution large distances

(a) (b)

Fig. 2 Map-diagrams of the zones of urban development impact on the territory of Burundi: (a) the scheme of the urban planning zones on the Google map, (b) the scheme of the urban planning zones on the Atlas. Maps compiled by authors

from the sources, (2) the upward light emission is not always proportional to the population (e.g. owing to differences in development and lighting practices), (3) some polluting sources are not represented in population data (e.g. industrial sites and gas flares) and (4) population census data are not collected using uniform techniques, timetables or administrative reporting units around the world [2].

It should be noted that there are little contributions regarding the use of the Atlas for urban planning purposes in scientific international citation bases, almost not a one [10–14] within the topic introduced in this article.

The most interesting experience of using the Atlas is described by Korean investigators [15–17] for the regulation of land-use within the residential development. Map of Seoul provides a detailed space grid of light pollution which allows for a quantitative analysis of the light pollution. There are four different environmental lighting zones in Seoul based on land-use: Commercial/Industrial zones, Residential zones, Green zones and Protected natural areas [15]. Those zones have corresponding light emission standards by regulation in which the emission standards decrease in the order listed.

Figures 4a, b, c confirm the investigation [15]. The new revelation in regards to this investigation is that the color differences are well seen for various types of housing by means of the Atlas. The urban regulation within Burundi settlements is at a low level and makes over to the land settlement [18–20]. The solution to the problems of urban transformations within the settlements' territory is very pressing for both an African country under investigation and many worlds' countries.

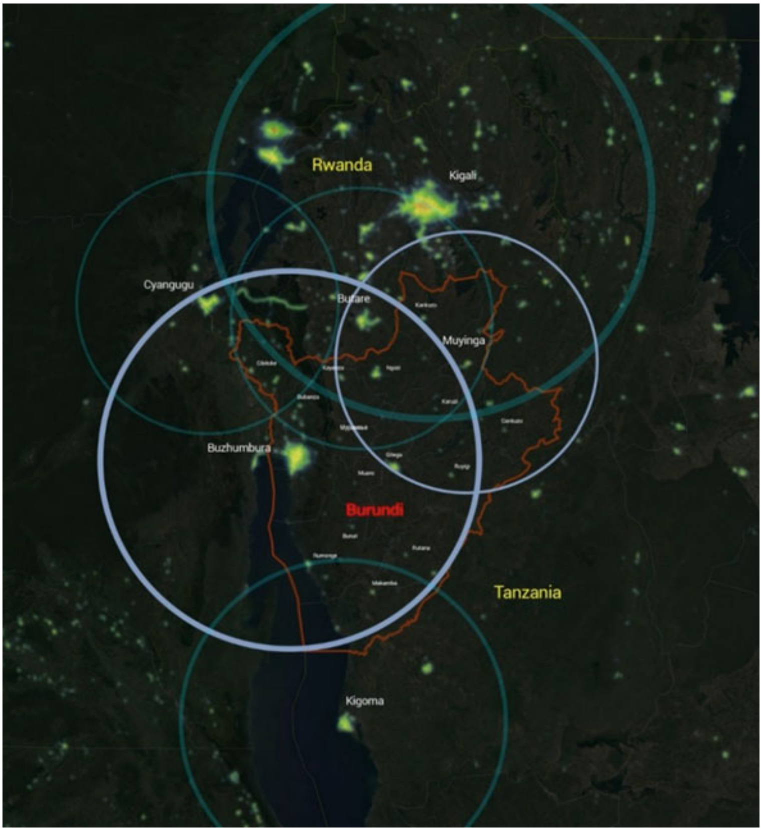
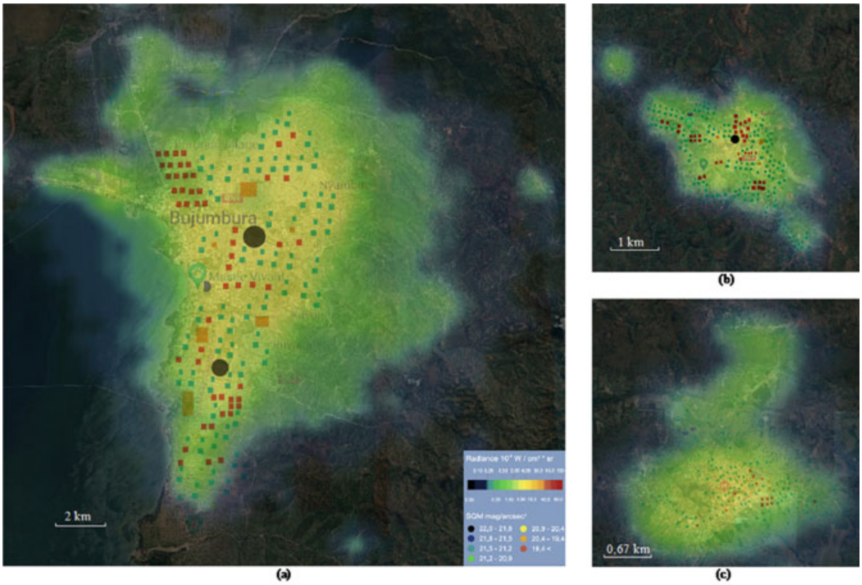


Fig. 3 A schematic map. The Atlas shows the zones of interconnection of SEG zones of settlements in part of the world. Map is compiled authors

The basic scheme of urban modeling rendered (Atlas and zones) is applicable to any territories and allows to get the latest and reliable data for urban planners, as well as to model the development of the settlements through the parameters; it also helps to draft proposals on choosing territory practice: either intensive or extensive settlements' growth; to justify the urban planning policy operating on densifying within the territory or vice versa and many other things.



Existing residential development by type: Traditional houses, Simple houses, Single-storey houses, Two-storey houses, Medium-rise buildings.

Fig. 4 A schematic map. Proportionate and large-scale representation on the Atlas of Settlements in Burundi (existing residential development by type): (a) Bujumbura, (b) Gitega, (c) Ngozi, compiled by graduate student of MGSU V E Emelanov and Master of MGSU I R Havyarimana

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Construction Project Management with the Implementation of Information Modeling Technology

Svetlana V. Shilkina

Abstract This article examines the problems associated with the implementation of digital project management technologies at the stages of the building life cycle, with the introduction and development of building information modeling (BIM) in the construction industry. The article is based on the review of international experience in BIM application, current industry trends and current shortcomings associated with the implementation of information models. BIM is more than a technology, as it involves much more than just 3D modeling. It is also defined in other dimensions, such as 4D—time, 5D—cost, 6D–site management, 7D (sustainability assessment), 8D (safety management). The material of the article explores the methods of BIM application. The article emphasizes the importance of an integrated approach at the design stage of a construction project, the need for the participation of specialists in many areas, including cost and process management of the facility, covering the fifth and sixth dimensions in the BIM environment (5D project cost and 6D site management). The article considers the practical implementation of BIM in the design of agro-industrial complex, provides an example of the development of financial and economic model and methods of site process management. The article is completed with conclusions that creation of an information model will allow to unite site data on the stages of the building life cycle for every participant of this process, which will allow to save all kinds of resources.

Keywords Information model · Building design · BIM technologies · Building life cycle · Construction industry · Project management

1 Introduction

Technological progress entails large-scale transformations, changing society, people and their environment. Modern life is becoming impossible without the use of digital

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technologies, covering more and more new areas and applications [1]. The construction industry is no exception. Information modeling technologies (BIM), construction of building digital twin, and solving issues related to the management of building project information using building information modeling at the stages of its life cycle are coming to the forefront [2–5].

Purposes of the article: analysis of BIM technologies of construction project management, presentation of BIM application algorithm, demonstration of importance of research of information models at the design and operation stages of the site and estimation of the results.

Today BIM is a digital model of physical and functional characteristics of the building project containing various types of information. BIM works not only during the design, but also serves as a reliable basis for obtaining information to make management decisions during the operational cycle of the building. The International Organization for Standardization recommends the use and development of the ISO 19650 standard "Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling" [6]. The Infrastructure and Projects Authority (under the UK government) published a policy document "Transforming Infrastructure Performance: Roadmap to 2030",[1] dated September 13, 2021, which outlines the prospects for innovation and reform in the field of infrastructure construction. It defines the concept of BIM as a combination of processes, standards and technologies through which information, including data, can be generated, visualized, exchanged, validated, used and reused to form a sound basis for decision-making for the benefit of building lifecycle participants. This concept includes, in addition to the construction phase, the organization, procurement and supply during the operational phase, asset and facility management, maintenance, renovation, disposal or reuse of assets.

2 International Practices of BIM Application

With increasing urbanization, the introduction of digital technologies in the economy, and smart cities gaining momentum, most developed countries are actively implementing BIM [7]. Norway, Denmark, Finland and Sweden were the first to introduce the mandatory use of BIM technologies in new construction projects. In France, the development of half a million housing projects using BIM began as early as 2014. In the UAE, the use of BIM is mandatory for all building projects with over 40 floors. The adoption of BIM in China is increasing since 2016. The Chinese government has not yet approved BIM as mandatory, but its use is encouraged. In Australia, a Smart Infrastructure Taskforce was established in 2016 in order to successfully implement BIM in all government projects over $50 million. In Germany, a BIM task force was

[1] https://www.gov.uk/government/publications/transforming-infrastructure-performance-roadmap-to-2030/transforming-infrastructure-performance-roadmap-to-2030#action-plan.

created in 2015—Digital Building Platform for the development of a national BIM strategy. In India, the construction industry is one of the fastest growing in the world. According to a study RICS India, approximately 68% of housing projects utilized BIM [7–9].

In Russia, the use of BIM technologies is just beginning to conquer the market. Many projects have already been implemented using various versions of software based on these principles. Analysis of materials [1, 9, 10…14] revealed that BIM is much more than just the technology. However, the current shortcomings include weak theoretical framework, insufficiently clear consideration of the issues of standardization, software, data presentation formats, there are also no methods for the use and implementation of BIM, etc.

3 BIM for Construction Project Management

BIM is commonly regarded as a technology that provides the right tools for specialists from different disciplines to collaborate in order to develop an integrated information model. The main task is to create a digital twin of the building, which provides a complete picture of the project long before construction begins. This way, design teams can prevent errors, detect inconsistencies, conflicts and eliminate most of the negative consequences of design. One of the basic principles of BIM is that project data is collected, accumulated, and stored throughout its life cycle, from the design phase to demolition [12…18]. Generally, one-way arrows are used to depict the transfer of information when representing the phases of a building's life cycle. In my opinion, this is not entirely correct, as the results obtained during the implementation of most stages allow to correct the overall building model (Fig. 1).

Collected project information may become necessary at any time to a sufficiently wide range of its consumers (Fig. 2). Moreover, some users are "passive consumers"

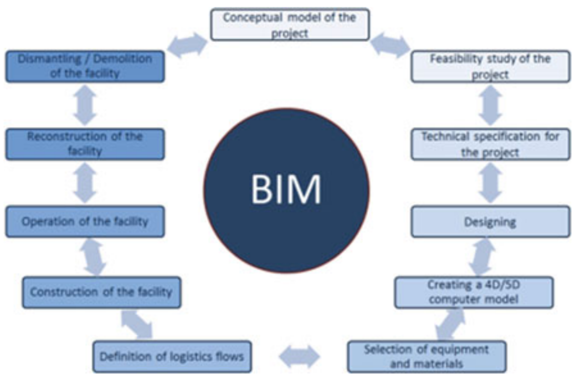

Fig. 1 BIM building model data consumers

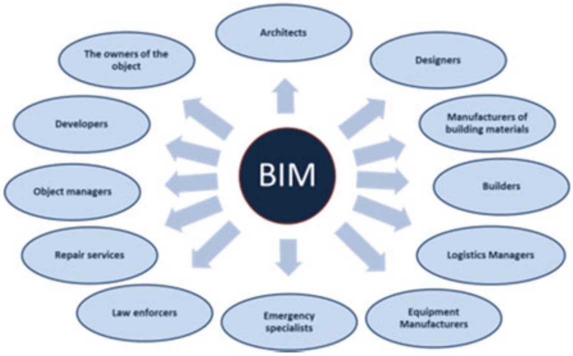

Fig. 2 BIM project model data consumers

that use BIM as an ordinary map, even if it is highly accurate (renovators, law enforcement agencies, etc.), while most are "active users" that not only receive project information, but also process it, and upload the results to the system (architects, planners, designers, builders). There is also a group that, after receiving project information, can provide recommendations for project changes in addition to uploading their data based on their experience and professional knowledge (builders, construction materials and equipment manufacturers, etc.). This brings a very important issue to the forefront—methods of exchanging information. Considering that most specialists work in their own environment, i.e. using software they are familiar with, it is necessary to have a common uniform format of storing and representing data, acceptable for any software product, that allows to transfer data without losses and distortions from one specialist to another. Therefore, the concept of OPEN BIM—a logical way to interact with each other—was developed and became relevant today. Open formats allow to transfer data regardless of the software used by the specialists. At present, there are several open formats, including IFC,[2] which allow to transfer data without any restrictions, and these tools are constantly being improved. The use of OPEN BIM is a logical way to develop information modeling in general. It is impossible to develop a building using just one program [19].

Of interest are the works and opinions of experts that BIM is more than just the 3D modeling and 4D dimensions for which it is known. BIM has other dimensions that describe its various subsets—3D (object model), 4D (time), 5D (cost), 6D (embedded work), 7D (sustainability), 8D (safety) [20, 21 and etc.]. Peter Smith writes that building models contain a large number of dimensions, he defines this multidimensional capability as "nD" modeling [20].

[2] Industry Foundation Classes (IFC) is a data format with an open specification that is not controlled by any company or group of companies. The file format was developed by buildingSMART (International Alliance for Interoperability, IAI) to facilitate interaction in the construction industry. It is used as a format for building information modeling.

4 Methods

This work used the methods of simulation modeling, technical, economic and financial analysis. The study of the management object includes the following work stages: 1. Description of the construction project and the idea of BIM implementation, concept formulation; 2. Information gathering: drawings, documents; 3. Construction of 3-dimensional models of the object; 4. Planning of construction and installation works (4D); 5. Development of financial and economic model, calculation of project cost parameters for the construction and operation phases (5D); 6. Project management based on the implementation of a fuzzy control system for the project microclimate parameters (6D); 7. Sustainability assessment, determining the impact on the external environment (7D); 8. Safety management in design and construction (8D). In the practical part of the article, It'll be examinen items 3–6.

5 Results

Let us consider the use of BIM technologies in the implementation of a construction project of a new agro-industrial greenhouse complex (hereinafter referred to as the Object). All basic stages of the BIM process were completed: the 3D model of the Object was built; the schedule of construction and commissioning works was defined (4D dimension). The cost parameters calculation software unit (5D) and fuzzy logic controller for the Object process control (6D) solution was implemented (Fig. 3).

In this article, I will present the results of calculations of one of the blocks of the project being implemented—design of the energy center providing electricity and heating for the designed Object. Greenhouse facility operation is an energy-intensive process, so the costs of energy consumption take a significant part in the cost of the final product. The main energy consumption occurs during the operation of the equipment that provides lighting and heating of the greenhouse interior space. Therefore, significant attention must be paid to optimizing the energy center structure, both in terms of the technology used, as well as the cost of construction and, naturally, the subsequent operation.

The data obtained during 3D modeling of the Object (configuration, equipment composition, modes of operation, power consumption, etc.) were used as input parameters for the calculations. Considering that the Object is to be built on a detached and empty plot of land, it is necessary to pay significant attention to its power supply. Three main options of power supply of the Object were considered in aggregate. Option No. 1: all power supply is provided only by a local power supply company. Option No. 2: the Object's power supply is ensured with the resources received from local suppliers: electric power for lighting and main process equipment operation, and natural gas for heating. Option No. 3: construction of an on-site natural gas power plant with a capacity of 20 to 32 MW. Installation of 3 or 4 gas reciprocating units (GRU) with a capacity of 8.18 MW each is planned, depending on the results of the

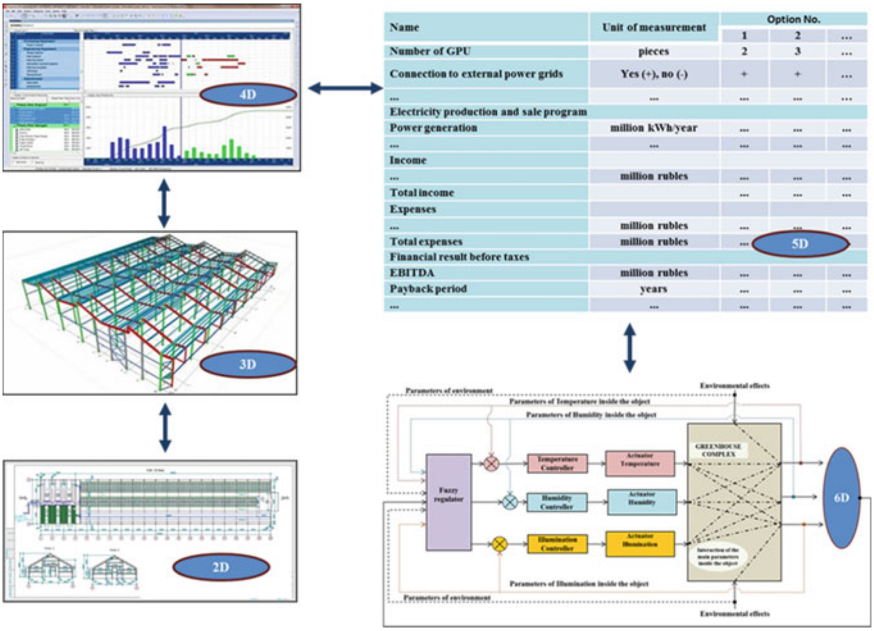

Fig. 3 BIM Object model development stages

study. The power plant capacity depends on the modes of operation of the equipment and methods of heating the Object using electricity or equipment utilizing the natural gas combustion process.

Due to the fact that various combinations of these options were considered, more than 10 models of energy center building configurations were analyzed. The equipment operation process taking into account the forecasted regional weather conditions, on the basis of which the required daily equipment load schedule as well as the approximate average monthly consumption of electricity and heat were determined (Fig. 4, Fig. 5).

Besides the results of various configuration development for 3D and 4D modeling stages, cost parameters in the construction region were taken into account as input data for calculations of financial and economic consequences of the decisions made: the cost of energy resources, the cost of process connection to the grid, the cost of building a gas pipeline to the facility, and other data.

The description of the calculation results is several pages long, therefore in this article, It will be presented only the main conclusions based on the results of the preliminary assessment of different options.

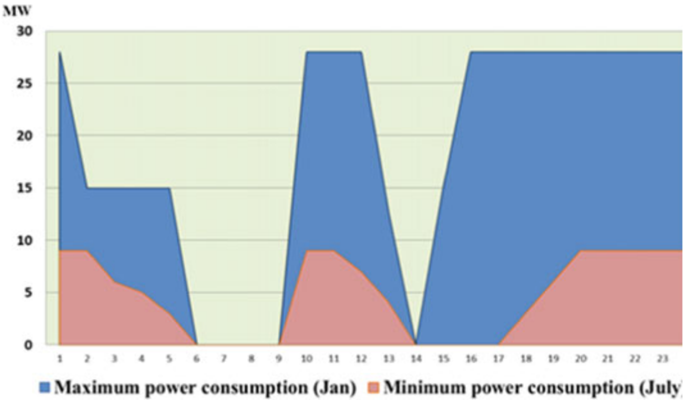

Fig. 4 Daily schedule of generation equipment loading at max (January) and min (July) consumption

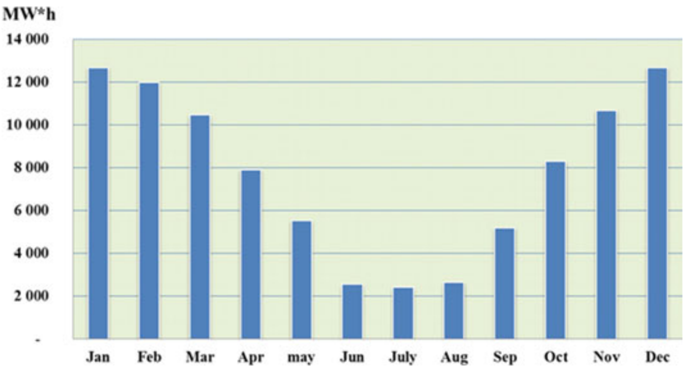

Fig. 5 Annual graph of average monthly power consumption

6 Discussion

According to the calculations of financial and economic indicators for most configurations of the energy center, we can confidently assert their economic feasibility: the EBITDA indicator calculated on the basis of cost reduction due to production at GRUs excluding the purchasing of electricity from local power suppliers, has a positive value. The preferred option is to build the energy center on the basis of four gas reciprocating units, one of which will be a reserve unit for preventive and unscheduled repairs.

The consultants proposed to change the technical configuration of the equipment used and make adjustments to the energy center operating schedule in order to improve technical solutions for reducing peak loads and mitigating dips in electricity consumption. Another recommendation is to use carbon dioxide from the GRU exhaust gases, both to increase the greenhouse efficiency and to reduce air emissions, which would reduce energy consumption by up to 25%. 6D and 7D dimensions of BIM technology were implemented to carry out the measures. Additionally, feedback on assessing the parameters of the main equipment operation in order to optimize its performance during the operation phase was taken into account. BIM modeling of the Object helped to develop a complete picture of the interconnection of all functional blocks and allowed to optimize the energy consumption of the Object due to application of control system based on fuzzy algorithms with automatic modification of process control system. The main energy-intensive parameters analyzed during the development of the fuzzy control system were: greenhouse interior temperature (especially at the soil level); greenhouse illumination; greenhouse interior soil and air humidity; external perturbing factors (environmental impact). The equipment operation control system proposed by the consultants will improve the efficiency of the energy center. This will be especially noticeable in the autumn–winter period due to the reduction of uneven operation of gas reciprocating units.

7 Conclusions

Technological integration of the shared data environment of all participants of the full cycle of the construction project and the information model created on this basis will significantly reduce the period of design and construction work, provide virtualization of workplaces using various BIM technology information systems at the developers' choice and allow remote access to specific workplaces throughout the design, construction, and operation cycle of the Object.

Each year, the construction industry is experiencing urgent need for the specialists with real experience and understanding of the principles of working with digital information model in a shared data environment. This refers not only to designers or BIM managers, but to all participants who have access to the shared data environment at all stages of the construction project life cycle. In the very near future, the availability of such specialists may become critical for every organization engaged in construction and investment activities.

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Methodology of Coding Building Information Model Elements at the Stages of the Life Cycle

Leonid Shilov and Liubov Shilova

Abstract The article discusses a database that provides storage of building information model at various stages of the life cycle. The assumption about the possibility of coding all elements of the building information model is made. The analysis of the research works in the area under consideration made it possible to identify the prospect of using the coding principles embedded in the KKS (Kraftwerk Kennzeichen System) coding system. This coding system has a hierarchical structure and divides the object into process-related systems. An assumption is made about the possibility of considering the building not from the position of the location-identification aspect, but from the process-related position.

The article presents a methodology of coding the elements of the information model of a construction object at the stages of the life cycle based on the provisions of the coding system for power plants (KKS). Using the presented approach, an example of coding a concrete element and its properties is given, considering changes in its properties. The conclusion about the possibility of expanding the use of KKS coding systems in information modeling of construction objects to ensure end-to-end coding of elements is made. For the subsequent management of the construction object and assessment of changes in the state of the object over time, analytical processing of the information presented in the database is possible.

Keywords BIM · KKS · Data base modelling · Life cycle management

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1 Introduction

The concept of building information modeling technology is based on information about a construction object, i.e. data and their structure. Thus, it is advisable to consider information modeling from the standpoint of the accumulation, transformation and analysis of information (data).

Currently, a significant number of publications are devoted to the development of these technologies confirmed by statistics collected in the Scopus database. In the period from 2011 to 2021, the specified database displays more than 17 thousand publications for the keyword BIM. At the same time, research in this direction, as a rule, is associated with the application of programming languages and various approaches to the integration of information modeling into the life cycle of capital construction objects [1–19].

The article presents a methodology for coding elements of the information model of a construction object at the stages of the life cycle, based on the provisions of the coding system for power plants (KKS).

2 Methods

2.1 Using Databases in Building Information Modeling

Figure 1 shows a structural diagram of a database developed by the authors [20], which allows storing, accumulating and systematizing information about the geometric characteristics of an object and their physical properties at various stages

Fig. 1 Structural diagram of the database that provides support for the information model of a construction object at the stages of the life cycle

id	stage_number	object_name	object_number	part_name	part_number	date	link_to_source
3	0	concrete	1	block	1	2019-01-01	(Null)
3	1	concrete	1	block	1	2019-08-10	(Null)

Fig. 2 An example of populating the objects_data table

of the life cycle. Analytical processing of the information presented in the database makes it possible to assess changes in the state of an object over time.

At the same time, data on the geometric characteristics of the information model, corresponding to the design and working documentation, and data on 3D scanning, obtained as a result of surveying the states of the object, it is proposed to bring (convert) into the "point cloud" format (x, y, z) with a given "thinness" (distances between points in space). The overlapping of the design information model and the subsequent states of the object is carried out by binding to geodetic reference points (information about them is in the «**service_data**» table (Fig. 1). At the same time, the authors propose elements of building structures in different states of the life cycle of the construction site identified by two columns «id» and «stage_number». The main table for linking all data is the «**objects_data**» table, which has links to tables of two types:

1 - tables containing information about the geometric characteristics of an object at various stages of life cycle (3D-geometry) (geometry_stage_ **number**) (Where number is equal to life cycle stage number).
2 - tables of properties of materials, products, etc. at different stages of life cycle. These tables are not typical, and their composition differs from each other. A set of data properties (characteristics of materials) can be taken in accordance with regulatory documents.

An example of a filled table «**objects_data**» which contains information about all structural elements at different stages of the life cycle, with each element being a separate object, is presented in Fig. 2.

Here the objects_data table contains information about monolithic reinforced concrete with id = 3 at two different stages of the life cycle stage_number = 0 and stage_number = 1. This element consists of 1 concrete block (part_name = block, and part_number = 1). The date column contains information about the binding of the life cycle stage to time, thus, 2019-01-01 is stage_number = 0, the date of release of design documentation, and 2019-08-10 is stage_number = 1, the date of laser scanning, at the stage of creating executive documentation. At the same time, it is possible to add links to estimate documentation to this structural element in the **link_to_ source** column. For example, for the first state, you can add the project cost of the object and for the second - a link to the actual capital investment, which will ensure the transition to 5D BIM.

2.2 Object Identification Systems in the Field of Power Supply

Power plant identification system (Kraftwerk Kennzeichen System - KKS) [21] is an identification system for uniform and systematic identification of objects, structures and equipment in the field of power supply and heat supply, which can be applied to all energy sources. This coding system was developed in the early 1970s by VGB PowerTech, and already implemented in 1976 by the operator of the power plant. Since the publication of the first VGB KKS manual in 1978, it has been used by power plant builders and power plant operators to clearly identify all plant components. The KKS is the basis for the digitization of processes, which has become widespread and was last updated in 2018.

The main provisions of KKS system are:

- Hierarchically structured format of code with 4 breakdown levels.
- Separate identification methods depend on discipline specific rules (aspects):
  - process-related identification;
  - point of installation identification;
  - location identification.

According to KKS coding capital construction objects are not divided into elements, but are coded with three letter designations in location identification aspect, like the building as a whole (Fig. 3).

At each object, at the design stage, a "coding agreement" is created in which a complete list of codes and their descriptions is presented. The format of writing codes depends on the aspect of coding. For example, the code format for process related identification is shown in the table in Fig. 4.

In this case, the coding uses the letters of the English alphabet, except for I and O (marked as—"A" in Fig. 4) and Arabic numerals (Numerical character) (marked as—"N" in Fig. 4).

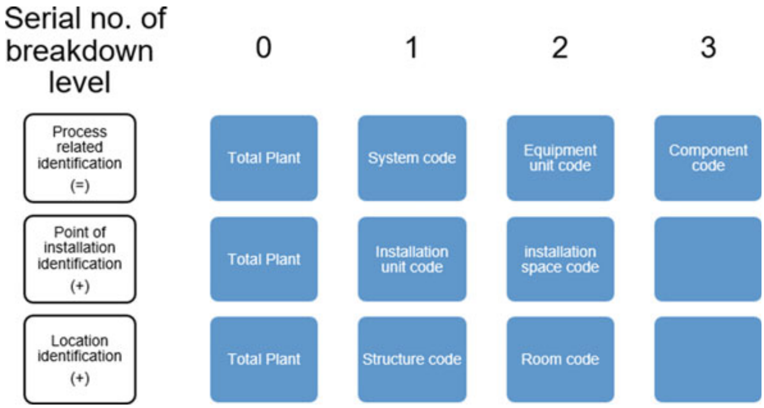

Fig. 3 Breakdown levels of KKS identification

Serial no. of breakdown level	0	1						2						3			
Designation of data character	G	F_0	F_1	F_2	F_3	F_N		A_1	A_2	A_N			(A_3)	B_1	B_2	B_N	
Type of data character	A\N	N	A	A	A	N	N	A	A	N	N	N	(A)	A	A	N	N

Fig. 4 Format of breakdown levels [21]

At the same time, in the KKS approach - buildings, rooms and premises are usually encoded in the aspect of "location identification". The KKS coding system does not allow tracking changes in the state of systems; instead, it is possible to transfer the system from one location to another through the aspect of location identification. With the obligatory introduction of BIM, the approaches of this coding should be transferred to the coding of the information model in order to ensure a unified and end-to-end marking of the MI elements.

3 Results

Marking of elements located in the database (Fig. 2) the columns object_name, object_number, part_name, part_number complicate navigation through the information model and contain only two levels of the hierarchy. Also There is a problem with the coding of all possible elements and their unification. Currently, there are several systems for coding the elements of building objects and systems. They are usually based on a process-related approach, i.e. dividing the object model into parts, according to the functional attribute (as an example, the already considered KKS coding system) Based on the KKS coding approaches, the authors propose to code the building in a process related identification system.

In this case, at the first level: three-letter designation, not only the object is marked, but also its floor-by-floor breakdown (column code F_N).

Let's make the coding of the elements shown in Fig. 2 by the KKS coding system. Let's omit the encoding of letters G and F_0, because as a rule, at this level, there is a division into separate buildings, sections of power plants (which is not in the example under consideration). The three-letter codes are taken from special collections included in the KKS coding documentation. In this example:

UAX—special structure (codes F_1, F_2, F_3) indicates the whole structure,

UAX01 is a special structure between $0 + 5$ m or first floor, then, for example, UAX02 is a special structure between $+ 5 + 10$ m or second floor.

Thus, at the first level, the building system is divided into subsystems—floors. At the second level, it is necessary to split the floor into structural elements. As a rule, there are three types of structures, these are RCS (reinforced concrete structures), MS (metal structures) and AS (architectural solutions). In this example, the database contains one concrete element, consisting of one "block". There is no level 2 coding for concrete in the KKS, so let's take the two-letter designation from the locked ones as an example. KR—RCS (reinforced concrete structures), LM—KM (metal structures) MA—AS (architectural solutions). Taking into account the fact that this block is located at the same level, UAX01, and the numbering of elements inside the subsystem starts from the beginning every time, we receive the marking of this concrete block UAX01 KR001, if necessary, the reinforcement and the concrete itself of this element can be encoded into level 3.

Since level 2 has an optional letter A_3, it is logical to use it to divide the elements of the KR group into classes: walls—letter A, floors—letter B, etc. Thus, a reinforced concrete wall with serial number 001 located in a special structure building between 0 + 5 m (or first floor) can be described with the following code: UAX01 KR001A.

The decoding of the code elements is shown in Fig. 5, and Fig. 6 shows the location of the coding letters of this element in the KKS Format of breakdown levels system.

Thus, not only is it easier to write information about an item into the database, but also the process of unloading the necessary items from the database and navigating through it. In this case, the objects_data table in the database will look like this:

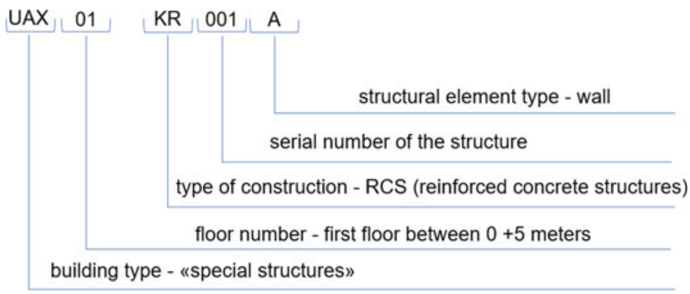

Fig. 5 An example of describing the code of an information model element

0	1						2					
G	F_0	F_1	F_2	F_3	F_N		A_1	A_2	A_N			(A_3)
A\N	N	A	A	A	N	N	A	A	N	N	N	(A)
		U	A	X	0	1	K	R	0	0	1	A

Fig. 6 The placement of coding letters of the element in the KKS system [21]

id	stage_number	object_code	date	link_to_source
3	0	UAX01 KR001A	2019-01-01	(Null)
3	1	UAX01 KR001A	2019-08-10	(Null)

Fig. 7 Filled the object_data table using the KKS coding system

id	object_code	discription
3	UAX01 KR001A	Concrete wall

Fig. 8 Filling the table coding agreement

This table contains the same item in its two states and thus it is possible to trace the change in the state of an element of a capital construction object at different stages of its life cycle, which in turn develops the KKS ideology to a new level, allowing not only to change the position of an element in the space, but also to change the properties and geometry of the object. Thus, the columns of the table object_name, object_number, part_name, part_number (Fig. 2) are converted into one column object_code (Fig. 8). Initially, the elements in the database were identified through the columns id and stage_number. However, the uniqueness of the id corresponds to the uniqueness of the object_code. To optimize the table, you can exclude the object_code column from it, while creating a coding_agreement table (a table containing information from the "Coding Agreement").

id	stage_number	date	link_to_source
3	0	2019-01-01	(Null)
3	1	2019-08-10	(Null)

Fig. 9 Updated table object_data

Then the objects_data table in the database will look like this:

With the help of SQL queries to the database, filtering becomes easier when you can select the entire building (system) UAX, the subsystem of a particular floor UAX01, etc. and then get geometric characteristics and properties from related tables.

The developed database allows collecting information on the elements of a construction object (their geometry and properties) at various stages of the life cycle of elements, and coding using the KKS system allows you to designate structural elements in a machine-readable sequence, which opens scope for building automated systems and analyzing the behavior of building structures. which meets the modern demands of the industry in the construction of systems at all stages of the object's life cycle.

4 Conclusions

The studies carried out allow us to draw the following conclusions:

1. to build information systems based on information models of objects, it is necessary to coding all elements, which will be constant at all stages of the life cycle.
2. for coding building objects, it is worth using already existing systems (as an example of KKS) with some revision (rules for the distribution of objects on floors (elevations) that is required in accordance with the approaches to creating an informational model. This will allow coding the elements of an object at the design stage. In this case, the building must be considered not from the point of view of location, but from the aspect of process related identification.
3. for the development of appropriate tools for analytics and management of construction objects, it is necessary to create a database that allows storing several states of one object in one space (for example, as the approach of the authors).

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Information Modeling Technique for Coliving Planning Solutions

Olga Shirokova, Alena Pavlyuk, and Anton Koshelev

Abstract The paper discusses a methodology for developing an information model for the synthesis of planning decisions in the construction of coliving. Following the results of the Eastern Economic Forum, special attention is paid to the development of the Far East. Based on the analysis, a shortage of housing in this region has been identified. Coliving, as a modern form of an operational solution to the housing issue, according to the authors, is the most optimal way to solve the problem. Typological solutions have been formulated for the settlement of specialists of various social statuses, which provide various levels of financial support and comfort. Grasshopper, Rhino 3d and Revit were selected for parametric design due to deep mutual integration of tools. The stages of developing an algorithm for the optimal layout of a building using parametric design tools in conjunction with a building information model are highlighted. This linking allows you to automatically make changes to BIM based on the analysis of new input data and automatically generate updated documentation.

Keywords Mathematical model · Coliving · Planning solution · Public space design · The infrastructure of residential and public spaces · The new type of housing

1 Introduction

Today, many projects for the development of Russian regions are being considered. In particular, according to the results of the Eastern Economic Forum, the President of the Russian Federation [1] instructed the government to deal with the development of cities in the Far East throughout 2022. One of the main directions of regional policy is the creation of agglomerations and macro regions [2]. Within the framework of

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the projects under consideration, it is planned to attract large-scale new specialists to these regions [3]. Therefore, the question of motivation for the Russians to move to the Far East becomes especially important. Accordingly, there is a need to provide housing. First of all, on a temporary basis with the provision of comfortable living conditions [4].

The traditional option of renting housing in the private sector has a number of disadvantages: dispersal of housing throughout the city and high prices. Other traditional types of temporary accommodation are hostels and hostels. The disadvantages in these cases are the lack of comfortable living conditions, especially for specialists with a family and the impossibility of delegating household tasks. A more modern option to avoid the listed disadvantages is coliving.

Colivings are a new type of collective living and represent a comfortable modern living place. An important distinguishing feature of coliving is the common interests of the residents [5]. As they work in the same company, their area of interest and occupation will be similar.

From an architectural point of view, its structure provides for zoning into several functional zones: residential, public and business zones [6]. The living area is private for each resident. At the same time, depending on the price category, the units have a different set of functions. For example, the minimum set of units would include place for work and sleep. Shared areas are located in the public area - such as the kitchen, dining room, coworking space, social space.

The aim of the study is to develop a methodology for constructing an information model for planning decisions of coliving.

2 Analysis of the Current Situation in the Regions

Based on statistics [7], more than 6 million requests for apartments for rent are realized every month in Russia. Figure 1 shows a map of the intensity of requests by region. Statistics obtained using analytics Wordstat.yandex.ru.

Today, on average, the demand for housing in the Chukotka Autonomous Okrug, Magadan Region, Kamchatka Territory, Khabarovsk Territory, Sakhalin Region, Primorsky Territory, and the Jewish Autonomous Region exceeds the average demand for housing in Russia by 41.6%. This allows us to conclude that housing in this region is especially in demand.

At the same time, the demand for rental apartments is much higher than the supply for the same period (Table 1).

In accordance with this, even at the moment there is a need for the construction of additional housing. Colivings will solve the problem of temporary residence, providing residents with the required level of comfort.

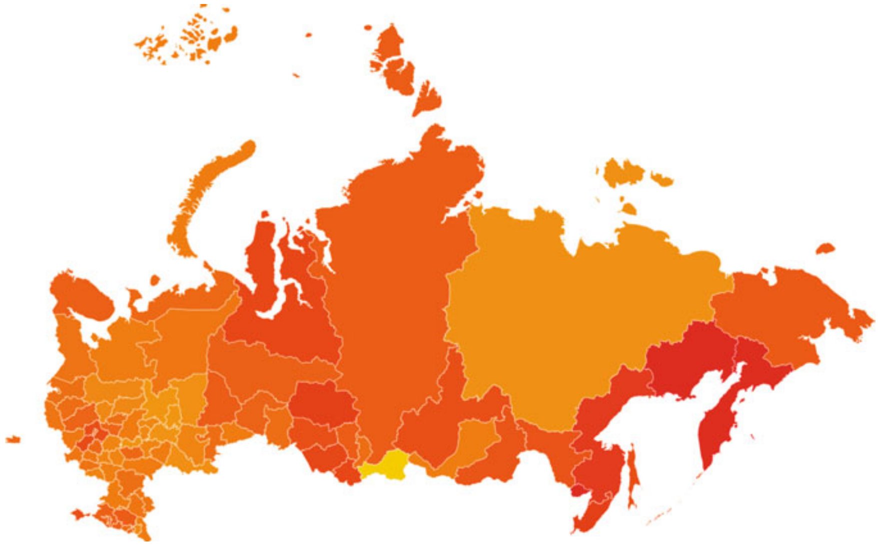

Fig. 1 Search statistics for the phrase "rent an apartment" in the regions of Russia

Table 1 Ratio between supply and demand for rental housing by region

Federal subjects of the Russian Federation	Number of requests "to rent an apartment	Number of requests "rent an apartment"	Ratio between supply and demand
Chukotka Autonomous Okrug	844	52	16,2
Magadan Region	6,115	203	30,1
Kamchatka Territory	13,487	509	26,5
Khabarovsk Territory	49,305	2,176	22,7
Sakhalin Region	15,017	881	17,0
Primorsky Territory	63,592	2,315	27,5
the Jewish Autonomous Regionthe Jewish Autonomous Region	5,846	262	22,3

3 Formation Typology of Residential Units

At the preliminary stage of development, it is necessary to identify the main groups of specialists who will be involved and their social status [8, 9].

In the model under consideration, we distinguish the following groups of employees involved:

– Seasonal employees;

Fig. 2 Residential unit typology

– For fixed-term contracts up to 3 years;
– Long-term contracts from 3 years.

Thus, if employees are visiting for a short period, for example, for one season, they will not be interested in moving the entire family from their original place of residence. If we are talking about longer contracts, then a larger module will be allocated to them, in which it is possible to accommodate both a married couple and a family with a child.

In accordance with this, six typical planning solutions can be distinguished, depending on the priorities of people and their financial capabilities.

The company can give a certain sum for accommodation on a monthly basis, while residents have a choice: rooms with the best amenities or a more economical option and the ability to save money.

For example, the most economical units include the minimum set of functions for life: in the private area there is only a sleeping and working place, as well as a wardrobe. In this case, the rest of the necessary facilities are located in the public area (such as a bathroom, a kitchen, a place for communication, coworking) (Fig. 2, unit 1). In units with the best conditions, a kitchen and a bathroom are added (Fig. 2, unit 4–6). In such cases, social spaces and coworking spaces are also in public area.

These planning solutions are developed taking into account different marital status (Fig. 2, unit 5). In addition, there are special units for families with children (Fig. 2, unit 6).

In addition to residential blocks, depending on the number of residents, it is necessary to calculate the area of public spaces. They include bathrooms, kitchens, dining rooms, social spaces, laundries, and coworking spaces. Optionally, the coliving can provide a cafe, play rooms for children [10, 11], a sports hall, a swimming pool, a lounge zone, a library, a mini-cinema and more. To save space, it is possible to use the roof as a recreational area [12].

All blocks must be provided with the minimum required public space. For this, the parametric method described below is used.

The most effective approach in the formation of planning decisions will be the use of information modeling, which has proven itself at various stages of the life cycle [13–15].

4 Parametric Problem Solution

Parametric design tools in conjunction with a building information model were used to facilitate the design process and increase the customization possibilities of modular coliving [16]. For this purpose, Grasshopper, Rhino 3d and Revit were chosen due to the deep mutual integration of the tools.

The algorithm for calculating the optimum building layout is divided into several steps.

The first step in the calculation uses the number of employees and their family composition as input parameters (Fig. 3). The calculation determines the number of required accommodation modules of each type.

Then, based on the data received, following “SP 339.1325800.2020. Rule book. Dormitories. Design Rules.”, the area and number of public areas, shared kitchens, bathrooms, laundry rooms, storage rooms, staircase and lift units, and the administrative block [17] of the coliving are calculated.

The resulting rooms are grouped into floors using spatial syntax and evolutionary optimisation algorithms along a common corridor.

At this stage of the calculation, new constraints are introduced: the permitted construction area, the maximum building height, and the orientation of the building.

The 3D model is generated based on the building’s informational structure and the functional relationships between its constituent parts.

A complex BIM solution with deep integration of the parametric tool is used to track the life cycle of the coliving building. Furthermore, this bundle makes it possible to automatically introduce changes into BIM based on the analysis of new input data and generate updated documentation.

The automated approach to modular coliving building design [18] allows for shorter architectural design times, taking into account the demographic composition of the employees. At the same time, the given approach facilitates the refurbishment of existing coliving houses to better accommodate new shifts of employees [19, 20].

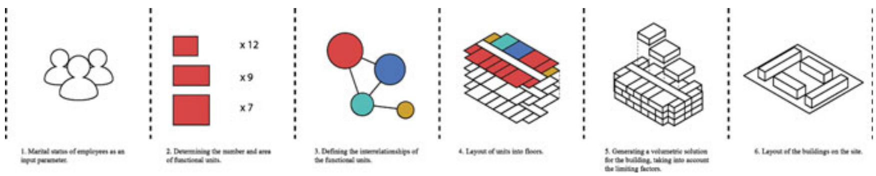

Fig. 3 Sequence of actions to form coliving

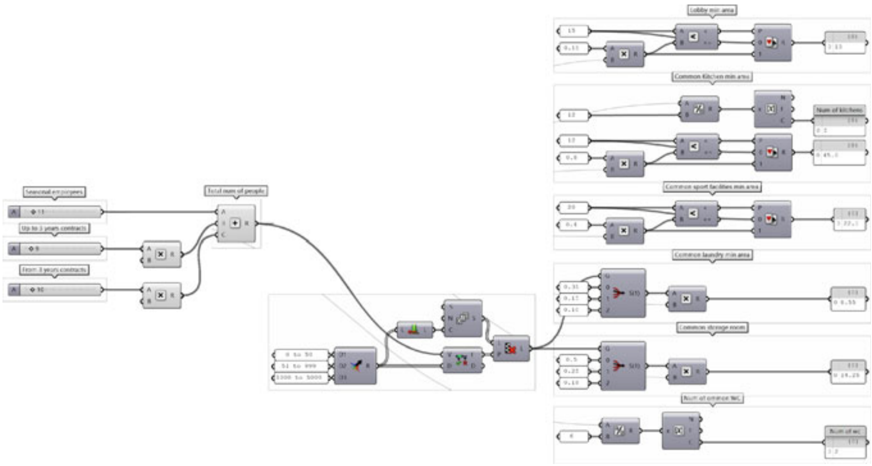

Fig. 4 Parametric block diagram

5 Conclusion

The work has developed a typology of residential units intended for attracted employees of various social statuses. The layouts of residential units were presented in Fig. 2.

The presented layouts were the basic modules for parametric design in combination with a building information model. For parametric design, it is advisable to use Grasshopper, Rhino 3d and Revit due to the deep mutual integration of tools.

The design algorithm is divided into stages. Figure 4 shows a parametric block diagram of the first design stage.

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Lifecycle Management of Industrial Facilities Using Risk Assessment with the Method of Hierarchy Analysis

M. N. Shutova, A. I. Shagina, A. A. Plahutina, V. A. Kuzheleva, and S. I. Evtushenko

Abstract An actual problem of digitalization of the construction industry in Russia is the creation and operation of an information model of buildings that takes into account the main stages of the life cycle of buildings: planning (terms of reference, preliminary design), design (project, analysis, working documentation), construction (production, logistics and installation), operation (operation, repair), and demolition (dismantling).

At each stage of the life cycle, certain risks arise, which form different combinations and cause critical consequences for the construction project.

The article presents a risk management model using the hierarchy analysis method. For this purpose, the following hierarchical structure has been adopted: as goals – assessment of the degree of influence of a particular risk on the cost, time of construction and durability; as criteria—risk groups distributed depending on the manifestation at a certain life stage, as alternatives - types of risks expressed in specific errors.

The calculation was carried out for the construction project of an industrial building, which was monitored from the planning stage. All realized risks and the degree of their impact on the main objectives of the model are taken into account. The most dangerous types of risks that have a greater impact on the main factors of construction are identified.

Keywords Information model of buildings · Life cycle of buildings · Risk management model · Hierarchy analysis method

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1 Introduction

An important and integral part of the construction industry is the study of risk factors in construction. The problem of risks and their assessment, thanks to recent large-scale studies, is becoming increasingly important at the international level. The consequences of delayed construction are not limited to the construction industry, but affect the overall economy of the country. It is necessary to learn how to manage the risks associated with international construction projects.

This problem has many approaches to the study of factors affecting the timing of the project. Construction delays are considered one of the most frequent problems in the construction industry. Delays negatively affect the success of the project in terms of time, cost, quality and safety.

Unforeseen cost increases, quality decreases in construction projects are caused by the owner, contractor, environment, etc. To meet the construction deadline due to the complex nature of construction projects, the schedule and cost must be flexible enough. It is necessary to take into account changes in the project eliminating negative impact on the total cost and duration.

Risk management is a systematic process of identifying, analyzing and responding to project risks, which includes maximizing the probability and consequences of positive attributes and minimizing the probability and consequences of attributes unfavorable to the project objectives [1]. In the process of risk management, decisions are made on the application of risk reduction measures on the base of considerations of economic efficiency or other criteria of social significance.

There are two options for unforeseen circumstances: necessary changes in the design process, for example, inaccuracy in determining the scope of work; changes in the construction process.

Research shows that a feature of public construction projects around the world is cost overruns [2]. Financial problems related to projects, accidents on the construction site and incorrect concepts are the most significant risks affecting most construction projects [3].

Many construction projects do not have time to meet the originally planned completion dates also due to weather conditions. There are studies on the possible inclusion of the influence of weather in the planning of the facility. The use of climatological data obtained from weather observations during planning can lead to a reduction in the duration of the project by an average of 16% with a proportional reduction in indirect and overhead costs [4].

Failure to meet construction deadlines may occur due to errors in planning and management. There are studies that show factors that negatively affecting coordination, and therefore higher productivity. Due to insufficient coordination, integration, communication between different parts of the project, and the performers of the work [5].

When taking into account risk factors, it is necessary to allocate a certain amount of time to the estimated performance of work, the use of complexity coefficients and non-fulfillment of agreements by subcontractors, as well as the measures that will take effect when these cases occur [6].

Also, the speed of construction is influenced by the social factor. Researchers have described a paradigm of relations when owners and contractors arrange flexible and solidary relations with each other, transactions will be satisfactory [7]. Also, risk management is influenced by the agreements that have arisen between the client and the contractor for the implementation of the project [8]. The agreements include: the method of project implementation, the form of payment and cooperation agreements.

Time, cost and quality are areas of productivity recognized by most researchers [9]. But also some research results show that project integration, communication, security, risks, human resource management, finance and costs have a direct impact, whereas scale and time management has an indirect impact on productivity [10].

The integration of the risk management system in construction should be focused on the progress of the project and permeates all areas, functions and processes. Engineering project management includes various contents (for example, time, cost, quality, resources, procurement, safety, environment, agreements between stakeholders) [11]. There are studies of the main components of the innovation process, such as the main drivers of innovation, barriers and obstacles to innovation, factors that stimulate innovation, methods of innovation and the benefits of innovation at both the project and company levels [12].

Today, there is concern about the relevance of more traditional approaches to project management to solve problems that are becoming more complex and limited and involve a large number of stakeholders [13].

Hierarchical structures are conceptually superimposed on space and make it easy to perform complex tasks in a very large context [14]. The hierarchical process model seems to be easily portable to other multi-organizational contexts, represents the functions necessary for the specified system to be effective in its environment, and gives an idea of processes and opportunities that require intervention—either to increase productivity (eliminate weaknesses) or to improve understanding (eliminate uncertainty) [15].

2 Hierarchy Analysis Methods of Risk-Management of Construction of Industrial Buildings And Structures

The hierarchy analysis method (HAM) makes it possible to structure a complex decision-making problem in a clear and rational way in the form of a hierarchy, compare and quantify alternative solutions [16]. Not all researchers consider this method optimal due to the high proportion of subjectivity in decision-making [17, 18], however, at the moment T. Saati's method remains one of the most effective in multi-criteria selection.

The use of HAM assumes the presence of a matrix of paired comparisons

$$A = (a_{ij})_{n \times n} = \begin{pmatrix} a_{11} \ldots a_{1n} \\ \ldots\ldots\ldots \\ a_{n1} \ldots a_{nn} \end{pmatrix}; \quad (1)$$

According to HAM, based on expert assessments, as a result of performing pairwise comparisons of objects, that part of the matrix of paired comparisons that is located above the main diagonal is formed [19].

Next, the maximum eigenvalue λ_{max} of the matrix of paired comparisons A is found, and then a homogeneous system of linear equations $(A - \lambda_{max})w = 0$ with respect to the vector w is solved, equivalent to the system $A_w = \lambda_{max} w$.

It is possible to use a simplified version of HAM. The main elements of the matrix of paired comparisons (1) can be found based on the following properties:

The matrix is inversely symmetric, $a_{ij} = 1/a_{ji}$ for all numbers;

The matrix A is compatible, i.e. the equality $a_{ij} = a_{ik}a_{kj}$ holds for all numbers i, j, k = 1, 2,…, n.

Matrix A, based on the elements of the first row, will satisfy the compatibility property:

$$a_{ik}a_{kj} = \frac{a_{1k}a_{1j}}{a_{1i}a_{1k}} = \frac{a_{1j}}{a_{1i}} = a_{ij}.$$

The main problem of risk management is not only to take into account all possible risks (there may be hundreds of them), but also to choose the most priority ones.

3 Result of Approbation of Methodology of Determining of Potential Risks of Construction of Industrial Buildings

In this article, the selection of the most important risk groups affecting the durability of buildings and structures, its cost and construction time was considered for the operated industrial facilities: the LNG plant in Magnitogorsk.

The LNG plant in Magnitogorsk (Fig. 1, 2) includes the following buildings and structures: a partial liquefaction unit; the building of the turboexpander unit; boil-off compressor building; drying unit; cleaning unit; block installation for fire heating of natural gas; nitrogen curtain supply unit; site of the SG inlet unit; SG outlet site; UIRG building; LNG storage and delivery site.

During the design and construction of these facilities, some risks were realized, which led to significant delays in deadlines and changes in the cost of projects.

For example, during the construction of the starch workshop, great difficulties arose with the search for experienced performers. This is due to the fact that in Russia the construction of food industry facilities is not developed sufficiently, whereas standard projects of previous years are functionally outdated.

During the construction of the LNG plant, difficulties arose at the stage of equipment installation. Since the plant was built during a difficult period of transition to

Fig. 1 NOVATEK LNG plant in Magnitogorsk

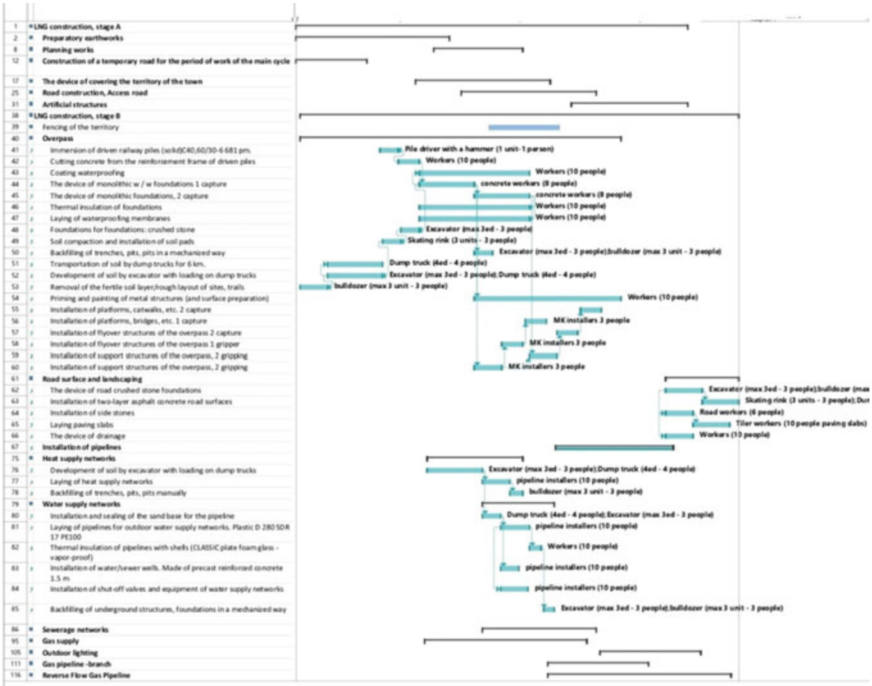

Fig. 2 Calendar schedule for the construction of NOVATEK LNG plant in Magnitogorsk

import substitution, all units and equipment of the plant had to be made at Russian enterprises. For domestic producers, this has become a significant challenge, not realized on the first attempt [20].

It should also be taken into account at what stage of the life cycle the risks arose. There are the following main stages of the life cycle of buildings: planning (terms of reference, preliminary design), design (project, analysis, working documentation), construction (production, logistics and installation), operation (operation, repair), demolition (dismantling).

The main risks in the construction of these production facilities, divided by the time of their manifestation at different stages of the life of the projects are presented in Table 1.

The indicated risks were collected by groups and indicated in the Fig. 3.

The scale of relative importance for the types of criteria: 0—options are not comparable, 1—equal importance, 3- moderate superiority of one over the other, 5—substantial or strong superiority, 7—significant superiority, 9—very strong superiority, 2, 4, 6, 8—intermediate solutions between two adjacent judgments.

Table 1 Types of risks in the construction of LNG plant

N	Causes (risks)	Investigations at the stage of		
		Project	Building/building operation	The operation of the building
R1R	Pre-project stage			
R1.1	Error in engineering-geological surveys	Incorrect structural solutions of foundations	Cracks, rolls	Reconstruction
R1.2	Errors in engineering at the technical task stage	Errors in the design of engineering systems and technological equipment	The inability to “fit” technological equipment into a given structure	Changes in technical solutions
R2	Designing			
R2.1	Incorrect determination of the cost and timing of work	Errors in the estimate	Inability to complete the scope of work at	–
R3	Building			
R3.1	Manufacturing of equipment that does not fit in size	–	Alteration of equipment	–
R3.2	Low qualification and unreliability of the SMR performer	–	Mounting errors	Difficulty of operation
		–	Delayed execution	
		–	Impossibility of operation	
R4	The operation of the building			
R4.1	Lack of overhaul	–	–	Reconstruction
R4.2	Violation of protocols for working with LNG	–	–	Difficulty of operation

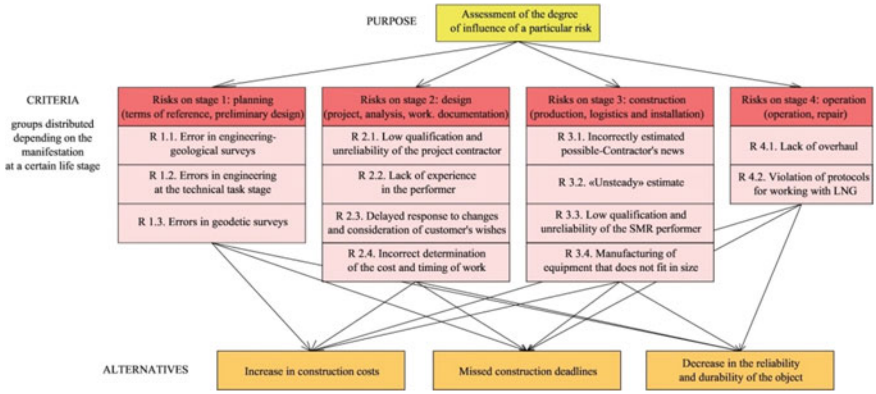

Fig. 3 Decomposition of a task into a hierarchy

Table 2 Matrix of paired comparisons for risk R 1.1 (Error in engineering-geological surveys)

№	A1	A2	A3	X	A
A1	1.00	3.00	0.25	1.10	0.14
A2	0.33	1.00	1.00	1.92	0.25
A3	4.00	1.00	1.00	4.62	0.60

For this, a matrix of paired comparisons of criteria is built for each of the types of risks. Alternatives are denoted as: A1—increase in construction costs, A2—missed construction deadlines, A3- decrease in the reliability and durability of the object.

An example of such a matrix for risk R 1.1 (Error in engineering-geological surveys) is presented in the Table. 2

4 Discussion of the Method of Risk Management of Building Construction, Using Hierarchy Analysis Methods

In a similar way (as in the Table 3), matrices are calculated for risk groups depending on the life cycle of objects (Table 4), as for local priorities of alternatives by criteria.

Table 3 Matrix of paired comparisons for risk groups depending on the life cycle of objects

	R 1.1	R 1.2	R 1.3	A	X
A1	0.14	0.32	0.42	0.27	0.28
A2	0.26	0.34	0.15	0.24	0.25
A3	0.60	0.34	0.43	0.44	0.47

Table 4 Matrix of global priorities of the alternatives in relation to the purpose

	R 1	R 2	R 3	R4	A	X
A1	0.28	0.43	0.32	0.37	0.35	0.36
A2	0.25	0.34	0.45	0.15	0.28	0.29
A3	0.47	0.23	0.23	0.48	0.33	0.35

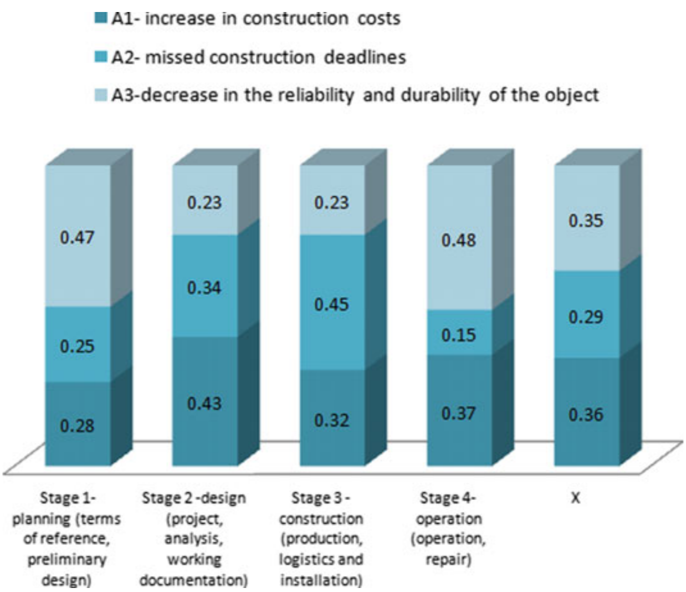

Fig. 4 Priority risk groups at different stages of a building's life

The final action is the calculation of the global priorities of the alternatives in relation to the purpose (Table 4).

The Fig. 4 shows an illustration of the calculation of the global priorities of alternatives in relation to the goal, which clearly shows at which stage of the building life cycle which risk groups are priority.

5 Conclusion

The study is based on a risk management model using the hierarchy analysis method. In a hierarchical structure, the objectives are to assess the degree of influence of a particular risk; as criteria—groups of risks, distributed depending on the manifestation at a certain stage of life, as alternatives—types of risks for the cost, duration of construction and durability of the construction object.

The highest priority alternative is to increase in construction costs (weight fraction 36%), then decrease in the reliability and durability of the object (weight fraction 35%) and missed construction deadlines (29%). The calculations were carried out for an industrial building and a resource processing plant based on the recorded real manifestations of risks at all stages of the building's life cycle.

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Cost Management in Construction Based on the Automated Identification of Construction Operations and Structural Elements of Information Models

Ilya Tyurin

Abstract The present paper deals with the existing methods for determining the estimated cost of construction and methods of cost management at the early stages of investment and construction projects realization. There was developed the methodology for generation of parametric representation of construction works and structural elements of buildings' information models followed by cost model formation. The developed methodology is based on the identification of construction works and structural elements of information models of buildings using databases of state estimated standards. The results of estimating project costs obtained by the tradition methods using the proposed methodology was considered. There was coined the notion of "project unit" and the approaches to project works implementation with its help were proposed. There were outlined the ways of proposed method development aimed at automation of project works. The approaches to estimated project cost management were introduced for the early stage of investment and construction project realization.

Keywords Information model · Computer-aided design systems · Methods of automated identification of construction works and structural elements · Cost estimation model · BIM

1 Introduction

The existing variety of approaches to designing infrastructure of computer-aided design systems (CAD), which is aimed at realization of the complex systems' emergence principle, does not typically consider the inclusion of formally new independent subsystems [1].

Design automation lightens and accelerates the work of engineers at a great extent. Without performing principal change to the design methods, it serves as a weak tool of design system development in the whole. This could be clearly demonstrated by the

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technologies of information modelling (TIM), the powerful tool with the potential exceeding well-established statutory approaches to design of capital construction projects by several times [2–4]. The use of TIM will make it possible to manage data throughout the life cycle of a construction object [5–8]. The similar situation is observed in the sphere of construction cost estimate, with the ubiquitous transition to TIM in design, whereas the fundamental approach to cost estimation model of construction facility remains unchanged. In order to form cost estimation model, the elements of the information model (IM), being the initial data, the software (SW) developers introduced into practice the modules that are supplementary to the main software of the IM-development, so-called “re-composers” [9–13]. The main purpose of re-composers is retrieving the data from the IM of a construction facility in the form the elements’ list followed by estimate information assignment taken from the statutory estimate data bases. This almost fully reproduces the well-established method of implementing estimate documentation whereas the design documentation is taken as initial data.

For the facilities financed from the budgets of the Russian Federation, determining the estimate cost of construction at the early stage of investment-construction projects realization (ICPR) is defined in the form of two approaches at the legislative level, such as the use of scaled-up regulatory collection of construction cost, and the use of cost estimate documentation of analogous facilities [14]. The situation when construction project owners have clear understanding of a construction facility’s future in the form of the work specification on development of design documentation is assumed as ICPR; meanwhile the design development itself was not conducted. Proceeding that price normal systems are developed on the framework of analogous facilities; it could be concluded that application of the mentioned approaches results in determining cost estimate on the base of analogous facilities. For investigating the proposed approach, 23 capital construction facilities with the similar parameters were selected (schools with 850 students [15]); the comparative analysis of construction cost estimate was conducted. In the course of the analysis, two facilities with maximum and minimum construction cost were excluded; then the average, maximum and minimum construction costs were estimated. The deviations from the mean value of construction cost estimate accounted for +42% and –35%, respectively. Also, there was conducted the search of tools for managing construction costs on ICPR that had proven the uniqueness of selecting the analogous facility with the most relevant cost as a management tool. As the result, it could be concluded that the actual method of determining cost estimate of construction cost on ICPR gives a significant price dispersion whereas the tools of cost management are not effective.

2 Methods

The investigation presented in the given paper is the continuation the research series dedicated to automation of construction works and structural members of the information models (IM). Earlier, the methods of automated identification of construction works and structural elements and the mathematical estimate model of construction facilities had been developed, whereas the existing approaches to computing construction cost estimate have been studied [16–18].

The present study is devoted to the development of initial data formation method based on generating parametric representation of the information system members on the ICPR.

The purpose of the considered method is to broaden the options for managing the cost on investment construction projects at the early stages of their realization. To achieve the set goal, there was conducted the analysis of design documentation of construction facilities (23 schools) considered at the earlier stage. As the results of design documentation study, the structure of the construction facility has been determined. It is presented in the form of two subsystems (Fig. 1):

The area of subsystems' intercrossing presupposes the exclusion of the technological core from environment by building structures. Then, decomposition of building structures' subsystem was done under the enlarged structural concepts, i.e. structures of frame, façade, internal/external envelope structures, floors/coverings; at the present stage of the research, the engineering systems were not taken into consideration. Decomposition of the subsystem "technological core" was done according to the technological spaces divided into main and auxiliary ones.

Premises preset by technical design specification were attributed to the main technological spaces, while auxiliary ones are the premises required for technology functioning and compliance with building codes and practices (technical premises, evacuation routes, exit ways, etc.). Thus, there was determined the simplest repeating subsystem of a construction facility, being sort of a "project unit", which consists of the chain of technological spaces preset by the project facility objective (.tsn) and technological space of an evacuation route conditioned by the building codes (.br) (Fig. 2):

The following determinants were used for the description of the "project unit":

- m. (model)---belonging to the system;
- e. (environment)---belonging to environment;
- .bs (building structures)---belonging to building structures;
- .tc (technological core)---belonging to technological core;
- .ts (technical specification)---belonging to technological space preset by the technical specification on design works;

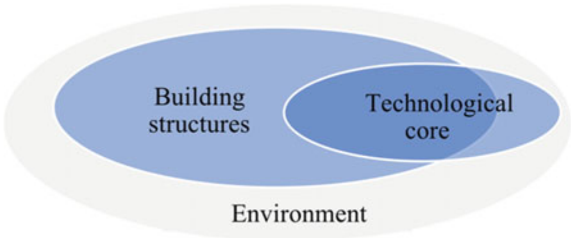

Fig. 1 The structure of a construction facility system

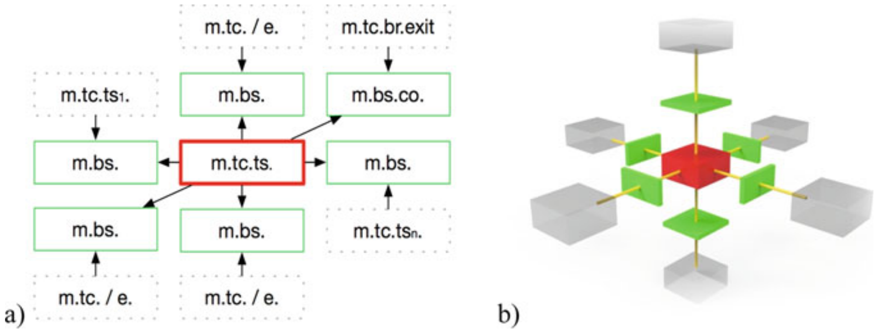

Fig. 2 «Project unit»: **a** structure diagram; **b** 3D-visualization

Fig. 3 «Project unit» in a generic form

- .br (building rules)---belonging to technological space that are essential for implementation of the technological process, in the system's elements marked.ts;
- .pr (protected)---the property of a building structure ensuring complete exclusion (protection) of technological space from the environment (e.);
- .co (coupled)---the property of a building structure ensuring the connection of the technological space with environment via a door (.dr) or a window (.wd).
- m. ….exit---the property of the system's element that presupposes the connection with environment via emergency escape;
- e.exit, e.ground, e.sky, e.air---the description of environment type bordering with the elements of the subsystem (design exit/entrance, soil, outdoor air from the covering/roof side, outdoor air from the façade side, respectively).

There are repeat system elements in the obtained "project unit", at their further aggregation the "project unit" takes the following generic form (Fig. 3):

Thus, building structures (m.bs.) are dependent on the type of the technological space (m.tc.) and the connection with environment directly (e.) or via a certain number of the system's elements ($(m.)_j$), under the condition $i \geq 6$. The condition $i \geq 6$ is determined from the perspective of technological space location in 3D-dimension, i.e. it is limited by 6 sides and the probability of the presence of one or more space types from each side. Also, there was assumed the probability of the absence of particular building structures (m.bs. = 0); in this scenario, the conditions of the impact on a building structure were summed up, for example, for linear objects.

3 Results

In the result of this, automation of identifying building structures' type was reduced to outlining the rules depending on interposition of technological spaces, while automation of positioning technological and auxiliary spaces (space and layout design) would be realized by means of posing the rules for formation of the facility's systems blocks outlined in the technical design specification.

In order to form the automated design rules, the derivation of determinant tree was implemented, whereas the rules were outlined for all possible links (Fig. 4):

The rules for choosing building structures in connection with e.ground, e.sky и e.air were designated for the structure of foundation, covering and façade, respectively. In a similar way, the rules for internal envelope structures were set for the connections .br-.br, .br-.ts и.ts-.ts. These structures were assumed as default structures but for.ts with the specific type of building structures, for example a brick partition for sanitary units, the priority of selection has been upscaled.

As initial data, there was used the specification of premises (technological space) with area parameters taken from the technical design specification; for determining auxiliary technological spaces, there were used the design standards for public buildings, sanitary norms for design of educational institutions, and fire regulations. The determinants of the initial data were set in a manual mode, for instance, for evacuation routes, the description in the form of «m.tc.bc.exit» was assigned (m. – belongs to the system/.ts – subsystem technological core/.bc – is an auxiliary technological space/.exit – the connection with external environment in the form of an emergence exit). Then, the rules of blocks placing relative to each other were formed, for example: «m.tc.ts.n12,e.exit,e.wd,m.tc.br.exit.co.n1–11» (m. – belongs to the system/tc. – subsystem technological core/.ts – is the main one/.n12 – counting number 12 in the technical design specification/«,» – the presence of the rules for elements bonding / e.exit – the connection with environment via an emergency exit/ e.wd – the connection with environment via a window/m.tc.br.exit.co.n1-11 – the connection with technological spaces of a system numbered from 1 to 11 via an emergency exit).

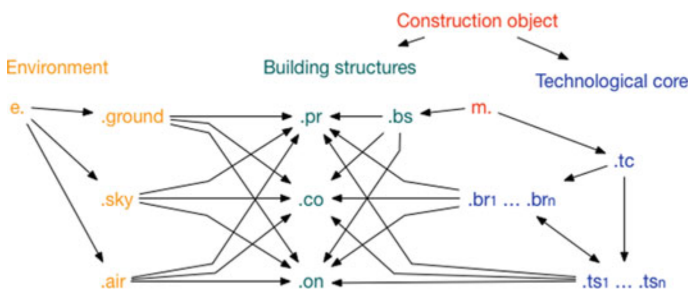

Fig. 4 Diagram of setting the rules for linking the elements of the description tree

Table 1 Accumulation of information with reference to the technological spaces

Space #	Name	Connections	Construction	Limits	…
1	Space 1	x_1	y_1	z_1	…
…	…	…	…	…	…
n	Space n	x_n	y_n	z_n	…

The following algorithm of method implementation was proposed: the specification of the premises (technological spaces) taken from the design technical specification is presented in the form of table (Table 1), while each technological space was allocated the properties of linking with adjacent spaces, determinants of envelope structures, and other constraints:

Then, chaining of interrelated technological spaces (premises grouping) is done in an automated mode under the principle of finding premises adjacent to the considered one (the main premises). Beginning with the limitation of the build-up area, the level of chains placement is oddly even (2, 4, 6, …). The given iterations emulate the architect's work of determining space planning solutions. The further work represents the computation of "construction planes", i.e. representing each technological space in the form of the cube inserted into building structures, whereas the system of a construction facility is presented in the form of interrelated technological spaces. It enables to eliminate duplicate (doubled up) volumes of building structures. By means of the computation of building structures' areas, the corresponding quotation from the costing standard database is allocated to each type of a building structure in an automated mode [19].

Thus, it allows for developing the cost estimate model of building structures of a facility at the ICPR and, as a sequence, obtaining the possibility of cost management for various types of building structures by means of assigning their type manually or in the automated mode.

Evaluation of the developed method was done on the construction facility "feldsher-midwife station" [20]. The estimated cost of building structures computed by means of the proposed method in an automated mode worked out 7% higher than the design estimated cost and 5% lower than the cost estimated under the analogous project. Further cost management iterations facilitated optimization the bottom-line cost by 11%.

The developed design method based on the "project units" represents an open system that enables to implement automation at all design stages while assigning the unlimited number of descriptions and rules.

4 Discussion

The developed method is a part of the research dedicated to automated identification of construction works and structural elements of buildings' information models.

The previous studies were aimed at developing methodology for correlation of information regarding the information models elements with pricing database, with further reinserting cost characteristics into the information model. The methodology described in the present paper enables to identify construction works and structural elements at early stages of investment and construction projects realization.

Complex application of the proposed methods allows simulating cost models for construction projects at the stage of implementing technical design brief. Factoring in the universal approach to information generation, the developed methodology has few development trends towards full automation of design works. The proposed developments trends encompass:

- structural analysis of building structures;
- thermotechnical calculation of building structures;
- laying out and selection of engineering networks' sections;
- automated elaboration of space and layout design;
- automated placement of engineering and technological equipment;
- etc.

5 Conclusions

The pre-requisite of the developed methodology described in the present papers is the lack of tools for cost management for investment and construction projects at the early stages of their realization. The existing methods enforced by the legislation enable to determine the estimated project cost only in the form of the final cost and do not give an idea about the constituent parts of this cost.

The result of methodology approval has shown that the model design aids, in particular in part of buildings' information modelling, enable to generate project cost management at the early stage of construction. Generated data represent cost estimate documentation with the detailing approximated to cost estimate computed at the design stage. This detailing allows for cost management of construction by means of enumerating of types of construction execution. For instance, it becomes possible to compare few variants of construction frame solution, such as: the skeleton frame made of in-situ reinforced concrete, prefabricated reinforced concrete or of metal members and to compare the project cost change as a function of the type of building materials for partitions, façade, etc.

Application of the present methodology would allow forming more detailed technical design brief whereas it makes possible to outline the types of buildings materials and structures. Drafting more detailed technical design brief causes the positive conflict between a construction project owner and a contractor that is expressed in the need for approval or rejection of the proposed solutions by a contractor. In this case, a designer acts as an expert operating the multitude of realized variants for specific types of structures that is more efficient than proposing one or two variants applied at the projects completed earlier.

The construction cost estimated by the proposed methodology is more accurate than the construction cost computed by the traditional method applying analogous projects. There appeared the possibility of cost management for construction projects at the early stage of design by means of enumeration of various project solutions non involving design works implementation. Thus, the proposed methodology enables to conduct the detailed estimate that do not require labor-consuming design works.

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SAFEFORM: A Prototype of Safety Knowledge Management for the Construction Companies

C. Vigneshkumar and Urmi Ravindra Salve

Abstract In recent years, construction organizations are showing interest in adopting new strategies of knowledge managing to enhance safety performance and productivity. The objective of this study was to design a safety knowledge management (SKM) prototype, SAFEFORM, to support construction companies in India to assess and review fall-related safety risks of formwork construction. This paper presented a five-step user-centered design approach to increase the use of SAFEFORM. SAFEFORM accommodates activities and processes of vertical plywood formwork used in construction projects. SAFEFORM will be tested and validated by a group of users involved in the hazard identification and risk assessment (HIRA) process. SAFEFORM is expected to assist users in identifying fall risks and providing decision support based on risk assessment and review for preventing fall-related incidents and injuries associated with formwork in the construction industry.

Keywords Safety · Prototype · Formwork · Construction industry · Knowledge management

1 Introduction

During the design stage of any construction project, hazard identification and risk assessment (HIRA) is essential [1] to prevent accident/injuries in the construction stage. HIRA is a knowledge-intensive process [2] and is being achieved through identifying and assessing safety risks and choosing control measures to prevent workers from risks associated with construction activities [3]. Considerable expertise is required to carry out this process [4]. In many countries, including India, the HIRA process is carried out by safety experts based on their individual experience [5] and using available resources such as regulations, guidelines, etc. [6]. However, many researchers [e.g., 6, 7] pointed that this conventional method does not reflect the dynamic of the construction process, and therefore many risky conditions remain

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hidden. To address these specific safety challenges, companies should rapidly adapt to new strategies for preventing accidents/injuries [8].

An effective safety knowledge management (SKM) could be one way to enhance the performance of safety in construction projects [8]. According to Reason [9], safety knowledge is defined as “a person in charge of the system is aware of the human, technical, and environmental elements that influence the system’s safety.” The construction industry has a wealth of knowledge that has yet to be utilized [10]. Furthermore, construction companies consist of individuals with different educational backgrounds and experiences [11]. Within the organization, everyone has the knowledge to contribute. Based on individual experiences, everyone has different approaches to decision-making and problem-solving [12]. Individual knowledge is insufficient to meet and address the challenges and issues that organizations face. The intelligence of an organization is a group of companies’ knowledge and the sum of the individuals’ knowledge [8].

Therefore, construction companies must be able to manage their safety knowledge. Companies need a safety knowledge management system (SKMS) to acquire and combine various types of knowledge within their company to be quickly obtained and efficiently chosen for use in a specific situation. A company will use the SKMS to collect, sort, and store all the individual’s knowledge before using it for creating an organization’s knowledge. This paper proposed an SKM prototype, SAFEFORM, focusing on fall-related safety risks associated with vertical formwork (i.e., wall and column).

2 Need for SAFEFORM in Indian Construction Companies

As a temporary structure, formwork has been widely used in construction projects. Formwork materials are designed into desired shapes and mounted into frames for assembly. Depending on the nature of the work, different types of formwork (e.g., timber, plywood, aluminum, and steel) are available on the market [13]. Work-at-height is often involved in formwork use, which could impact the construction workers’ safety [14]. In addition, workers are at certain fall-related safety risks during erection and stripping of formwork construction [15]. Hence, both companies’ productivity and workers’ safety are highly influenced by the formwork activity. Although there have been many studies related to fall, no research has addressed the fall-related safety risks involved in the formwork activities in construction. Till now, research that relates to formwork-HIRA-fall incidents is not conducted in India [16]. Vigneshkumar et al. [17] suggested that implementation of information and communication technologies (ICTs) could enhance the performance of safety in Indian construction companies.

Furthermore, Vigneshkumar and Salve [18] conducted interviews with the safety experts of eight leading construction companies in India. The study found that the companies understood well the benefits of SKM and believe SKM is a strategic asset. Although the companies are setting efforts to capture and reuse safety knowledge, the result indicates inadequacy of SKM in most of the firms. Subsequently, Vigneshkumar and Salve [19] conducted interviews with safety experts (users) to understand the challenges in HIRA and users' requirements to facilitate their safety knowledge during the HIRA process. The finding of the study shows that safety knowledge is not available when and where it is needed. Many users indicated that identifying hazards and risk assessment of particular activity itself is a big challenge. This indicates a need for SAFEFORM to review fall-related safety risks involved in formwork construction to facilitate users' safety knowledge during HIRA.

3 SAFEFORM Model

Everyday safety practices such as site observations, safety meetings, communication, and management meetings contribute to organizational safety knowledge. Safety knowledge is acquired and structured, stored, and then maintained systematically, known as the SKM process during these activities.

The SAFEFORM model includes acquiring, storing, and disseminating safety knowledge. HIRA consists of three significant steps: risk identification, risk assessment, and choosing control measures. Risk identification includes identifying safety risks and near misses associated with a particular activity. Risk assessment is evaluating potential risks (i.e., severity x probability) that may be involved in each activity. Once the potential risks are evaluated to prevent workers the control measures are selected. Researchers [e.g., 13] stated that construction practitioners have more experience and have adequate knowledge about particular activity than safety experts, as they are involved in a dynamic working environment and can make the potential to make decisions related to safety in many situations. Therefore, the first step is to capture fall-related safety knowledge (i.e., safety risks in each activity, causes of accidents, and control measures) associated with vertical plywood formwork activity from construction practitioners. During this step, the formwork activities (assembly, erection, concrete pouring, and stripping) that influence workers' fall risks are illustrated by digital human modeling (DHM), a 3D CAD model. DHM gives practitioners a real-life working environment to readily recall their experience and recognize fall-related safety risks. The gathered safety knowledge is structured or categorized into formal method in the knowledge bank (i.e., Microsoft Excel worksheet). This information is stored as explicit knowledge in SAFEFORM and can be handled easily during the project's lifecycle. The final step is disseminating where users can access and re-use it in further projects. The SAFEFORM model is shown in Fig. 1, and more details about SAFEFORM model can be found in [5].

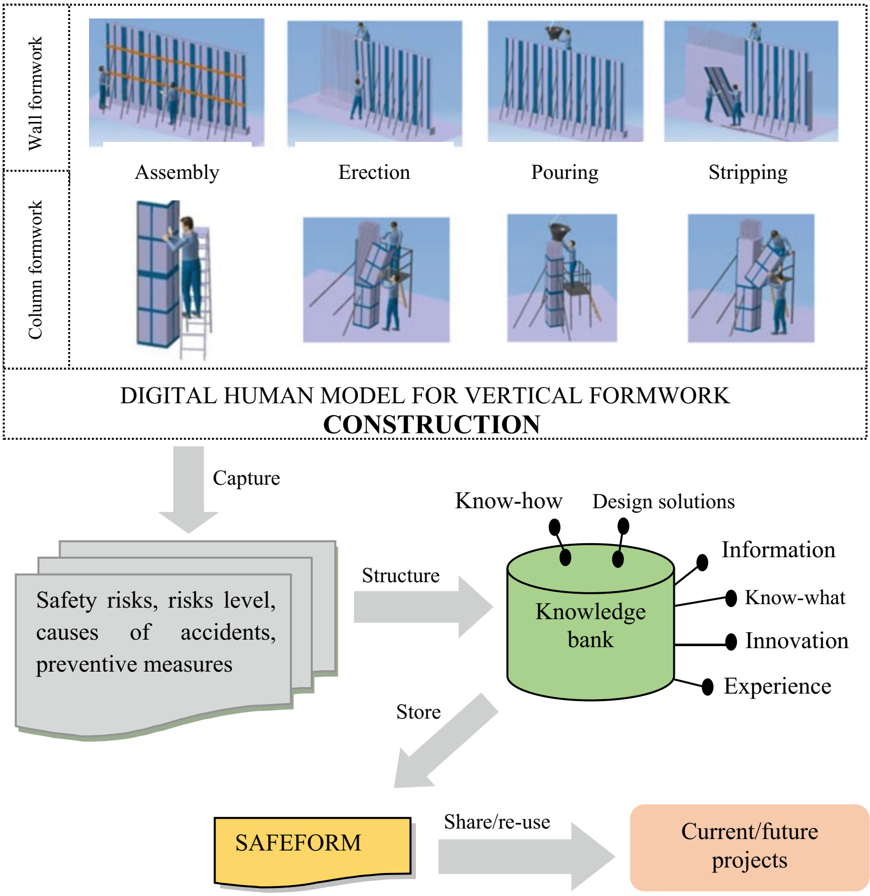

Fig. 1 Model of SAFEFORM (SKM process in HIRA)

4 Development of SAFEFORM: User-Centered Design Approach

Companies have long recognized the value of organizational safety knowledge and establishing SKM. Some of them have already invested in these methods but were unable to produce a functional method. Therefore, a prototype, SAFEFORM was designed that is focused on establishing an SKM system for fall-related HIRA. This study approach is considered a conceptual framework of [20] and is divided into five stages.

4.1 User Needs

In this stage, we propose to understand the users' needs and the system's goals. This data collection helps us to focus on capitalized knowledge, the market context, and the users' and company's expectations. The aim is to observe user challenges about the existing HIRA and come up with suitable solutions. This was achieved through face-to-face interviews with sixteen users from different construction companies. Interactions with users during this process allowed them to express their desire for a commonly accessible platform that is simple to learn but efficient, reducing the time spent assessing and reviewing information that simplifies data search and allows professional exchanges.

4.2 Functional and Content Requirements

This step identifies the features that meet the needs for managing knowledge (information seeking, collaboration, and learning). Functional requirements are concerned with the product's functions or features and how certain features interact with one another. These are the features that users need to achieve their goals. The information required for value provision is known as content requirements. Text, photographs, audio, videos, and other types of data are all examples of information. This was achieved through surveys among construction practitioners from different construction companies closely involved in formwork activities. The SAFEFORM model showed in Fig. 1 was followed to capture and manage safety knowledge.

4.3 Interaction Design and Information Architecture

This phase specifies interaction formats that are tailored to the system's functionality and information architecture. It entails creating interaction patterns and templates to organize knowledge that is familiar to users. We established informative trends related to HIRA at this stage: operations done by the users on construction projects are described in the description of activities (wall and column), the risk level of activities, measures to control risks, causes of accidents, best safety practices, accident statistics, regulations, case studies, etc.

4.4 Skeleton Design

The key functional areas and their interconnections are designed in this phase. Justinmind, a content management system (CMS), was used to bring this step to reality.

The CMS allows the prototype to be developed and modified more quickly. The system was arranged in various functional areas based on the gathered opinions, with the critical features of SAFEFORM: information, communication, review, and navigation.

4.5 Visual Design

This process will form the overall graphical appearance as well as the textual fonts. On the visual aspects of the platform, we began with a "theming" proposal and then revised the various options based on user feedback. During this process, depending on the use case, decisions were taken to make the tool easier to use. Using the assess risk area as an example has been enlarged and placed prominently on the right, with Arial as the default font.

4.6 SAFEFORM

The production of SAFEFORM has been made through this 5-step approach. During HIRA activity, features have been proposed to enhance the user experience in terms of difficulty and period. The front page of SAFEFORM is shown in Fig. 2.

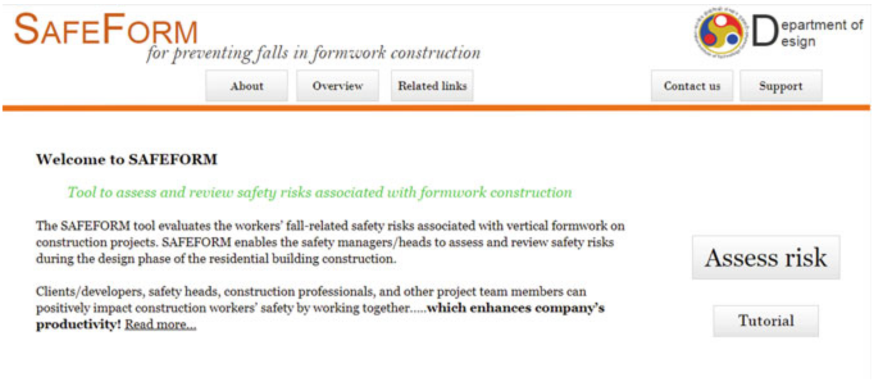

Fig. 2 Front page of SAFEFORM

5 Conclusion and Future Work

In recent years, construction companies are formulating new strategies and adopting new methods to manage safety knowledge to improve organization safety performances. In this study, a prototype, SAFEFORM was designed and proposed based on a user-centered approach to facilitate the safety knowledge of users to assess and review fall-related safety risks associated with vertical formwork construction in India. For system evaluation, ergonomic cognitive psychology assumes three dimensions: usefulness, usability, and acceptability. Evaluation criteria will be established in the future to measure the degree of utility, usability, and acceptability of SAFEFORM to validate. The major limitation of this SAFEFORM is that it only addresses the fall-related safety risks associated with vertical formwork (column and wall) construction. In the future, other safety risks involved in vertical formwork construction and other formwork activities such as slab and beam could be considered by the researchers to carry out HIRA for better safety performance. SAFEFORM could also be widely applied in other countries for similar projects based on the nature of activities.

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Information Processing Technique When Choosing Technical Solutions for Enclosing Structures of the Zero Construction Cycle

Yulia Zheglova and Boris Titarenko

Abstract This paper is devoted to the description of the information processing technique when choosing technical solutions for enclosing structures of the «zero» construction cycle. Currently, information modeling is actively used in the construction industry, since the choice of construction technology is associated with the processing of large amounts of information. An important task of the «zero» cycle construction is to substantiate the technology for erecting the enclosing structure of the pit, which depends on a multitude of conflicting data. The developed method of information processing when choosing technical solutions for enclosing structures of the «zero» construction cycle is based on the integrated assessment mechanism, which is one of the many mechanisms of the theory of active systems, which allows taking into account variables of a qualitative and quantitative type and is effectively used in constructing control mechanisms in conditions of uncertainty. The work expands the class of problems of applying this theory, since it is the first time for the construction industry that the theory of active systems is applied. The developed methodology allows processing large information arrays and is simply necessary for the designer to solve the practical problem of substantiating a rational technical solution for the enclosing structure of the «zero» construction cycle, since this is a very difficult task due to the existence of many factors influencing his choice. The paper also presents the results of the practical application of this technique for the designed object.

Keywords Information modeling · Technical solutions · Enclosing structures · Zero construction cycle · Comprehensive assessment · Construction efficiency · Efficiency factor · Theory of active systems

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1 Introduction

The requirements for the tasks of the zero cycle of construction, the performance of geotechnical surveys and hydrogeological studies are increased [1, 2]. Zero construction cycle includes a complex of preparatory work. In this complex of works, in addition to the preparation of project documentation, construction work is also carried out. The most important engineering structure erected at the zero construction cycle is the foundation pit, and the safety of existing facilities and those under construction is provided by technical solutions for its fencing - enclosing structures of the «zero» construction cycle [3–7].

The choice of technical solutions for the enclosing structures of the pits is associated with the processing of large amounts of information. In order to choose a technical solution that meets not only the calculations for limit states, but is the most rational from the point of view of economic efficiency, it is necessary to take into account many factors affecting the choice of technical solutions for enclosing structures, including climatic and architectural and construction requirements, which are both quantitative and qualitative characteristics of a construction object [8–11].

In this work, for the first time in the construction industry, it was decided to apply the theory of active systems [12–19]. The use of the mathematical apparatus of this theory will make it possible to increase the efficiency of the choice of technical solutions for enclosing structures erected at the «zero» construction cycle and reduce labor costs for working out a variety of possible solutions, and also improve the quality of their elaboration [20].

2 Methods

2.1 Comprehensive Assessment Calculation

The developed technique was used to select a technical solution for the «zero» cycle enclosing structure during the construction of a residential complex. The following technical solutions were considered for fencing the foundation pit, such as "wall in the ground", pile fencing, sheet piling and beam fencing.

Lets describe the territory for the location of the capital construction object. The territory of the projected construction site is located in the North-West Administrative District of Moscow, it is built up, the modern relief has been technologically changed, most of the site is asphalted. The geological conditions are predominantly sandy. In hydrogeological terms, the construction site is characterized by the presence of five aquifers: alluvial Jurassic, Perkhurovsky, Ratmirovsky and Podolsko-Myachkovsky aquifers. The groundwater level is above the bottom of the pit.

The projected multifunctional complex consists of three buildings located on a common stylobate with built-in non-residential premises and an underground parking lot on two levels, in terms of rectangular shape with overall dimensions in the axes of

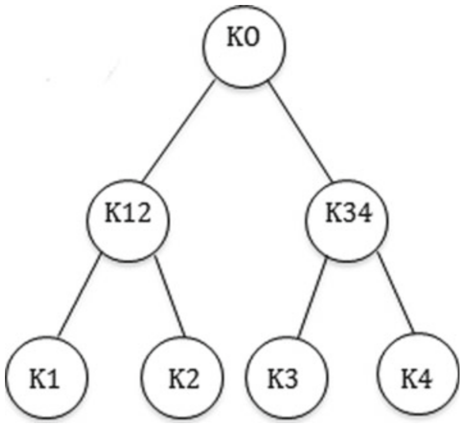

Fig. 1 Binary structure of four enlarged groups of criteria characterizing the development area

58.50 × 171.51 m. During the construction of the underground part, the pit depth will be from 7.0 to 9.3 m. The level of responsibility of the facility is KS-1 in accordance with GOST 27,751–2014 and I - increased in accordance with 384-FZ.

The radius of the zone of influence of new construction does not exceed 20.0 m. There are no cultural heritage objects located in the zone of possible influence of new construction.

Based on the tree structure shown in Fig. 1, a comprehensive assessment of the technical solution is built.

where K1-K4 are local assessments based on enlarged groups of criteria that influence the choice of technical solutions for fencing pits.

The idea is to organize all the criteria into a certain hierarchical structure, at each level of which an aggregated assessment of the criteria of the previous level is being built. Thus, the aggregated groups of criteria "Geological conditions" K1 and Hydrogeological conditions "K2 are combined into one aggregated criterion" Characteristics of the environment "K12. Similarly, it is possible to combine the aggregated criterion group "Distance from existing buildings to the pit" K3 with the aggregated criterion group "Categories of existing buildings by technical condition" K4 into one aggregated criterion "Characteristics of the surrounding development" K34. After combining the aggregated criteria "Environmental Characteristics" K12 and "Characteristics of the surrounding development" K34, we obtain an assessment of the technical solution of the building envelope in a complex form that ensures the technical parameters and safety of the development area. Thus, after carrying out these operations, we get the coefficient KO, which is an indicator of the assessment of the enclosing structure of the «zero» construction cycle in an integrated form and shows the possibility of applying one or another technical solution for a given development area.

Local assessments of the enclosing structure of the «zero» construction cycle are determined as follows:

$M_1=$

3	3	3
2	2	3
1	2	3

$M_2=$

2	3	3
2	2	3
1	2	2

$M_3=$

1	2	3
1	2	2
1	1	1

$M_4=$

2	2	3
1	2	2
1	1	2

$M_5=$

3	3	3
2	2	2
1	1	1

$M_6=$

2	3	3
2	2	2
1	1	2

Fig. 2 Convolution matrices (basic)

$$O_i = \frac{1}{\sum_{j=1}^{l} v_{ij}} \sum_{j=1}^{l} v_{ij} a_{ij} \tag{1}$$

where a_{ij} is the scoring of the j-th parameter by the i-th criterion, and v_{ij} is the importance of the scoring of the j-th parameter by the i-th criterion, l is the number of parameters that determine the i-th criterion.

Further, for pairs of directions, the local estimates are collapsed into a generalized estimate with the provision of the formation of a binary convolution structure.

For each pair of convolutional evaluations, its own logical convolution matrix is formed, selected from the library set of binary convolution matrices when forming the logical convolution matrix. Evaluation was carried out on a three-point scale: 1 - was defined as an "unsatisfactory" score (the values of the criteria do not allow the use of this enclosing structure), 2 - as a "satisfactory" score (the values of the criteria recommend using it), 3 - "good" (values criteria are very favorable for its application). Figure 2 shows the basic (library) convolution matrices:

Graphical schemes for the formation of integrated assessments of technical solutions for enclosing structures of the «zero» construction cycle according to the built binary structure (see Fig. 1) are shown in Fig. 3–6.

Let's write down the received complex estimates (see Fig. 3–6) in the Table 1:

Thus, it can be seen from Table 1 that the most preferable options for technical solutions for enclosing structures of the «zero» construction cycle are "wall in the ground" and "pile fencing".

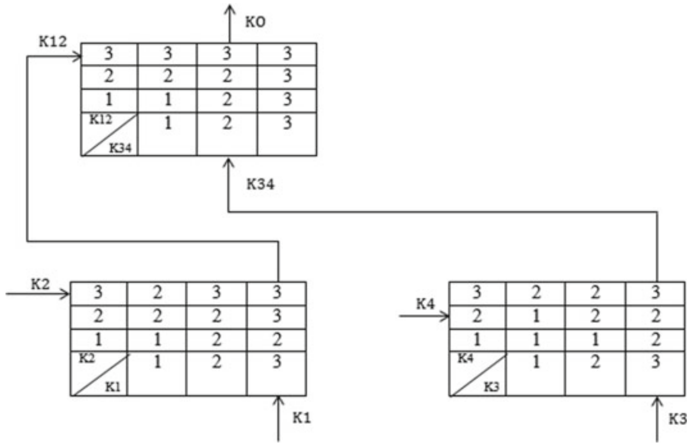

Fig. 3 Block diagram of the procedure for determining a comprehensive assessment for the technical solution of the enclosing structure "wall in the ground"

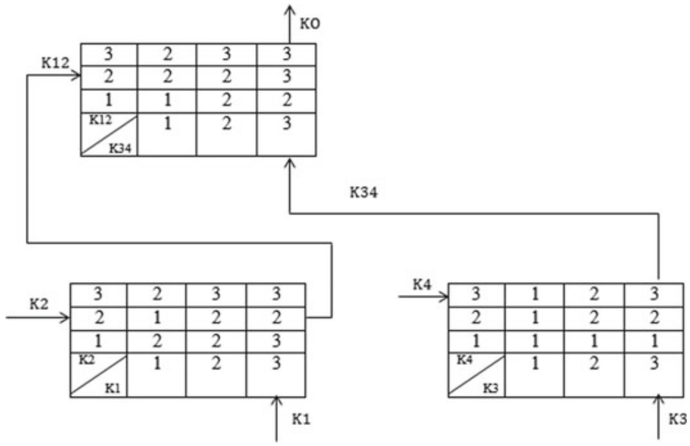

Fig. 4 Block diagram of the procedure for determining a comprehensive assessment for the technical solution "pile fencing"

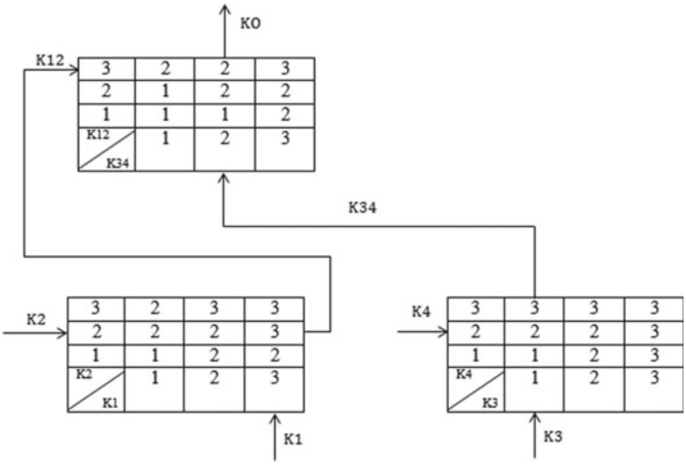

Fig. 5 Block diagram of the procedure for determining a comprehensive assessment for a technical solution “sheet piling”

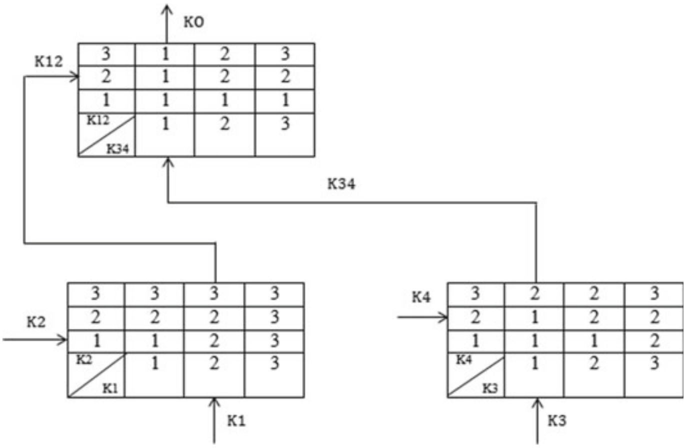

Fig. 6 Block diagram of the procedure for determining a comprehensive assessment for a technical solution “beam fence”

Table 1 Comprehensive assessment of the application of technical solutions for enclosing structures of the zero construction cycle

	Wall in the ground	Pile fencing	Sheet piling	Beam fence
Comprehensive assessment (*KO*)	3	3	2	1

2.2 Calculation of the Efficiency of Erection of Technical Solutions for Enclosing Structures of the «Zero» Construction Cycle

Further, at the second stage, the cost-effect mechanism was applied and the effectiveness of the construction of each technical solution for the construction of this facility was assessed.

The resulting costs for the construction of C_i by introducing a scale for recalculating the values of indicators are translated into local estimates:

where P_{ij}^{y} is the best, and P_{ij}^{x} is the worst value of the indicator of costs of implementation. The Table 2 shows the costs for the implementation of each type of technical solution of the enclosing structure for the object under consideration, converted using a conversion scale (see Fig. 7) into points:

To determine the efficiency of the construction of each type of technical solution for the enclosing structure of the «zero» construction cycle, the concept of the efficiency coefficient *KE* was introduced, which is determined by:

$$KE_i = \frac{KO_i}{C_i}, \quad i = 1, \dots, 4 \tag{2}$$

where KO_i is a comprehensive assessment of the technical solution for pit fencing, and C_i is the cost of its construction.

In fact, the efficiency factor determines the economic efficiency of using this type of fence. It takes into account a comprehensive assessment of the application of this technical solution, factors affecting the choice of a technical solution for fencing a pit, parameters of the development area and the cost of erecting this type of fencing.

When choosing technical solutions, such a solution is considered rational, for which *KE* - max.

The results of calculating the efficiency coefficient for this object are listed in Table 3:

From Table 3 follows the conclusion: for a given object, the most rational in relation to the technical characteristics and economic efficiency of the device is the

Table 2 Costs for the implementation of technical solutions for enclosing structures of the «zero» construction cycle

	Wall in the ground	Pile fencing	Sheet piling	Beam fence
Implementation costs (C)	5	8	5	3

Fig. 7 Scale for converting the values of sales costs into scores

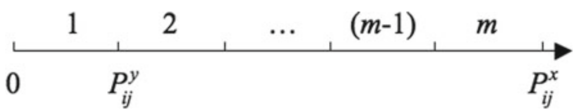

Table 3 The effectiveness of the application of technical solutions for enclosing structures of the «zero» construction cycle

	Wall in the ground	Pile fencing	Sheet piling	Beam fence
Efficiency (*KE*)	0,6	0,375	0,4	0,3

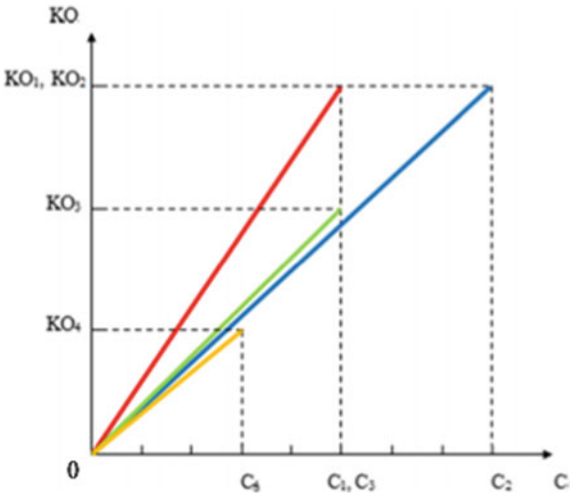

Fig. 8 The effectiveness of technical solutions for enclosing structures of the «zero» construction cycle

technical solution "wall in the ground". This technical solution has an efficiency factor of 0.6, which proves that the selected technical solution is rational.

If we postpone the values of implementation costs on the abscissa, and the values of complex estimates on the ordinate, then we can clearly represent the effectiveness of the construction of each technical solution of the enclosing structure of the «zero» construction cycle (see Fig. 8).

Thus, *KE* is the determination of the effectiveness of the device for each type of fence or the tangent of the angle of inclination (see Fig. 8). The graph in Fig. 8 demonstrates the effectiveness of the construction of the fence in a visual way.

3 Results

For the projected object, using the developed methodology, an assessment of various types of technical solutions for enclosing structures of the «zero» construction cycle was carried out. Based on the results of the proposed method, the decision was made "wall in the ground", since the obtained comprehensive assessment of this technical solution was the highest and had good efficiency, on the basis of the data obtained, it was concluded that the use of the structure "wall in the ground" is the most rational. Then a geotechnical calculation of this technical solution was carried out in the

PLAXIS 2D software package. The obtained results of the geotechnical calculation confirmed the safety of the decision.

4 Discussion

The results obtained showed that the use of this technique made it possible to reduce the time spent on justifying a technical solution by almost 2 times, significantly reduce labor costs for the development of various options for technical solutions for enclosing structures of the «zero» construction cycle and improve their quality, as well as reduce the actual cost of erecting the enclosing structure by 28%. The developed methodology makes it possible to improve the quality of technical solutions for enclosing structures of the «zero» construction cycle, reducing the time for justifying a technical solution, cutting off unsuitable options, and also significantly reduces the risk of errors during project implementation, which will ensure safe and trouble-free construction.

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Methodology for Creating a Digital Map of Al-Diwaniyah City (Iraq)

Zheleznov Maksim and Haidar A. N. Al-dami

Abstract The study focused on defining the methodology and technique of creating a digital map using GIS program in order to build a spatial database for various natural and industrial phenomena. And how to create layers for these phenomena, remove distortions from satellite images, geometric correction, and build topological relationships between different phenomena. Al-Diwaniyah city, one of the main cities in Iraq, was taken as a case study. The study included the creation of a digital map of the city and a statement of the construction methodology for this map, starting with the accuracy of the satellite image, its geometric correction, the identification and distribution of ground control points, and the conversion of raster information to vector information using its various elements; Point, line and polygon. In this study, spatial matching was performed between the drawn layers and the satellite image after its geometric correction, and descriptive tables were drawn from the vector layers and the spatial information displayed for the various phenomena. The study concluded that digital maps must be created on a correct basis by correcting satellite images using previously known ground control points or by monitoring them with high-precision GPS devices so that the spatial relationships between the plotted phenomena are correct and accurate, which makes the analysis and interpretation processes correct and provides real information for decision makers.

Keywords GIS · Digital map · Satellite image · Geometric correction · Methodology

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1 Introduction

There are many uses of GIS among different scientific fields, which made it very important in the areas of development, planning, resource management, emergences management and decision-making. But all these uses agree on one basis, which is the digital map [1]. If the digital map was based on a correct framework, all the information and decisions extracted would be correct and save time, effort and money. But if the digital map is incorrect, this will naturally lead to incorrect results and information, and therefore incorrect decisions [2, 3]. From here came the idea of the research, which is to identify the methodology and technology to be followed in establishing a correct and accurate geographic information system. As GIS has the ability to produce many maps in the form of digital layers through which different relationships can be made between geographical and spatial phenomena, and its ability to extract descriptive tables and charts from digital maps, which allows a clearer understanding of natural and industrial geographical phenomena and spatial relationships between them [4, 5].

2 Methodology

2.1 Satellite Images

Over the past decades, reliance on satellite images and their applications in many scientific and developmental fields has increased at the global level [6]. The satellite image consists of a network of columns and rows, which are small square areas called a cell or a pixel. Each cell has a number that represents the amount of radiation reflected from the surface area of the earth represented by this cell, and from this number the computer program can determine the surface material of the earth represented by this cell [7].

2.2 Satellite Image Processing

Satellite image processing operations aim at preparing images in the best and most accurate forms before interpreting them and extracting information from them. The raw satellite images, have some defects that must be corrected first before completing the process of classifying the geographical features and phenomena appearing on the image. Image processing include geometric correction, optimizing, merging and classifying images [8].

2.3 Geometric Correction of Satellite Images

The speed of the satellite, the refraction of rays in the layers of the atmosphere, the displacement resulting from the terrain and other factors affect the raw image so that it has some geometric distortions that prevent it from being used directly in the production of accurate maps and measurements. In the first steps of processing, engineering correction is done to overcome image distortions, and it consists of two steps: Correcting uniform distortions by applying mathematical equations based on the data and characteristics of the satellite, and correcting irregular distortions by linking the image to ground control points with known coordinates [9].

2.4 Correction of Satellite Images (Irregular Distortions) Using Ground Control Points (GCPs)

This method is known as the interpolative approach, which corrects the satellite image geometrically without taking into account its geometrical position at the moment of capture by the sensor. Polynomial equations are used in this method that relate the coordinates on the satellite image to the real ground coordinates observed [9]. The basic inputs to this method are: the satellite image and the measured ground points. The processing is carried out according to the following steps:

A- Determining the locations of the ground control points in the satellite image of the headquarters that must be clear and well visible.

B- Choosing the polynomial equation and calculating its coefficients, which are the transformation coefficients.

C- Testing the accuracy of the conversion through check points and studying the mean squared error.

D- Create an output file for the corrected satellite image.

Using the Global Positioning System (GPS) to determine the coordinates of GCP [10].

If the transformation equation is of the first order, this means that the transformation is linear, as shown in the Eq. 1

$$\begin{aligned} x_0 &= b1 + b2xi + b3yi \\ y_0 &= a1 + a2xi + a3yi \end{aligned} \tag{1}$$

Whereas: X0, Y0 = They are the coordinates of GCP, xi, yi = They are the coordinates of image and b1, b2, b3, a1, a2, a3 = Transformation matrix coefficients that describe the projection of the imaged element GCP onto the image plane.

For some of these coefficients (physical meaning (skew, rotation, change of scale, etc.) and for some of them only algebraic meaning. If the transformation equation is of the second order, this means that the transformation is nonlinear, or rubber sheeting. The number of parameters of the polynomial equation is determined by Eq. 2

$$(t + 1) \times (t + 2) \tag{2}$$

Whereas:

t = order of polynomial equation.

The minimum number of ground control points needed to determine these parameters can be obtained through equation No. 3, [11].

$$((t + 1) \times (t + 2))/2 \tag{3}$$

Many research works have proven that a significant increase in the number of adjustment points does not steadily increase the geometric accuracy of correction, and that it is financially costly and time-consuming [12, 13].

2.5 Production of Digital Maps Using GIS

GIS varies in terms of the nature of information to Raster and vector.

Raster Network Maps:

They are the maps and images that are dealt with by the GIS program on the basis that they are a set of pixels depending on the accuracy of the spatial discrimination, which becomes a digital location projection system after being linked to one of the surveying or geographical coordinate systems.

Linear Maps (Vector):

It is a system for digital projection of maps, as each line on the map is drawn through a large number of points, and each point has (x, y) coordinates. Vector data is the main objective of creating a GIS program, through which it is possible to design new digital maps and make modifications to them at any time and link them to attributes of data, analysis, information extraction, decision-making, and export operations to other programs [14].

2.6 Methodology of the Study

The process of producing a digital map of the city of Diwaniyah, located in central Iraq, requires many scientific steps to be followed, which are shown in Fig. 1.

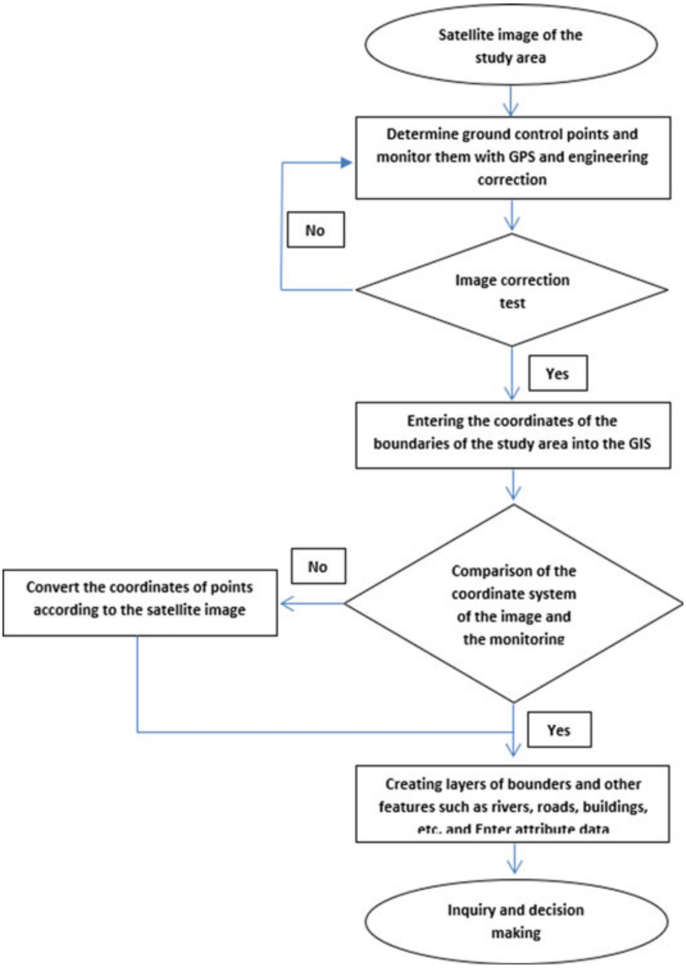

Fig. 1 Scientific steps to producing a digital map

2.7 Determine Ground Control Points

Ground control points have been determined at 6 points (5 GCPs monitoring + reference point) for each scene distributed over the scene in a special geometric arrangement shown in Fig. 2. It is recommended to collect GCPs from a bunch mark, from permanent buildings or houses and not in temporary buildings or structures. The height of the buildings selected as ground control points should not exceed a maximum of two floors and not be close to high-rise buildings, as the signals reflected from those buildings will interfere with the signals received from the GPS satellites [15].

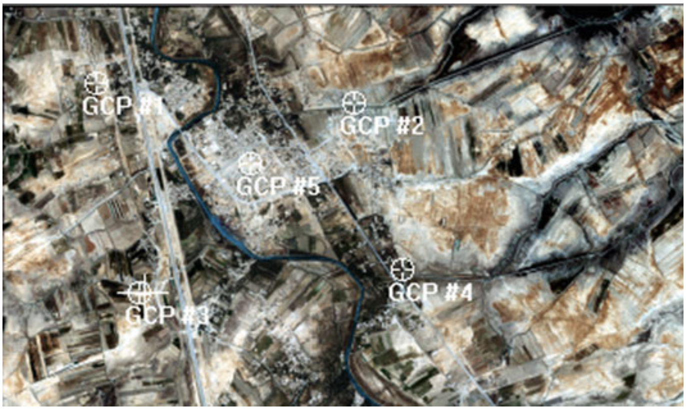

Fig. 2 Indicates GCPs on one of the satellite image scenes

3 Results

The ERDAS program, when geometrically correcting satellite images, depends on Eq. 4.

$$\begin{aligned} u &= a0 + a1x + a2y + a3xy + a4x2 + a5y2 \\ v &= b0 + b1x + b2y + b3xy + b4x2 + b5y2 \end{aligned} \tag{4}$$

Whereas: x,y = They are the coordinates of GCP, u,v = They are the coordinates of image and a0, a1, a2, a3, b0 b1, b2, b3 = Transformation matrix coefficients that describe the projection of the imaged element GCP onto the image plane [16].

Eq. 4 is a polynomial equation from the second order, and by connecting it with Eq. 3, the minimum number of points required to correct the satellite image is 6 points. In the first step of the geometric correction, the coefficients of the polynomial equation are calculated using the ground control points with known coordinates, and then the locations of the points on the satellite image are recalculated, and the ground control point is evaluated based on the value of the squared mean error on this point, which is calculated from Eq. 5 [17].

$$RMS = \sqrt{Vxi^2 + Vyi^2} \tag{5}$$

Vxi, Vyi = Error between the coordinates of the ground control point and the coordinates of the satellite image.

Calculations using the above equations are shown in Table 2. The ground control points were monitored using a GPS type (TPSGRS3) device with a detection accuracy of + —1 mm in WGS84 coordinate system and UTM projection system. As shown in Table 1.

Table 1 Shows the ground control points observed for one of the satellite images of Al-Diwaniyah city.

Name	Grid North (m)	Grid Easting (m)	Elevation (m)
GCP#1	3,521,561.746	493,520.237	20.752
GCP#2	3,521,379.741	495,828.104	20.082
GCP#3	3,519,684.117	493,909.111	20.661
GCP#4	3,519,885.558	496,267.275	20.531
GCP#5	3,520,836.246	494,899.692	21.045
Reference point	3,520,708.942	494,574.400	19.942

Table 2 Shows the residual error for (x,y) coordinates and the root mean square error values.

Point#	Vxi	Vyi	RMS
GCP#1	0.976	− 1.108	1.477
GCP#2	− 0.358	0.988	1.051
GCP#3	− 0.355	0.779	0.856
GCP#4	0.971	− 1.225	1.563
GCP#5	− 1.234	0.565	1.357
Reference point	− —-	− —-	− —-

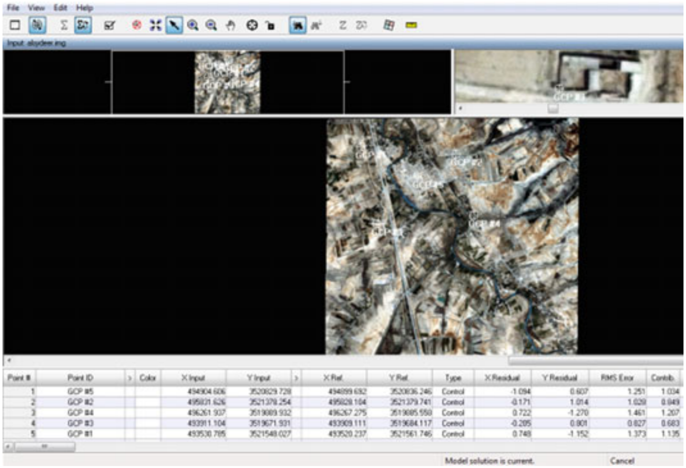

Fig. 3 Shows correction process for the satellite image using the ERDAS 14.

Establishing or intensifying horizontal and vertical control point observations using a differential carrier phase-based GPS is often cost-effective, faster, more accurate, and more reliable than most conventional methods [18]. Differential carrier phase-based GPS is particularly attractive for horizontal control surveys compared to conventional surveys because visibility is not required between adjacent stations and

GPS equipment is not limited to optics for its range of operations as in most conventional surveying [19, 20]. The correction process for the satellite image was made using the ERDAS 14 program and the amount of engineering error in the satellite image was determined as shown in Fig. 3.

4 Conclusion

After performing a correction process for the satellite images of the study area and verifying them by re-dropping the control points in the GIS program, the production of the digital map of the study area is now started according to the following steps:

1- Entering the data of the boundaries of the study area according to the coordinates received from the competent authorities in the process of demarcating the boundaries between the governorates. as shown in Fig. (4).

2- Convert a point layer to a GIS polygon layer as shown in Fig. (5).

3- Converting spatial information from a raster system to a vector system: At this stage, vector information bases (point, line and polygon) are drawn and

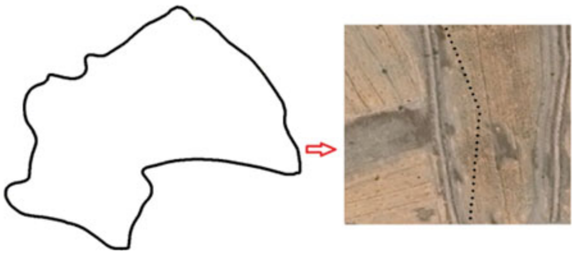

Fig. 4 Points layer representing the boundaries of the study area

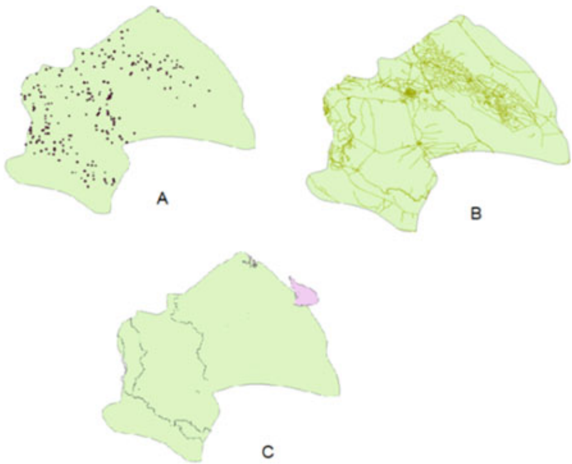

Fig. 5 Shows: **A** the centers of major cities and villages were represented by layers of point. **B** road networks and **C** rivers were represented by layers of linear. Note: The boundaries appear as polygon layer.

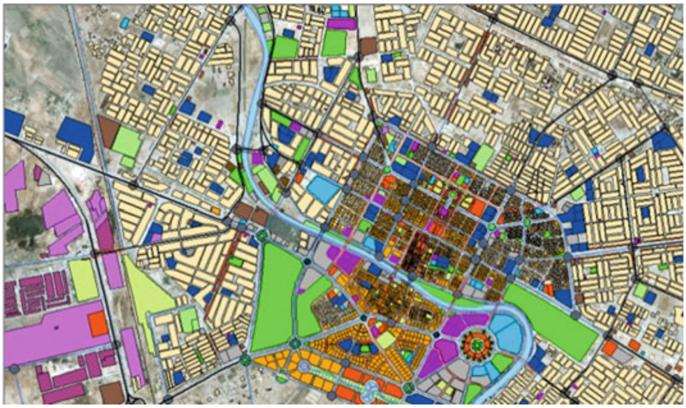

Fig. 6 Merge the different layers and satellite image in GIS program.

established. Spatial information systems depend in their design on the vector principle with its three elements, points, line and polygon. These maps are only useful if they are linked with the correct and real spatial features.

4- Creating digital map layers: In this study, all layers of the map were drawn using the GIS program; each of these layers represented a specific spatial phenomenon. As shown in Fig (5).

Geographical information systems provide a good possibility to make spatial matches between the different layers, regardless of their number, provided that they are in one coordinate system and projection. as shown in Fig. (6).

5- Establishing topological relationships: Conducting this process is one of the important and main steps in the preparation of a GIS database. Through it, spatial relationships will be built between the various geographical phenomena with their three elements: point, line and polygon. It provides the possibility of measuring those phenomena, whether they are longitudinal, spatial or numerical measurements.

Creating digital maps is the basic step in building a database for geographic information systems, building topological relationships between different phenomena, extracting geometric measurements, digital classification of different phenomena, and creating three-dimensional models. It also allows the creation of various additional maps and extract tables and graphic relationships that reflect the nature Spatial relationships between different phenomena, allowing the possibility of analysis, interpretation, comparison and spatial linkage of these phenomena. The GIS program saves time and effort and is highly efficient in drawing, storing, processing, managing and extracting data, compared to traditional methods. Digital maps must be created on a correct basis by correcting satellite images using previously known ground control points or by monitoring them with high-resolution GPS devices so that the spatial relationships between the plotted phenomena are correct and accurate, which makes the analysis and interpretation processes correct and provides real information for decision makers. It is proven the necessity of creating a digital map of the Republic of Iraq with a correct methodology aimed at providing a clear vision for decision makers and saving time, effort and money.

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Management of Organizational Processes in Construction

Normative and Methodological Support of the Organization Work on Demolition and Dismantling During Renovation

Amar Alhamd and Marat Kuzhin

Abstract A significant part of the modern housing stock in Russia was built in the first period of industrial housing construction, which began in Moscow with a plan for the reconstruction of the capital in 1951–1960, and lasted until the end of the 60s. A significant part of residential buildings in the country's housing stock, built during this period, are large-panel buildings of mass series. The volume of dilapidated housing in Russia is increasing every year. This means that this problem must be urgently solved, since with the passage of time, the volume of emergency housing will only increase. There will be an urgent need to relocate a huge number of people to new housing in a short time, which, given the limited amount of time for construction and affordable free housing on the market, will be extremely difficult to implement. Therefore, there is an urgent need for people's relocation from this housing to a new one and for demolishing (dismantling) the old one. Thus, issues related to the demolition and dismantling of residential buildings built in the first period of industrial housing construction, whereas massive series of large-panel buildings occupy a significant place, is an extremely relevant and in-demand topic in our country at this time. The purpose of the study is to propose and substantiate the optimal (rational) set of organizational and technological parameters for dismantling large-panel residential buildings of the first mass series. In recent years, the construction industry has come to the conclusion that the one-time costs of capital investments for the demolition (dismantling) of a residential building and the construction of a new one in its place are less than the one-time costs for major repairs. Also, the liquidation of these objects allows getting additional free space for housing and civil construction, which is already insufficient in large cities of our country, given that significant areas are occupied by buildings of historical and architectural value. Therefore, it is timely now to relocate people from this housing to a new one and to demolish (dismantle) the old one. The assessment of the physical and technical parameters of the construction site territory is quite accurate and objective. Determining the parameters of the construction site and temporary infrastructure facilities will make it possible to design construction production more accurately and keep within the

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standard time frame. Thus, the planning of construction production largely depends on the organization of the construction site.

Keywords Reconstruction · Demolition · Dismantling · Organizational and technological parameters

1 Introduction

The purpose of the study is to propose and substantiate an optimal (rational) set of organizational and technological parameters for dismantling large-panel residential buildings of the first mass series in the context of renovating urban areas. A significant part of the modern housing stock in Russia was built in the first period of industrial housing construction, which began in Moscow with a plan for the reconstruction of the capital in 1951–1960, and lasted until the end of the 60 s. A significant part of residential buildings in the country's housing stock, built during this period, are large-panel buildings of mass series. The volume of dilapidated and dilapidated housing in Russia is increasing every year. This means that this problem must be solved today, since with the passage of time, the volume of emergency housing will only increase. There will be an urgent need to relocate a huge number of people to new housing in a short time, which, given the limited amount of time for construction and affordable free housing on the market, will be extremely difficult to implement. Therefore, it is already necessary to relocate people from this housing to a new one and to demolish (dismantle) the old one. Thus, issues related to the demolition and dismantling of residential buildings built in the first period of industrial housing construction, in which massive series of large-panel buildings occupy a significant place, is an extremely relevant and in-demand in our country at this time. The purpose of the study is to propose and substantiate the optimal set of organizational and technological parameters for dismantling large-panel residential buildings of the first mass series [5, 6].

The concept of dismantling and demolition has different definitions that differ from each other, but have a single semantic core. Here is some of them:

- dismantling of an object is the liquidation of a building by dismantling prefabricated and collapsing monolithic structures, with preliminary dismantling of technical systems and finishing elements;
- demolition of an object is the liquidation of a building by one of the methods of collapse (mechanical, thermal, explosive or their combination) with preliminary dismantling of technical systems and finishing elements [7, 8]. The essence of dismantling is to liquidate the object, i.e. dismantling the building in the reverse order of assembling structures from top to bottom according to the "crane" principle, in order to free up the development area occupied by this or that building. Dismantling or dismantling of a building can be carried out in one of two ways: element by element or in separate blocks. Dismantling by element-by-element method allows ensuring the maximum possible safety of building structures, units

and parts for their reuse in construction [9, 10]. The second method of dismantling in separate blocks is more progressive than the first, due to its efficiency in terms of organizational and technological parameters, namely, in terms of labor intensity, duration and cost. Also, a feature of dismantling is the ability to reuse building structures and materials. This is ensured by dismantling utilities, finishing elements, door and window blocks prior to the commencement of dismantling the building, element-wise dismantling of structures while preserving their volumetric design indicators, units and parts, as well as sorting construction waste by type of material during the liquidation of the facility.

After dismantling, building structures undergo technical diagnostics for compliance with regulatory requirements, for possible reuse, and on this basis are divided into conditioned and substandard. Air-conditioned building elements can be used for reuse in the construction of objects for various purposes: warehouses, storage facilities, repair shops, garage-building cooperatives, parking lots, individual housing construction and other outbuildings. Substandard elements and building materials are sent to processing plants for the production of new materials and products from them or to specialized landfills for burial [11, 12]. Thus, dismantling (demolition) of large-panel housing construction objects should be understood as liquidation or disposal of this object, depending on the requirements imposed by territorial executive authorities, technical regulations on the safety of buildings and structures, methods and forms of organizing construction production, the selected technology and subsequent appointment in terms of the use of construction waste.

In recent years, the construction industry has come to the conclusion that the one-time costs of capital investments for the demolition (dismantling) of a residential building and the construction of a new one in its place are less than the one-time costs for major repairs. Also, the liquidation of these objects allows getting additional free space for housing and civil construction, which is already insufficient in large cities of our country, given that significant areas are occupied by buildings of historical and architectural value.

2 Materials and Methods

When carrying out the research, research methods were used: the method of statistical analysis, the method of expert assessment, the method of mathematical analysis based on statistical data. The developed set of optimal (rational) organizational and technological parameters for the dismantling of buildings of the first mass series will be necessary and sufficient for making effective organizational and technological decisions that allow the participants of the investment and construction project to determine the most significant parameters of the production process.

The section includes the following:

- description of the study location;
- materials used, with exact technical specifications.
- assumptions made and their rationale;
- statistical and mathematical procedures used to analyze and summarize the data.

Description of the study location. This article considered and analyzed the materials of projects for the production of works of facilities located in Moscow. The survey included objects located in cramped urban environments, as well as industrial buildings subject to demolition.

Materials used. The materials considered were obtained based on the results of the activities of contractors. In total, about 20 projects were analyzed.

The advantages of the renovation program include the following points:

- apartments in new buildings will be more convenient in layout, communications, sound and heat insulation;
- they are designed to be more modern and comfortable;
- in new residential complexes, organized parking spaces are immediately created, while next to the old housing there is no zoning of hard surfaces for parking and recreation areas of the population;
- construction of new buildings leads to positive change the architectural appearance of the capital;
- an ambitious program will provide significant support construction industry, new jobs will appear, and business development will entail large contributions to the budget.

The development of the construction industry entails the development of technologies used in the process of erecting buildings and structures. In addition to traditional methods of performing, managing and controlling the production of work, flexible technologies are also emerging that prove their practical effectiveness in a dynamically developing urban environment.

3 Results and Discussion

When justifying the liquidation of buildings and structures, the technical survey reports mention such concepts as the moral and physical deterioration of the building in general and structures in particular. As you can see, obsolescence today lies in the inconsistency with the laid down architectural and structural standards, functional purposes and financial cost in the design of a building with modern requirements, consisting in the levels of comfort and technical equipment, architectural and planning solutions, engineering systems, networks and equipment, improvement and landscaping of the territory, as a result of the development of technological progress and increased social demands of the population. Physical deterioration of a building (element) is a value that characterizes the loss of its consumer value, performance and technical properties: strength, rigidity, heat-shielding and operational properties and appearance" [13, 14, 15, 16]. In large-panel buildings, the physical deterioration of structures can primarily be caused by poor-quality connection of individual elements to each other, i.e. in the places of their docking, as well as the use of materials and structures that do not meet regulatory requirements. In addition to the technical condition of buildings, the reason for the liquidation of facilities may be certain programs for the demolition and dismantling, renovation [17, 18] or the integrated development of territories, which in fact is a derivative of their technical condition. The solution to the problem related to the dilapidated and emergency indicators of the housing stock was started even before the renovation program. In the capital, in the first period of industrial housing construction, whole blocks of residential buildings were built according to standard designs. In the past years of the last century, all these houses came to the end of their normative life cycle, had significant physical and moral deterioration, which required a comprehensive reconstruction of these quarters. The houses of the first industrial generation, built in 1957–1968, fell under the modern Renovation Program. series of panel houses [19, 20]. Houses of these series have significant physical and moral deterioration, requiring significant financial investments and organizational solutions for major repairs. However, as a result of the implemented studies, it was revealed that significant improvements in the condition of buildings and the comfort of living in them would not occur. Therefore, it was decided to include houses of these series in the renovation program, i.e. on carrying out the following organizational measures: resettlement of people, liquidation of a facility and construction of new residential buildings with landscaped public areas. Renovation will have a favorable effect on the architectural appearance of the capital, new well-equipped quarters with all the necessary infrastructure will appear [21, 22]: overground parking lots, landscaped and landscaped public spaces, children's and sports grounds, places for recreation. Not only dilapidated or emergency buildings can be demolished or dismantled. It can be liquidated buildings that do not have centralized engineering and technical support systems, buildings that have a certain physical deterioration of the main supporting structures (roofs, walls or foundations), and also if the cost of capital repairs exceeds the standard indicators determined by regional authorities.

At present, it is very difficult to overestimate the importance of regulatory support in the context of the development of a particular sector of the national economy. In Russia, one of the main directions for the development of forms and methods of organizing demolition and dismantling works is the development and improvement of regulatory and methodological documentation in order to create an integrated and interconnected system of organizational and technological preparation of dismantling works, increasing its efficiency, safety and quality. Demolition and dismantling works are extremely dangerous for the life, health of people taking part in the liquidation of the facility, and the population living or being in the immediate vicinity of the construction site, and also carry risks of harm to the environment, movable and immovable property of individuals and legal entities. persons and engineering infrastructure. Therefore, to ensure the safety of the work performed, it is necessary to have a set of standards that establish the rules for the design of organizational and technological documentation for demolition or dismantling, performance of work during the liquidation of an object and strict control over the implementation of technology and safety measures.

One of the main regulatory documents governing the rules for the production of work during the liquidation of buildings or structures is SP 325.1325800.2017 [22, 23]. This set of rules spells out the requirements for organizational measures in the production of work on the demolition or dismantling of civil and industrial buildings and structures, their individual structures and elements, as well as the disposal, processing and disposal of construction waste. This set of rules does not apply to unique, specialized and linear buildings and structures. SP 325.1325800.2017 was developed in accordance with the requirements of the Federal Law No. 384 and other regulatory legal acts. The main document that currently regulates the organization of work during construction, reconstruction, overhaul and demolition (dismantling) of buildings and structures is SP 48.133330.2019. The requirements of this set of rules include civil and industrial facilities, as well as processes associated with the re-profiling of industrial territories in the conditions of the existing development. This set of rules indicates the strict observance of the requirements described in the project for the production of work, and reveals the general rules of organizational preparatory, the implementation of which must be carried out before the start of work, and the main measures for the production of dismantling works, storage and storage of materials, products and structures, safety and security labor and much more. In addition to the aforementioned normative legal acts regulating organizational and technological design and decisions to liquidate facilities, there is also a large number of regulatory documents in the field of organizational and technological parameters that ensure optimal (rational) decision making.

The adoption of the optimal (rational) decision in the production of dismantling works directly depends on the technical and economic parameters, which include: the amount of work, duration, labor intensity, production, cost, time rate, machine time rate and output rate. These parameters can be determined using calculations (calculation) or accepted standard indicators. The main parameters that must be taken into account in urban conditions and affecting the psychophysical state (health) of the population are: the magnitude and duration of noise, the maximum permissible dust value and the amount of construction waste generated. The most difficult to solve problems that arise during the production of dismantling works are the generated noise and dust. In this regard, legislative restrictions were adopted in the field of their formation and distribution at both the regional and federal levels.

Thus, the regulatory framework for the organizational and technological parameters of dismantling is represented by a complex of interrelated regulatory, legal and methodological documentation that ensures efficiency, safety and quality at each stage of dismantling works (survey, design, facility liquidation, waste disposal). Analyzing the regulatory and methodological documentation in the field of organizational and technological parameters for dismantling large-panel residential buildings of the first mass series, we can draw the following conclusions and practical recommendations on the quality of domestic legislation:

- there is no possibility of determining the standard duration of dismantling of large-panel residential buildings for each individual series or for each individual building element of this series, which is necessary for the accurate development of schedules and work schedules in the organizational and technological documentation for the production of dismantling works;
- there are no prices for determining the composition and consumption of materials, machines and labor costs of workers, machines and mechanisms for many structural elements of large-panel residential buildings;
- unit prices and state element estimate rates, as well as indicators of the time rate and the composition of the link of workers in the Unified rates and prices when calculating estimates and calculations for dismantling work;
- It is required to introduce in the form of separate collections into the existing documentation the standard duration and prices to determine the composition and consumption of materials, machines and labor costs of workers, machines and mechanisms when dismantling large-panel residential buildings for each separate series or for each individual element of this building;
- It is necessary to update the regulatory documentation in the field organizational and technological parameters for replacing outdated methods of work production with modern, more progressive and demanded technologies with modern means of mechanization;
- It is necessary to develop a joint methodological documentation in the form of a "Builder's Handbook", in which all the necessary organizational and technological measures, labor protection and safety measures, tolerances and restrictions, labor costs, mechanical equipment and materials consumption, which require dismantling work, would be spelled out with graphic illustrations.
- introduction of amendments into the domestic legislation in the field of urban planning on the need to develop organizational and technological documentation for the demolition and dismantling of capital construction facilities, as well as possible processing and / or disposal of construction waste, at the design stage of the facility during the implementation of an investment and construction project.

Thus, this set of organizational and technological parameters concentrates all the most significant indicators of dismantling operations:

- data necessary for the development of a project for the organization of work on the demolition and dismantling of buildings and structures, scheduling and weekly-daily schedules;
- conditions necessary for the safe production of work for the life and health of workers, minimizing the negative impact on the population and the environment;
- distribution of the scope of work, cost, duration, the selected technology, the required amount of labor, material and technical resources, high quality, productivity and production efficiency. Organizational and technological parameters presented above systems, will act as comparison criteria, which are the constituent elements of the model for the analytical choice of the optimal (rational) population.

As a result of the theoretical study and analysis of the practice of dismantling large-panel residential buildings of the first mass series, the following conclusions, recommendations and proposals were obtained in this work. The concept and essence of dismantling: dismantling (demolition) of large-panel housing construction objects should be understood as liquidation and / or utilization of this object, depending on the requirements imposed by territorial executive authorities, technical regulations on the safety of buildings and structures, methods and forms of organizing construction production, the selected technology and subsequent purpose in terms of the use of construction waste.

After conducting a statistical analysis of the structure and condition of the housing stock of the Russian Federation, the following conclusions can be drawn:

- a significant part of the modern housing stock in Russia was built in the first period of industrial housing construction, which began in Moscow with a plan for the reconstruction of the capital in 1951–1960, and lasted until the end of the 60 s;
- the modernization of the construction industry and the subsequent development of housing construction and the country's housing stock is divided into five periods, which have certain characteristic features;
- a significant part of residential buildings in the country's housing stock, built in the first period of industrial housing construction, are large-panel buildings of mass series;
- by the form of ownership, the overwhelming part of the housing stock is privately owned by the population of the country, an insignificant and very small part belongs to the municipality and the state, respectively;
- the percentage of physical deterioration of buildings and the area of dilapidated and dilapidated housing in the country is increasing every year, which in turn affects the general condition of the housing stock;
- currently, almost all buildings of the first period of industrial housing construction have a significant degree of moral and physical deterioration;
- in our country, more and more often decisions are made on the demolition (dismantling) of residential buildings, as an alternative to major repairs. These include houses of the first industrial generation, as well as houses of the first mass series, built in the 50–60 s of the last century;
- in addition to the technical condition of the building, the reason for liquidation may be certain programs for demolition and dismantling, renovation or complex development of territories.

The choice and justification of the demolition (dismantling) method depends on what is indicated in the customer's assignment: demolition-destruction or dismantling-dismantling of the object. When demolishing an object, mechanical, explosive or combined methods can be selected. The choice and justification of the dismantling (demolition) method depends on what is indicated in the customer's assignment: if the liquidation of the object is specified by the "dismantling" method, then the object will be disassembled, if "demolition", then its destruction.

The execution of work is selected as a result of comparison according to the following criteria: cost; duration.

Considering the duration and cost of work, you should prefer smart demolition to element-by-element disassembly.

4 Conclusion

Organizational and technological solutions are a complex of organizational, technological and technical measures, the rational choice of which determines the optimal (rational) organizational and technological parameters that make it possible to achieve the liquidation of an object in one of the possible ways: dismantling or demolition, with the most beneficial indicators. To date, many effective organizational and technological solutions have been developed and introduced into production, which make it possible to liquidate an object with optimal (rational) organizational and technological parameters. These solutions are used in innovative and traditional technologies for the dismantling of buildings in many countries of the world and make it possible to provide the required values of certain organizational and technological parameters. Organizational and technological solutions are a complex of organizational, technological and technical measures, from rational choice of which the optimal (rational) organizational and technological parameters are dependent, allowing to achieve liquidation of the facility in one of the possible ways: dismantling or demolition, with the most advantageous indicators. To date, many effective organizational and technological solutions have been developed and introduced into production, which make it possible to liquidate an object with optimal (rational) organizational and technological parameters. These solutions are used in innovative and traditional technologies for the dismantling of buildings in many countries of the world and make it possible to provide the required values of certain organizational and technological parameters.

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Construction Project Management by Controlling the Time, Cost and Quality

H. M. A. Asfoor, A. A. T. AL-Jandeel, Konstantin Kozhevnikov, and Alena Lykova

Abstract Time, cost and quality are considered the most important factors in the process of construction project management to finish the project on the schedules using all the means and resources available in the most efficient possible by means of the Fast Track method, beneficial to the concerned owners, consultants, and supervision engineers. The research aims to develop essential and practical proposals to control general planning mechanisms for fast track construction projects besides detailed plans for controlling time factor and other two basic factors being cost and quality. This will help to eliminate any causes of delays when assessing the time of completion for any project. Many site visits and personal interviews were carried out with numerous prominent specialists and engineers concerned with Fast Track methods in order to enrich the study with their actual onsite experience on some of the construction projects implemented by such method. Many useful conclusions and recommendations have been deduced to build a complete and serious vision for all project activities and works for continuous improvement by implementing this system in fast track projects.

Keywords Project management · Time · Cost · Quality · Developing countries · Investment and stockholders

1 Introduction

The Efficiency assessment of construction companies of various formations can be determined based on performance, which has long-term and short-term scenarios.

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Project management strategies for modern construction projects and investment residential complexes include solving the actual problem of increasing efficiency or quality with reducing costs. However, an objective is set to improve these strategies, starting from quality enhancing by managing the cost of projects in the shortest period of implementation [1]. Moreover the logic of any business first needs to explain its purpose and how it can support the main purpose, [2, 3].

Choosing the definition of the purpose of the management process must be recognized as the most complex work that can be faced by the top management of companies. Ordinarily, the management body, especially coordinating with quality control and work efficiency with cost management, has resulted in a reasonably brief understanding of the purpose of the company. The lack of necessary useful skills and competencies must be replaced by skills from other fields - jurisprudence, office work, and social philosophy - leads to a distorted opinion about the actual course of work in the company, goal setting and the possibility of achieving goals, [4]. So, it is not acceptable to say that the management of quality control is ineffective, which indicates a distorted view of the content of the company's field of work which will directly harm the company in a different field, [5].

Replacing role-playing activity creates a positive environment for the effective managerial process when the passage of the document experiences external differences, but traditionally management is locked down, immersed into ritual processes when the functionally producing role is replaced by the formal process. The company experiences losses by actually neglecting its activities, engaging in management equipment and producing documents abstract from an objective view, overcoming the rational activity of the continuous reproduction of the same forms and trading with the direct function of management on the principle of residual, [6–9].

Implementation activities are chosen by some contracting companies in developing countries in the world and have deficiencies and sometimes failures due to the increase in cost or low level of quality, as determined by the field survey, in addition to the difficulty of that. Working methods and the many types of waste of building materials will lead to inexperience in this field despite its increasing impact. Therefore, the research aims to develop and apply the mechanisms of general project planning with the development of detailed plans to control the time factor while controlling the cost of the project and the quality of the executed works [10].

2 Management Success in Construction Projects

The success of the project can be achieved by implementing the design requirements to reach the purpose that the project established due to it. Project management must reach the equilibrium between the highly efficient with lower cost in the shortest time, and project preferences must be recognized by providing all sources for project management in this integration between these elements and suitable use to complete any section with optimal use of time during implementation.

Commence in establishing the different environments of work for employees to get the effective work team, that can be applied by:

1. The leading staff on the top of management administration should be selected carefully.
2. Creating a work environment with a friendly atmosphere prevailing.
3. Holding the coordination meetings between the project parties, including implementers and designers, and supervision and follow-up to change designs, solve problems and obstacles, expedite the use of alternatives and reduce time.
4. Providing all the supplies and equipment necessary for the establishment and success of the project according to pre-prepared plans to reduce wastage in time and cost. This can be done by choosing sources of raw materials in the proximity to the worksite with ease of processing upon request.
5. The projects in which project management was used in the implementation. It was noted that time is considered the influential element in the project first, quality second, and cost third, whereas the balance must be achieved between the three elements.

Due to the focus on the time factor in construction projects, the following shortcomings usually appear:

A - The quality level is influenced by poor implementation due to the speed.
B - The percentage of building materials' waste will increase.
C - Spending workers' energy by employing them for overtime, which negatively affects the quality of workers' productivity and production.

3 Master Plan Preparing

The rule of achieving a standard central plan for the implementation of the construction project in an expedited method depends on the integration of all the main elements of production and implementation. The stability of the production process is the main purpose of it due to reducing the duration of the activities, taking into account the determinants of cost and quality required for the project and being in full agreement with the requirements of the standard of the designer and the stakeholders in the same time [11].

The stimulated implementation of the project in addition to the central concern in the fact that these variables can be understood, adjusted or fixed, including raw materials, instruments, types of equipment or work activities. In this study, possibility to suggest project planning in an accelerated way of implementation, Fig. 1.

The use of this model in the general planning of the company's management will provide opportunities to respond to the needs that depend on the following variables, [14]:

1. Change in the size of the labor force.
2. Take advantage of overtime.

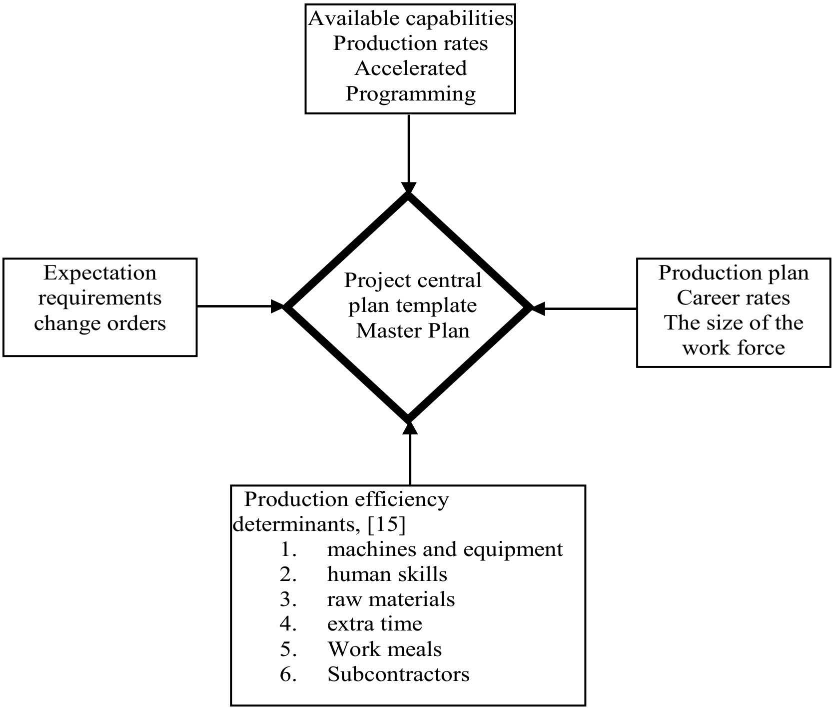

Fig. 1 The proposal of the central plan for the accelerated implementation of the project

3. Add necessary work meals.
4. Managing in bearing possible difficulties.
5. Use of subcontractors to divide the workload.
6. Expecting the possibilities of change orders from the employer.
7. Expect variations in market prices to meet needs.
8. Take advantage of potential technological development.

4 Planning by Linear Programming

Linear programming can be defined as a mathematical modelling technique that uses to find the level of operational effectiveness for the purpose of achieving a target with certain constraint′s influencing. Most of the stakeholders of the project play the main role to select the main activities that are used as a tool to manage the project implementation to reach the best way to achieve the company's goals that are subjected to constraints required by the environment and conditions of implementation. These conditions can be specific resources such as raw materials, labor, machinery, cash flow, and these constraints can be general determinants of accelerated implementation such as the work of the sequence or engineering specifications and others, [12].

There are several stages of modelling and analysis of linear programming in projects management, such as follows, [13]:

1. Problem Formulation: This stage starts data collection and identification of limitations with the operational study of the problem and its system.
2. Mathematical Modeling: It is the description of the problem or projects implication gaps through mathematical modelling, certainly this model represents the system that will be analyzed while retaining the probability of following the mathematical model.
3. Model Testing & Analysis: It is the collection and analysis of the solution of the model and its sensibility to various factors of the system.
4. Implementation: It is the use of the established system as a foundation for the stockholder's process and not as a substitute for the one who decision-making.

The shortest way to the target function, here the linear programming solutions can be used early or late start times for each event or node in the project schedule, where the early start times of the project must first be fixed. The project network is assumed to include a number of nodes ranging from 1 - m, as node 1 represents the opening of the project activities and node m represents the end of the project, as shown in formula (1), Objective Function, [11].

$$M_{in} = \sum_{i=1}^{m} x_i \tag{1}$$

Where:

M_{in} – Objective Function;
m – represents the project's termination,
x – The project objectives.

This function is subject to the following parameters as shown in the formula (2):

$$x_j - x_i \geq D_{ij} \tag{2}$$

For each pair of nodes of the activity (*i,j*) as well as specified as shown in the formula (3):

$$x_i \geq o \quad for \quad 1 \leq i \leq m \tag{3}$$

These determinants assure that there is enough time departing each node from the other in the series of shares between the activities described by the node. Furthermore, to the fact that the objective function decreases the values of x_i, the early ending times will get as an instant solution. Also, the late start times can be determined by replacing the goal function, as shown in the formula (4):

$$M_{in} = \left\{ m \cdot X_m - \sum\nolimits_{i=1}^{m} x_i \right\} \quad (4)$$

where:

X_m – is the total time required to complete the project. It is found useful to achieve the lowest possible value of X_m so that its symbol should always remain positive because the multiplication factor m in X_m assures that the objective function remains positive to ensure that realistic values are obtained for outcomes analysing will produce to the stockholders.

5 Results and Discussion

The linear programming method has been applied to the proposed housing complex project in middle of Iraq, which consists of housing units (apartments) within buildings, each of which has three floors, and each floor consists of two apartments, in a total of (432) apartments within (72) buildings.

Table 1 illustrated the main activities included in the table of quantities, and these activities were considered basic construction element. The project will be implemented in a pre-cast manner and in an accelerated manner of implementation, and the basic data of the project was entered into the program, which included 26 basic activities for all the buildings. This table includes the estimated time to complete the activities for one building, as well as the total time to complete the activities for all the buildings included in the project, and due to the large number of activities included in the project and consequently the large number of determinants of the input equations, the programming of the periods of completion of the basic activities for one building has been approved.

The previous Eqs. (1–4) have been applied into the linear program procedure according to the Table 1, which represents the entry list or the main input panel. xi represents the activity according to its sequence in the equations, such as A represents x_1 and B represents x_2 and so on for all activities. The Table 2 shows the shortest and optimal time for the completion of work.

Table. 1. Determinants of the objective function

Activity	Constraints	Activity	Constraints
A	$x_2 - x_1 \geq 3$	V	$x_{13} - x_9 \geq 0$
B	$x_3 - x_2 \geq 4$	W	$x_{13} - x_{10} \geq 0$
C	$x_4 - x_3 \geq 7$	X	$x_{13} - x_{11} \geq 0$
D	$x_5 - x_4 \geq 3$	Y	$x_{13} - x_{12} \geq 0$
E	$x_6 - x_4 \geq 3$	M	$x_{14} - x_{13} \geq 5$
Z	$x_6 - x_5 \geq 0$	N	$x_{15} - x_{14} \geq 4$
F	$x_7 - x_6 \geq 2$	R	$x_{16} - x_{15} \geq 5$
G	$x_8 - x_7 \geq 8$	Q	$x_{17} - x_{16} \geq 5$
L	$x_9 - x_8 \geq 10$	O	$x_{17} - x_{14} \geq 7$
K	$x_{10} - x_8 \geq 7$	S	$x_{18} - x_{17} \geq 5$
I	$x_{13} - x_8 \geq 6$	T	$x_{19} - x_{18} \geq 3$
J	$x_{11} - x_8 \geq 6$	V	$x_{20} - x_{19} \geq 5$
H	$x_{12} - x_8 \geq 6$	P	$x_{19} - x_{14} \geq 10$

Table. 2. Results of project timing calculations

No.	Activity	Decision variable	Solution value
1	A	X1	0
2	B	X2	3.00
3	C	X3	7.00
4	D	X4	14.00
5	E	X5	17.00
6	F	X6	17.00
7	G	X7	19.00
8	H	X8	27.00
9	I	X9	37.00
10	J	X10	34.00
11	K	X11	33.00
12	L	X12	33.00
13	M	X13	37.00
14	N	X14	42.00
15	O	X15	46.00
16	P	X16	51.00
17	Q	X17	56.00
18	R	X18	61.00
19	S	X19	64.00
20	T	X20	69.00

6 Conclusion

1. It turned out that for the general planning of the project, the importance of building levels of planning is commensurate with the nature of the rapid implementation tools and includes detailed plans to control all these processes while supporting and taking into consideration the factors of time, cost and quality.
2. The aims of the development of the central plan model for rapid implementation to improve the entire regulatory process in the project by setting the objectives, resources, increase the production rates and the necessary skillfulness into the scheduled applying, in a manner that ensures its practical ability to complete the project.
3. This plan is aiming to get the effective control production levels by defining an element of a special system to control the production processes in the project by building a model for procedures that determine the scope of administration, measure performance, compare it with standards and targets results, recognize variations, and take suitable and ready improving measures to reach the highest possible level of workability.
4. The control of time and cost has been resulted to get excellent outcomes by applying the use of modern computer technologies such as linear programming, which can be explained in more detail to the investors or the stockholders to make the central plan more clearly reduce the project fulfilment period and the critical activities of time pressure technology program at the lowest possible cost to control both time and cost.
5. The employer's provision of the cash flow is one of the important things because it is necessary to pay the financial dues on time without delay to all project workers, material suppliers, equipment contractors and others to ensure the flow of work within the schedule of timetable.

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Development of Modeling of Construction Production

Tatiana Barabanova and Roman Korol

Abstract The object of the study is the modeling of technological and organizational relations during construction and installation works, relations of fronts and relations by type of work. The need for research is due to the following difficulties: In solving problems in the process of designing models of construction production, in the distribution of labor and material resources by processes, in linking processes with the shift work of labor resources, the connection between procurement and main processes with the distribution of material resources, and others. Research method: each technological process is divided into stages, then assigned an ordinal number on the scale of stages and processes. Research results: an organizational and technological model for managing processes and operations during construction and installation works (CIW) has been developed. In project management software packages, it is not possible to determine the duration based on established relationships, and using the proposed methodology, this becomes possible. Conclusion: in the construction sector, there should be the introduction of ERP systems, i.e. systems that allow you to manage a huge variety of construction processes and their participants, using the flow method of work production. By developing the capabilities of tools for creating organizational and technological models, the implementation of ERP systems in the construction industry will be effective.

Keywords Modeling of technological and organizational relations · Labor and material resources · ERP systems

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1 Introduction

Within the framework of the modern theory of project management, the main representations for displaying the relationship of processes in time are: the Gantt chart with its subtypes and the Perth chart (network graph view). As is well known, four types of relationships serve as a means for determining the sequence of processes in time. However, we inevitably run into many difficulties when trying to model processes performed by the flow method [1].

One of the main problems is that when using the above concepts, we do not distinguish between technological and organizational links, links of fronts with links by type of work. In other words, we can only guess about the difference in the types of connections by the names of the processes between which there is a connection. And in many cases, it is necessary to study a much larger amount of information about the processes (for example, the number of the capture, the number and type of performers, etc.) in order to understand the logic of the connection [2–4]. The construction of any large facility involves a huge number of different works (about 10,000). By creating streams of construction links, we divide the object into many captures (for a 10-storey residential one-section building - about 50 captures). Naturally, when the user is faced with so many processes with connections in one view, the model becomes difficult to understand and difficult to work with. As a result, it is more difficult to make organizational and technological decisions.

In short, difficult to solve problems in the development of a model of construction production are the distribution of labor and material resources by processes, linking processes with the shift in work of labor resources, the connection between procurement and basic processes with the distribution of material resources, and others [5–8]. To solve this problem, it is proposed to introduce a new presentation format. For this, another spatially discrete scale is introduced. We get a diagram with three scales - a discontinuous time scale, a discrete scale of processes and a discrete scale of spatial characteristics.

2 Materials and Methods

For each process that takes place during the production of work, we divide the object into a certain number of captures. Each process has its own serial number, both on the scale of processes (Table 1) and on the scale of spatial characteristics (capture number) [9]. The process number on the process scale will be denoted by Arabic numerals, and on the seizure scale - by Roman numerals. For example, the 5th process on the 6th capture has the number 5/VI. All processes in all captures are a matrix of processes with program-calculated time parameters (early start and end, late start and end) based on user-defined links, constraints and durations. The ordinal number of the process on the process scale means that it is performed unchanged in the number of performers (by a person or by a link) in all captures of this process. If on another

Table 1 Matrix of processes, where Tij, aij, bij, cij, dij - duration, early start, late start, early end, late end of the i-th process at the j-th capture

Scale of captures Process scale	I	II	III	IV	Contractor
1	$\frac{\alpha 1I}{b1I}T1I\frac{c1I}{d1I}$	$\frac{\alpha 1II}{b1II}T1I\frac{c1II}{d1II}$	$\frac{\alpha 1III}{b1III}T1I\frac{c1III}{d1III}$	$\frac{\alpha 1IV}{b1IV}T1I\frac{c1IV}{d1IV}$	#A
2	$\frac{\alpha 2I}{b2I}T2I\frac{c2I}{d2I}$	$\frac{\alpha 2II}{b2II}T2I\frac{c2II}{d2II}$	$\frac{\alpha 2III}{b2III}T2I\frac{c2III}{d2III}$	$\frac{\alpha 2IV}{b2IV}T2I\frac{c2IV}{d2IV}$	#B
3	$\frac{\alpha 3I}{b3I}T3I\frac{c3I}{d3I}$	$\frac{\alpha 3II}{b3II}T3I\frac{c3II}{d3II}$	$\frac{\alpha 3III}{b3III}T3I\frac{c3III}{d3III}$	$\frac{\alpha 3IV}{b3IV}T3I\frac{c3IV}{d3IV}$	#C
4	$\frac{\alpha 4I}{b4I}T4I\frac{c4I}{d4I}$	$\frac{\alpha 4II}{b4II}T4I\frac{c4II}{d4II}$	$\frac{\alpha 4III}{b4III}T4I\frac{c4III}{d4III}$	$\frac{\alpha 4IV}{b4IV}T4I\frac{c4IV}{d4IV}$	#D
5	$\frac{\alpha 5I}{b5I}T5I\frac{c5I}{d5I}$	$\frac{\alpha 5II}{b5II}T5I\frac{c5II}{d5II}$	$\frac{\alpha 5III}{b5III}T5I\frac{c5III}{d5III}$	$\frac{\alpha 5IV}{b5IV}T5I\frac{c5IV}{d5IV}$	#B
6	$\frac{\alpha 6I}{b6I}T6I\frac{c6I}{d6I}$	$\frac{\alpha 6II}{b6II}T6I\frac{c6II}{d6II}$	$\frac{\alpha 6III}{b6III}T6I\frac{c6III}{d6III}$	$\frac{\alpha 6IV}{b6IV}T6I\frac{c6IV}{d6IV}$	#E
7	$\frac{\alpha 7I}{b7I}T7I\frac{c7I}{d7I}$	$\frac{\alpha 7II}{b7II}T7I\frac{c7II}{d7II}$	$\frac{\alpha 7III}{b7III}T7I\frac{c7III}{d7III}$	$\frac{\alpha 7IV}{b7IV}T7I\frac{c7IV}{d7IV}$	#C
8	$\frac{\alpha 8I}{b8I}T8I\frac{c8I}{d8I}$	$\frac{\alpha 8II}{b8II}T8I\frac{c8II}{d8II}$	$\frac{\alpha 8III}{b8III}T8I\frac{c8III}{d8III}$	$\frac{\alpha 8IV}{b8IV}T8I\frac{c8IV}{d8IV}$	#B

capture the process of the same name has a different executor, then two processes with the same name have different serial numbers on the process scale. Processes for procurement of materials for the specified grip can also be tied to the sequential number of the capture.

When creating a model, the user works with information in two presentation sections - technological (Fig. 2) and organizational (Fig. 3). Thus, it is easier for the user to think over the sequence and logic of the process connections. First, the technological chain of processes is set for each grip. Then the organizational sequence of the execution of work by one performer (person or link). Restrictions are set. After that, the program analyzes all the placed connections and constraints and gives the user the generated model in a familiar view, for example, a Gantt chart. This graph shows each process with sequence numbers ij, i is the sequence number of the process in the column of the left tabular part of the diagram. And j is the sequence number of the capture process. Processes with the same serial number I will be represented in one line on the right side of the diagram as segments. Having selected the i-th capture, we will be able to edit and obtain the required information on this process on the left side of the diagram. As we can see from the matrix (Table 1), there are works that can be performed by the same link at the same grip at different times (for example, setting up the formwork, dismantling the formwork). In this case, an organizational sequence is set separately for each process corresponding to the activities. If any processes with the same executor coincide in time scale, then you can run the standard algorithm for leveling the load by resources and the model will be rebuilt in accordance with the links set, the restrictions set by the user and obtained during the leveling (Figs. 4 and 5).

Capture for processes 1–8 (Fig. 1).

In software packages for project management, there is no possibility of determining the duration of the established links, as shown in the example. In them, the duration and connections of tasks are used only as two independent parameters. This means that the project manager will have to manually read similar task bindings each

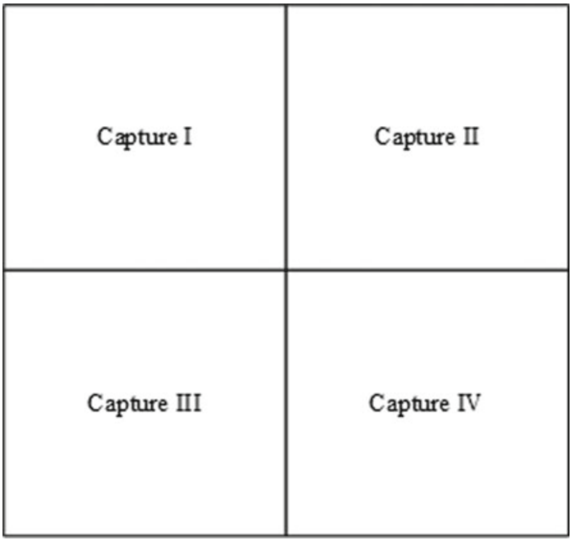

Fig. 1 Splitting the object into captures for each process. In this example, we take all the captures the same for each process

Fig. 2 Technological sequence of processes

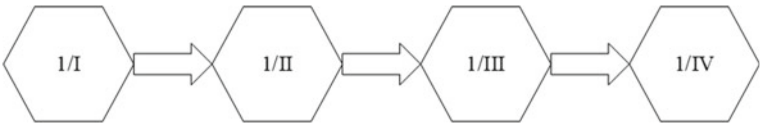

Fig. 3 Organizational sequence of processes

time. In order to implement this approach, it is proposed to introduce functionally new types of work relationships [13]. These connections should not only connect the ends/beginnings of various works, but also influence the duration of their implementation. A mechanism of shifts in time by absolute units should be used here.

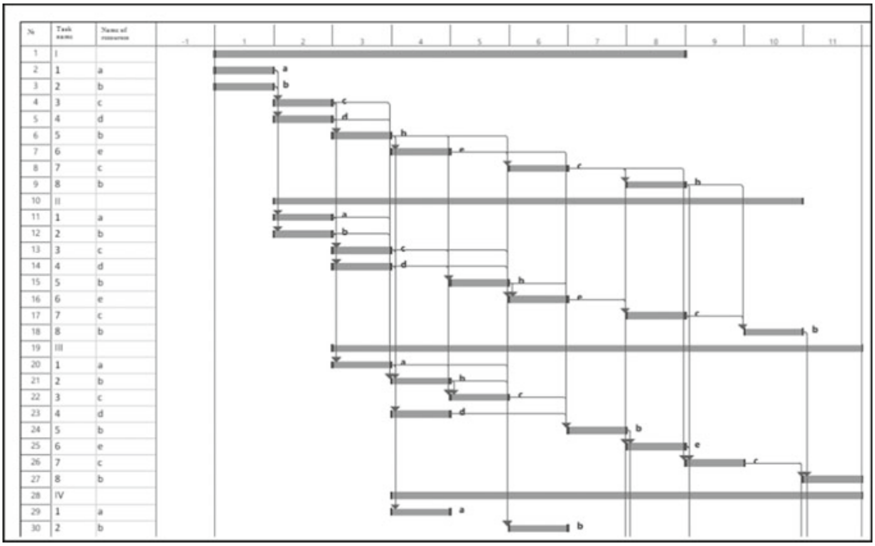

Fig. 4 Classic Gantt chart after resource leveling

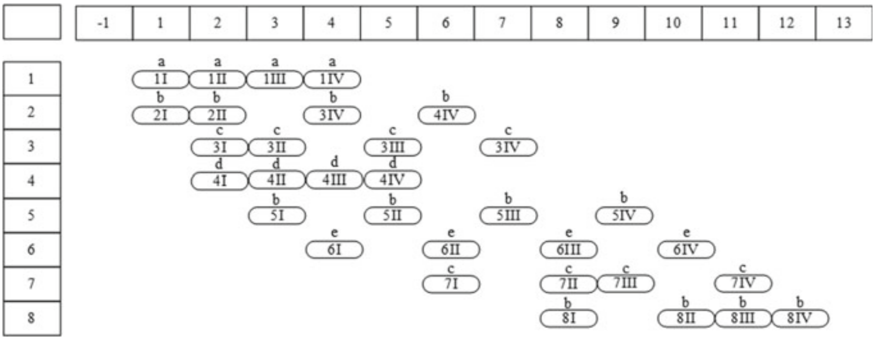

Fig. 5 Received view (links not shown)

At the same time, the classification of tasks by the type of calculation of the main parameters of the "project triangle" remains the same: with a fixed duration, labor costs, performers [14]. In this case, for production tasks, the most frequently used task type will be with fixed labor costs, since in them, as a rule, the physical volume of work does not change. This calculation type is typical for cases when it is required to minimize the use of labor resources. However, in a number of cases it would be correct to apply the computational type of the problem with a fixed duration. In this case, labor costs will change. For example, this can be typical for the task of maintaining the laid concrete and controlling the temperature and humidity conditions. If there is a temporary buffer left before the start of the stripping of the structure, we can use it for longer maintenance and control of the temperature and humidity conditions of concrete curing. In general, this computational type in problems with constraints affecting the duration is typical for cases when it is desirable to improve product quality by increasing labor costs in the presence of a free temporary buffer [15].

Another type of relationship that affects the duration of work is interdependent relationships. An example of this is the work of excavators and the work of dump trucks in the process of digging out the excavation with an excavator and loading the soil into dump trucks. The problem lies in the fact that the duration of the entire process will be determined by the leading type of machine, that is, the one with a higher utilization rate over time, provided that the work is simultaneous. In this case, the link must change direction depending on which type of machine is the master.

3 Results and Discussion

The duration of construction processes depends on many factors: on the volume of work, the degree of their mechanization and forms of organization, the number and skills of workers, the design features of labor objects, the productivity of equipment, etc. processes were evaluated according to standard labor costs. The documents by which the normative labor costs were determined were collections of norms and prices for work processes (UNaP, DNaP and LNaP), collections of enlarged estimated norms and prices (Building code Part 4), as well as collections with complex norms. Currently, these documents have expired (5 years from the date of publication). Collections of consolidated estimate norms have been reissued in the form of hydroelectric power stations, which in a market economy are not mandatory for use (except for capital construction projects with the involvement of state budget funds). They are primarily focused on determining the estimated cost and total duration of construction. Collections of norms and prices for work processes (hereinafter referred to as collections of norms) have not been released since Soviet times. They were intended mainly for the development of consolidated and complex norms and the preparation of calculations of labor costs and wages, as well as other similar regulatory documents for the remuneration of workers.

In order to create an organizational and technological model, it is necessary to apply workflow maps with the corresponding norms. In the standard methodology, UNaP are used to compile organizational and technological systems. However, studying the structures and methods of designing the norms of the UNaP, one can find a number of significant drawbacks for using them for this purpose. Next, we will consider the elements that are absent in the collections, without which it would not be possible to obtain an organizational and technological model that meets real production conditions.

The code books are only a summary of the data obtained during the design of technically sound time standards. Most of the information related to technology and organization remains in the project explanatory note. At the same time, the data that have a significant impact on the organizational and technological model during its development remain fixed in the explanatory note either in the form of averaged values, or in the form of conventionally adopted for a given construction process. That is, at the stage of developing time norms, a certain rigid model of the organizational and technological process is created. When we are faced with the need to determine the duration of a similar process with changed characteristics and other organizational and technological conditions, then applying the time rate of a rigid process model, we risk getting a duration that significantly differs from the actual duration of the projected process.

With the development of information technologies, the need to consider the total and average values in organizational and technological design has disappeared. Therefore, it became possible to determine the standard duration of production processes directly. A classifier is created according to the types of construction and installation works, types of processes and the field of factors affecting the duration of these processes. The procedure for determining the standard duration of the working process is a tree-like structure in which branches are sequentially selected from the general field of decisions, in which the factors presented in a particular production are located. Each type of construction and installation work should be studied in detail, and the main processes and factors affecting their duration should be highlighted, and organizational and technological solutions and techniques should be clearly described. Each type of construction and installation work may have its own characteristics for determining the standard duration of processes. Let us consider this approach using the example of reinforcement work during the construction of a monolithic reinforced concrete building.

4 Conclusion

As a result of the research, a key parameter for organizational and technological modeling was determined - this is the duration of work processes and operations. Now it is possible to determine the standard duration of production processes directly, without calculating the average and total values. For the organizational and technological model, a classifier is proposed by the types of construction and installation works, types of processes and the field of factors affecting the duration of these processes. For different types of construction and installation work (CIW), it is necessary to categorize by type of structure, for example, walls, columns, beams, foundation slabs, floor slabs, flights of stairs, arches and vaults. Once the design type has been determined, the number of possible solutions in the form of a specific product range is reduced. The next stage will be the choice of the technology for performing the work. Thus, there is an element-by-element and step-by-step variable modeling. The proposed methodology allows organizing a strategy for the integration of production and operations, the most effective management of labor resources. Currently, some construction trusts from around the world are implementing ERP systems. And if in the field of trade, the oil and gas industry, ERP systems became the modern standard of doing business, then in the construction sector it would difficult to give examples of firms that have implemented this implementation sufficiently. This is due to the huge variety of construction processes and their participants, the use of the in-line method of production of work. It seems that in the near future, developing the capabilities of tools for creating models, the introduction of ERP systems in the construction industry will be successful.

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Integrated Control and Protection Systems for Transport Facilities

Evgeniy Degaev

Abstract Bridge structures are strategically important objects of transport infrastructure and require special responsibility in their design, construction and operation. Violation of the efficiency of the functioning of road facilities, taking into account the transported goods, leads to economic and environmental losses, as a result of which people die, the level and living conditions of the population of the country are significantly reduced. During the operation of bridges in case of emergency situations (emergencies), local or complete technical failures of structures of the facilities may occur. The list of design (calculated) threats includes: terrorist threats; criminal threats; technogenic threats; threats related to the "human factor". In this regard, it is necessary to develop integrated protection systems for bridge structures, which contain technical solutions for the prevention, minimization and elimination of emergency situations. The article presents design solutions for the integration of various protection systems into a single control and protection center.

Keywords Automated control systems · Bridge structures · Transport infrastructure · Automated security systems

1 Introduction

Highways play a very significant role in the development of the country's modern transport infrastructure. In terms of the volume of goods delivered, road transport in 2020 dropped to the level of 2016, when the industry had just begun to recover after the crisis of 2014. As follows from the data of Rosstat, compared with 2019, the number of goods transported by road decreased by almost 6% at once. At the same time, cargo turnover in 2020 "lose ground" not so significantly - by only 1.4% [1, 2].

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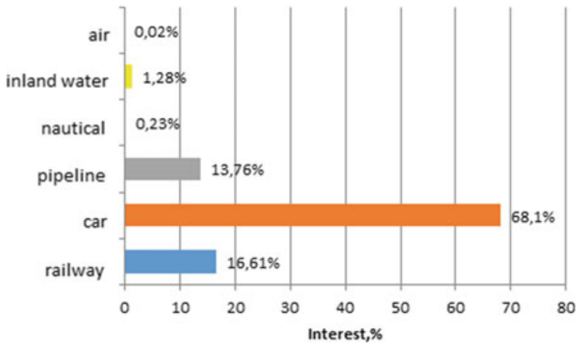

Fig. 1 Distribution of cargo transportation by modes of transport

In 2019, about 10.6 billion passengers and more than 5.7 billion tons of various cargoes were transported by road, which accounted for more than 68% of the total freight traffic in the country (Fig. 1).

Bridges play an important role for humanity. Their presence reduces the time spent on the road, allowing you to directly overcome obstacles (rivers, water reservoirs, cliffs) that have economic and practical value.

Violation of the efficiency of the functioning of road facilities, taking into account the transported goods, leads to economic and environmental losses, as a result of which people die, the level and living conditions of the population of the country are significantly reduced. Therefore, road facilities are strategically important and must be reliably protected from all kinds of security threats [3, 4].

The purpose of this work is to develop recommendations for reducing design (calculated) security threats during the operation of bridge structures.

2 Materials and Methods

The main objectives of the integrated safety of the bridge structure are:

- protection of human life and health, as well as protection of property and the environment;
- early determination of the degree of threat and implementation of preventive measures for the complex security of the facility;
- ensuring the implementation of priority rescue and other measures.

During the operation of bridges in case of emergency situations (emergencies), local or complete technical failures of structures of the facilities may occur. The list of design (calculated) threats includes:

Terrorist threats;
Criminal threats;
Technogenic threats;
Threats related to the “human factor”.

1. Terrorist threats;
   - attempts to break through the terrorist group into the territory of the bridge structure and into separate rooms of the central control room (CCR);
   - attempts to destroy a bridge structure by placing explosive devices or detonating explosives near the object, or in the premises of the structure;
   - attempts to disable engineering equipment systems;
   - disabling of the safety systems of the bridge structure;
   - hostage-taking;
   - reports about the threats of explosions and arson of the facility's structures or in the adjacent territory.
2. Criminal threats:
   - causing harm to the life and health of people located on the territory of the bridge, in the premises of structures;
   - theft of material assets;
   - illegal retention of premises;
   - vandalism, as well as premeditated (from hooligan motives) local emergency impact on the equipment, systems and elements of the bridge.
3. Technogenic threats;
   - the occurrence of a fire on the territory of the bridge or in the premises of the facilities of the object;
   - emergency failure of engineering equipment and life support systems with consequences that threaten the safety of the bridge structure.
4. Threats related to the "human factor":
   - predicted erroneous actions when using equipment, systems and components of a bridge structure, including by persons of various categories (personnel of the facility operation services, personnel of the facility security service, etc.) [5, 6].

The above list can be supplemented depending on the region and operating conditions of the bridge structure. The threats of an emergency with unlikely initial events (an airplane crash, earthquake, etc.) are attributed to an out-of-design accident or emergency, since they cannot be prevented or limited by reasonable measures within the framework of the design, construction and operation of a bridge structure.

3 Results and Discussion

The approach to building a comprehensive security system and anti-terrorist protection based on the categorization of dangerous and critical objects has been adopted and enshrined in the Federal Law "On Transport Security", the State Concept of

Transport Security of Russia, documents of the Ministry of Transport of Russia, etc. [5, 6]

This approach allows the most efficient allocation of financial, material and human resources allocated to transport security [7, 8].

To ensure the comprehensive safety of the bridge structure and its territories, the project should provide a complex of architectural and engineering solutions:

– the system of anti-terrorist protection of road traffic flows and their redistribution in emergency situations;
– technical solutions for the deployment of special equipment for the prevention and elimination of an emerging or implemented project threat;
– sites for the placement of evacuated people in buildings and structures for the provision of assistance (medical, psychological, etc.);
– technical solutions for the access of special units for the prevention and elimination of the arisen or realized project threat of emergency services to the zone of the roadway for emergency response (special metal stairs, platforms, etc.);
– technical solutions to ensure the safety of power supply and electric lighting of the bridge structure.

All systems and subsystems should be combined into a single complex of engineering solutions to ensure comprehensive security and anti-terrorist protection of the bridge structure, and the fullest possible use of the capabilities of each of the systems in order to detect and prevent the advance preparation of terrorist acts, technogenic emergencies, as well as illegal actions of people. In turn, this increases the reliability of each element of integrated security systems at the expense of resources and duplication of the corresponding systems.

Design solutions for the equipment of the bridge structure and the adjacent territory with engineering and technical means of integrated security should be aimed at achieving the following objectives:

1. Under normal operating conditions - maintenance of the integrated safety system of the bridge structure in a state capable of effectively resisting the accepted design threats and the adversary model in the normal mode of operation;
2. Timely transmission of necessary information to rescue and other services in case of possible occurrence or implementation of a project (calculated) threat;
3. In case of an emergency - take measures to reduce the risk of harm to the life and health of people, property and the object itself.

According to the accepted design threats, the bridge structure should be equipped with the following engineering and technical systems of integrated security:

– subsystem of video monitoring and management of motor vehicle traffic of entrances, exits, overpasses, bridge crossing with integration into the automated control system of engineering and technical systems (ACS ETS);
– subsystem of video monitoring of the sub stack space with integration into the ACS ETS;

- subsystem of video monitoring of water transport in the riverbed with integration into ACS ETS;
- subsystem of notification and management of evacuation of people from the bridge crossing zone, notification and management of special units for the prevention and elimination of an emerging or implemented project threat, emergency services with integration into the ACS ETS;
- subsystem of operational emergency communication;
- information protection subsystem;
- automated workplace;
- central control room.

To ensure the fire safety of the bridge structure, the project should provide the following technical solutions:

- provision of outdoor fire-fighting water supply;
- fire-fighting water supply (dry pipe) for supplying water from mobile fire equipment to the emergency zone;
- subsystem for transmitting a signal about the occurrence or implementation of project threats (terrorist, criminal, fire, etc.) to the service "01" of the Ministry of Emergency Situations of Russia with integration into the active fire protection management system (ACS AFP) [9, 10].

The complex of organizational measures to prevent project threats should include a number of instructions, regulations, rules, the development of which during construction and operation significantly reduces the likelihood of an emergency situation, and when implementing project threats contributes to successful elimination.

The main organizational measures that ensure the achievement and maintenance of the required level of safety of the bridge structure are:

- measures to counteract fires and explosions;
- measures to counteract terrorism and hostage-taking;
- measures to counteract the use of radioactive and dangerous substances with the aim of harming human life and health;
- measures to counteract telephone terrorism;
- means of vehicle inspection;
- means of localization of explosive devices [11, 12].

To optimize the operation of the integrated security and anti-terrorist protection system of the bridge structure, integration of subsystems into a single software and hardware complex should be provided (Fig. 2).

According to its functional purpose, ACS ETS solves the following range of tasks in automated mode:

- detection and timely notification of emergency services and special units about an emerging or implemented project threat, its parameters and coordinates;
- prediction of the development of the operational situation of the implemented project threat;

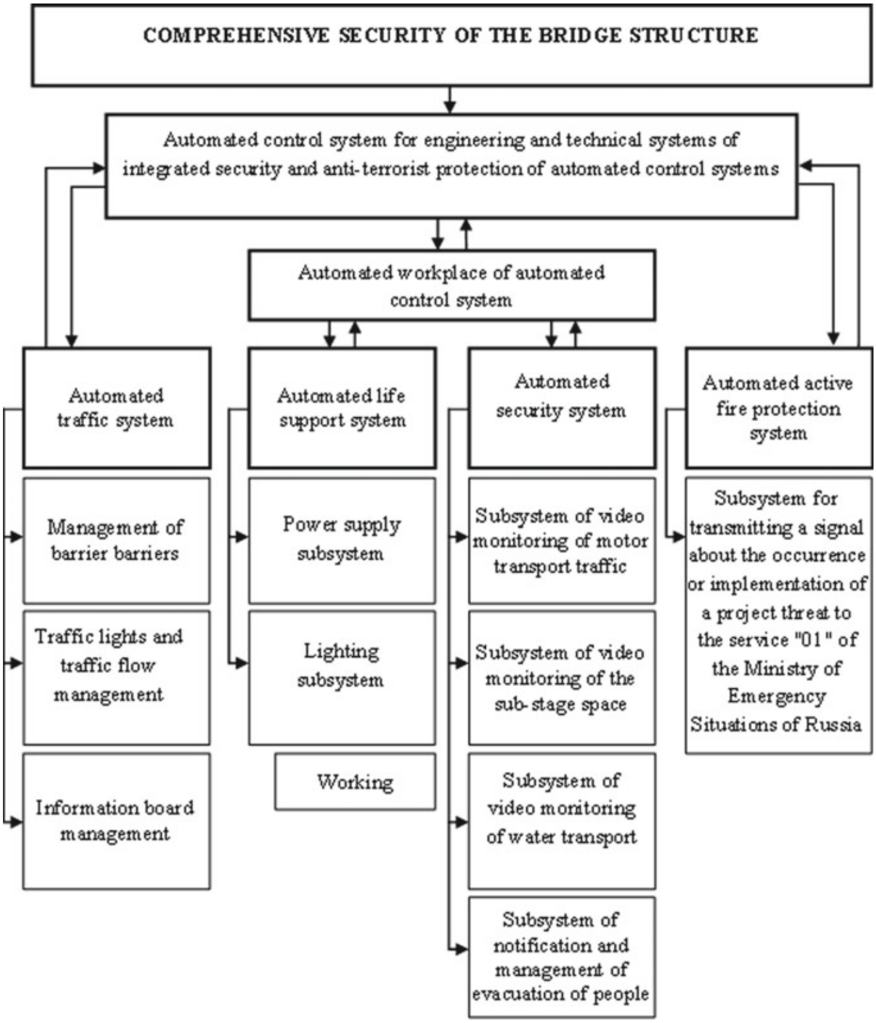

Fig. 2 Structural and functional diagram of ITS automated control system

- determination of the sufficiency of the first level of protection to assess the ability to cope with a dangerous emergency situation;
- calculation of the necessary forces and means that should be involved as the main echelon of protection and as a reserve;
- optimization of the delivery of the necessary forces and means, their deployment and operational efficiency;
- coordination of the interaction of various emergency services with different levels of training and equipment, arrival time, deployment and entry into force.

Let's take a closer look at the organization of the work of an automated fire safety system, since the most common emergency at road facilities is a collision of cars with a subsequent fire or explosion.

The integrated fire safety system complex includes the following fire protection installations:

- automatic fire alarm and automation installations;
- automatic fire extinguishing systems (water, foam, gas, powder and aerosol);
- warning and evacuation management systems in case of fire;
- technological and engineering equipment associated with the above-mentioned installations (smoke protection, supply and exhaust ventilation, etc.) [13, 14].

The structure and the diagram of the construction of an automated fire protection system consists of three levels. The functional diagram is shown in Fig. 3.

All address/addressless devices and control modules are located on the lower level. They monitor the fire safety of the protected object and transmit information to the middle level for its processing and decision-making. At the lower level, all the warning, fire extinguishing, smoke protection and other engineering systems are directly controlled. Address modules provide the ability to connect non-address devices.

At the middle level there are autonomous receiving and control devices, control and display controllers. At this level, network interaction between controllers is implemented and management of lower-level devices is organized. Controllers provide the collection, processing and storage of information coming from lower-level devices, decision-making in accordance with the programmed logic of operation

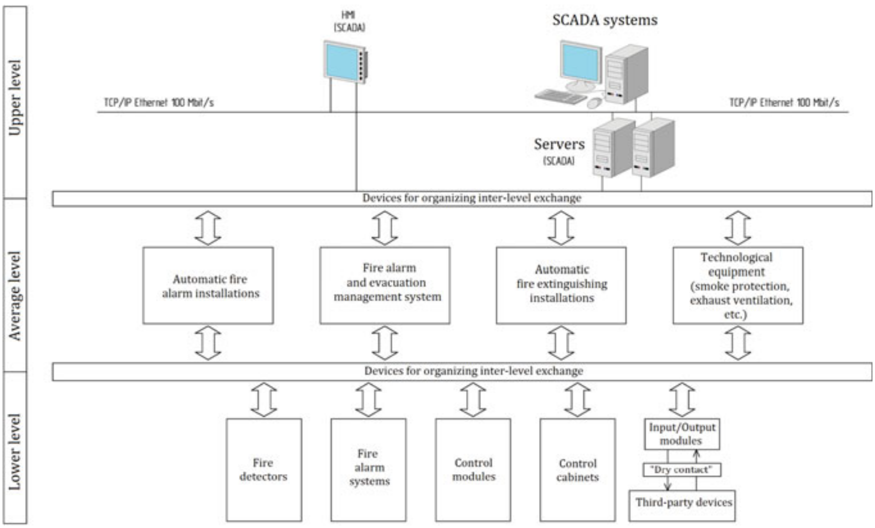

Fig. 3 Scheme of construction of an automated fire protection system

and the issuance of control commands to the actuators. The structure of the middle-level devices should include a central cabinet located at the central control point, which provides an indication of the status of the devices of the entire system and, if necessary, manual remote control of the lower-level devices [15, 16].

The upper level is automated workplaces and servers with specialized top-level software, as well as operator panels of the human–machine interface (HMI). At this level, the following main tasks are solved:

- organization of automated workplaces;
- integration of several local subsystems with their network controllers using a computer with specialized software;
- network interaction between mid-level controllers;
- data collection and processing from medium-level devices;
- archiving and provision of the received information;
- visualization of all events and status monitoring;
- differentiation of access to the system;
- creation of the configuration and logic of the entire system;
- recording the configuration in the controllers.

4 Conclusions

The integration of automated bridge construction systems with an automated workplace (AWP) together solves the complex task of ensuring the safety of the facility and guarantees a visual and accessible to the operator view of displaying information that meets the following requirements:

1. Display of an integral indicator of the traffic systems state, life support, safety, active fire protection, allowing the operator to assess the condition of the object (on a scale: NORM-RISK-DANGER-ALARM) and the level of risk of an calculated crisis situation (CCS);
2. If there is a threat to the implementation of the CCS and the recognition of the type of threat on AWP will be displayed on ACS ETS, allowing to assess the situation as a whole and in the appropriate area of the facility to take measures to eliminate the threat that has arisen;
3. When CCS occurs and develops, information about the most likely scenario of an accident/incident and recommended actions to minimize the consequences of the incident will be displayed on the AWP ETS;
4. When a calculated crisis situation arises and develops, information on the timeliness and quality of the recommended actions will be displayed on AWP ACS ETS to minimize the consequences of the incident, and to determine the need for intervention by external or territorial emergency services.

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Digitalization of the Network Schedule of Design and Construction Works

S. V. Fedosov, V. N. Fedoseev, O. V. Blinov, and S. A. Loginova

Abstract The level of digitalization, based on integrated automation and robotization of construction production in the conditions of modern computer systems, is determined by the creation of flexible industries and auxiliary structural elements of various scales. Network planning is an accurate tool for organizing design work, reflecting the duration, sequence and interconnection of parts of the design process. Competent rational planning of the construction process allows to improve the technology and organization of work, and also ensures the consistency of the actions of the performers. The digital construction management project, as a connecting link between the design processes of the entire construction, acquires particular importance in the process of digitalization of full-fledged construction, which in turn ensures the project's operation in the format of a digital twin of a construction object in a single data environment. The article presents the basic mathematical and algorithmic aspects of building network diagrams, considered using the apparatus of formal logic and rational mathematization of the technique for finding critical paths.

Keywords Digitization · CAD system · Network schedule · Calculation model · Matrix

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1 Introduction

For the current state of the design of the life support of buildings, a process of mastering and introducing information technologies in the construction industry is required. Today it is necessary to use the achievements of digital computing technology to process the wide functionality of object solutions. In a number of areas of the extensive construction industry, very interesting results have been achieved related to technical progress, the recognition of construction images with technical vision, functional robots and digital holography, statistically multifunctional analysis of various objects and elements, thermal imaging analysis, which makes it possible to determine the thermophysical and thermodynamic characteristics of the processes occurring in the construction object.

The process of digitalization and the spread of digital technologies in the organization and management of production occurs intensively in all industries. Initially, these processes were evolutionary, automating individual processes of the production cycle. Today, the strategy of digital transformation of business processes is a priority task for most large organizations, regardless of the industry, production specifics or legislative specifics [1, 2].

The digitalization of construction should be considered as the management of economic activities of life support and resources in construction, including a digitized (digitized, suitable for recording on electronic media) production process system.

At present, architectural and construction design is based on the use of automation systems and computerization of design work, which allow the designer to collect and process information on a personal computer [3, 4]. The main function is to carry out computer-aided design at all or individual stages of the design of objects and their component parts. The foreign equivalent of CAD is CAD—systems (computer—aided design/drafting), which are integrated automated systems for design, design and project management. Modern CAD systems include modules for modeling a three-dimensional volumetric structure, drawing design, and text design documentation [5–8].

The emergence of BIM (or in Russian science TIM—information modeling technology) fundamentally changed the approach to design. Previously, projects of construction projects were developed as a set of two-dimensional drawings (planimetry) created using lines and other graphic elements that do not carry any semantic load by themselves, then the use of TIM implies object design (axonometry), namely, the creation of a model of a construction object as a system containing the characteristics of a given object, algorithmically and programmatically developed for recognition by a computer [9].

POS is the basis for all construction processes, terms, on its basis, developing network schedules, schedules, delivery schedules of materials, products and structures, it is planned to move labor resources, financial flows.

Existing linear network diagrams when organizing a construction project do not reflect the interdependence of works when the conditions for their implementation change and do not have the ability to quickly respond to the compliance of the assigned tasks [10–14].

2 Methods

The use of modern software products today makes it possible to create a universal digital PIC. Currently, digital automation of the network schedule of design and construction works allows it to respond flexibly to the process of operational changes in the technological positions of the project. As an example, consider the graph below (Fig. 1).

3 Results

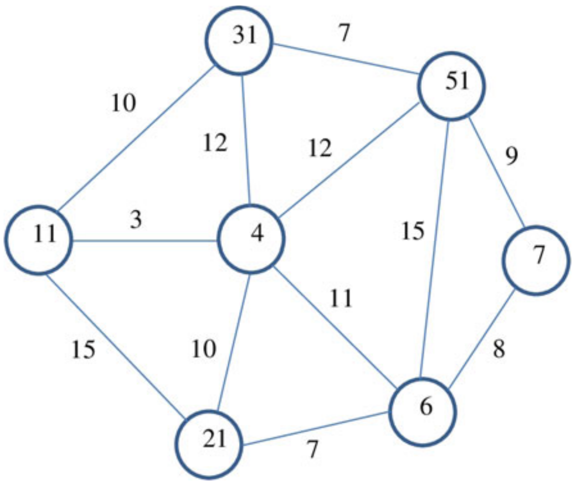
First, we form a square matrix of connections from the network graph (Fig. 1). Then, after starting the program, we sequentially enter the distance from one vertex of the graph to another (the length of the edge of the graph), starting from the first [15].

If the next vertex is located through one or more other vertices, then specify zero in the distance, for example, for 1–2, specify 7, for 1–4, specify zero, as well as for 1–5, and for 1–6, specify 14 and so on for all vertices.

After that, the program forms a matrix of links (Fig. 2, 3).

A square matrix is used to store the graph weights. The headings of the rows and columns contain the vertices of the graph. And the weights of the graph arcs are placed in the internal cells of the table. The graph does not contain loops, so the main

Fig. 1 An example of building graphs



	1	2	3	4	5	6	7
1	0	15	10	3	0	0	0
2	15	0	0	10	0	7	0
3	10	0	0	12	7	0	0
4	3	10	12	0	12	11	0
5	0	0	7	12	0	15	9
6	0	7	0	11	15	0	8
7	0	0	0	0	9	8	0

Fig. 2 Relationship matrix

```
Enter distance 5 - 6: 15
Enter distance 5 - 7: 9
Enter distance 6 - 7: 8

 The matrix of bonds has the view:
    0    15    10     3     0     0     0

   15     0     0    10     0     7     0

   10     0     0    12     7     0     0

    3    10    12     0    12    11     0

    0     0     7    12     0    15     9

    0     7     0    11    15     0     8

    0     0     0     0     9     8     0

Enter the number of the vertex to which you want to find the shortest path:
```

Fig. 3 The matrix of links of the developed program

diagonal of the matrix contains zero values. Then you need to enter the number of the vertex to which you need to find the smallest distance, for example, enter 5.

Next, the program calculates the shortest distances from vertex 1 to vertices 2, 3, 4, 5, 6. And displays the shortest path to the top 5.

An example of using the program is shown in Fig. 4.

The calculation algorithm is based on the use of Dijkstra's algorithm. Dijkstra's Algorithm is a graph-based algorithm invented by the Dutch scientist Edsger Dijkstra in 1959 [16, 17]. Finds the shortest paths from one of the vertices of the graph to all the others. The algorithm works only for graphs without edges of negative weight. The algorithm is widely used in programming and technology, for example, it is used by the OSPF and IS-IS routing protocols.

The calculation algorithm is as follows. First, the nodes of the graph and the distance between them are initialized. Then the formation of the matrix (two-dimensional array) is performed in accordance with the network diagram, in the cells of which the lengths between the corresponding numbers of the vertices, respectively indicated in the row and column, are indicated.

At the next step, the array of auxiliary labels is initialized, the number of which is equal to the number of graph nodes, while the label of the first vertex is equal to zero,

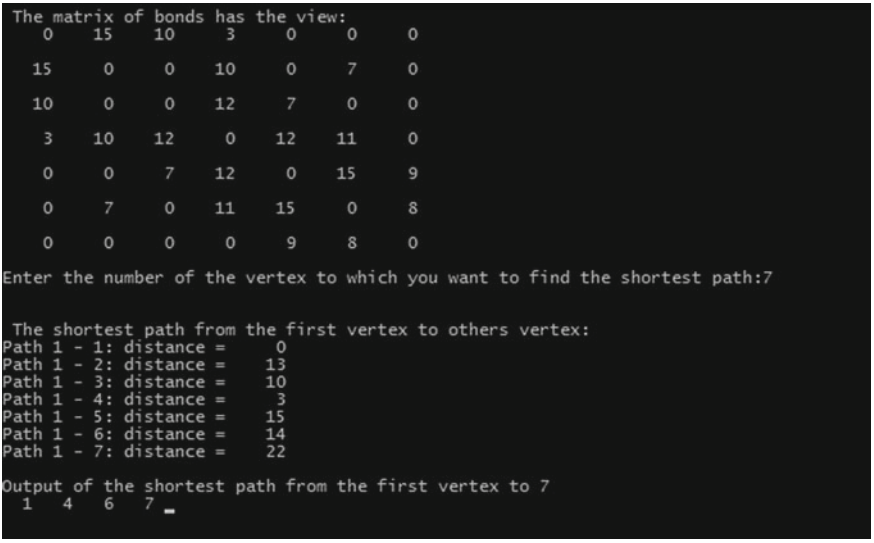


Fig. 4 An example of using the program

and the labels of the remaining vertices are equal to 1,000,000 (machine infinity). Then the one-dimensional array of flags is initialized to indicate the checked (passed) vertices, while all values at the initial stage are set to one [18–20].

At each step of the cycle, we are looking for the vertex with the minimum distance relative to the current vertex (matrix row number) and neighboring vertices (labels), i.e. of all vertices of this line, while the check starts from the number of the vertex, the flag of which is equal to one and the saved found minimum distance is greater than the current found one. After such a mark (vertex) is found, we set the flag corresponding to its number to zero, save the current distance and the vertex number of the found mark. Next, we check if the sum of the values of the current distance and the found minimum value is greater than the distance to the found vertex, then we save the found distance in the corresponding label. Thus, repeating the above steps, we check all the cells of the matrix (vertices) and find the smallest distances from the starting vertex to each vertex of the network graph.

The cycle ends when the flags of all vertices become equal to 0. Then, in reverse order, using a special procedure, we display the value of the shortest distance to the specified vertex of the network graph on the computer monitor.

Based on this, we see that the network schedule of the construction organization project, which defines the main issues on the organization and technology of construction production in a digital format, provides ample opportunities both for the timing of the project and the coordination of financing. It is important to note that the POS is developed by the general design organization, which the developer chooses, offering to include their modern technical solutions at any stage of construction.

As a rule, the POS is developed by the general design organization, which the developer (customer) chooses on the basis of a competition. By order of the general design organization, the POS can be developed by a specialized design organization. The development of a PIC can only be carried out by an organization that has an SRO certificate with admission to this type of activity. As part of the project documentation, the POS section is subject to examination and approval.

4 Conclusions

The data of the calculation system of the network diagram are based on network models, planned processes when using computers, allow you to quickly determine various options for control actions and select the rational-optimal ones. Network planning and management allows enterprise managers to receive up-to-date reliable information about the state of affairs, about the delays and opportunities to accelerate the progress of work [21]. The duration of the construction process as a whole makes it necessary to improve the technology and organization of work, helps to draw up rational plans, and ensures the consistency of the actions of the performers.

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Technology of Construction of the Outer Containment of Nuclear Power Plants with VVER Reactors

A. A. Gaysina and B. K. Pergamenshchik

Abstract The construction of the NPP involves large volumes of general construction and, in particular, concreting and reinforced concrete works. More than 800 thousand m^3 of concrete will be laid on the structures of the Kursk-2 NPP with two power units of 1255 MW under construction, including almost 250 thousand m^3 in reactor buildings. The metal content in the form of reinforcement, lining and embedded items in many components exceeds 400 kg/m^3. It is the reactor building and concreting that largely determine the total duration of construction and, as a result, the final costs. As before shortening of the duration today is associated with the use of large-block technology. At some NPPs the weight of mounting blocks reaches 700–800 tons with linear dimensions up to 20 m. The installation of large blocks, increasingly with permanent shuttering, involves the use of cranes with high lifting characteristics, appropriate vehicles, availability of conditions, workshops for blocks manufacturing at the NPP construction and erection base. The organization of such construction is associated with additional significant costs and, as a rule, is justified only for objects, individual structural parts, work on which is on a critical path. For NPPs this is an internal protective shell and structures of the confinement area. In recent projects of domestic NPPs has been designed and implemented a block solution for the outer containment (OC). Blocks with double-sided permanent shuttering are made of steel sheet. In this paper was made an attempt to compare the traditional technology for the construction of outer containment (OC), which is implemented at a number of NPPs, and block technology.

Keywords Reinforced metal structures · Blocks · Enlargement · Labor costs · Deadlines · Cost

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1 Introduction

According to most analysts, there is no alternative to nuclear power in the coming decades. The most restrained forecasts say that in the future by 2030 year, up to 500 power units will be operated on the planet, today there are 444 of them with a total capacity of more than 394.5 thousand MW [1].

It is well-known that the construction of NPPs is associated with large volumes of general construction and, in particular, concreting and reinforced concrete works. More than 800 thousand m^3 of concrete will be laid on the structures of the Kursk-2 NPP with two power units of 1255 MW under construction, including almost 250 thousand m^3 in reactor buildings. The metal content in the form of reinforcement, lining, and embedded items in a number of structures exceeds 400 kg/m^3.

It is the reactor building and concreting that largely determine the total duration of construction and, as a result, the final costs. Such works are performed both in traditional way - piece reinforcement using relatively small grids, frames, large and small collapsible shuttering, and by industrial methods. With an industrial approach, reinforcement is performed with large reinforced metal blocks. In the latter case, fixed shutters (including made of steel sheet) is already added into the composition of the blocks during manufacturing. There are solutions where the sheet performs the functions of the rod reinforcement, and sometimes completely replaces it. In modern indigenous developments, it is proposed to use fiber-concrete slabs as permanent shuttering for a number of structures.

The success of the Toshiba Corporation (Japan) in the construction of NPPs at one time was largely attributed to the widespread use of large-block construction. In 1996, at the Kashiwazaki Kariwa-7 NPP with the ABWR reactor, construction and erection work was completed in 46 months. In a joint report by specialists from Toshiba and General Electric [2], it was noted that one of the solutions that made it possible to achieve such results was the technology of large-block erection. The record construction rate of 44 months (before physical start-up), achieved in the 80s at the third and fourth power units with VVER-1000 reactors of the Zaporizhzhia NPP, is also largely associated with large-block erection of containment structures and confinement areas.

Today, the actual construction time of nuclear power plants at most sites is noticeably higher than planned. This is due to an increase in the volume of work, which, in turn, is mainly due to safety requirements. One of the ways to reduce the duration is large-block erection for NPP buildings and their parts, work on which is on a critical path. First of all, it is a protective shell and structures inside it. At some modern nuclear power plants, the weight of mounting blocks reaches 700–800 tons.

The negative aspects of this approach include an increase in the duration of the preparatory period, the appearance of additional cost items. It is necessary to add additional metal into the composition of large mounting blocks to create the necessary transport and installation rigidity, to provide well-equipped workshops for blocks manufacturing. Special vehicles and cranes with increased lifting characteristics are usually required.

Dozens of works have been devoted to the efficiency of industrialization in the construction of NPPS and oil and gas facilities. It is possible to point out [3–13], where solutions for the enlargement of structures are analyzed and advantages and main problems of this construction method are identified.

Large-block erection, widespread use of permanent shuttering made of steel sheet, which usually performs the functions of hermetic lining, is included in the projects of modern nuclear power plants with VVER reactors and is being implemented today at a number of sites, in particular at Kursk-2 NPP. The expediency of this approach in the construction of an inner containment or a number of structures inside it is beyond doubt. However, such a solution for the outer containment (OC) is quite criticized.

In this paper is made an attempt to evaluate the effectiveness of the structural and technological solution of the outer containment (OC) of the reactor building. Reinforcement works are performed with reinforced block structures with double-sided non-permanent shuttering made of steel sheet. It should be noted that in most known cases OC is erected in piece reinforcement using relatively small grids, frames and the installation of embedded items and penetrations during the reinforcement work. The shuttering is small and large-panel.

Only reinforcement, shuttering, installation of embedded parts are considered, which, to the greatest extent, in comparison with the rest, determines the cost and duration of the construction of the outer containment. Performance of construction joints, concreting and concrete curing were not taken into account.

2 Methodology and Calculations

The reactor building consists of a double cylindrical reinforced concrete containment, where the reactor plant is located, and an outbuilding in which a block control room and systems ensuring the safety of the plant's operation are located. The containment of the reactor building belongs to the most critical structures of the NPP. The containment is the last safety barrier to the spread of radioactive products into the environment in case of accidents, including the maximum design-basis accident. In addition, the containment protects the reactor plant from external influences. The inner containment is made of prestressed reinforced concrete with a thickness of 1200 mm with a steel sheet lining on the inner surface. It is designed for an accident with an internal pressure of 0.5 MPa. In the parts covered by the outbuilding structures from the possible crash of the aircraft the outer containment is designed with a thickness of 500, 1000 mm. The upper part, where the plane may fall, is 1500 mm. The outbuilding is a multi-storey box-shaped structure rigidly connected to the outer containment. Outside the upper part of the outer containment, from the level of the roof covering of the outbuilding, there is a gallery of rooms of the passive heat removal system heat exchangers, which are designed to remove residual heat from the reactor. The rooms of the heat exchangers are a two-story circular gallery, the outer walls of which perceive loads from operational and external natural and man-made impacts.

At a number of constructed NPPs, the reinforcement of the outer containment was performed in piece reinforcement using traditional technology. On the construction site are installed rods of principal and structural reinforcement. The embedded items and penetrations are fixed in place, or in the workshops of the construction base reinforcement grids and frames made in advance are erected. The shuttering is being installed. In the latest domestic project, it is proposed, in order to shorten the construction time, to perform work using reinforced blocks with permanent shuttering made of steel sheet, which has already taken place at a number of NPPs during the construction of walls, floors.

In this paper is made an attempt to evaluate the effectiveness of this block technology compared to traditional one.

There was considered a fragment of the OC structure at minus 0.050 - plus 8.950 level. The inner diameter of the containment is 50.8 m, the thickness is 0.5 m. The volume of concrete is 725 m^3. The containment is designed for the technology of block manufacturing and erection with a permanent shuttering made of steel sheet. The lining sheet is taken into account in the work of structures as sheet reinforcement. The main reinforcement is carried out by rod reinforcement of class A-IV with a diameter of 16, 32 mm with a step of 200 mm.

Reinforced blocks are manufactured in the workshop at an on-site construction base. Vertically, the coupling of reinforced blocks is carried out using a “loop connection”. After installing the unit in the design position, the embedded parts of the hermetic passages are welded along the contour to the lining. Flat reinforcement frames are installed in the joint area, horizontal reinforcement is performed and facing sheets are welded.

The total weight of the metal in the fragment under consideration is 307.8 tons, taking into account working, sheet, structural and additional reinforcement to ensure transport and installation rigidity, as well as embedded parts. The weight of traverse and conductors for the installation of blocks is taken into account the turnover.[1] The construction option is also considered, in which the steel sheet of the lining is not taken into account in the calculation of structures, but only performs the function of a fixed shuttering. The total weight of the metal is 384.3 tons.

During the construction of the OC by the traditional method, the weight of principal, structural reinforcement and embedded items are accepted invariant to the project under consideration. Connection of rods is made on couplings. The area of the inventory-panel shuttering is 2899 m^2.

To assess industrial and traditional technology, specific indicators for work in the workshop of the construction and erection base and on the construction site were adopted on the basis of data from nuclear power plants under construction and built in recent years according to domestic projects. The total labor costs were calculated by summing the main components, each of which was defined as the product of specific labor costs for the corresponding volumes of work.

[1] The mass of metal was adopted according to the analog project, taking into account the use of traverse and conductors in the construction of 2 power units.

Actual data and methodological documents in construction were used to estimate the cost of work and materials, operation of the machines and mechanisms involved, workers' wages, overhead costs and estimated profit [14, 15]. The cost of work in both variants is calculated by the resource-index method in base prices and converted into prices for the first quarter of 2021.[2]

Labor costs and the cost of work in the metalwork shop are determined by the obtained indicators of the average monthly productivity of the analog object, adjusted for the weight of reinforcement products.

It is accepted that during the construction of the outer containment structures by the industrial method for transportation to the construction site and erection of reinforced blocks, a heavy-duty trailer with a tractor, an on-board vehicle with a manipulator crane and two tower cranes with a lifting capacity of up to 40t and a mobile crane with a lifting capacity of up to 400t are involved.

For the traditional technology, the transport was adopted according to the Novovoronezh NPP-2 production project. The blanks of the working reinforcement rods are delivered to the site by an on-board vehicle. At the site, work is carried out with the help of two tower cranes with a lifting capacity of 40 tons.

At the construction site, for the methods under consideration, the specific labor costs and the composition of the team for erection and reinforcement work are accepted for analogous projects under construction.

3 Results

Below are the results of calculations, including for clarity in graphical form (Fig. 1 and Fig. 2):

Total labor costs:

– with the industrial method of construction, in which the steel sheet is taken into account in the work of the structure, amount to 38220 people-hours, of which labor costs on the construction site – 3185 people-hours;
– with the industrial method of construction, in which the steel sheet is not taken into account in the calculation of structures and performs the function of permanent shuttering - 46309 people-hours, of which labor costs on the construction site – 2264 people-hours;
– with the traditional method of construction – 17460 people-hours, of which 10260 people-hours on the construction site.

The cost of the industrial method, in which the steel sheet is taken into account in the work of the structure – 65423 thousand rubles.

[2] The cost is calculated in base prices without VAT as of 01.01.2000, converted into prices for the first quarter of 2021. The conversion indices of the estimated cost were adopted for the Kursk region (Annex 3 Reactor Building).

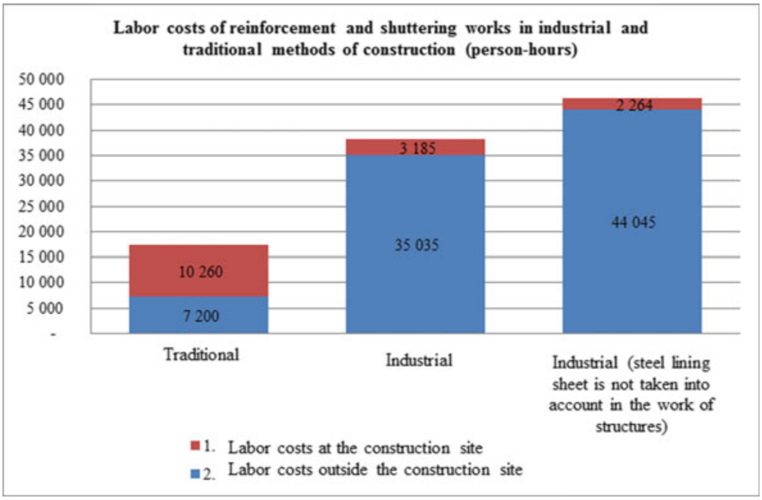

Fig. 1 Comparative labor costs when performing reinforcement and shuttering works by industrial and traditional methods

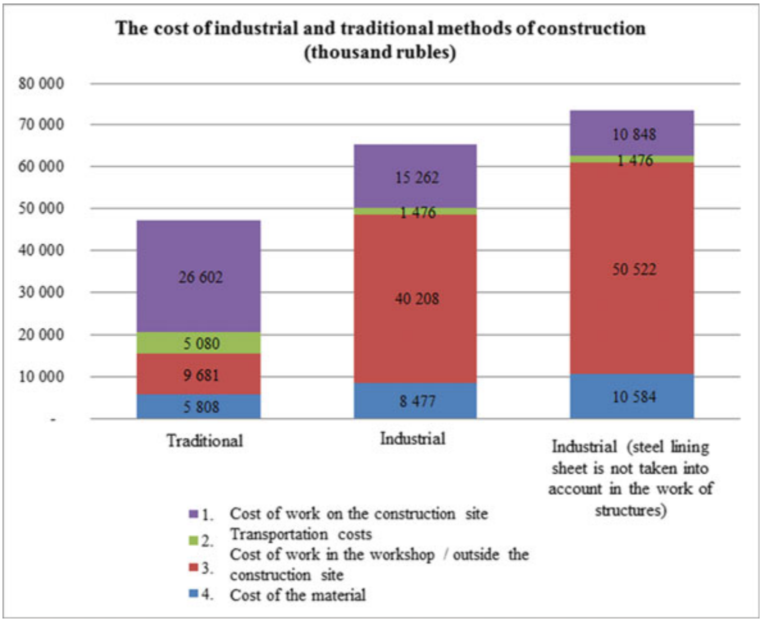

Fig. 2 Comparative cost when performing reinforcement and shuttering works by industrial and traditional methods

The cost of the industrial method, in which the steel sheet is not taken into account in the calculation of structures and performs the function of permanent shuttering – 73430 thousand rubles.

The cost of the traditional method is 47171 thousand rubles.

The construction of the outer containment structures in the considered marks by the industrial method allows to reduce labor costs on the construction site by 3 times, the total labor costs increase by 2 times compared to the traditional method.

The cost of reinforcing and shuttering works on the outer containment when using blocks increases by 18.3 million rubles compared to the traditional method of construction. In the considered version of the industrial method of construction, in which steel lining is not taken into account in the work of structures and performs the function of only permanent shuttering, leads to an increase in price by 26.3 million rubles.

The technology of construction of reinforced blocks with double-sided steel lining for the fragment under consideration leads to a noticeable reduction in the duration of work. The main advantage is the transfer of a large part of the labor costs for the construction of structures to factory conditions. This makes it possible to improve the quality of construction work, to smooth out as much as possible the inevitable seasonal factors that negatively affect the construction process during construction in harsh climatic conditions, and to reduce the number of workers at the facility.

The main disadvantages of the considered industrial method of performing reinforcement and shuttering works are an increase in material intensity, cost and total labor costs.

4 Findings

a. The technology of construction of reinforced blocks with double-sided steel lining for the fragment under consideration leads to a noticeable reduction in labor costs and, as a consequence, the duration of work on the construction site. A significant part of the work has been transferred to factory conditions, which makes it possible to improve the quality of construction work, to smooth out the inevitable seasonal factors as much as possible. Insufficiently studied negative factors that can increase the duration include:

   – work on the creation of an equal-strength joint between the lining sheets of neighboring blocks, work on the alignment and erection of embedded parts and penetrations;
   – delays in the delivery of rebar products from the metalwork shop;
   – insufficient degree of readiness of the adjacent structures of the building and the inner containment space.

b. The work on the construction of the outer containment and the construction does not lie on the critical path of the network schedule and access to it is unlikely. The work front with traditional technology makes it possible to involve the necessary number of workers in reinforcement and shuttering work and, if necessary, reduce their duration.

c. Block technology with double-sided shuttering in comparison with the traditional one is associated with a significant increase in cost. It is advisable to consider it only when taking into account the sheet in the work of the structure, if there are fears that the work will reach a critical path, as well as during construction in harsh climatic conditions. In countries with a warm climate, the traditional construction option is preferred.

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The Impact of Digitalization on the Life Cycle Management of an Object to Ensure the OTR

Nikolay Ivanov and Maksim Gnevanov

Abstract One of the important tasks of the construction industry is asset lifecycle management. In particular, an important stage in the life cycle of a completed facility is maintaining its operational characteristics. This requires periodic repair and construction work (RC-W), whereas their organization requires careful preparation in order to complete them in the appropriate time frame within a certain number of resources.

Information technologies are actively developing today. And they are the basis of the growing up process of digitalization that is taking place in various industries, including construction.

One of the progressive technologies today is the "big data" analysis. This article presents the concept of using "big data" in the organization of RC-W, which allows increasing the efficiency of organizational decisions, proceeding from the characteristics of a particular repair and construction organization and, as a result, to manage the life cycle of an object more efficiently.

The article presented by the authors gives an idea of the importance of digitalization and its application for managing such an important stage in the life cycle of an object as organizing RC-W, which includes solving a number of tasks, such as assessing organizational decisions that are developed as part of a production project. management of work, determination of the level of organizational and technological reliability (OTR) and, as a consequence, the choice of the best solution.

Keywords Big data · Repair work · Organization of work · Organizational and technological reliability · Digital economy

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1 Introduction

1.1 Digitalization

Currently, the digitalization process is gaining momentum and greatly affects the spheres of human activity. The concept of "digital economy" was introduced in 1995 by Nicholas Negroponte [1]. In Russia, there is currently no official concept of the term "digitalization", but you can find its various interpretations [2, 3].

In the materials of the report of the National Research University "Higher School of Economics", the following definition is proposed—"Digital economy are the activities for the creation, dissemination and use of digital technologies and related products and services" [2].

In 2017, at the St. Petersburg Economic Forum (PEF), the President of the Russian Federation V.V. Putin stressed that "the digital economy is not a separate industry, in fact, it is the basis that allows you to create qualitatively new models of business, trade, logistics, production, changes the format of education, healthcare, public administration, communication between people, and therefore sets a new paradigm for the development of the state, economy and society as a whole".

According to the research "Digital IQ 2020 Russia", Russia is facing a number of obstacles in the process of digitalization, which are presented in Fig. 1.

According to the report "Global Information Technologies" for 2016, Russia is ranking 41st in readiness for digital economy, with a significant gap from dozens of leading countries, such as Singapore, Finland, Sweden, Norway, the United States of America, Netherlands, Switzerland, UK, Luxembourg, and Japan.

Digital technologies are technologies for collecting, storing, processing, searching, transmitting and presenting data in electronic form [2]. At the heart of

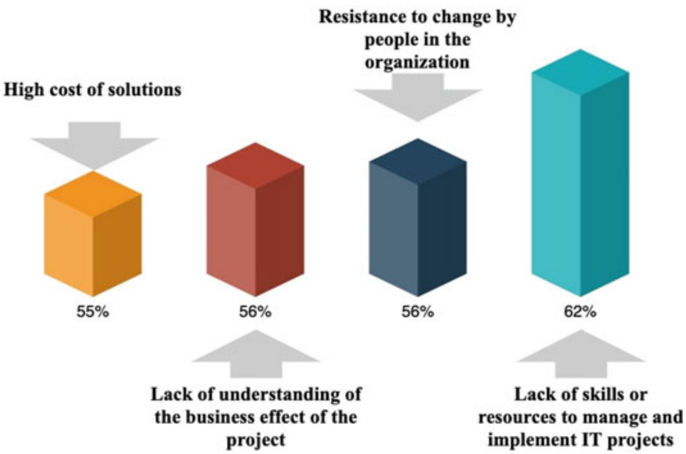

Fig. 1 Obstacles in the digitalization process

"digital" technologies are software and hardware tools and systems that are in demand in all sectors of the economy, creating new markets and changing business processes. If we consider the distinctive features of automation from digitalization, then we can conclude that digitalization can increase the productivity of any processes through the use of digitized information.

One of the rapidly developing digital technologies is big data analysis, thanks to which it is possible to take into account heterogeneous unstructured information, which, in turn, allows a significant influence on various processes.

1.2 Object Life Cycle

An important task of the construction industry is the object lifecycle management [1]. The life cycle of an object can include five stages: pre-design, design, construction, facility operation, demolition. The general diagram of the interconnection of the stages of the life cycle of an object is shown in Fig. 2.

At its core, the life cycle of a construction object can be divided into two large stages—the construction of the object and its operation. When a building is constructed and the process of its operation begins, then over time there is a need to carry out various kinds of RC-W, which may relate to current or major repairs, or to reconstruction [5, 7]. The same type of work can be performed in different ways using different tools, which depends on a number of conditions and resources of the construction organization. An important task in the production of work is to ensure their timely execution [4]. The construction industry differs from a number of other organizational features, which entails the need to take into account many factors affecting its functioning. The more factors are accounted for when organizing a RC-W, the more efficiently they can be implemented.

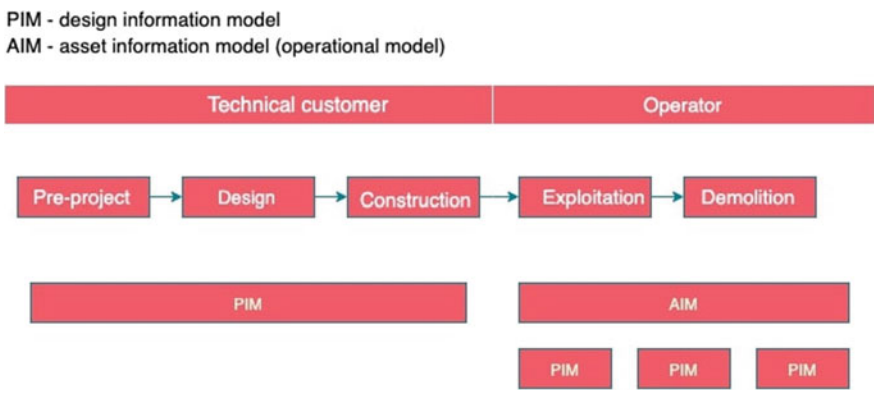

Fig. 2 Two types of information models of a construction object (according to international standards PAS-1192-3:2013 и ISO 19,650)

One of the actively developing technologies for collecting and processing significant arrays of heterogeneous information is "big data" [6, 7, 11]. The term "big data" in a general sense means technologies for collecting, processing and storing structured and unstructured data arrays, characterized by a significant volume and rapid rate of change (including in real time) [5]. Within the framework of this work, working with big data implies to a greater extent the processing of unstructured and heterogeneous information. Thanks to their use, it is possible to take into account the influence of various factors corresponding to a particular type of work and, as a consequence, the ability to ensure organizational and technological reliability (OTR) when organizing a RC-W. By providing OTR, the authors of the article mean compliance with the terms and quality of work with limited resources that a particular repair and construction organization has.

2 Methods

In most of the works devoted to the provision of OTR [8–10], it is proposed to estimate the duration of the use of workings or productivity. The authors propose to proceed from the complexity of the work. In the study under discussion, the formula (1) was taken as the basis for assessing the duration of each type of work:

$$t_i = \frac{V_i * Y_i}{Q_i} \tag{1}$$

where t_i—duration i-th work, i—view R-CW, Y_i—an indicator of the complexity of the i-th job, (person-day/unit units), V_i—total amount of i-th work (unit of work), Q_i—the amount of labor resource (people).

The labor intensity indicator Y_i is a random variable, which means that the work duration will be a random variable.

As part of the study, a survey of experts in the construction industry was conducted, according to the results of which factors were selected that affect the labor intensity of the RC-W. The list of factors is presented in Table 1.

Table 1 Factors affecting the labor intensity of the RC-W

Factor number	Factor name	Designation
1	Experience	X_1
2	Work experience	X_2
3	Constraint	X_3
4	Localization of the work front	X_4
5	Weather conditions	X_5
6	Level of complexity of the work	X_6
7	Innovative technologies	X_7

Table 2 Work experience

Name	Value
No experience (0 objects)	1
Average experience—up to 3 years (3–5 objects)	2
Work experience over 3 years (more than 5 objects)	3

Linear multiple regression was chosen by formula (2) as an application of the tool for analyzing large ones to predict the values of the labor intensity of the RC-W:

$$\mathrm{Y_i} = a_0 + b_1 a_1 X_1 + \ldots + b_k a_k X_k + \varepsilon_i \tag{2}$$

where

$X_1, X_2, \ldots X_\kappa$—parameters (factors) of regression dependence;

$a_1, a_2, \ldots a_\kappa$—coefficients (weights) of parameters;

$b_1, b_2, \ldots b_\kappa$—binary coefficient of significance of parameters for the i-th work (0—not significant factor, 1—significant factor);

ε_i—forecast error.

Each factor can have a different degree of influence on the same type of RC-W. To measure the gradation of the degree of influence for each factor, a list of values is formed that it can take in the opinion of a company specialist. To implement this approach, the authors propose to use the Harrington scale. An example of using the Harrington scale is shown in Table 2.

3 Results

A feature of the mechanism for predicting labor intensity values, in addition to big data, is the generation of values that the labor intensity of an individual RC-W can take in accordance with the range of its normal distribution.

Presented in the Fig. 3, a simplified OTR algorithm for organizing RC-W is a result of the generalization of the above approach to modeling RC-W implementation.

To select the best organizational solution, it is necessary to predict the likelihood of completing work on time for each organizational decision, if there are several. In order to do this, it is necessary to calculate a duration of work for each organizational decision with random values of Yi. Thus, using formula (1), calculate random values for each Yi and then iterate Nr times (where Nr is the number of model iterations, Nr >= 100) for each task in each organizational decision.

To approximate the values of the labor intensity of the RC-W using regression the factors from the Table 1 are used.

In addition of use of "big data", the predicting mechanism for labor intensity has another special characteristic—a generation of all values that the labor intensity of an individual RC-W can take in accordance with the range of its normal distribution.

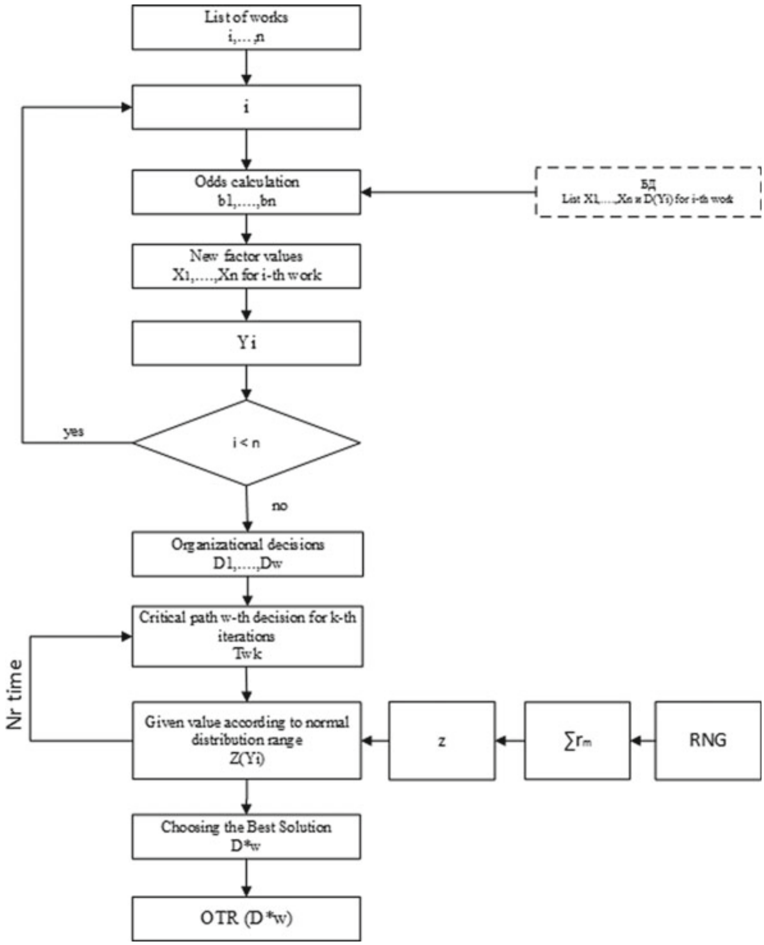

Fig. 3 An enlarged algorithm for providing OTR in the organization of R-CW

To simulate random values corresponding to the labor intensity Yi, it is necessary to generate a series of random numbers r_m, which are uniformly distributed, and then converted into a normal distribution with an expected value of labor intensity Yi:

$$V = \sum_{1}^{12} r_m \tag{3}$$

where m—a quantity of randomly distributed numbers, r_m—a random number, obtained through the use of a random number generator (RNG).

For uniform distribution normalization, the formula (4) is used:

$$Z = \frac{(V - m_v)}{\sigma_v}, \tag{4}$$

where mv—the expected value of the set (3),

σv—the standard deviation of the set (3).

To obtain a new series z with mathematical expectation, the formula is used:

$$Z = z * \sigma(Yi) + \widehat{Yi} \tag{5}$$

In order to estimate the duration of the work of each organizational solution, it is necessary to repeat formulas (3)–(5) Nr times. As a result, the duration of each task in each organizational decision will be predicted Nr times.

To assess the total duration of the RC-W at the time of formation of organizational decisions, we have to determine a total time spent of a most critical path, and then, based on this value, determine a probability of finish all work in a given time frame.

4 Discussion

The study result is the generalized presentations of the methodology based on the use of big data. The use of big data makes it possible to increase the efficiency of the construction organization, namely, to ensure high-quality and timely implementation of the RC-W. Thanks to its applied application, the ability to account for resources and the characteristics of a specific repair and construction organization, it becomes possible to organize work in such a way that the use of the company's resources is most efficient.

5 Conclusions

Summing up, it can be noted that digitalization brings significant changes to the foundations of modern society. The development of digital technologies forces the owners of the management staff of companies to adapt and adapt to modern conditions in order to maintain their competitive advantages.

Big data is one of the progressive technologies that allows increasing the efficiency of a company due to the ability to process heterogeneous information, the results of which, in turn, enables to influence important components of the life cycle of an object. By accumulating data over a certain period of time, it is possible to change and improve many processes within the construction organization, thereby making it adaptive and sustainable in today's changing conditions.

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Transformation of a Small Company's Organizational Structure in the Construction Industry

Nikolay Ivanov, Tatyana Fedoseeva, and Olga Mezentseva

Abstract Almost every commercial organization strives to improve its efficiency and generally sets the main goal of making a profit from the realization of products and services. A great role in this goal achievement is played by a properly formed organizational structure and chosen management mechanism. Therefore, owners of a newly established company willing to become a part of the construction product chain more and more often face the question: what should the organizational structure be and what management mechanism should be implemented for its successful functioning. This article presents the author's concept of applying methods of system analysis and synthesis, the theory of organizational management, and organizational modeling in order to create a rational organizational structure relevant to the specifics of newly created small construction organizations. As part of their research, the authors have defined the possible ways of a company's development in terms of organizational structure transformation that allows implementing a process approach to management. As a result of the study, the hypothesis of the possibility of forming a rational management system for a small construction organization with the transformation of the organizational structure, factoring in the mechanism of its management, was confirmed. Also, there was confirmed the assumption that effective organizational structure depends on the type of core business activities of the company.

Keywords Organizational structure · Transformation · Management mechanism · Small organization · Construction

1 Introduction

During Soviet times, the over fulfillment of plans defined how efficient the management apparatus of the typical construction organization at the level of a trust or construction and installation company was. In this case, the key to success was a rigid hierarchical system that is now known as a line organizational structure. The

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planning and economic department took a central place in this system, with its results becoming an informational and regulatory basis for solving problems of providing the necessary resources for production.

A series of economic crises that shook the Russian economy in the late 1990s and early 2000s led to significant changes in the participants of the Russian construction market. It led to the formation of new organizational structures and widespread introduction of new management mechanisms [1]. Alongside the classical line and staff structure, divisional and matrix structures, still present in some companies, project structures started to form. The process approach started to supplement or simply replace the functional one [2]. The implementation of quality management systems (QMS) in a great number of large construction companies played a significant role in this [3].

The purpose of this study is to analyze different solutions for selecting or forming the most suitable organizational structure to improve the manageability and efficiency of a young company at the stage of spontaneous management that penetrates the market and focuses on the process approach.

2 Methods

Choosing the type of the organizational structure, its formation or transformation is currently a topic of scientific studies in Russia and overseas [4, 5]. Performing in digital economy conditions involves creating an improved organizational structure which becomes one of the tools for increasing the efficiency of an industrial enterprise's management system [6]. Speaking about the importance of organizational structure as a "key element of the corporate structure", Henriques D. and others note that "organizational structures ensure the maximum efficiency of the organization's activity (including internal business processes)" [7]. According to these authors, "creating and implementing these structures helps the staff of commercial and IT departments to maintain a balance between these areas of activity, sets the preferred behavior of employees, simplifies strategy development and tasks setting" [7].

However, most of the research on this topic is focused on industrial corporations and large enterprises [8, 9]. So, the results of these studies cannot be fully applied to organizations classified as small companies. One of the factors that define the competitiveness of a small enterprise is the ability of owners and managers to systematically adapt the business to the market conditions [10]. Forming an organizational structure that fully meets the needs of the enterprise and takes into account external environment factors becomes "an important tool of competitiveness management" [11]. The author of the article [12] says that reorganization brings a significant impact on small and growing companies.

Besides choosing the rational organizational structure for a particular company, an equally important issue is making sure that structure elements fulfill management functions and perform tasks needed for achieving goals. Different approaches to realization the management mechanism, their positive and negative sides are being discussed and compared in the scientific literature [12–14]. The advantages and disadvantages of project management in a company with a functional structure and the role of a project manager in this structure were reviewed in the article [13]. In his work [12], Magdanov P. offered to integrate structural–functional and goal-oriented approaches to management. In her work [15], Knyazeva H. refers to a management model where companies are seen "as complex systems where the processes of self-organization, synergy, and diversity are stimulated to achieve optimal development trajectories". She claims that it is important to consider the elements of spontaneity, non-linearity, self-management while managing these models as well as to keep the balance between these elements and their opposites, which are typically used in traditional management.

Today's operating conditions are characterized by a highly dynamic external environment which means that businesses constantly need to adapt to them, be more flexible in various aspects of their activity, and be prepared for changes in the external environment as well as within the company. As a scientific hypothesis, we propose the thesis that in the mentioned conditions it is necessary to form/transform the organizational structure of the enterprise in interaction with its management mechanism to form a rational management system. This approach will increase the efficiency and therefore the competitiveness of the company, particularly due to the synergistic effect of joint changes, coordination of departments, identification of rights, allocation of duties, authorities, and responsibilities of all participants in the management process.

In general, when the company starts operating on the market and forming an organizational structure, its management apparatus is not very large [16, 17]. The "starting" structure usually represents one of two options: a rigid hierarchical structure in the form of a linear structure (Fig. 1a), or a flat structure (Fig. 1b) [16].

The first option arises when a chief executive is either a founder of the company, taking an active part in its work, or a clear leader authorized by the founders. The second option is a case when the founders of the company are equal partners actively participating in the development of business and daily operations.

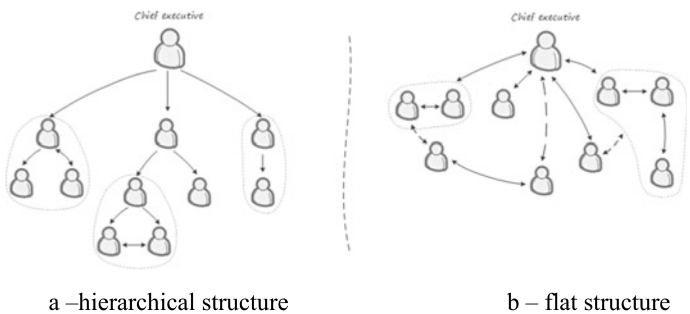

Fig. 1 «Starting» organizational structures of a newly created small company

The small number of employees forces each particular employee to simultaneously perform a number of processes in order to make competitive products meeting the customer s' requirements. And although each process is aimed at performing one of the primary or secondary management functions, there is no regulations description (the regulations have not yet been formed, as the organization is at the initial stage of the process of formalization). Limited human resources in this organization become a barrier to augmentation of the amount of performed work/services. As the solution, the most suitable management mechanism can be introduced and the most rational organizational structure can be formed.

Any organizational structure involves the realization of at least three main connection types between its levels: administrative, technological and socio-psychological. It's not advisable to rely only on the formal methods of modelling while forming an organizational structure. It is also important to consider the experience of successful companies in the industry, the practical experience of specialists, and consultants.

Today, the most important method of organizational design is the systems approach [18], which is being realized through the following interrelated methods (Table 1).

Based on the theory and practice of organizational design in Russia and abroad and considering the specifics of the methods described in the Table 1, we suggest an enlarged list of stages (Fig. 2) that are required when forming the structure of a new company or transforming a current structure into a more rational one that meets the company's goals and objectives.

The desire to formalize the chain of operations and make it practically realizable leads to the necessity of developing an algorithm that describes the list and the order of steps that have to be completed during the analysis and design of organizational structure.

1. Identifying the stage of the company's lifecycle (newly created/young/mature/long time on the market) and its category (small/medium-sized/large).
2. Setting company's goals and strategy.
3. Analyzing if the current organizational structure and management mechanism allow to achieve listed goals.
4. If the answer to paragraph 3 is yes, go to paragraph 13.
5. Carrying out diagnostics of the manageability of the company/state of the organizational system.

    5.1. Checking whether the business process system has been developed in the company.

        5.1.1. If the business processes (BP) are developed.

            5.1.1.1. Is the organizational structure corresponded with them?

            5.1.1.2. If it doesn't correspond. If the organizational structure doesn't correspond to the well-functioning business process system, the departments should be formed according to this system.

Table 1 Components of the systems approach

Method	Example
The analogy method	Suggests designing and forming typical organizational structures based on the industry of activity and the size of the company
Expert system method	Consists of identifying specifics and bottlenecks of the current organizational structure that leads to its ineffectiveness and forming a new rational structure
Goal-oriented method	Involves creating a tree of objectives, developing several organizational structure options to ensure that the objectives of each level are accomplished, comparing these options and selecting the best one in terms of achieving the goals and costs
The method of organizational modeling	It is based on the principle of correspondence of the management unit and the managed units. For this purpose, statistical data and logical analysis are used. Regression analysis in particular helps to establish functional dependence of quantitative parameters of the structure on various factors. Most often this parameter is the number of administrative and management personnel, and the factors are the production volume, the cost of fixed assets, etc. Based on the received dependences the number of administrative personnel is calculated and the decision on formation of necessary departments is made
The method of functional modeling	Involves the identification of all types of organization's functions that are needed for achieving company's goals and ensuring its normal work. Then the number of management staff for each type of activity is calculated and compared with the optimal number of management staff. At last, the decision about the formation of necessary departments is made

5.1.2. BP have not been developed/are partially developed: the business process system is developed along with the organizational structure.

5.2. Analyzing the current manageability level through formalized and systematized description of the organization's operations, including determining the values of manageability parameters of the current management system.

5.2.1. Auditing the manageability of the current management system the following parameters are assessed: the time frame for the implementation of management decisions (MD), % of on-time completed MD, frequency/level of mistakes in the implementation of MD, variability of made decisions, cost price/expenses of the implementation of MD, possibilities for cost reductions, amount of resources needed for the

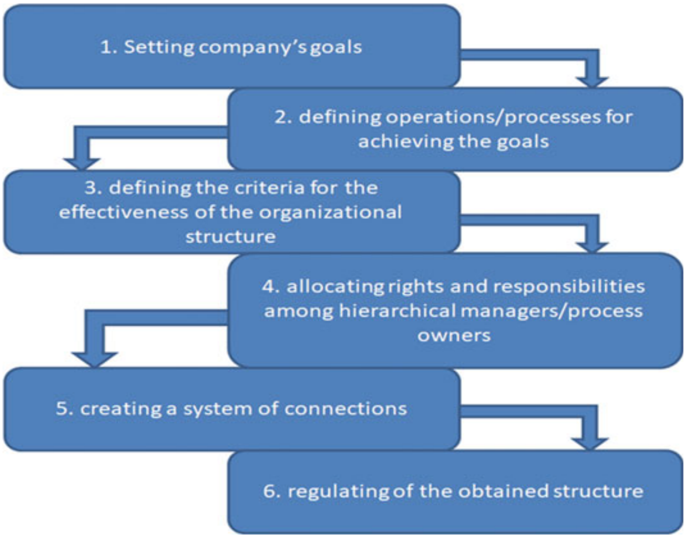

Fig. 2 Enlarged list of structural design stages

implementation of MD, centralization/bureaucratization of made MD, delegation of authority and responsibility, duplication of operations, % of regulations usage, % of formalized operations, % of deviations that are identified and corrected, repeatability of deviations and difficult situations.

5.2.2. Comparing manageability parameters of the current management system with the span of control as well as highlighting problems that need to be corrected, seeing if it compliances with management system properties (integrity, isolation, centralization, adaptability, compatibility, synergy, multiplicity, multicriteria) and then transforming the management system.

6. Identification of other significant factors affecting company's management (market conditions, used technologies, market size, firm size, management style, etc.)
7. Making decision regarding the transformation of organizational structure and choosing the approach to the transformation: revolutionary or evolutionary.
8. Developing a mechanism to eliminate bottlenecks within the chosen approach and according to company's goals, strategy and dominant factors with the allocation of priority areas of management system reorganization.
9. Outlining ways of solving problems for the described events, taking into account the type of business activity and market conditions.

   9.1. Outlining goals achieved with each possible solution.
   9.2. Outlining advantages and disadvantages of each solution.

9.3. Outlining possible priorities and/or criteria for each possible situation.

10. Identifying existing/possible constraints and contradictions for the considered options (resources, role of project manager, etc.)
11. Considering problems that might occur while changing the management system (staff growth, disruption of communications, loss of control over the activities of the organizational structure elements, etc.)
12. Selecting the most suitable option and making a plan for its implementation.
13. Developing measures to maintain the level of manageability of the formed management system (technology and frequency of self-audits, a list of corrective actions).

3 Results

As mentioned before, it is necessary to analyze the situation in terms of significant factors, to choose the management mechanism and the type of organizational structure, as well as their rational combination. These factors may include: the type of activity (production, design, construction or repair and construction, specialized activities); stability/invariability of the product and/or services range (duration of the period when the organization does not change the parameters of production: the object/subject of work); leadership style; availability of funds for the changes to be implemented; business development opportunities; product demand; etc.

As for a particular company, the most effective approach and structure will be those that are maximally adapted to the situation and the company itself. There can be countless number of factors. The most significant factors should be selected and analyzed for choosing the possible option. Working with these factors will have the greatest impact on the result of the organizational structure and management system reorganization.

In our study, we've analyzed a number of Russian companies of construction industry in terms of their organizational structures and mechanisms. Descriptions of these companies and analysis of management mechanisms performed by the "Information systems, technologies and automation in construction" department students as their diploma projects served as information basis for this research. The results of the analysis are shown in Table 2.

The table shows the types of organizational structures used by different companies in terms of their category: large, medium, small, micro companies and enterprises. As can be seen, organic structures focused on the project management are mostly used. The size of the company usually affects the preferable type of project management: micro and small businesses use projectized structure as a regular one, medium-sized companies often prefer to form a separate and temporary project structures and large companies often implement total project management. Various types of mechanistic organizational structures are also in use. In this case, the size of the company often defines the role of functional departments. Thus, large companies prefer a line and staff, engaging experts well-known in a particular field. Small and medium-sized use

Table 2. Relevance of organizational structures depending on the company's size

	Mechanistic	Transitional	Organic
Large	line and staff	divisional product divisional territorial	total project management projectized structure
Medium-sized	line and staff	divisional territorial	separate project structure
Small	line and staff		total project management projectized structure
Micro	line functional		projectized structure

the proven line and staff structure. To some extent, automation tools have an impact on the choice of this structure. Most of automation tools offered on the Russian market are designed mainly for automation a set of tasks of various functional subsystems.

4 Discussion

We have also made an attempt to correlate the organizational structures of the analyzed companies and their management mechanisms. Feasibility of these approaches to the management mechanism realization with the existing organizational structure is shown in Table 3.

Most of the elements in Table 3 reflect the historical correlation of mechanistic management structures with functional and process approaches to management. Project approach has become widespread in Russia over the past 5–7 years; however, it has some significant limitations with mechanistic and transitional structures. In the first case, of all the variety of options for project management only a separate project structure has found application in business. It is used by companies for the one-time or irregular internal needs that are unrelated to the core business. In the second case, the project approach is also irregular. It is most commonly used in the development and/or implementation of a new product in divisional-product structures. At the same time, being a type of organic management structures, project structures allow to implement all the advantages of the project approach to management.

However, the use of organic structures is not always reasonable. It is important to take into account the company's main activity when choosing the organizational structure. Table 4 reflects our views on the feasibility of a certain organizational structure for companies of the construction industry.

Table 3 Feasibility of management mechanism depending on enterprise's OS

Organizational structure		Management approach		
		Functional	Process	Project
Mechanistic	Line	++	+−	−
	Line and staff	++	+	+−
	Functional	++	+	−
	Line and staff	++	−+	−
Transitional	Divisional	++	+	−+
Organic	Weak matrix	−	−	++
	Balanced matrix	−	+	+
	Strong matrix	+−	+	+−
	Project	+−	+	++

Legend: ++ high feasibility of realization; + realization is feasible; +− high rather than low; −+ low rather than high; − low/non feasible.

Table 4. The feasibility of organizational structures depending on company's activity

	Mechanistic	**Transitional**	**Organic**
Construction industry companies	++	++	-
Design firms, Architectural and design offices	-	-+	++
Construction and installation, repair and construction, specialized construction organizations	++	+-	-

Taking into account all of the above, we will consider the possible solutions of the stated problem of choosing/forming the most suitable organizational structure in order to increase the manageability and efficiency of a young company entering the market focused on the process approach.

We believe there are two possible fundamental options:

1. Recruiting qualified employees and combining their knowledge, experience, skills by creating functional departments. Assigning a certain part of the processes to be performed to each of the departments. As the result, a full-fledged line and staff structure will be formed and the process approach will be implemented.
2. Implementing total project management assumes that the entire activity is organized as a group of ongoing projects. In case of the shortage of staff, employees from the outside might be engaged and become part of a project team. Each project is a set of tasks and processes that are performed by the team member who has the most experience and knowledge to complete them on time and at the lowest cost. Project manager is the owner of these processes. A project organizational structure where each project is performed on the basis of process approach is the result of this option.

The final choice should be made basing on the company's activity. Option 1 is preferable for a small enterprise or building company performing a fixed set of construction and installation activities as a general contractor or a subcontractor. For a company whose main activity is the architectural and design or implementation of complex "design+build" turnkey projects, the best choice would be option 2.

5 Conclusions

Over the past 5 years, the Russian construction market has experienced many events, both positive and negative.

In 2017 escrow accounts came into use in residential building construction and the Central Bank of Russia plans to use them in the individual house construction as well. In April 2020 the program of preferential mortgages for apartments in new buildings was launched as an anti-crisis measure and was later prolonged till July 2022. For citizens with children born in 2018 and later another even more favorable program "Family Mortgage" was created. These measures increased housing demand and, as a consequence, the volume of construction. Increased demand has given the opportunity for a large number of small and micro companies to enter the market. These companies offer their services at different lifecycle stages of construction products: providing submittals for individual properties, building materials production, and the construction itself.

At the same time, starting in late 2019 and early 2020 pandemic and its resulting forced self-isolation led to reduction in the activities of a significant number of small construction companies. Some of them could not cope with the consequences of the restrictions that arose during the isolation regime (the need to switch to remote work, the withdrawal of employees on paid leave) and were shut down. The lockdown also led to a shortage of skilled workers on construction sites and caused difficulties for construction companies to find contractor workers. Therefore, some of the companies had to lower the contractor's qualification requirements. Engaging low-skilled contractors required to increase the level and the scope of control which led to the necessity of creating and extending control management departments.

This makes the owners and managers of newly created companies think about managing the business effectively at the first stage of company's formation. Owners of a newly established company that plans to become a part of the construction product chain more and more often face the question: what should the organizational structure be and what management mechanism should be implemented for its successful functioning.

So, the situation discussed in the study is quite real, and therefore the study is relevant and practical. The study results will allow developing construction industry companies to form a modern effective management mechanism considering the specifics of a particular organization.

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Intensification of Timing of Construction Works Under Resource Constraints

Kustikova Yuliya and Korol Svetlana

Abstract The intensity of a single construction process depends on many factors: the number of workers, means of mechanization, weather and climatic parameters and others. Quantitative characteristics of some of them can be established and accepted from the number of possible variants. Such factors are called capacity type resources (renewable resources).

The need for renewable resources at a certain point in time is characterized by the intensity of their consumption and is expressed by the number of simultaneously used units of the resource (workers, means of mechanization, and others).

Resource consumption intensity is the main organizational and technological parameter of buildings erection, which determines the development of construction processes in time and the duration of construction as a whole.

Keywords Construction process · Intensity · Construction organization · Volume of work · Working area

1 Introduction

The planned scope of work of the building organization (production program) is considered satisfactory if it meets the following conditions:

a) the need for workers equipped with mechanization means performing the leading process during the planned year at each moment of time remains constant and corresponds to the labor resources available in the building organization for this purpose;
b) the need for workers for any other (non-leading) processes does not exceed a given value;

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c) the terms of putting into operation of the facilities do not exceed the Policy deadlines.

The use of methods of network planning in their original interpretation, in the process of analyzing the simulation of calendar plans of its implementation, is the cause of frequent deviations of actual project indicators from their predicted values.

Presented in the literature [11–20], the existing methods and models for the study of projects consider the task of reducing the project duration as a priority, but the application of these methods in the resource and calendar planning leads to the fact that the project management largely neglects the multiple aspects of different nature of the project in question.

2 Materials and Methods

The following procedure for organizational and technological calculations is recommended when forming the planned scope of work of a building organization.

Let the project of the planned scope of work have N_i objects (buildings) (where i—1, 2, 3…, n) and processes (main types of work, specialized flows) M_j,; (where j—1, 2, 3…, n), performed by the building organization on its own or by the forces of specialized contracting organizations, the production capacity of which is fully used to perform work in this general building organization.

For each of the objects, the draft of the planned work plan defines the deadlines for putting them into operation t^i_{dir}. It is assumed that the planned (directive) terms of commissioning of facilities are determined both for individual facilities and for facilities that are part of complexes (enterprises). Moreover, when determining t^i_{dir} conditions and requirements for their organizational and technological linkage within the complex are taken into account for the latter [3, 5].

Where $\varphi_в(t)$—is a function expressing the need for labor resources to perform the leading process, which has the greatest specific weight, both in terms of the volume (labor intensity) of work and the duration of its execution;

$f_в(t)$—function expressing the (given) availability of labor resources for the execution of the leading process.

$f_i(t)$—function that expresses the availability of labor resources for any other type of work;

$\varphi_i(t)$—function that expresses the need for labor resources to perform any other type of work.

t^i—completion date of construction of the facility according to the plan model;

t^i_{dir}—directive deadline for completion of construction.

$R^C_в, R^C_i$—general availability of labor resources (number of workers) of the relevant specialty in the building organization.

T_Π—the total annual fund of working time in the planned period (days, weeks, months, etc.);

$Q^i_в$—the planned scope of work on the leading process at the facility, expressed in terms of labor intensity;

$R_в$—The number of labor resource units (work links) required to complete this work for all objects or the intensity of labor consumption.

ΔR—the given value, the question is raised about the inclusion of additional objects (volumes of work) in the contract work plan.

$t^н_i, t^н_{i+1}$—respectively, the start times I-th и $(i + 1)$-th processes;

T_i,—duration of I-th process;

$\tau_{i,(i+1)}$—the size of the organizational break between the beginning of I-th and $(i + 1)$-th processes.

When determining $\varphi_i(t)$ we proceed from the following conditions:

the planning period is divided into elementary time intervals (month, week, day, shift), during which all intensities of resource consumption r^i_i by individual work at each of the objects are considered constant duration of each work T^i_i is taken as a multiple of elementary intervals (days, shifts), that is, it is expressed as an integer. In this case $\varphi_i(t) = R_i(t)$ and a schedule of resource requirements (intensity) for any type of work, except for the leading one $i{=}в$, refers to the number of piecewise-constant (stepwise) functions, or otherwise, the change in the required intensity of resource consumption occurs at times that are coinciding with the ends of elementary time intervals [6, 8, 10].

In these cases, the issue of exclusion from the plan or assignment to the next period after the planned period of some objects or works is resolved, as well as the revision of the terms of commissioning of those objects for which $t^i > t^i_{dir}$. On this basis, proposals are developed for the final formation of a contract work plan.

Solving the problem of finding a satisfactory draft work plan, taking into account the conditions (goals and limitations), is practically reduced to building an initial and subsequently optimized organizational and technological model of the planned scope of work. Such models are developed on the basis of network, cyclogram or linear models for individual objects. At the same time, the main attention is paid to the mutual coordination of construction and installation works (special streams).

The coordination of works is carried out in terms of organizational and technological-logical sequence, combination, direction of development, methods of organizing construction processes, duration and timing of their implementation. Variants of the sequence of processes are determined by possible permutations in the order of their execution and are associated with the composition and placement of structural types in the building, as well as the technological connection of structural elements with each other.

In all cases, when choosing the sequence of execution of processes for the construction of facilities, it is necessary to strive to provide convenient conditions for the continuous work of individual teams, open a wide front for general construction work and work on the installation of technological equipment, and maximize their implementation [1, 4, 9].

The interconnection of related processes with their combined execution is carried out by two different methods, depending on the nature of the formation of working zones (work front).

The linking of processes by the first method is carried out in the case when the working area of each subsequent process is directly formed by the products of the previous one, and the front of the work is a finished structural element or part of it. In other words, in this case, there is a direct technological connection between the structures, and the formation of working zones (work front) is associated with the conditions for the sequential emergence of individual structures and parts.

The main condition for linking processes with the first method is that the size of the grips can be taken in a wide range, from the size of the working area per unit (link) of contractors to the size of the full front of work in the process, that is, throughout the object.

The linking of processes by the second method is carried out in the case when the working area of the process is formed as a result of the execution of one or more previous processes, the products of which are not the immediate front of the work. The working area (front of work) is formed in this case by a certain building volume and is associated with the conditions for the sequential emergence of parts or the entire building. The condition for linking processes with the second method is that the size of the working areas is limited by the requirements for the readiness of certain parts (sections) of the building, depending on the organizational decisions made for the production of work, for example, finishing work, installation of technological equipment with the launch of the heating system in parts of the building, etc.

The working area (front of work) in all cases is understood as a section of the building that determines the spatial, temporal and technological possibilities for placement and productive work during a set period of time for the accepted number of contractors [2, 7].

3 Results

Let us consider the conditions for linking the first method of two organizationally related (adjacent) construction processes.

Let there be two adjacent undivided (simple) processes (private flows) with numbers i and $(i + 1)$, performed in combination. We denote by Q_i; Q_{i+1} (the required labor intensity or the amount of work for each of them, through r_i; $r_\mathrm{i} + 1$, respectively, the number of contractors (the intensity of consumption of labor or machine resources) for the execution of each process.

It is required to find the size of the organizational break between the beginning of each of the processes (or the time during which the work front for the $(i + 1)$-th process is formed in the i-th process), denoted by $\tau_{i,(i+1)}$, after which the process $i + 1$ could be executed for a given number of contractors r_i and r_{i+1} and a given complexity of execution of each of the processes Q_i and Q_{i+1} continuously, with a necessary and sufficient front of work at every moment of time.

Let us introduce the value $q'_{i,(i+1)}$, which characterizes the scope of work (the size of the plot), expressed in terms of the labor intensity (or the amount of work) of the

i-th process and required for one contractor (link, team, machine) of the $(i+1)$ -th process. Let's name this value an organizational and technological module.

For example, $q'_{i,(i+1)} = 10 men$[1] $=$ day./men[2] means, that in order to provide the scope of work for one worker (or link) of the 2nd profession (performing the second process), according to the first process, it is necessary to complete the amount of work with a labor input of 10 men—day., which is, for example, 10 m of an open trench, etc.

Then, in time $\tau_{i,(i+1)}$ for the i-th process, the amount of work with the complexity of $r_i \tau_{i,(i+1)}$ will be completed, and for the $(i+1)$-th process—0. During the time Δt the amount of work with the complexity $r_i \Delta t$ will be performed for the i-th process, and by the $(i+1)$-th process $r_{i|+1}\Delta t$. Through time Δt, thus, the scope of work on the i-th process, expressed in terms of the complexity of the i-th process for the $(i+1)$-th process, will be equal to.

$$r_i \boldsymbol{\tau}_{i,(i+1)} + r_i \Delta t - r_{i+1} \Delta t \frac{Q_i}{Q_{i+1}}, \quad (1)$$

where $r_{i+1} \Delta t \frac{Q_i}{Q_{i+1}}$—a value expressed through the labor intensity of the i-th process, by which during the time Δt the scope of work on the i-th process decreased due to the fact that the $(i+1)$-th process began to be performed.

Thus, for all Δt at $0 \leq \Delta t \leq T_i - \boldsymbol{\tau}_{i,(i+1)}$ this inequality must be fulfilled like this

$$r_i \boldsymbol{\tau}_{i,(i+1)} + r_i \Delta t - r_{i+1} \Delta t \frac{Q_i}{Q_{i+1}} \geq q_{i,(i+1)} r_{i+1} \quad (2)$$

By transforming this inequality, we get

$$r_i \boldsymbol{\tau}_{i,(i+1)} \geq q_{i,(i+1)} \frac{r_{i+1}}{r_i} - \Delta t \left(1 - \frac{r_{i+1} Q_i}{r_i Q_{i+1}}\right) \quad (3)$$

Exploring it, we get it
if $\left(1 - \frac{r_{i+1} Q_i}{r_i Q_{i+1}}\right) > 0.$
or that the same,

---

[1] r_i—the number of contractors for the i-th process out of the total accepted number of them, which is busy preparing the work front for all accepted performers of the $(i+1)$-th process.

[2] Due to the fact that the working area and scope of work for contractors of the $(i+1)$-th process (flow) is formed by the finished product of the organizationally related (adjacent) i-th process (flow), by the size of the "scope", which determines the size of the organizational and technical module, we mean the scope of work on the production of the finished products by the i-th process, enclosed in the work area, necessary and sufficient for placing materials, equipment, fixtures and fittings in it and the smoothness of labor movements of workers. The scope of work in such a work area should be at least one shift.

$$\frac{Q_{i+1}}{r_{i+1}} > \frac{Q_i}{r_i},$$

inequality (3) will hold under the condition

$$\boldsymbol{\tau}_{i,(i+1)} = \frac{q'_{i,(i+1)} r_{i+1}}{r_i}$$

i.e. at $\Delta t = 0$
if $\left(1 - \frac{r_{i+1} Q_i}{r_i Q_{i+1}}\right) < 0$, that is $\frac{Q_{i+1}}{r_{i+1}} < \frac{Q_i}{r_i}$.

inequality (3) begins to be fulfilled under the condition $\boldsymbol{\tau}_{i,(i+1)} = \frac{q_{i,(i+1)} Q_{i+1}}{Q_i} + \frac{Q_i}{r_i} - \frac{Q_{i+1}}{r_{i+1}}$ i.e. at $\Delta t = T_i - \boldsymbol{\tau}_{i,(i+1)}$.

Since $\frac{Q_i}{r_i} = T_i$ $\frac{Q_{i+1}}{r_{i+1}} = T_{i+1}$ the condition for linking two processes for the case when the scope of work is not idle can be written by communication equations that determine the value of the minimum organizational break (readiness of working zone) between two adjacent processes:

$$\boldsymbol{\tau}_{i,(i+1)} = \frac{q'_{i,(i+1)} r_{i+1}}{r_i}, \text{ when } T_i < T_{i+1}, \tag{4}$$

$$\boldsymbol{\tau}_{i,(i+1)} = \frac{q'_{i,(i+1)} Q_{i+1}}{Q_i} + T_i - T_{i+1} \text{ when } T_i > T_{i+1} \tag{5}$$

The second method linking condition is written by the following coupling equation

$$\boldsymbol{\tau}_{i,(i+1)} = \max\left(\sum_{\nu=1}^{n} \frac{Q_i^{\nu}}{r_i} - \sum_{\nu=1}^{n-1} \frac{Q_{i+1}^{\nu}}{r_{i+1}}\right) = \max\left(\sum_{\nu=1}^{n} T_i^{\nu} - \sum_{\nu=1}^{n-1} T_{i+1}^{\nu}\right) \text{with all } 1 \leq n \leq l. \tag{6}$$

where l-number of sites $Z\nu$, $\nu = 1,2,3,\ldots l$.

Under this condition, the (i + 1)-th process can be performed continuously at the scope of the I-th process, and the downtime of the sections will be minimal.

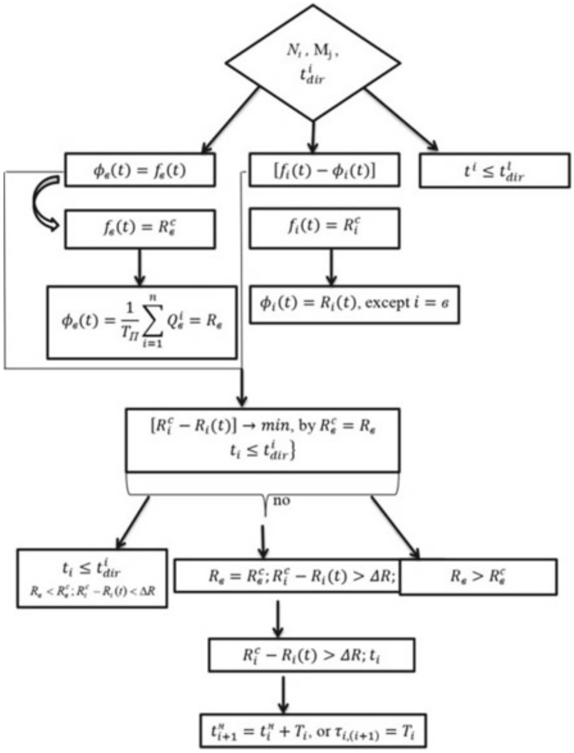
In this case, the parameters (duration, labor intensity, intensity of resource consumption) are related by the following relationships:

$$T_i = \sum_{\nu=1}^{l} T_i^{\nu} \tag{7}$$

$$Q_i = \sum_{\nu=1}^{l} Q_i^{\nu} \tag{8}$$

$$T_i^{\nu} = \frac{Q_i^{\nu}}{r_i} \tag{9}$$

Fig. 1 Algorithm of a rational sequence of complex construction works



4 Conclusion

The main rule when choosing the sequence of repair and construction processes is to ensure sufficient front and scope of work for the continuous work of all specialized teams, as well as the maximum combination of individual types of work in order to reduce the total duration.

The interconnection of work in terms of the organizational and technological sequence in the formation of a plan for the implementation of a complex of construction and installation works by a contractor is based on the principles of providing convenient conditions for the continuous operation of individual links or teams, the maximum combination of work to reduce the timing of their implementation.

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Application of Time Reserves for Risk Management in Design

Galina Malykha and Alexander Pavlov

Abstract Although the design takes a relatively small share in the cost of a facility, it is comparable to construction in duration. The authors have developed a list of factors that can potentially influence the duration of design for government orders. They include the modification of a technical assignment by a customer, contradictions in the current legislation, difficulties in the recording of equipment characteristics, the insufficient cost of orders, etc. The specified list of factors was distributed in the form of a questionnaire among designers who assessed the probability of the occurrence of any factors, as well as the potential damage by them to the time limits for the execution of the design documentation.

As a result of analyzing the questionnaires, the main factors affecting the design process have been determined. The largest weight was obtained by the risk of the modification of a technical assignment by a customer, as well as the necessity to constantly revert to the fulfilled project for making alterations and amendments. As estimated by specialists, the possible risk of increasing the design duration was more than 33% with a mean square deviation of 15%.

For compensation of the possible slippage of design works from the contractual duration, it is expedient to include the time reserve, which would allow to agree upon and approve design decisions, to make necessary amendments, and to participate in the state expert review procedure in a calm atmosphere. Thereby the risk of an unexpected increase in the duration of the investment cycle of the construction facility is reduced.

Keywords Investment cycle · Design of buildings and structures · Design delays · Risk · Reservation

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1 Introduction

Design is one of the most important stages of the life cycle of the capital construction facility. It is at the design stage that the key technical decisions are laid out. At the same stage, the improvement of decisions, their optimization are carried out, the requirements to construction are created, and the value and efficiency of the facility are determined. This is the explanation why the "project" word means both the totality of necessary documentation for the construction or reconstruction of a facility and the goal-oriented process of creating or improving a large system (national project, investment project).

For a construction project, it is highly important to forecast the development in time and in space, to assess the division of works concerning time [1]. The critical success factors of the construction project are not only the cost and quality of works but also the timing for their completion [2, 3]. Time lags and cost overruns are noted to be customary in the construction of different facilities [4]. Delay in the commissioning of the facility even with preserving the planned cost does not enable to describe the project as successful [5, 6]. This was particularly evident during the pandemic [7, 8].

In the majority of publications, the main indicator of project failure is cost overruns [9, 10]. However, one of the reasons for cost overruns and time lags is the non-fulfillment of critical events during the project development, including delays in the design documentation [11–13]. Some researches show that large projects demonstrate a lesser deviation according to the value, however a greater deviation according to the timing for completion [14, 15]. Excessively large projects do not often show expected effectiveness because of insufficiently good construction management [16, 17]. Broadly speaking, the increase in the cost and the increase in the construction period do not necessarily correlate [18].

A relatively small number of papers are devoted to the assessment of delays in the design period. It is emphasized that the factors increasing the design period and compromising the quality of design are financing delays, absence of risk management, insufficient qualifications of the staff, poor communications among the contractors, etc. [19, 20]. Some papers take into account the national peculiarities of design and construction processes [21, 22]. The specialists questioning and polling methods were generally used for research.

Although the design takes a relatively small share in the cost of a facility (usually about 5–7%), it is comparable to construction in duration, and taking into account front-end engineering design and detailed design it exceeds the duration of construction. Therefore, the reduction of the design period decreases the duration of an investment cycle. On the contrary, the increase in the design period leads to the growth of the cycle duration. However, the capital efficiency is adversely affected to a far greater degree by the design errors and untimely issue of detailed documentation.

2 Methods

A wide range of factors affects the quality and time limits of issuing the design and detailed documentation. The authors analyzed the progress of designing several socially significant construction facilities and prepared the list of primary factors that have a considerable influence on the results of design works.

The authors performed an analysis of the significance of factors by polling the specialists. More than twenty specialists involved in the design of eleven facilities under construction and reconstruction were polled; they included healthcare organizations, expert centers, exhibition buildings, etc. Questionnaires with a list of factors that may affect the duration of the design were distributed.

Potentially significant factors included the following.

Modification of a technical (architectural) assignment by a customer during the performance of the project. Such changes very often occur without extra payment and additional time allocated for design. In any case, the standard terms and conditions of a design contract do not stipulate this. Making amendments to the assignment is forbidden only concerning the material conditions of a contract, while it is a disputable matter whether a customer considers, for example, the change in the composition of premises to be the material condition or not.

Entry of new technical guidance documents and design rules into effect. The designer must take into account the availability of thousands of technical regulations, codes of practices, international and Russian standards, state, regional and local rules and regulations. About 5–10 new documents, amendments and supplements to them are approved daily. If a document came into effect before the time of carrying out an expert examination, the designer should take it into account.

Contradictions in the current legislation. For example, the price of design work of the first stage is usually 40%, and that of the second stage is 60% of the total cost of design. At the same time, for carrying out the expert examination (usually after the first stage) the exact estimate cost of the facility to an accuracy of not more than 2–3% is necessary. i.e. almost all design documentation must be prepared. Such contradictions increase the uncertainty, under which the design organizations operate.

The contradictions may also include *the impossibility of determining the model* and recording the parameters of equipment if there has not been a competitive tender concerning it before design. Otherwise, the designers cannot take into account the equipment loads and its dimensions. But the competitive tender could not be held, because the design documentation is not fulfilled – as a result, we face a vicious circle.

Difficulties in design management with the *involvement of subcontracting organizations.* The disintegration of large design institutes and their replacement by architect bureaus, which sometimes cannot provide a full cycle of design and survey works, leads to the existence of small subcontracting organizations and individual entrepreneurs. In such a case, the general designer has to spend time and efforts on the arrangement of contractual relations, inspection, and correction of the results of subcontracting design. Additional difficulties are caused in this case by modification of a technical assignment by a customer since the assignments have already been issued to subcontractors, and it has the right to demand payment for readjustments.

Concurrent execution of several projects by the same team of designers. After supplements of the customer, changes during the approval process, amendments of the expert examination, the corrections are made by the employees who already engage in a different project. They have to get distracted, recollect “affairs of the long past days”, and even search for subcontractors. In so doing the labor productivity is lost.

Low costing standards for design and survey works. In foreign countries, the fee of a design organization is usually set as a percentage of the planned cost of the facility, while the designer earns about half of the funds on project administration during the period of holding tenders and erecting the facility itself. In Russia, to avoid the increase in the cost of facility construction financed by the state, the prices for design are fixed and relatively low. There are no rates for a considerable part of design works, especially in the field of reconstruction and overhaul repairs.

Deterioration in quality of specialist training for the construction industry. In post-Soviet times, new non-state educational institutions appeared which even for a valuable consideration may not always ensure an adequate level of education, despite the paper barrage of attestations, accreditations, and licenses. Joining Russia to the so-called “Bologna process” has not added the quality of education as well: it is no secret that the graduate with a Bachelor’s degree looks like an alien at the construction site and by his/her knowledge differs little from the graduate of a college (read: a former vocational-technical school).

The listed negative factors lead to time delays and increased costs for the development of projects. Lack of financing was not discussed because the considered projects had government financing. The issue regarding the change in the prime cost is subject to further study with an analysis of change in labor inputs and salary of designers. In this paper, such a task has not been set.

3 Results

As a result, the following average values were obtained (Table 1).

The average weighted increase in the duration was determined taking into account the frequency of observation of each factor. The specialists polled put the modification of a technical assignment by a customer in the first place, this was followed by the concurrent execution of projects and corrections. The impact of other factors is considerably lower. In general, the risk of increase in the design duration with the combined effect of the specified eight factors was 33.6%. The mean square deviation for different projects was 14.8%.

Please note that the specialists were also asked questions on changes in the cost of works because of the impact of the specified factors. Almost all of them answered that no change in the cost occurred.

Table 1 Analysis of the factors affecting the design period

Influencing factor	Occurs with frequency (%)	Extends the period by: (%)
Modification of the technical assignment	30.0	31.8
Changes in the regulatory documents	10.9	14.5
Contradictions in the legislation	11.8	11.8
Recording of the parameters of equipment	15.5	15.0
Engagement of contracting organizations	25.5	6.4
Concurrent execution of projects and corrections	50.0	20.9
Low prices for design	18.2	13.6
Quality of specialist training	3.6	10.0

4 Discussion

The specified impacts are risk factors in the operation of a design organization. Please note that most of the specified factors are external, i.e. cannot be managed promptly by designers. For example, to reduce the risk of modifications of the technical assignment it is necessary to describe in detail in contracts the obligations of customers and to demand compliance with contractual terms. However, according to the existing rules, a government contract shall be formed by a customer, and, as a rule, making amendments shall not be allowed. Concurrent execution of projects and correction of remarks are practically impossible to exclude because it depends on the design sequence. The same applies to other factors.

Thus, it is necessary to ensure minimization of risk for design organizations, without recourse to significant changes of legislative and economic principles of design. The theory offers plenty of ways of risk management, but the principal ways come down to two methods: insurance and reservation.

The design organizations seldom resort to insurance against contracting risks. Firstly, the conditions of such insurance have not been sufficiently developed. Secondly, the tariffs for such insurance can be rather burdensome for the budget of an organization.

As for reservation, it is provided for by the rules only for the estimated cost of a facility and makes up 2% for civil buildings, 3% for industrial buildings and 10% for unique, technically complex and dangerous buildings and structures. As a rule, the customer leaves this reserve for the construction stage and does not transfer it to the designers. The authors also consider it expedient to reserve the cost for design and survey works, but this issue requires further investigation.

No reservation of time is carried out either for the design stage or for the construction stage. The timing schedule of design and construction is calculated, as a rule, without time reserve. Therefore any failure during the critical path works (design and survey, construction and installation, when purchasing equipment or services) has an impact on the subsequent processes or leads to the project delay in general.

Thus, the introduction of a time reserve for design and construction may be considered an efficient method of risk mitigation. For design and survey works it can be about 15%, thus sharing the risk equally between the customer and the work performer. The contractual period for performance can be left under regulations, and the reserved time will be allocated by the customer upon appropriate justification. For instance, additional time must be allocated for the introduction of modifications of the technical assignment not stipulated by the contractual terms or of the technical guidance documents. A similar reserve must be provided for the subcontractor agreements between design firms.

5 Conclusions

Based on the achieved results, the authors offer to include the time reserve of about 15% of design works according to the contract for compensation of the possible slippage, which would allow agreeing upon and approving design decisions, to make necessary amendments, and to participate in the state expert review procedure in a calm atmosphere. Thereby the risk of an unexpected increase in the duration of the investment cycle of the construction facility is reduced.

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Development of a Model for Managing the Terms of NPP Construction Projects Based on Production Control

Ostrovskii Roman

Abstract It is impossible to manage a large-scale construction project, such as power plants, without working out issues of time and resource management. The main method of building duration management is calendar and network planning. The development and updating of schedules are carried out at different levels, usually 3–4 levels are used. Lean production methods are used in planning to reduce losses. They enable to optimize the planning system, improve the quality of construction and installation work, and ensure the profitability of contracting organizations. Monitoring and analysis of level 4 schedules, as well as weekly daily and shift tasks is carried out at the information center of the construction manager. Analyzing the schedules of work, schedules of personnel and construction machines, a pattern was noticed: with an increase in the number of resources, production also increased over a certain period of time, and the pace of work increased. This was facilitated by a set of tools for production control and analysis: visualization, timing and mapping of technological processes. As a result of the analysis, it was recommended to use the mechanisms of the production system based on the concept of lean production at all stages of construction and installation work. The use of the reviewed software packages to improve project management, including time and risk management, is also recommended. The directions of further research are justified.

Keywords Power plant construction · Project management · Terms management · Risk management · Scheduling · Lean production

1 Introduction

The project management of nuclear power plants construction as technically complex and unique objects is methodologically based on the latest and effective tools in the activities of design and construction organizations, municipal and state customers, developers and other project participants [1, 2]. However, this activity is not possible

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without careful consideration of issues that occupy a special place among the general principles of project management [3, 4] and related to the management of time and resources [5]. To this end, it is necessary to develop a model for managing the duration of NPP construction projects based on production control and analysis, risk management parameters and the implementation of production system tools.

The purpose of this study is to study processes for which it is possible to use the system of time reserves [6, 7] for optimizing the project implementation time at all stages of the construction [8]. We use also the production system of Rosatom (PSR) as a culture of lean production and a system of continuous process improvement to ensure a competitive advantage at the global level [9].

Lean production is a concept of business organization focused on creation of attractive value for the consumer by formation of continuous flow of value creation with coverage of all processes of organization and their constant improvement through involvement of personnel and elimination of all types of losses [10–12].

The PSR is based on several principles that urge employees to be attentive to the requirements of the customer (not only in relation to the final consumer, but also to the consumer site, consumer workshop and even the subsequent operator); solve problems at the place of their occurrence; integrate quality into the process, do not scrap; identify and address any losses, and others.

When studying these instruments, it is possible to conduct their conditional division into two large blocks: humanitarian-psychological and technical-applied. The first block includes office standards that describe behavioral and organizational recommendations. However, within the framework of this article, technical and applied tools lying in the plane of construction production and sold at the NPP construction sites are of interest.

These areas of project management in the nuclear industry are managed at various stages with the help of many tools [13, 14], among which four main aspects should be highlighted, interconnected and more influential to the correctness of decision-making by the project management. Consider these directions.

Risk identification and rapid response are carried out by project managers and their deputies at operational meetings, sessions, headquarters meetings and Obey meetings. In the process of risk management, process managers and coordinators are obliged to use and timely enter risk information into the automated risk management system (further—ARMS) [15].

On the basis of the performed work on risk management through the developed and implemented preventive measures, part of the risks from the list of active at the beginning of the reporting period (for example, year) may not be realized and closed [16]. The risks realized and the impact on the timing shift of key events can also affect the adjustment of production programs and the approval of the budget for subsequent periods. Sustainability integration in the processes of managing and delivering projects is essential to ensure the sustainability of the projects [17].

Project timeline management includes processes that ensure timely execution of the project plan. The main sub-processes of time management are:

1. Definition of the scope of work of the project;
2. Definition of work relationships;
3. Evaluation of duration of works;
4. Scheduling of the project;
5. Schedule management.

Inputs to the project timeline management process are the contract, the Work Breakdown Structure (WBS) and the project description. When implementing schedule management in the project execution phase, the main task of the project manager is to reasonably choose the necessary maneuvers of resources—material, temporary, human, financial—in order to prevent disruption of project deadlines.

2 Methods. Scheduling and Network Planning

The main output of the business process is the project time schedule (project baseline). Structurally, the time management process for NPP construction projects in Russia and abroad is divided into the following stages:

<table>
<tr><th>№</th><th>Scheduling</th><th>Network planning</th><th>Time management</th></tr>
<tr><td>1</td><td>Development and updating of Level 1 schedule</td><td rowspan="5">Develop network maps (models) for any processes and key events in order to find and work with critical (problem) areas</td><td>Signing contracts, concluding an intergovernmental agreement, drawing up an investment program</td></tr>
<tr><td>2</td><td>Development and updating of Level 2 schedule</td><td rowspan="2">Development and updating of schedule of key payment events, production programs</td></tr>
<tr><td>3</td><td>Development and updating of Level 3 schedule</td></tr>
<tr><td>4</td><td>Development and updating of Level 4 schedule</td><td>Development and updating of thematic plans for the quarter, month</td></tr>
<tr><td>5</td><td>Development and updating of weekly daily assignments</td><td></td></tr>
</table>

It should be noted that this approach has a number of drawbacks in the management of NPP construction time. A large number of structural subdivisions that have certain terms management provisions in their functionality are in many cases understudies of each other—there is a factor in the introduction of management functions. This can ultimately lead to different scenarios in which participants in the same project «live».

3 Production Control and Analysis

As part of the work of the engineering division of State Atomic Energy Corporation Rosatom or ROSATOM, local administrative and regulatory acts have been adopted that determine the goals, tasks and standard process of planning and production control to identify, reduce losses in the processes of the planning system, based on weekly daily planning, the use of lean production tools.

These guidelines are used when optimizing the planning system to improve the organization and quality of construction and installation work, to prevent the breakdown of construction deadlines and to ensure the profitability of organizations.

On a daily basis, process deviations from targets are monitored at key stages of the process in order to quickly identify deviations and take measures to eliminate them.

In order to increase the efficiency of information perception and make correct operational management decisions, the production indicators of the facility construction process are visualized on production control and analysis stands, and in the information center of the construction manager. These resources monitor and analyze level 4 schedules, weekly daily and shift assignments, identify conflicts and problems, as well as develop compensating measures and plan backup operations.

To study the work of services whose functionality includes production control and analysis, we give an example of the project of the El Dabaa NPP. As part of its implementation in the Arab Republic of Egypt, it is planned to build 4 power units with a capacity of 1200 MW each with reactors of type VVER-1200 (water-water power reactor) generation 3+. NPP construction is carried out in accordance with the package of contracts, which entered into force on December 11, 2017.

Turning to the terminology used in construction to indicate the time frame, the project is at the beginning of the active phase of construction and installation work of the preparatory period and is partially in the design stage [18, 19]. The completion of work on the removal of fertile soil in the patch of the development of 1 and 2 NPP units and the construction of the pit of block No. 1 by the Egyptian Contractor Arab Contractors was on May 29, 2021 [20].

According to the working documentation, the total volume of excavation of the pit of unit 1 is 1,048,065 cubic meters. Contract completion date October 28, 2021. Based on the data of weekly daily tasks and daily reports for the summer period of 2021 on the daily development of the contracting organization, verified by the Field Engineering employees of the ASE JSC branch, it is possible to draw up an actual schedule for the performance of work in m cubic meters on excavation with accumulative total (Fig. 1):

The production of equipment for the indicated period of work amounted to about 50 thousand machine hours (6,250 machine-shifts). The number of employees of the contracting organization amounted to about 130 thousand person-hours (16,250 person-shifts).

Analyzing the traffic schedules of machines and mechanisms (blue), as well as the movement of contractor personnel (orange), a pattern can be noted—with an

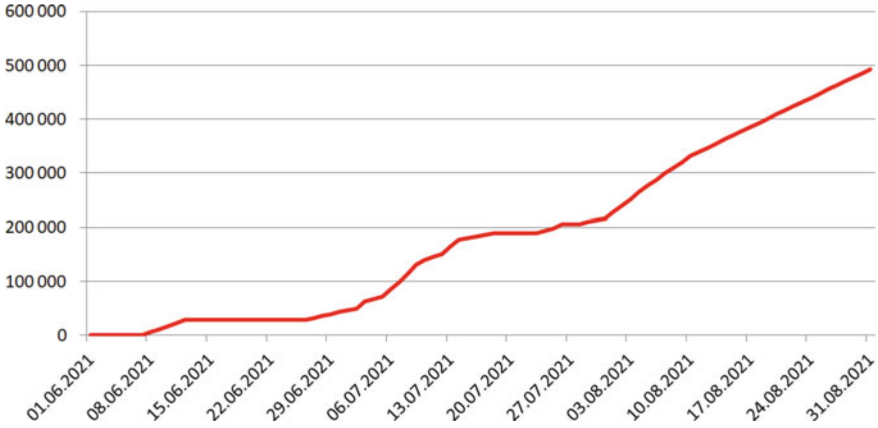

Fig. 1 Dynamics of excavation in the pit of the main body of power unit No. 1 of El-Dabaa NPP

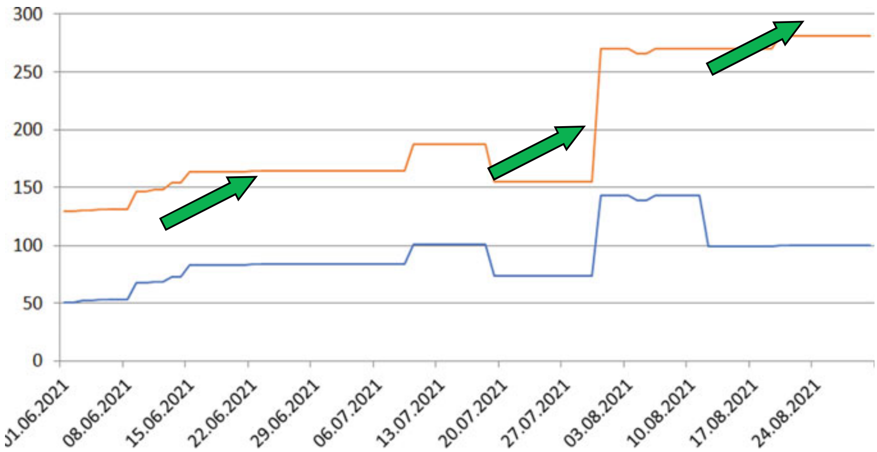

Fig. 2 Dynamics of the contractor's personnel movement

increase in the number of resources, the production curve showed an increase in the pace of work in three sections of the schedule (Fig. 2).

These areas (stages) correspond to the periods of active study of problems and forecasting of risks of deadlines failure directly at the construction site between the contractor's personnel and representatives of the general contractor—ASE JSC using visualization tools, timing and mapping of the excavation process.

Systematic analysis by the author of the study of the average daily production according to the data of daily excavation monitoring showed significant delays from the approved schedule of work. Timing observations and measurements of the average rate of work of individual units of construction equipment made it possible to calculate and map the entire process. The analysis at all three stages resulted in the number of equipment that needed to be further mobilized in order to increase daily production and to avoid disruption of the deadlines. The graphs presented show that these compensating measures were successfully implemented on site.

However, according to the author of the study, who oversees this area of the project, a high-level assessment of the timing and cost of the project by his management at various stages of its implementation is often made without taking into account the data provided on the fact of production control and analysis. This factor can lead to negative consequences in the form of accumulation of "snowball" of unfinished and unfinished works, to delays in the timing of key events of KPI maps of company leaders, divisions and the State Corporation. This, in turn, often leads to a change in project management.

4 Results. Analysis of Design Risks at all Stages of Work

As a result of the analysis, it was established that during the implementation of projects in the nuclear industry there is insufficient clear management of potential and emerging risks in the process of main activity. Planned risk management procedures are implemented cyclically and are implemented in three areas:

- systemic risks;
- risks of key events of the project;
- budget risks.

As part of the response strategy, risks can be divided into three levels of manageability:

1. High manageability—controlled risks, the causes of which can be eliminated by management efforts;
2. Average manageability—uncontrolled but managed risks, the causes of which cannot be eliminated by management efforts, but the probability and consequences of implementation, which can be changed by proactive measures;
3. Low manageability—uncontrolled and unmanaged risks, the causes of which cannot be eliminated by management efforts, and the probability and consequences of implementation of which cannot be changed by proactive measures, but information about them can be escalated to a higher level of management.

Several risk response strategies can be distinguished:

- Evasion: a method that involves changing the planned actions in such a way as to eliminate the threat or protect the project from its impact.
- Transfer: a method involving the transfer of part of the consequences of a risk event to a third party (including insurance, guarantees, etc.).
- Reduction: a method to reduce the risk probability and/or risk impact on the project by developing preventive measures.

- Acceptance: a method of conscious acceptance of the possible consequences of risk realization, where the implementation of activities is not feasible or economically feasible. If you choose the "Acceptance" strategy for critical risks, a program for monitoring this risk must be established.
- Escalation: a risk response method that recognizes that risk is outside the scope of project management, and risk management information/responsibility is transferred to a higher level of management, preventive and responsive actions are developed and timelines are defined.

As a result of the research, it was recommended to introduce separate tools of the Rosatom production system (PSR). These standards have clear and consistent mechanisms over the years on various projects. For example, the standard for organizing the work of the production control and analysis facility stands or the construction manager's information stand allows the design services to collect information and analyze it, as described above using the example of the pit arrangement of El Dabaa NPP unit 1. Standards for working with lessons learned and best practices of reference projects make it possible through certain databases and software to prevent the implementation of risks and problems and to carry out their mitigation in advance.

Thus, the study of the planned and actual data of the 4 time management bases mentioned above for nuclear power plant construction projects is possible using several software complexes and resources. To improve the reliability of the commissioning of the facility, it is necessary to establish not only a cost reserve, but also a time reserve. The calculation of such a reserve and the stimulation of reducing the duration of construction can be areas of further scientific work.

5 Conclusions

A systematic study done by the author starting from 2018 has revealed:

- lack of time reserves and, as a result, significant financial costs in the implementation of NPP construction projects;
- excessive duplication of many functions within projects;
- actual absence of interconnection of scheduling and network planning units for management standards, production system and risk management;
- fundamental differences in approaches and tools for managing these blocks among organizations of the nuclear industry and even within the engineering division of Rosatom.

The elimination of these contradictions becomes necessary in the conditions of fierce competition in the nuclear industry market, requires deep scientific research and the creation of conditions for the most optimal project management.

The analysis of the aspects listed in the article, the development of a model and formula for calculating the timing and cost of NPP construction projects, as well as the creation of a system of time reserves on pre-contract, preparatory and main implementation periods is of scientific interest and can be used as a subject of dissertation research.

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The Distribution of Capital Investments in the Construction Process for Multifunctional Buildings

M. A. Razakov, A. V. Gorbenko, S. A. Sartekenova, and R. V. Razakova

Abstract There are the distribution of enlarged indicators costs for the multifunctional business center with a hotel and sports complex in Nizhny Novgorod. This facility was designed for the 2018 FIFA World Cup hosted by the Russian Federation. Construction period lasted four years starting in 2014. Authors have described the distribution of various stages total costs for this type of buildings. Researchers have investigated the estimated costs of salary fund and materials sections for all multifunctional building construction's stages. Authors have deeply analyzed the capital costs for engineering parts of this type of building. The most expensive engineering systems were identified and described by researchers in field of salary fund and purchasing equipment and materials sections. Authors have described the modern and promising ways to improve the comfort and environmental friendliness of civil and industrial buildings. There is the description of additional costs for modern devices which are included in the other low electric systems section. The main trends in improving area of building engineering system efficiency were outlined in this paper. Also, there are the trends in improving field of building's enclosing structures. This article will be of interest for economists, developers and investment companies that are involved in assessing the cost of capital investments to multifunctional buildings construction process with various purposes.

Keywords Multifunctional buildings · Distribution · Investments · Capital investments · 2018 FIFA World Cup · Construction stages

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1 Introduction

The first and important stages of any construction process are the preparation of project's documentation and the determination of construction costs. Design and estimate documentations are the main documents that construction organization have to work with during all stages of the construction life cycle and sometimes at the operation of facility [1, 2]. Reliability of the future facility and commissioning speed depend on the quality of completed project. The project includes documents in text and graphic forms which are reflecting the technological, functional, architectural and other requirements. They are necessary for construction work, overhaul or restoration of the building. The term "Design documentation" is fixed in the main regulatory document regulating the building and construction industry in Russia—"The Town Planning Code of Russian Federation". The composition of the design documentation could be found in this documentation and in GOST 21.001–2013 "System of design documentation for construction. General provisions". The main purposes of estimate documentation are to determine the size of required capital investments to the construction process and to outline the structure of these investments [3]. In other countries, it is possible to use the additional types of documents [4]. There are special estimated standards for all constructions regions in Russia which could be used for costs composition. Designers have use various software systems to facilitate the preparation of estimates [5, 6]. They consist of the work cost, equipment and materials parts which are regularly updating. If there some sections of in the current estimate base are missing, it could be used the individual estimate preliminary agreed with the customer. The total estimated cost of all work and costs provided by working project is determined by the consolidated estimate of construction cost. This document includes the estimated cost of construction and installation work, purchasing equipment, inventory and etc. The consolidated estimate of construction cost includes 6 chapters: Preparation of the construction site; Design and survey work; Construction of temporary and auxiliary buildings and structures (auxiliary and service facilities; energy facilities; transport and communication facilities); Construction of the main facility with the engineering systems connection; Landscaping of the territory; Other work and costs.

Sometimes, construction companies try to reduce the cost of construction by the climatic construction region's features. They use the local raw material base or attracting various kinds of investments [7, 8]. The organizational, technological and manage decisions of construction organizations are the important part of constructions process as well [9, 10]. They depend on the complexity of construction object, experience and the current state of the company, the available production and technical base of the construction organization and other factors. Particular accuracy and correct decisions are necessary for the construction and reconstruction of industrial facilities [11].

2 Methods and Materials

We analyzed the estimate cost for the design and construction of a multifunctional business center with a hotel and sport complex in the Nizhny Novgorod in this work. The total cost of the facility was 3999.75 million rubles. Construction period was from 2014 to 2018. To simplify the distribution of capital investments for construction process, some points of consolidated estimate calculation were combined into 3 large groups: Preparation stage and construction of main structure building's parts (walls; roofs and etc.) with their preparation for expertise; Engineering systems; Landscaping of the territory.

All groups included the total costs of the design and construction parts of the project. First group includes pre-design work and direct construction with final processing of the building envelope. Modern enclosing structures consist of environmentally friendly materials and elements that increase the strength of main structures [12–15]. Second group includes all engineering systems that ensure the comfort of a person living in a building. At the moment, the researches in this area are aimed at reducing the energy consumption of existing engineering systems and increasing the accuracy at methods for calculating the energy consumption [16–21]. Third group includes activities which related to the courtyard area. They are necessary to improve the psycho-emotional state of residents, as well as to increase the level of environmental friendless of construction area. During the improvement of the territory, "Green Structures" became widespread. Some of their types are presented in the works of N. Shushunova and other authors [22–24]. It should be noted that they can also be used in industrial buildings [25]. In the consideration building these structures were not used.

3 Results

There are the primary data on the wage fund distribution, the purchasing equipment and materials cost during the construction process of the multifunctional business center with hotel and sports complex in Fig. 1.

The estimated cost distribution diagram of multifunctional business center with a hotel and sports complex construction by enlarged sections has shown in Fig. 2.

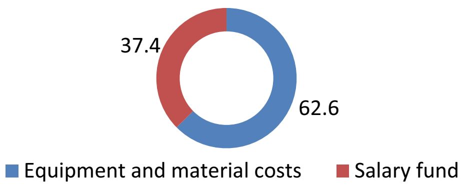

Fig. 1 Distribution of total capital costs for wage fund, equipment and building materials

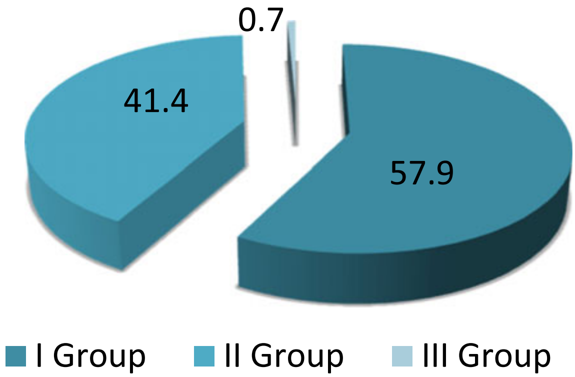

Fig. 2 The total capital costs distribution for the construction of a multifunctional business center with hotel and sports complex in Nizhny Novgorod

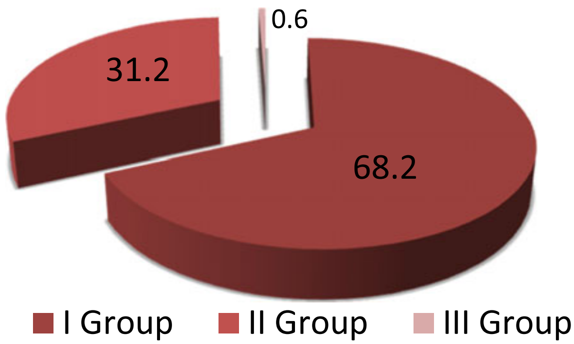

Fig. 3 The wage fund distribution during the construction of a multifunctional business center with hotel and sports complex

The salary distribution during the construction process of a multifunctional business center with hotel and sports complex by enlarged indicators and sections is shown in the Fig. 3. The total salary fund for the entire construction period was 1,496.32 million rubles.

The diagram of the costs for the equipment and building materials purchase during the construction process is demonstrated in the Fig. 4. The total amount of expenses for the materials and equipment purchase for this type of building was 2503.43 million rubles.

The diagram of the cost distribution for the design and engineering systems installation for a multifunctional business center with a hotel and sports complex is shown in the Fig. 5. The total costs for the engineering systems of the building accounted for 1,653.15 million rubles. There are some new devices in complex that are part of engineering systems. Electric heating of pipelines and ramps was included in the section "Power supply and lighting". Other low-current systems included rodent protection devices, parking automation and visitor registration systems. The structure has its own boiler room, therefore, as part of external engineering systems, there is only an external storm sewer and external power supply. Internal engineering systems include heating; cold and hot water supply; sewerage.

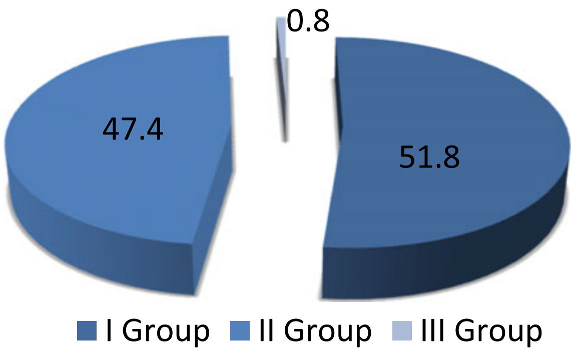

Fig. 4 Costs distribution for equipment and materials during the construction process of a multifunctional business center with hotel and sports complex

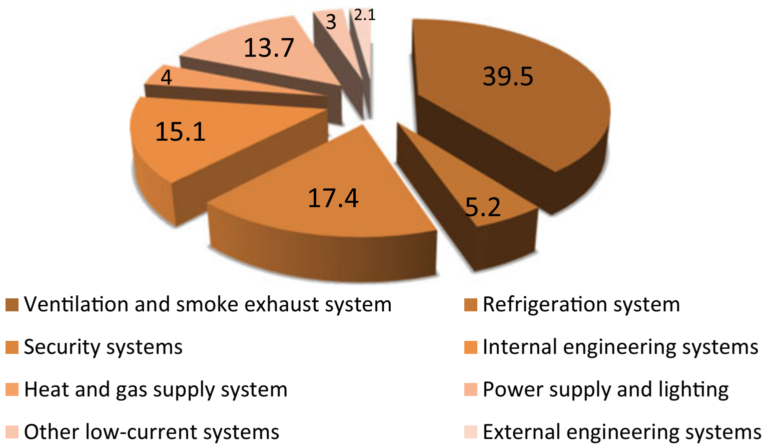

Fig. 5 The capital costs distribution to the construction process of engineering systems for a multifunctional business center with hotel and sports complex in Nizhny Novgorod

The costs distribution information for equipment, materials and salary during design and installation of consideration building's engineering systems has shown in Figs. 6 and 7. The total cost of equipment and materials which used in the building's engineering systems construction process was 1185.83 million rubles. The salary fund of engineering systems section was 467.32 million rubles.

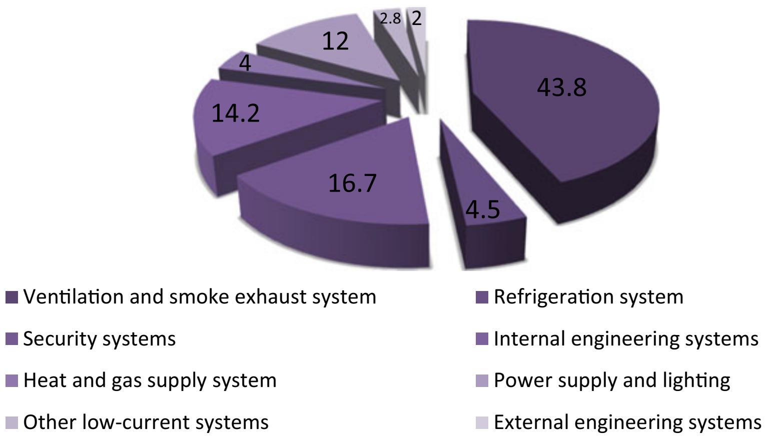

Fig. 6 Costs distribution for equipment and materials during the construction process of engineering systems of a multifunctional business center with hotel and sports complex

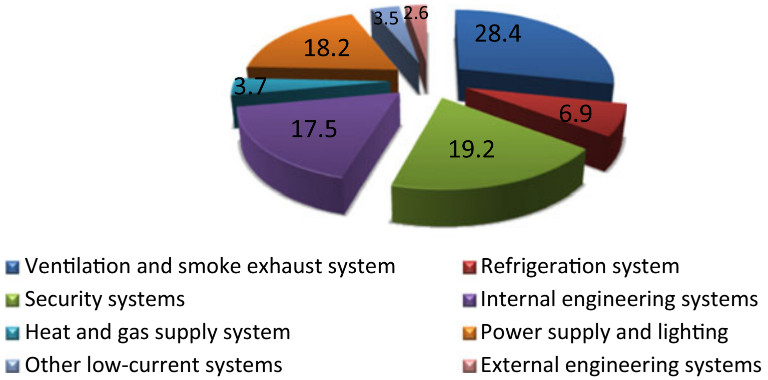

Fig. 7 The wage distribution in the engineering systems construction process for a multifunctional business center with hotel and sports complex

4 Discussion

Construction of buildings group (not the multifunctional complexes) by various purposes in the advanced countries of European Union [26] has been thoroughly studied. An exception is Spain where it is possible to find the investments to the construction of multifunctional buildings [27]. The distribution of capital investments will be completely different because of particular climate in Spain. In the advanced countries of Asia, for example China and India, there are the extensive process of residential construction which is connected with the historical events in these countries [28–30]. Less attention has been paid for the construction of multifunctional buildings in these countries because structures of this types were had been erected in the period from 1995 to 2010 and had not exceed their services life. The capital investments to multifunctional buildings in United States are also low due to high density of modern constructions built after 1990. Most of investments are directed to the development of territories, particular for green construction and living comfort [31, 32]. It is difficult to compare the capital investments to multifunctional buildings in other countries because of low investment level to multifunctional business center construction process. But it should be noted that their construction will be less costly in southern countries, where it will be a decrease in capital cost for heat consuming engineering systems.

5 Conclusion

Having studied the distribution of wages fund and the cost of purchasing equipment and materials, it was determined that 37.4% from the total cost of consideration building presumably was attributed the workers' salary fund. Other 62.6% were used to purchase construction materials and equipment. The design and installation of engineering systems takes a significant part in the construction of this type of building and accounts for 41.4% from the total construction costs. When the costs are divided into large groups, these indicators are 31.2 and 47.4%, respectively. An in-depth study of costs in the "Engineering Systems" group made it possible to reveal that the largest capital costs are for ventilation and smoke removal systems, security systems, and internal engineering systems. During the analysis of the building a multifunctional business center with a hotel and sports complex estimated cost in Nizhny Novgorod, it was also revealed that the cost of improving the territory did not exceed 0.7% from the total cost of construction process. Insignificant differences were noticed in the total distribution of the salary, as well as the costs of equipment and materials in this section of the building construction estimated cost. The results of this work can be used to compare the investments for countries with different climates.

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Risk Management of Construction of Industrial Buildings and Structures

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Abstract When developing design and estimate documentation for construction projects, it is mandatory to determine the estimated cost of construction and the duration of work. This is due to certain regulatory values and aggregated indicators, but it does not take into account possible risks. Risks, in turn, can not only lead to a failure of deadlines and increase the cost of construction, but also results in deterioration in the operational properties of buildings and structures, which entails a significant reduction in the service life of the construction project.

The article provides a qualitative assessment of the risks arising during the construction of industrial buildings and structures, using the example of the design and construction of an industrial workshop for the production of native starch in the Rostov region. Potential and realized risks were considered, the mechanism of their influence on the increase in the duration of construction and the cost of the object was established.

The implementation of this mechanism in the form of a network graph can be possible with the help of probabilistic methods and allows, at the pre-project stage, estimating the most probable terms of construction and design work (with the maximum duration of work in the implementation of adverse risks).

Keywords Risk management · Life cycle of construction projects · Industrial construction · Construction's cost · Construction's time

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1 Introduction

Risk management is an integral part of the management of organizational processes in construction. The peculiarities of risk management in the construction of industrial buildings and structures are the presence of specific factors related to both the technological process, for which the construction object is intended, and constrained construction conditions, dependence on the technological equipment of a particular supplier, as well as the tight deadlines for construction work.

If earlier there was a significant impact of risks associated with the deterioration of the technical condition of building structures due to miscalculations at the design stage or non-compliance with installation technology, now the proportion of risks has increased—errors in estimates, non-compliance and penalties for obligations (mainly temporary) contracts [1].

The risk management process in construction consists of six stages.

The first stage: identification of risks. In particular, the following risks might arise in projects: quality risks; personnel risks; price risks; risks of failure to meet deadlines; risks of strategic decisions; external risks.

Second stage: risk analysis. At this stage, an analysis of the priority of risks and the degree of their impact on the life cycle of the construction project as a whole is carried out.

The third stage: risk measurement. Mathematical and statistical accurate methods commonly used in risk assessment in other industries cannot adequately reflect typical risks in the construction industry.

The fourth stage is risk control. Risk management strategies are adopted as follows: avoidance, reduction, transition to risk, taking risk on yourself.

The fifth stage represents risk monitoring, that is, continuous operational control of the effectiveness of risk management and the adoption of timely measures.

The sixth stage is goal control. After recognizing, analyzing and assessing risks, measures should be taken to control the goals. The whole management process can be divided into subprocesses: determination of the target value, the actual value, comparison of values and analysis of variance [2].

The risk management methodology at the procurement stage was reviewed in [3]. A simple and unified methodology has been successfully tested in determining the systematic risks of the construction of a real construction object.

When determining the risks directly from work on the construction site, the authors [4] proposed a method for calculating: weight factor; weighted average value of risk; exceeding the value of the weighted average risk value; the additional value of exceeding the weighted average risk value; the total amount of risk.

In modern risk management models, the following basic actions are proposed [5]:

risk avoidance (risk prevention, risk avoidance, risk elimination), that is, avoidance of activities that cause the realization of risk. Often the level of this risk is too high, it needs to be brought to an acceptable level; risk minimization (risk reduction, risk optimization and control over it), that is, risk reduction through a system of anti-crisis measures; the use of risk (risk acceptance, risk neglect, risk limitation) is characteristic of minor risks that cannot be eliminated, but with successful management, the realization of this risk makes it possible to increase the profitability of construction.

Risk management in construction mainly depends on intuition, judgment and experience [6]. Formal risk analysis and management methods are rarely used due to lack of knowledge and doubts about the suitability of these methods for activities in the construction industry.

The authors [7] suggest using a construction risk management model (CRMS) based on the method of constructing impact diagrams and Monte Carlo modeling. Alternative risk management strategies include: risk prevention, risk transfer, risk retention, loss reduction, insurance.

As one of the methods for assessing the implementation of risks, a model.

(RMMS) was proposed—a system for implementing the risks of large-scale projects based on the use of the Analytical Network Process (ANP) method to measure the overall effectiveness of risk management in relation to the main risk factors [8].

An approach to decision–making based on fuzzy multiple criteria (FMCDM) was also proposed, in particular for the construction of critical structures such as subways. At the same time, the assessment was carried out on 20 risk factors identified at four sites [9]. To analyze the probability of occurrence of multiple risk factors, the method of direct ranking of fuzzy multiple attributes (FMADR) is used.

Another approach is the use of fuzzy Bayesian networks (FBN) based on the analysis of the risk mechanism to investigate the cause-effect relationships between the stress–strain state of the foundation soil caused by the construction of the tunnel and the variables affecting it [10].

The problem of the impact of failures in construction on the cost of production and on the quality of construction projects was studied by Abdul-Rahman [11].

The security risks at the construction site have a fundamental impact on the lines and construction costs, and the reliability of building structures. Research on this topic was carried out by scientists from China [12], Pakistan [13], North Korea [14].

To assess the risks of increasing the cost and predict the real cost of construction contracts, a method was proposed in terms of a construction cost index [15].

Some opportunities for better risk allocation mechanism and contracting strategies that are based on a trust relationship between the contracting parties were analyzed using the data from the surveys of Canadian developers [16].

When building global facilities, specific risks should also be accounted for:

– social sustainability (on the example of researching survey data from 120 leading Pakistani experts [17]);
– political risks for multinational contractors [18];
– specific risks of geotechnics for underground structures [19] or extreme climatic influences [20].

Minimization of the consequences of the manifestation of the main risks can be carried out using the Cost Contingency Reserve (CCR) for a project. Post-mitigation simulations show that value of CCR is 2.88% of project cost [21].

2 Methodology of Risk-Management of Construction of Industrial Buildings and Structures

All the described studies were taken into account in the process of risk management of the construction of a dry starch production workshop in the Rostov region.

The decision to open the project: “Construction of a starch drying shop with a capacity of 300 tons/day” was made by the management of Amilco in December 2018 in order to expand the production capacity of the enterprise and further release of new products.

At the same time, the design deadlines were extremely tight. In this regard, there were additional risks of errors in design decisions due to lack of time for detailed study.

In addition, the design of building structures had to be developed taking into account the ready-made scheme of engineering communications and ready-made technological equipment, which also increased the risk of errors in the design of structures (Fig. 1).

When searching for a contractor, another non-obvious risk was revealed: due to the reduction in the pace of construction of industrial buildings in Russia, the number of design organizations specializing in this area has also significantly decreased.

The main requirements for the tender among contractors were: experience in the design and construction of industrial facilities, reliability and high quality of the work performed by the counterparty; minimum project implementation time; optimal price/quality ratio; sociability, mobility and quick response to changes while taking into account the wishes of the customer company with the full implementation of the turnkey project; legal and tax audit of the counterparty.

All the considered phases of the project are included in Table 1.

Similar assessment methods were used when searching for an organization that conducted pre-project surveys (geological, geodetic, environmental and hydrometeorological).

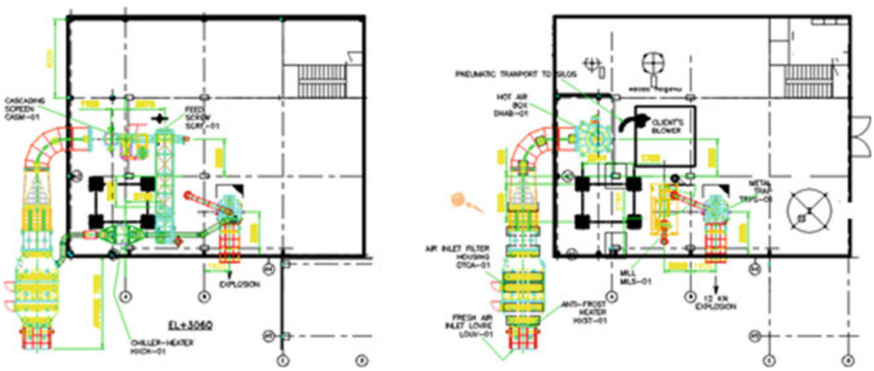

Fig. 1 Technical specification for design—engineering

Table 1 Project phases

	Stage 1	Stage 2A	Stage 2B	Stage 3	Stage 4
Result	Approve that the project complies with the company's strategy	Confirmation of preferred solutions (options)	Final confirmation of the scope (boundaries) of the project and tasks (goals)	Confirmation of fulfillment of financial promises	Project acceptance
Important questions	Does the project correspond to the company's strategy? What problems are being solved by the project?	Does the project continue to comply with the company's strategy?	Does the project continue to comply with the company's strategy?	Does the project continue to comply with the company's strategy?	Does the project continue to comply with the company's strategy?
Risk assessment issues	Is there an economic justification for the project? Is there a financial justification, strategic compatibility, customer orientation, competitive advantages?	Have all the alternative solutions of this project been adequately evaluated? Is there a single agreement on the chosen solution?	Are there changes in the list of works on the project and the project, schedule, budget, key economic indicators, project managers or the composition of the project team?	Project solution management plan Are there changes in the list of works on the project and the project, schedule, budget, key economic indicators?	Is it possible to implement the project on site and is the company ready for implementation? Is the organization and the project team ready for implementation?
General conclusion	How can shareholders help? Should this project be cancelled?	How can the shareholder team help? Should this project be cancelled?	How can the shareholder team help? Should this project be cancelled?	How can the shareholder team help? Should this project be cancelled?	How can the shareholder team help? Should this project be cancelled?

The process of selecting a general contractor for the construction of the facility was carried out at a time when the design was not yet fully completed, and was based not on estimates, but on the prices of enlarged types of work. A tender with enlarged cost indicators was very risky for concluding a contract, so a decision was made:

1. Selection of a general contractor, with the possibility of involving subcontractors by agreement for the full implementation of the project;

2. On the approval of prices for enlarged types of work (i.e. the estimate is not "solid" because there is no full explication of the project).

3 Result of Approbation of Methodology of Determining of Potential Risks of Construction of Industrial Buildings

In addition to the risks that appeared directly in the specified phases of the project (pre-design, design and construction), there are also hidden risks—those whose implementation is possible only at the next stage.

For the customer, the main criterion for evaluating the effectiveness of decision-making and consequently risk minimization was the earliest possible time for putting the workshop into operation.

The mechanism of the relationship of risks at different cycles of the building's life is presented in the form of a directed graph (Fig. 2), where the initial vertex is risk, the final vertices differ depending on the impact of risks—M (money) is the risk of financial losses, T (time) is the risk of temporary losses, MT is the combined risk of time and material losses.

The risks are grouped depending on which stage of the vital cycle of buildings this risk is laid: the pre-project stage (group RI), the project stage (group RII), the project stage (group RII), the construction and operation stage (group RIII).

The types of risks are indicated in Table 2.

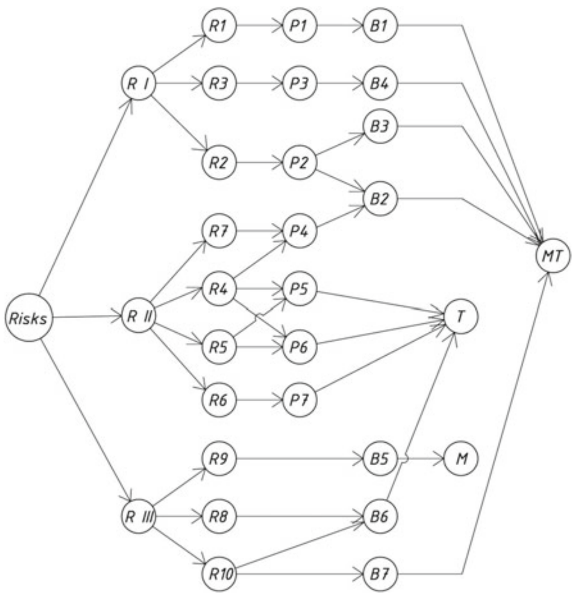

Fig. 2 Oriented graph of the system "Risks of life cycles of a building under construction"

Table 2 Types of risks in the construction of an industrial building

Causes (risks)	Investigations at the stage of		Remove
	Project	Building/building operation	
Pre-project stage (RI)			
Error in engineering-geological surveys (R1)	Incorrect structural solutions of foundations (P1)	Cracks, rolls (B1)	Reinforcement design and reinforcement of foundations
Errors in engineering at the technical task stage (R2)	Errors in the design of engineering systems and technological equipment (P2)	Impossibility and inefficiency of operation (B2)	Engineering Change
		The inability to "fit" technological equipment into a given structure (B3)	Changing design solutions with unchanged engineering
Errors in geodetic surveys (R3)	Errors in the design of SPOSU (P3)	Inability to land on the ground (B4)	Changing the land plan and sections of the design
Designing (RII)			
Low qualification and unreliability of the project contractor (R4)	Project errors (P4)	Impossibility and inefficiency of operation (B2)	Redesign of the project
	Delayed execution (P5)		Change of performer
	Inability to execute (P6)		
Lack of experience in the performer (R5)	Delayed execution (P5)		Collaboration of several contractors
	Inability to execute (P6)		
Delayed response to changes and consideration of customer's wishes (R6)	Long response to operational changes (P7)		Collaboration of several contractors
			Search for other communication channels
Incorrect determination of the cost and timing of work (R7)	Errors in the estimate (P4)	Inability to complete the scope of work at the specified time (B2)	Adjustment of the estimate

(continued)

The calendar schedule without taking into account the implementation of risks is shown in Fig. 3.

The main stages of construction are shown in Fig. 4.

Table 2 (continued)

Causes (risks)	Investigations at the stage of		Remove
	Project	Building/building operation	
Building (RIII)			
Incorrectly estimated possible-Contractor's news (R8)		Delay and disruption of work deadlines (B6)	Simultaneous work of several subcontractors
«Unsteady» estimate (R9)		Change in the cost of work in the process (B5)	The contract on the enlarged rates taking into account the cost of works and materials
Low qualification and unreliability of the SMR performer (R10)		Mounting errors (B7)	Change of performer
		Delayed execution (B6)	Collaboration of several contractors
		Impossibility and inefficiency of operation (B2)	Change of performer
The operation of the building (RIV) has not been considered in this article			
The dismantling of the building (R V) was not considered in this article			

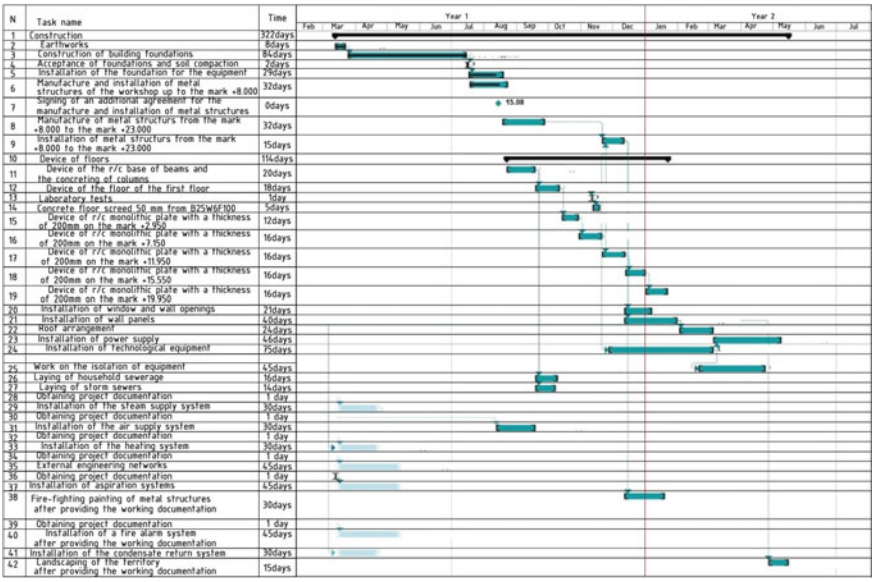

Fig. 3 Calendar schedule without taking into account the implementation of risks

Fig. 4 The main stages of the construction of an industrial workshop

4 Discussion of the Method of Risk Management of Building Construction, Using Oriented Graph

The proposed method of risk management of industrial buildings using the graph theory apparatus is relevant and new in comparison with existing methods. Currently, it is possible to assess the possibility of risk manifestation only on the basis of an expert's subjective assessment based on his experience. And this experience is associated only with a narrow field of work, and cannot be extended to objects with dissimilar specifics.

During the implementation of this project, several risks were realized at once at different cycles of the building's life, as a result of which:

- the design stretched from the planned period of 6 months to a year (with the receipt of a positive expert opinion);
- the construction period has increased from 10 to 19 months.

5 Conclusion

This hierarchy and risk system, as well as the implementation of a risk interaction mechanism in the form of a network graph, allows us to estimate the most likely production dates for construction and design work at the pre-design stage.

Such an assessment can be possible thanks to probabilistic methods, as well as a simplified version: the introduction of a system of coefficients (by analogy with reliability coefficients) that enable to determine the most probable timing of construction and design work.

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Digital Design of the Organization of Construction When Installing Bored Piles in Winter Conditions

Anna Tsarenko and Chakhkiev Islam

Abstract The purpose of the article is to analyze the use of information models in the design of construction projects, the availability of a regulatory and technical framework governing the development of digital models, and the presentation of one of the possible approaches to the design of the construction organization. The problem of the construction of bored piles in the frozen ground is based on the complexity of the set of concrete strength in the upper part of the monolithic structure. The analysis of scientific research of concrete hardening at negative ambient temperatures is carried out. Topical organizational and technological modeling issues in winter concreting processes are considered, adjusted for variability depending on the applied method of intensifying concrete hardening of foundation structures. The results obtained in the form of a principled approach to modeling and accounting for additional operations in organizational and technological models make it possible to ensure advanced planning of works when organizing the construction of underground parts of facilities, to level the risks of financial planning, and to comply with the target dates of the zero cycle of the facility.

Keywords Modeling · Information model · Concrete · Winter concreting · Frozen ground · The preheating · Bored piles · Factors

1 Introduction

Digital technologies in modern reality are replacing more and more manual labor processes. Construction is a complex process, and according to William Ashby's law of necessary diversity [1–4], it is impossible to manage complex processes using a simple system. Therefore, to optimize construction, minimize costs and time, and achieve the requirements for the functionality of the finished object, it is necessary to consider the introduction of digital technologies already at the design stage [5–8].

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Digital modernization of the construction industry will improve the quality of the surveys, design, expertise, construction, and operation of the objects. Therefore, in the Russian Federation, the essential priority aim today is developing regulatory and technical documentation.

An advanced level of automation and the use of an information model makes it possible to reduce the need to involve specialists with extensive work experience in the design and to carry out variant study in a short time, which means to choose optimal, constructive, technological and organizational solutions.

2 Materials and Methods

In order to make organizational, technical, administrative, and technological decisions when installing bored piles in winter conditions, the parameters influencing the strength increase of concrete in the pile head have been determined and analyzed [9–13]. The composition of the parameters influencing organizational and technical decisions in the construction of monolithic structures in winter is determined; also, the degree of influence of the parameter is determined [13–15].

After consulting with experts and specialists in the field of concrete works in winter conditions, it was possible to identify several main parameters that affect the choice of the method of winter concreting of bored piles. Each parameter was evaluated according to the level of significance. To obtain a comprehensive indicator of the effectiveness of organizational and technological measures during winter concreting of bored piles, the main parameters (×1, …, xi) used in calculations were identified (Table 1).

Based on the obtained data of the expert survey, the weights of the parameters were determined, which are x1—9,5; x2—9,3; x3—5,2; x4—7,3; x5—5,9 (Fig. 1).

Based on an expert survey to determine the significance of the selected parameters of contour construction, a reduction in the number of parameters has been achieved, which leads to obtaining the necessary and sufficient model. Four main parameters have been identified: ambient air temperature, concrete temperature, soil temperature, soil type, and pile diameter.

Table 1 Parameters influencing the strength set of concrete in the heads of bored piles

№	Title	Notation	To determine the significance of each parameter, 10 expert groups were formed, each of which had from 5 to 7 people with sufficient experience in the construction sector and relevant education. Each expert group was asked to rank the parameters by assigning points from 1 to 10
1	The surrounding air temperature	$x1$	
2	Ground temperature	$x2$	
3	Temperature at the contact surface of concrete and seasonally frozen soil	$x3$	
4	Pile diameter	$x4$	
5	Type of soil	$x5$	

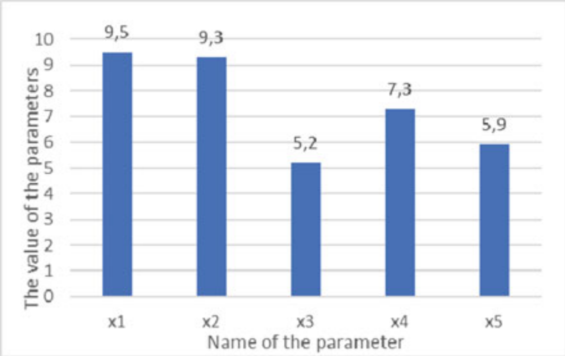

Fig. 1 Diagram of the significance of parameters

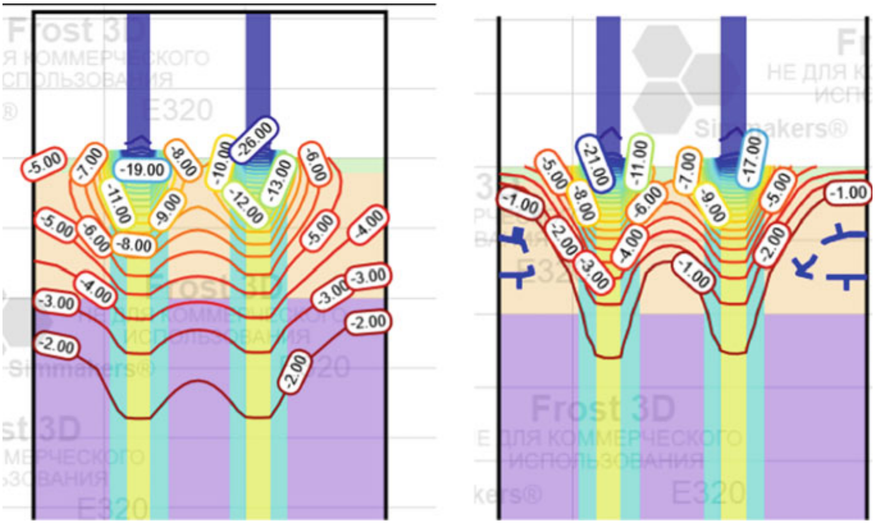

Fig. 2 The obtained models are the distribution of temperature gradients in the concrete thickness of bored piles and contacting soil for one experiment

In this work, the modeling of the thermal field of the soil and the distribution of thermal gradients in the body of the bored pile was carried out based on calculations in the Frost 3D program. The purpose of the modeling was to identify, based on a thermal engineering calculation, the patterns of heat and mass transfer of hardening concrete, depending on the different composition of the concrete mixture, the preparation method, also depending on the various atmospheric and soil conditions, allowing an objective approach to the assignment of the parameters of concrete curing in winter conditions until reaching a required strength of monolithic structures [15–18].

To make a model of the thermal field of the soil and the distribution of thermal gradients in the body of a bored pile, a model of a bored pile was formed in the Frost

3D program, soil conditions were set taking into account the thickness of the layer, initial meteorological data were entered into the program, and the temperature of the concrete mixture was set. The physical and mechanical characteristics of the soil were set as well.

As a result of the initial input data, a thermal engineering calculation was performed in the Frost 3D program, based on which models of the distribution of the thermal balance in the soil thickness in contact with the bored pile were obtained, including the distribution of temperature gradients in the solidifying concrete body (Fig. 2).

3 Results and Discussion

Based on the revealed patterns of heat and mass transfer of hardening concrete, depending on the different composition of the concrete mixture and depending on different atmospheric and ground conditions, it is possible to calculate the strength set of hardening concrete, which in turn will allow an objective approach to the assignment of the parameters of concrete withstanding in winter conditions to the set of bored piles of the required strength.

The ConcreteTermo computer program, created on the developed methodology by L.M. Kolchedantsev, based on the formula of B.G. Skramtaev, was used to obtain calculations of the relative strength of concrete (relative to grade strength), depending on the temperature and type of soil, as well as on the temperature of hardening concrete, obtained based on performed thermal calculations in the Frost 3D program (Fig. 3).

As a result of the performed research of the strength increase of hardening concrete in the pile head, performed in the ConcreteTermo program, based on the actual

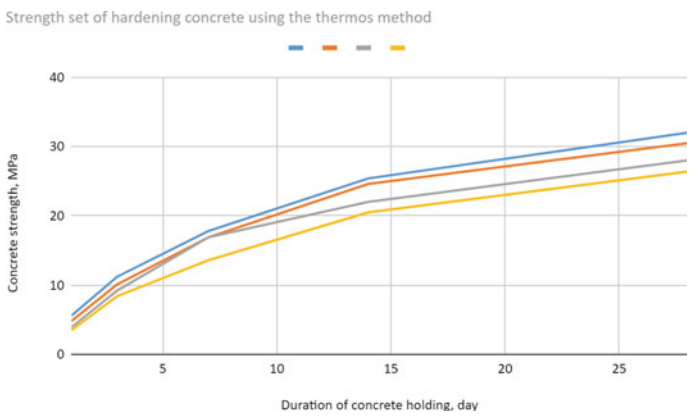

Fig. 3 Concrete strength set depending on the duration of concrete holding

concrete temperature obtained as a result of thermal calculation in the Frost 3D program, depending on the ambient temperature, temperature, and type of soil, it is possible to adjust the parameters of concrete withstanding in winter conditions, adjusting the criteria of the winter concreting method used.

3.1 Conclusion

Based on the above, we point out that there is a necessity for implementing technological models in the design of construction projects. This need is expressed in state policy, reflected in the President of the Russian Federation's decrees and amendments to existing legislative documents and economic effects.

Visualization of construction and installation works with a high degree of probability will optimize production processes, both at the planning and construction stages, taking into account the insertion of actual values and operational changes in the work schedule.

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The Impact of Organizational and Technological Factors on Energy Efficiency of Complex Renovation of Residential Development

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Abstract In this paper, there were systemized organizational and technological factors reflecting specific peculiarities of energy-efficient renovation of residential development affecting the terms of construction works execution and the cost of construction products. Two groups of factors were identified such as organizational and technological factors related to energy efficiency of buildings and organizational and technological factors attributed to energy efficiency of engineering systems of neighborhood units. When developing and grounding organizational and technological decisions, the presented factors should be accounted for.

Keywords Energy efficiency · Energy saving · Residential development · Organizational and technological factors · Renovation

1 Introduction

In the conditions of finiteness of energy resources, provision of rational energy consumption determines the pace and quality of modern society development. Nowadays, the level of energy savings' potential use in Russia is rather low regardless the set of enforced regulatory and other statutory instruments aimed at efficient use of fuels and energy resources. The effectiveness of energy resources use is extremely low in the housing sphere. The situation is exacerbated by the presence of constantly growing energy losses in the communal networks due to their technical condition, physical depreciation, essential physical depreciation and, as a consequence, their failure. Annually, 30% of state's energy costs are allocated to construction and housing and utilities sector of Russian economy. The main reserves of energy saving in construction and housing and utilities sectors are in the sphere of upgrading of energy efficiency of the existing housing stock.

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Scientific works of such Russian and foreign scientists as E.P. Uvarov, V.T. Shalenny, S.G. Shein, V.I. Livchak, Yu.A. Tabunshchikov and O.D. Samarin and others are dedicated to the issues of energy efficiency and energy saving [1, 2, 4–10, 16]. The results of the implemented analysis of scientific works published by the leading scientists and specialists in the sphere of maintenance and extending operational life of housing stock [3, 11, 12] enabled to make the conclusion about the lack of the definitive scientific grounding of projected technical and economic indicators of the projects of energy efficient complex renovation of residential development that would account for the influence of the summary of organizational, technological and other factors.

Therefore, when making organizational and technological decisions for energy efficient complex renovation of housing development, determination and accounting for the impact of systemized factors is of actual importance.

Forming energy saving at complex renovation of residential development is done by means of increasing energy efficiency of buildings and engineering systems of neighborhood unit (estate) that is subject to complex renovation [13, 14], due to this, it becomes logical to subdivide organizational and technological factors affecting the duration and cost of energy efficient complex renovation of residential development into two corresponding groups.

2 Methodology

The first group of factors comprises organizational and technological factors related to energy efficiency of buildings, whereas the second one—organizational and technological factors describing energy efficiency of engineering systems of a neighborhood unit (or estate).

Along with that, among the variety of factors one can identify those affecting the efficiency of energy saving events for the estate in whole, i.e. complex factors [15].

On the base of the implemented research, we propose to single out the organizational and technological factors affecting technical and economic indicators of projects of energy efficient complex renovation of residential development (Table 1).

The main factor describing the efficiency of energy saving measures in general for a neighborhood unit (residential estate) is the factor of complex workability.

Table 1 Organizational and technological factors affecting the duration and the cost of energy-efficient complex renovation of residential development

NN	Factor	Calculation formula	Conventional notations
1.	Factor of building compactness	$F_C = 1 - \frac{\Lambda_{c\,build}{}^{n}}{\Lambda_{c\,build}{}^{\partial}}$ (1)	$\Lambda_{c\,build}{}^{\partial}$, $\Lambda_{c\,build}{}^{n}$ – the indicator of building compactness according to and after renovation
2.	Factor of altering shaper of a building	$F_{S\square} = 1 - \frac{m^n}{m^\partial}$ (2)	m^∂, m^n – the number of polygon legs representing the plan of standard storey of a building under the renovation and after the renovation
3.	Factor of maintenability	$F_{PhD} = 1 - \frac{PhD}{100}$ (3)	PhD – the value of physical depreciation of a building, %
4.	Factor of number of storeys in a building	$Fs = 1 - \frac{n^\partial}{n^n}$ (4)	n^∂, n^n – the number of storeys under the renovation and after the renovation
5.	Factor of improvement of heat insulation of a building	$F_{TI} = 1 - \frac{k_{\Sigma ar}{}^{n}}{k_{\Sigma ar}{}^{\partial}}$ (5)	$k_{\Sigma np}{}^{\partial}$, $k_{\Sigma np}{}^{n}$ – coefficient of heat transfer of heat insulating envelope of a building under the renovation or after the renovation, $Wt/(m^2 \cdot K)$
6.	Factor of glazing	$F_{glaz} = 1 - \frac{m_{glaz}{}^{n}}{m_{glaz}{}^{\partial}}$ (6)	$m_{glaz}{}^{\partial}$, $m_{glaz}{}^{n}$ – the factor of glazing of a building under the renovation or after the renovation
7.	Factor of renewable energy sources use	$F_{RES} = \frac{Q_{RES}}{Q_{gen}}$ (7)	Q_{RES} – the amount of energy received by a building from the renewable energy sources; Q_{gen} – general energy requirements
8.	Factor of heat networks spread	$F_{H.N.} = 1 - \frac{l_{ssn}{}^{n}}{l_{ssn}{}^{\partial}}$ (8)	$l_{ynm}{}^{\partial}$, $l_{ynm}{}^{n}$ – specific spread of heat networks under the renovation and after the renovation of neighborhood unit (estate) F_{free} – free area of an ob-

(continued)

Table 1 (continued)

9.	Strangulating factor	$F_{sf} = \frac{F_{free}}{F_{gen}}$ (9)	ject (construction site) F_{gen} – on-site area of a renovation project
10.	Factor of heat balance improvement of a neighborhood unit (estate)	$F_{HB} = 1 - \frac{Q_{жс.м.}{}^{n}}{Q_{жс.м.}{}^{\partial}} \cdot \frac{1}{\Delta S}$ (10)	$Q_{жс.м.}{}^{\partial}$, $Q_{жс.м.}{}^{n}$ – the value of heat balance of a neighbood unit (estate) under the renovation and after its complex renovation; ΔS – increment of residential (floor) area
11.	Factor of complex workability	$F_{tec}^{comp} = F_{tec}^{o} \cdot k_1 + F_{tec}^{eng} \cdot k_2$ (11)	F_{tec}^{o} – resumptive factor of project decision manufacturability on renovation of residential buildings in an estate (quarter) estimated under the formula; F_{tec}^{eng} – resumptive factor of projects decisions manufacturability on reconstruction of estate (quarter) networks calculated under the formula; k_1 – significance of the impact F_{tec}^{o} – on the factor of complex manufacturability; k_2 – significance of the impact F_{tec}^{eng} – on the factor of complex manufacturability

3 Results

We assume that the summary of design concepts' features ensuring the minimum expenditures on energy during further maintenance of residential developments is understood as workability of design concepts.

Determining the factor of complex workability for design solutions of energy efficient residential development is implemented under the scheme represented in the Fig. 1.

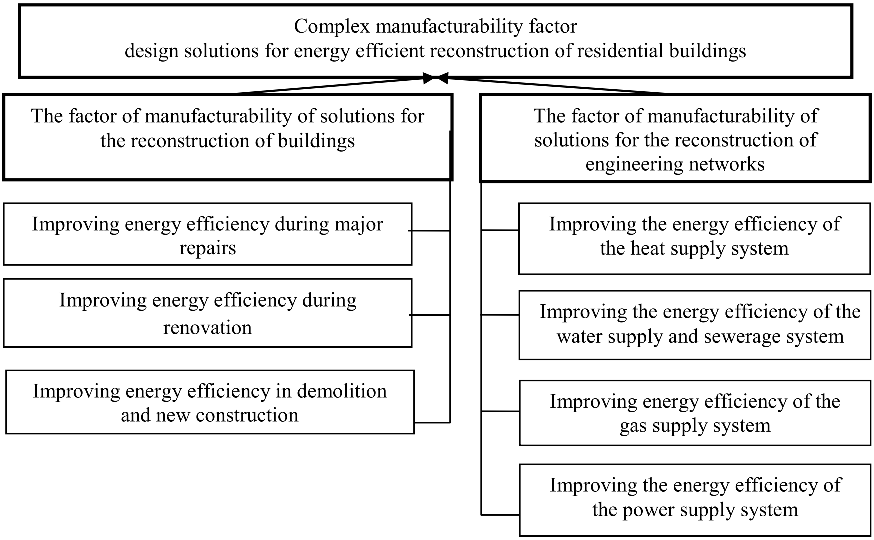

Fig. 1 The diagram of determining the factor of complex manufacturability of project decisions during renovation of residential development

Thus, the factor of complex manufacturability could be estimated by the formula (4):

$$F_{tech}^{compl} = F_{tech}^{o} \cdot k_1 + F_{tech}^{eng} \cdot k_2, \quad (1)$$

where F_{mex}^{o}—generating factor of manufacturability of design solutions on renovation of residential buildings of a neighborhood unit (estate) that is calculated under the formula (5):

$$F_{tech}^{o} = \frac{1}{3} \times \left(\frac{\sum_{i=1}^{n} F_{tech\,i}^{c.r.}}{n} + \frac{\sum_{j=1}^{m} F_{tech\,j}^{dn}}{m} + \frac{\sum_{z=1}^{k} F_{tech\,z}^{ren}}{k} \right), \quad (2)$$

Where $F_{tech\,i}^{c.r.}$—the factor of manufacturability of energy saving events during major repairs and the new construction of an estate; $F_{techx\,j}^{dn}$—the manufacturability factor of energy saving during demolition and new construction of j-building in a neighborhood unit; $F_{tech\,z}^{ren}$—the factor of manufacturability of energy saving during renovation of z-buildings in a neighborhood unit; n—the number of buildings in a neighborhood unit that are subject to major repairs; m—the number of buildings in a neighborhood that are subject to demolition; k—количество зданий микрорайона, подлежащих реконструкции; F_{tech}^{eng}—the resumptive factor of manufacturability of design solutions on renovation of engineering networks of a neighborhood unit (estate), is determined under the formula (6):

$$F_{tech}^{eng} = \frac{\sum_{s=1}^{t} F_{tech\,s}^{eng}}{t}, \tag{3}$$

Where $F_{tech\,s}^{eng}$—the factor of manufacturability of energy saving measures at renovation of s-engineering network of an estate; t—the number of engineering networks of an estate subjected to renovation; $\varkappa_1$—significance of F_{tech}^{c} impact on the factor of complex manufacturability; $\varkappa_2$—significance of F_{tech}^{eng} impact on the factor of complex manufacturability.

4 Conclusions

Thus, it is obvious that the higher manufacturability of decisions on the particular objects, the higher complex manufacturability of the decision on energy efficient renovation of housing development in whole.

When making organizational and technological solutions for energy efficient complex renovation of residential development, accounting for systemized factors enables to achieve more accurate estimates for construction works duration and the cost of building products under the limited resources conditions.

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Dynamic Visualization of Construction Schedules on the Example of the Spring Chart Technique

Vadim Undozerov

Abstract Many visualization techniques are used for construction scheduling – the Gantt chart, network diagrams, cyclograms, etc. As a result of a critical review, it was revealed that these methods are not effective enough in terms of considering and understanding the dynamics of changes in project. It negatively affects the quality of decision-making on project time and resources management. To increase the efficiency of visualization in terms of changes, the author proposes a new technique - "the Spring chart". The technique is a modification of the Gantt chart by replacing the bars, which reflect activities, with the image of springs used in mechanics. The application of the technique is demonstrated by an example. The demo version of the web-application has been developed for creating schedules in the form of the Spring chart. Further directions of the technique and application's development are discussed.

Keywords Visualization · Decision-making support · Change management · Scheduling · Rescheduling · The Gantt chart

1 Introduction

Construction schedule is developed at the project's design stage, but during construction stage multiple changes are made periodically [1, 2]. This is due to the high degree of uncertainty of construction projects [3–5], especially such complex ones as nuclear power plants (NPPs) construction. In complex projects, even small changes can lead to critical consequences [2, 6, 7]. Therefore, in such projects there are special requirements on the quality of decisions on changes (rescheduling). Due to the huge quantity of activities (for NPPs, it is measured in thousands), as well as large number of stakeholders and their interactions' complexity, making decisions on changes is an extremely difficult task [8]. Thus, it requires special techniques to support such decisions.

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One of the most effective directions in the decision-making support area is visualization techniques [9, 10]. The article presents a review on traditional, widely used techniques for construction scheduling visualization. As a result of the review, it was revealed that these techniques are mainly aimed at primary planning and are not very convenient for rescheduling. This is expressed in the fact that the current schedule does not reflect previous changes and the degree of deviation of the activities' duration from the baseline schedule. That results in insufficient consideration of previous changes when making decisions, which can lead to serious mistakes [6, 8].

The alternative solutions are also considered as they give more opportunities for visualization of changing schedules. They also have some limitations. To overcome them, the author suggests the new "Spring chart" technique [8]. The technique is based on the classical Gantt chart, but the bars depicting the activities are replaced by the images of spring used in mechanics. This representation allows one to reflect the degree of activities' duration deviation from the baseline schedule by "compressing"/"stretching" the springs. This allows tracking the dynamics of changes and thereby improving quality of decisions.

The article is structured as follows. Section 2 "Methods" comprises the critical review on the existing techniques for scheduling visualization. Section 3 "Results" introduces the author's technique "the Spring Chart", as well as the Web-application developed for the technique's implementation. In Sect. 4 "Discussion" the technique's performance is discussed, as well as its advantages and drawbacks in comparison with the existing techniques. In Sect. 5 "Conclusion" the main theses of the article are summarized, the perspectives for further research are outlined.

2 Methods

To date, many techniques have been developed for different processes' visualization. Some of them are universal and applicable in any field. For example, these are the "boxes" used in cybernetics [11] or "causal cycle chart" used in system dynamics [12]. Other techniques are specialized on some area. In project management area both universal [6] and specialized techniques are used. In the article, we will limit ourselves to considering only specialized ones, and only those of them that are focused on project scheduling. Another restriction is that we will consider only techniques which are focused on non-routine processes. It excludes, for example, the widely spread visualization standard for routine business-processes BPMN (Business Process Model and Notation) [13].

A systematic overview of visualization techniques in project management can be found in the works of R. Lengler, M.J. Eppler [14], V.D. Kolychev [15], M. Hajdu [16], etc. Langer and Eppler developed the table [14] which can be considered as the quintessence of this systematization. The table resembles the periodic table of chemical elements, but the "elements" of this table are visualization techniques. Two scheduling visualization techniques are presented in the Lengler-Eppler's table: the Gantt chart and network diagrams.

The Gantt chart is a scheduling visualization technique in which activities are represented as horizontal bars, the length of which is proportional to the activities' duration. The start and end points of a bar correspond with the start and end dates of the activity on the calendar. Sometimes, but not necessarily, precedence and other relations between activities are indicated by arrows.

Network diagrams represent the schedule as an oriented graph, the elements of which are arranged from left to right in accordance to the succession of activities. There are two main types of networks [16]. In the first type, called "Activity-on-node", the nodes of the graph represent activities, and the edges reflect relations between them. In the second type called "Activity-on-arrow", nodes represent events (start and end points of activities), edges represent activities.

Not all types of scheduling visualization techniques are represented in Lengler-Eppler's table. For instance, cyclogram [17] isn't there. Cyclogram is a technique mainly oriented on projects with cyclic structure of processes, e.g., high-rise buildings. Such projects can be decomposed into the equal stages which correspond to the similar parts of the building's structure (in this case – floors). In cyclogram these stages are depicted as the equal intervals by which the vertical axis is broken down. The horizontal axis reflects time. Every activity is shown as a line segment which horizontal projection is from the start to finish date of the activity and the vertical projection is the whole unit of the vertical axis (referring to the stage which the activity belongs to). Cyclogram seems to be more suitable for visualizing changes than network diagram or the Gantt chart, since it is two-dimensional, which gives more opportunities for placing options on one "sheet".

B.A. Rutenberg [18] developed a technique based on "Activity-on-edge" network diagram (the patent holder is the Russian automobile company "AVTOVAZ"). The inventor added a calendar scale to network diagram, like one used in the Gantt chart. The nodes (representing the events) are tied to this scale by placing the center of a node under the date when an event happens. Visualization is effective for comparison of different variants of the schedule on the planning stage and for reflecting the dynamics of changes during execution stage. It is because different variants of a schedule can be reflected on one "sheet".

Some researchers focus explicitly on project dynamics visualization. For example, Taylor and Ford [6] consider the visualization technique which demonstrates the dynamics of the backlog between actual and planned progress during the execution stage. The two-dimensional space is used which can be called "the phase space of backlog". On its vertical axis the current backlog (t) is shown, on the horizontal axis – backlog at the previous moment (t−1). The dynamics of backlog is demonstrated as the trajectory, which the point depicting a backlog follow through the whole project. This visualization allows one to see and predict the occurrence and cessation of problems (they are shown as the turns in the trajectory), as well as the evolution/degradation tendencies in a project, thereby to assess the level of the current situation's stability.

In the technique proposed by Richardson et al. [19], a special shape is used to visualize processes. This shape can be called "fractal spiral". It is a spiral coiled into a spiral coiled into a spiral, and so on. Each cycle of a spiral represents a certain unit of time. The inventor proposed the technique as universal and showed it on the example of daily individual planning, but it can also be applied to construction schedules.

D. Huang et al. [20] draw attention to the Gantt chart's inefficiency in comparing multiple variants of a schedule (or changing schedules in a sequence). The author suggests two directions to overcome this limitation. The first is to overlay two Gantt charts one on top of the other. The other one, called "Tbarview", allows one to compare several charts in one space at once. The technique uses special signs for different states of activities: "lag", "ahead of schedule", "missed", "deleted", etc.

To manage the NPP construction projects, Engineering Division of Rosatom State Corporation developed special scheduling and resource management system "Unified Schedule" [21]. It uses the traditional techniques like the Gantt chart, and it is based on the widely used program systems like Primavera (Oracle), but with some important improvements. Some of them are related to the better adaptation and management of changes. It integrates 3 main schedules – of construction activities, of procurement and of the working documentation development. The first is a core schedule, other two can be called auxiliary. System recognizes and highlights "clashes". Clash is an expected or occurred violation of an activity's deadline in an auxiliary schedule which might lead to violations in the core schedule. Clashes' visualization is carried out by a system of signs, the shape of which indicates the type of auxiliary graph, the color - the presence and severity of a clash. However, the use of only 3 colors (green – for lack of clash, yellow – for possible clash in the future, red – for realized clash) allows one to make only rough qualitative assessment. To get (at least) approximate quantitative idea of the severity of a clash, it would be possible to use a spectrum of colors, as, for example, in heat detectors. But the problem of such an approach is subjectivity of color perception, as well as the difficulty of perceiving minor differences in shades. Finally, colors may be displayed differently on different screens and when printed and require the use of color printers.

Based on the review of dynamic-oriented scheduling visualization techniques, we can draw a conclusion that they have the drawbacks related to perception complexity (cyclograms, Rotenberg's calendar-network diagram) or ambiguity (using colors), or constructing complexity (Richardson spiral diagram). The drawbacks of the existing techniques necessitate development of new ones. In the following section the author's suggestion in this direction is disclosed. This suggestion is to use springs' image to activities' visualization. Choosing this image is caused by its natural capability to provide the sense of tension or weakness, which is needed to draw managerial attention to the activities with some problems. The author's technique has been named "the Spring chart".

3 Results

The algorithm for constructing the Spring chart is described in [8]. It can be summarized as follows. The baseline schedule is depicted similarly with the Gantt chart, but the bars which depict activities are replaced by the images of springs with right angles at the vertices of the "teeth". A right angle means an "equilibrium" state. With changes in the activity's duration, its "spring" is "stretched" or "compressed" proportionally.

In [8], the creation of a spring chart is shown in an example. The resulting charts for this example are shown in Fig. 1. The left side shows the baseline schedule and the schedule after the first set of changes in the form of the Gantt chart, the right side shows the same schedules in the form of the Spring chart.

The team of the Novosibirsk company "Edison Studio" has developed a demo version of a web application for visualization of schedules in the form of the Spring chart technique. The dynamics of changes in schedule can be presented in the application in two ways (at the user's choice): 1) as a sequence of charts; 2) as an illusion of a changing chart (animation).

The initial data given by the user includes: 1) a list of activities; 2) their durations; 3) precedence relations between activities; 4) changes in the activities' duration (for each set). The interface has been developed for user interaction with the application, as well as the database for storing information (Module 1). Module 2 is used to calculate schedules based on initial data. Module 3 is aimed at representation of schedule in the form of the Spring chart. Module 4 is a user interface of a Spring chart with visualization itself.

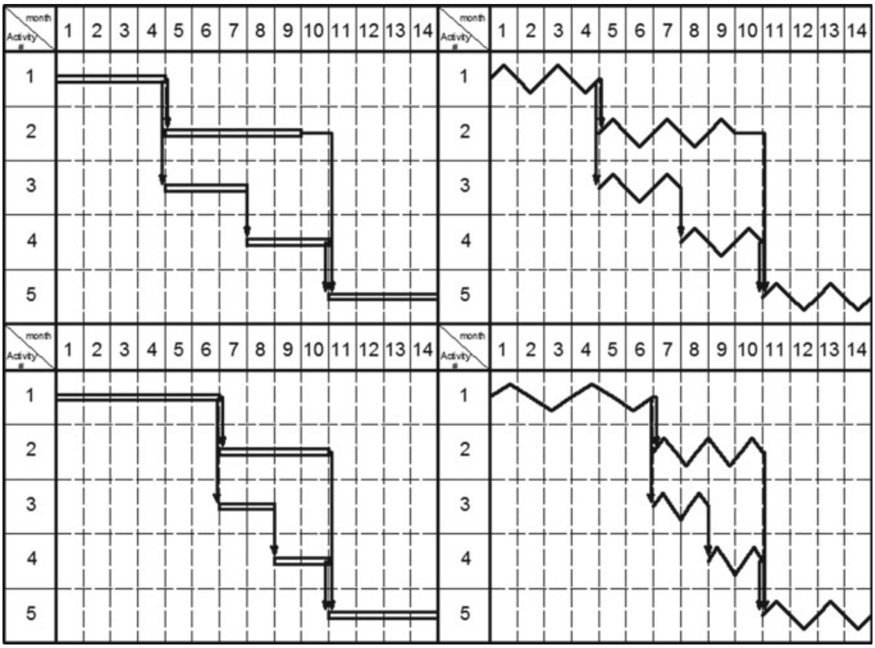

Fig. 1 "The spring chart" visualization technique implementation (an example). At the left – the Gantt chart, at the right – the Spring chart. At the top – the original schedule, at the bottom – the schedule after rescheduling

4 Discussion

The examples presented in the Fig. 1 show clearly that the use of the Spring chart, unlike the traditional Gantt chart, allows one to get an insight into the dynamics of changes in the activity's duration, thereby improving the quality of decisions on new changes.

It is also relevant to identification of the most variable activities (the variability of the expected activity's finish may be caused by the frequent occurrence of defects). This is especially important if analogous projects are planned in the future, since the study of the "history of spring fluctuations" can provide the better assessment of the activities' duration and risks at the planning stage.

The Spring chart overcomes the drawback of the techniques which use color for deviations' depiction: the different angles are used instead.

Noteworthy that the technique is only a tool for *supporting* decision-making, of signaling about *possible* problems. The final risk assessment and decision-making on changes remain the prerogative of the human manager, because of the high complexity, uncertainty and ambiguity of the tasks [8].

One might say that all the data about changes in activity duration can be attained without visualization whatsoever. It is true, but first visualization makes it much easier, which is especially important when there are too many activities and too short time to make a decision, as it is often the case in complex construction projects. The second, it is plausible that visualization like that might give one an emotional respond and general view better than dry numbers.

5 Conclusion

"The Spring chart" technique developed by the author was discussed. This technique is the Gantt chart modification, which facilitates considering previous changes during rescheduling. In the technique the image of spring used in mechanics is applied to represent activities. Springs are "compressed" or "stretched" proportionally to the changes in a schedule. Such representation contributes to intuitive understanding of an activity duration's degree of deviation from the baseline schedule. This is important for deciding the duration of which activities should be changed and how much. The proposed technique can improve quality of decision-making in dynamic construction project environment. Besides, the technique can become a convenient tool (a kind of illustration) when analyzing a "project history", which is especially important when the similar projects are planned. Despite of the technique's advantage for representing changes, it has the drawbacks related to some visual complexity and lack of data. These drawbacks might be overcome by integration with the existing techniques. Another perspective for further research is considering of the peculiarities of perception of this visualization. By tentative experiments it was found that this perception is not linear (if we make angle sharper it is not *considered* proportionally sharper). So, there is probably a need to make some corrections in the existing linear formula which describes how springs change. Besides, the developed web application should be improved by creating more convenient interface and widening of functional. As a further direction we also consider the integration of the application into BIM-models.

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End-Users' Opinions to Enhance the Process of Hazard Identification and Risk Assessment (HIRA) in Construction Projects

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Abstract Hazard identification and risk assessment (HIRA) is found to be an essential safety process in construction projects. Though many countries addressed the challenges of HIRA and developed many risks assessment approaches, HIRA-related studies in the Indian construction context are still rather scarce. This study aims to identify the challenges in HIRA and gather the safety head (end-users') opinions to enhance Indian construction projects' HIRA process. Face-to-face interviews were conducted among six leading organizations that are involved in all construction types of projects around the country. The finding shows that safety knowledge was not available to carryout HIRA when and where it was needed. From the end-users' view, this study suggested that the firms should adapt to new strategies to capture, store, and disseminate safety knowledge in organizations to make HIRA effective.

Keywords Risk assessment · Construction safety · Indian construction · End-users · Safety knowledge

1 Introduction

The construction industry persists in reporting high fatalities/injuries rate, making it one of the world's most dangerous sectors [1]. In the USA, construction-related injuries and deaths are 50% higher than in any other industry [2]; in the U.K., they are 25% of the overall accidents, 40% in Japan, and 50% in Ireland [3]. In developing nations, more extreme situations are reported [4] due to the lack of strict safety and construction legislation [5] and high rates of unskilled workers and unemployment [6]. Several research attempts have been made recently to study the efficiency of safety globally in the construction industry [1, 7–9]. Despite the number of significant studies and changes made over the years, construction accident rates are still high [1]. Nevertheless, some researchers have developed safety efficiency tools [10, 11]. However, these were either too difficult to translate to practical use or did not have

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a clear safety performance management strategy [12]. A simple, detailed, and yet practical approach is possibly lacking in the industry. This could be achieved through a risk assessment approach based on comprehensive HIRA [12]. All other processes are likely to be ineffective if HIRA fails [13].

In any construction project, HIRA is carried out by safety experts. Many researchers (e.g., [14]) stated that the traditional method of HIRA is not sufficient and adequate to prevent hazards as it is carried out based on the individual experiences and available sources. Li and Hua [15] pointed out that the traditional process does not represent the dynamic nature of construction processes. Many hazardous conditions go hidden [16], where adequate control measures cannot be provided. While some researchers [9, 14] have addressed these challenges of HIRA in many countries, including the USA and China, specific studies related to HIRA in the Indian construction industry is an uncharted area. Therefore, in this study, the focus was placed on identifying the reasons for HIRA failure, challenges faced by safety heads (end-users') during the HIRA process, and collecting the end-users' opinions to enhance HIRA in the Indian construction sector.

1.1 HIRA in Construction Projects

HIRA is a method of activity to identify causes of uncertainty (hazard identification), estimate the impact of unpredictable events/conditions (risk analysis), and generate response plans concerning anticipated performance and finally based on the feedback obtained on actual results and threats, detection, review and response generation measures have been consistently carried out during an object's life cycle to ensure that the project objectives are met [17]. Construction risk management is a repetitive task since the target functions appear to shift over the object's life cycle [18]. Several researchers in the construction domain have proposed many risk assessment techniques to facilitate this process. For example, an analysis of the ontology-based risk management system of construction projects was proposed by Tserng et al. [19] through project life cycle variance-covariance. Recently, to enhance construction projects' safety performance, Sanni-Anibire [12] developed a risk assessment model by employing pair-wise comparisons. The work of the entire project life cycle is defined by the construction project's risk management processes. Many researchers [e.g., 14, 20] discuss the risk assessment issues. Proper risk allocation has come to gain dominance in construction contracts because risk recognition and risk allocation directly affect risk management decisions [21].

2 Safety Context in Indian Construction

Construction is one of India's largest sectors, contributing around 8.2% to the gross value added (GVA) of the country in 2017–2018 [22], but accident statistics are not reported adequately and regularly [23]. Patel and Jha [24] predicted that Indian construction would account for many fatal and non-fatal accidents because of the dynamic nature and involvement of many stakeholders. To record and compile these statistics, a system is developed, but this is not done at a serious level at every point in the country. This is one of the reasons why adequate research on the construction safety of India has not been performed [25].

Due to the implementation problems of safety legislation, safety in the Indian construction workplace is still at its beginning stage. India has a poor record of implementing safety directives in the workplace relative to other developed and emerging nations [26]. India, however, has no loopholes in regulations such as "India's National Building Code 2005" and "The Factories Act of 1948," under which some of them are put into effect [27]. These are the national tools that provide procedures for controlling construction activities. Contractors and builders are also pushing workers' safety priorities to the lowest level [26]. The safety manual is being developed in the Indian construction industry, set as part of decision-making criteria typically submitted by bidders and tenderers.

End-users' scope the proposed job and establish a method of conducting the task safely to ensure workplace safety throughout their working day. Based on his own job experience, or his creative ability to invent possible risky conditions, safety heads predict safety concerns (or hazards). Depending on a specific form of work/place location, this may involve various details, i.e., the order of subsidiary duties, types of materials/plant, etc. Safety heads then identify suitable solutions, using risk assessment methods to compare the effect of these hazards and whether their solutions have an appropriate safe working system. Usually, this procedure is reported as a method statement and provided in a report to the site safety team. Safety practitioners train workers in the construction workplace. Workers are also instructed at the site in how to operate machinery safely. In addition, some of India's leading construction firms are catching up with developed nations in order to improve a safe working atmosphere [27].

3 Face-to-Face Interviews

To understand the safety experts' perceptions and opinions, interview was conducted among six leading Indian construction companies. All the companies are members of the Confederation of Real Estate Developers Association of India (CREDAI) and are actively participating in safety programs with more than 20 years of experience in the construction sector. These companies have been chosen since they are considered the most famous contractors in the Indian construction industry. Among six companies, three of them were listed in the 2018 Top 250 International Contractors of Engineering News-Record ranking (ENR 2018). Table 1 provides some information about these companies. Face-to-face interviews were conducted with safety heads or safety managers, as they are the ones who play a significant role in HIRA in the construction industry. The interview took place over two month period between

Table 1 Company profile

Company	Age of company (years)	Participants	Headquarters'	2018 total revenue ($ billions)
A	82	EHS manager	Chennai	20
B	41	Safety head	Hyderabad	2.4
C	38	Safety head	Hyderabad	0.6
D	25	Safety head	Mumbai	5.2
E	28	Safety head	Erode	0.1
F	23	Safety head	Chennai	0.2

October and November 2019 and lasted approximately 1 h. Interviews focused on the participants' details, reasons for inappropriate HIRA, the users' challenges during HIRA preparation, and users' opinions to further enhance the HIRA process. The participants were asked to give free answers for each question with explanations. Although the interview reflects the experts' view from six companies, it is believed that they can present essential aspects of HIRA within large Indian construction companies.

Qualitative interview data transcribed into narratives were coded in Atlas.ti 8, qualitative data analysis software. Interview data on safety management have been examined concerning HIRA. Data on common themes and related semantic definitions were primarily coded together as the same group. For instance, the guidance concepts and practice notes in transcripts were coded in the same group. During the coding process, each group was then continuously compared to the other groups for alteration until each had a clear-cut and straightforward categorization.

4 Results

The interviews' results are grouped into three key topics: reasons for HIRA failure, challenges in the preparation of HIRA, and opinions of end-users to improve the HIRA process. This is in line with the important aspects of HIRA stated in the introduction, with issues and challenges corresponding to the first and second topics and the third topic corresponding to the main improvement area.

4.1 Reasons for HIRA Failure

During the interview, participants were asked why sometimes HIRA fails to match with projects. All participants were aware of the HIRA failure, and different reasons were mentioned. For example, one participant, company A, stated that, *"Knowledge applied in this process may or may not be suitable to site conditions." Hence when the scenario changes, the HIRA, which is prepared for the new site, will be zero, and that could result in an accident(s).*

Another participant, company B, stated that,

"Some people get less duration to conduct HIRA." Due to client requirements and project duration, people get less time to conduct it. In this case, they have to run with what they have in hand, and here updating of existing HIRA fails.

Some participants considered "*lack of knowledge*" as the main reasons. The participants used different phrases and terminologies like "*low understanding level,*" "*not knowing the procedures,*" "*unaware of the hazards,*" and "*unaware of the sequence of the job*" to express their lack of knowledge.

Finally, one participant, company E, stated that,

"Following the copy of old documents could be the reason for this." HIRA, which has been already prepared for older projects, could be used for future projects without updating.

4.2 Challenges Faced by Users' in Preparing HIRA

Among six participants, two stated that there are no challenges to face while carrying out HIRA. They stated that,

As per the challenges concern, we don't have anything to say. We have a proper system here, and whenever we face some difficulties, we call our team members who have field experience. Their inputs are also necessary for carrying out HIRA.

One participant, company C, mentioned that *"in many cases, there is a chance of preparing HIRA without technical details"*. Another participant pointed that,

If hazards and risks are the same as previous projects, then it is relatively easy to tackle, but if it changes, then it is a challenge. There is a need to search for the required knowledge for providing the best control measures to prevent hazards and risks.

The other two participants stated that *"due to sudden change in the design of the building, the HIRA has to be changed accordingly and there will not be much enough time to do it."*

4.3 End-Users' Opinions to Enhance HIRA Process

Finally, the respondents were asked for their opinions for the better enhancement of the HIRA process. Participants shared their thoughts about why accidents are happening and what kind of systems are lagging to prevent those. For example, two of the participants pointed that, *There is no such government initiative to enhance the accident prevention system. Also, there is no safe work statement in which activities are yet to happen and what precautions need to be taken. Most of the companies fail to work this in the pre-construction stage, which could lead to accidents during the construction stage.*

One participant, company B, mentioned that,

There is no standardization in the accident prevention system and no online platforms to share safety knowledge related to near-misses and incidents. An online platform could be able to access safe work statements, including near-miss and incidents.

In the same line, another participant, company D, stated that *"there should also be a common platform in which all the details could be shared related to safety so that everyone can quickly access and come up with decisions."*

One participant considered that *"the work should be explained briefly by the engineers before the HIRA preparation to make decisions related to safety."* Surprisingly, one participant, company A, stated that *"the on-going procedures are enough to manage knowledge effectively in their company."*

5 Discussion

This research investigates the perceptions of safety experts in Indian construction companies concerning different aspects of HIRA. Firstly, across construction companies, different views about the reasons for inappropriate HIRA were observed from the participants. Most of them pointed that lack of safety knowledge is one of the main reasons for HIRA failure, which correlates with the similar research carried out by Nadhim et al. [28]. Where potential risks are not identified in the pre-construction stage, adequate training and measures cannot be given during construction stages [14]. Secondly, it was found that sometimes participants had to prepare HIRA without technical details and in less duration. This implies that the safety knowledge is not available when and where it was needed, and people did not know how to perceive or use the information available to them. These findings are largely attributed to the construction industry's project-based nature and the fact that knowledge is rooted in social relations [29]. Since the most experience, know-how, know what exists in people's minds [30], the companies must capture and re-use knowledge of experts involved in projects in the future. However, information mobilization techniques are critically essential for those large organizations that may carry out international projects [31]. Therefore, effective safety knowledge management (KM) is vital for construction companies to avoid losing safety knowledge acquired during construction projects.

Finally, users' opinions were collected to improve the process of HIRA. Most organizations suggested that an online platform where they can access safety knowledge could enhance the HIRA process when and where it is needed. However, the system could be misused in this case, and essential knowledge or innovative methods could be shared with competitors [32]. Therefore it is recommended that a closed system could manage safety knowledge within different construction firms. In designing such a safety KM strategy, organizations should identify the most effective KM solution for their businesses and choose the right methods, techniques, and practices. Researchers from different countries are showing more interest in recent decades to facilitate the safety knowledge of designers/safety heads (users) who predominantly work with the construction industry's risk management process. For example, Hadikusumo and Rowlinson [14] developed a design-for-safety-process (DfSP) tool to assist safety engineer to recognize hazards and establish control measures in the American construction industry; Cooke et al. [33] developed ToolSHeD, a decision support tool for Australian construction companies, to integrate the health and safety risks with the construction design process for facilitating the knowledge of designers. Recently, Goh and Guo [34] developed FPSWizard, a knowledge-based system for supporting active fall protection system (AFPS) selection in Singaporean construction companies. These studies aimed to minimize construction accidents by facilitating safety knowledge among professionals in the construction project's design stage. The government should put more effort into developing safety strategies to prevent accidents in the Indian construction industry. Although there is a scheme to record construction accidents in India, it has not been carried out profoundly. Therefore, the government should pay more attention to such plans to record construction accidents all over the states of India. This could help construction companies in understating accident cases, including workers' characteristics and trends of accidents. In countries including the USA [35] and Hong Kong [36], researchers are using their government accident statistical records to highlight the trends and causes of construction accidents. Such studies help academicians and researchers to examine risks and provide adequate control measures to prevent workers from accidents, judging from the number of journal articles and availability of report achievement cases at different levels on its implementation in construction companies.

6 Conclusion

One of the most important safety processes has been defined to be HIRA, which requires the ability to adjust appropriate techniques and communicate knowledge in a manner that effectively communicates risks. Over the years, a range of studies related to HIRA has been conducted, and various risk management methods have been developed. They have subsequently evolved into unique ideas on par with discoveries, communication, and technology. Till now, up to the author's knowledge, there is a lack of study related to HIRA in the Indian construction context. In this study, the face-to-face interviews were carried out among major Indian construction companies was presented. The overall finding of this study was the lack of safety knowledge when and where it was needed. The end-users' opinions to enhance the HIRA process are illustrated. The result shows that these firms should adapt to new strategies to capture, store, and transfer safety knowledge in organizations to make

HIRA effective. The limitation of this study is that the data collection was restricted to only six companies. Future research could be expanded to many contracting companies and compare the HIRA process performed by contractors. Besides, this study proposes that future researchers should evaluate the different HIRA methods' relative efficacy. For organizations with insufficient resources to execute every strategy, such studies will be essential.

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Managerial Features of the Design of Technical Solutions for Engineering Protection of the Territories During the Life Cycle and Their Reengineering

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Abstract The development of the integrated (spatial) planning of the territory is necessary to form modern comfortable urban environment. An important part of the integrated planning of the territory is an engineering protection, ensuring infrastructure construction, organic placement of construction objects in the ecosystem while preserving its natural relationships, protection of constructed or under construction objects from hazardous natural processes, as well as protection of population from the risk of possible consequences of ecosystem intervention. The purpose of the research is to form principles (conditions) and requirements for decision-making on the arrangement of the engineering protection of territories and objects, ensuring their long-term and safe operation, the possibility of the spatial planning reengineering. Current urban planning standards are reviewed, according to them the principle of the efficient use of territory is legislated, it is reflected in the preparation and approval of the spatial planning documentation for the placement of capital construction objects, engineering infrastructure, as well as design, construction, reconstruction of these objects. A list of measures and structures for engineering protection of territories, buildings and structures is determined at the stages of spatial planning, design and site preparation. The necessity of the integrated approach to the engineering protection arrangement at each stage of planning, design and development of the territory is noted, it is based on the development of various design solutions, optimization of the design process, assessment of the prevented damage, justification of the investment and estimation of the consolidated approximate cost.

Keywords Reengineering · Spatial planning · Architectural design · Construction design · Engineering protection of buildings and territories

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1 Introduction

The successful development of the national economy and prosperity of Russia' population are directly related to the security and efficiency of land development, environment in cities and rural settlements. A significant part of the Russia's residents lives in cramped conditions and needs more living space, at the same time facing with a shortage of public, business, trade and leisure-and-cultural infrastructure, low transport accessibility of urban and rural areas, traffic jams, shortage of parking areas, lack of parks, squares, low quality of urban land planting and improvement and, poor ecological situation, noise and atmospheric pollution.

The main objective of spatial development strategy of the Russian Federation is to achieve sustainable and balanced spatial development of the country, aimed at reducing interregional differences in living standards of the population, accelerating the pace of economic growth and technological development, as well as ensuring the national security of the country.

Main objectives of the national project "Housing and Urban Environment" ("Zhil'e i gorodskaia sreda") implementation are an efficient land use, increase in housing construction, holistic development of cities and towns, reduction of unlivable housing accommodation, this creates conditions for the implementation of renovation programs, as well as possibility of subsequent reengineering of both local capital construction objects and whole development areas. The result of the realizing these objectives is the formation of a comfortable and safe living environment.

An important component of the integrated (spatial) organization of the country, regarding the organization of land and settlement development, is an engineering protection of territories, buildings and structures. As infrastructure construction element, it ensures reasonable placement of construction objects in the ecosystem while preserving its natural relationships, safety of constructed objects or those under construction from hazardous natural processes, as well as protection of population from the risk of possible negative consequences due to disruption of natural processes during large-scale development of territories and construction.

As a result, a set of measures for engineering protection of buildings, structures and territories takes an important place in the urban environment development, being an essential part of infrastructure project implementation, spatial development, so this context acquires a complex structure, covering all areas of activity (socio-economic, environmental, investment ones) [1–8].

The objective of the work is to formulate principles and requirements for decision-making on the arrangement of the engineering protection of territories and construction objects, ensuring their long-term and safe operation, the possibility of reengineering of the spatial planning (development) of the territory.

2 Methods

Technical solutions to ensure engineering protection of the territory are aimed, in one way or another, at resolving the problems of the same name, that arise in the process of design, construction, operation. They should prevent negative impact of hazardous geological, environmental and other processes on a land plot and the buildings and structures, located on it.

Technical solutions to ensure engineering protection of the territory are regulated by the provisions of construction standard technical documentation (STD), in which the requirements for their formation and documentary representation are established (Fig. 1).

Requirements for technical solutions for engineering protection may be structured according to such stages as spatial planning, architectural and construction design, accounting the following requirements:

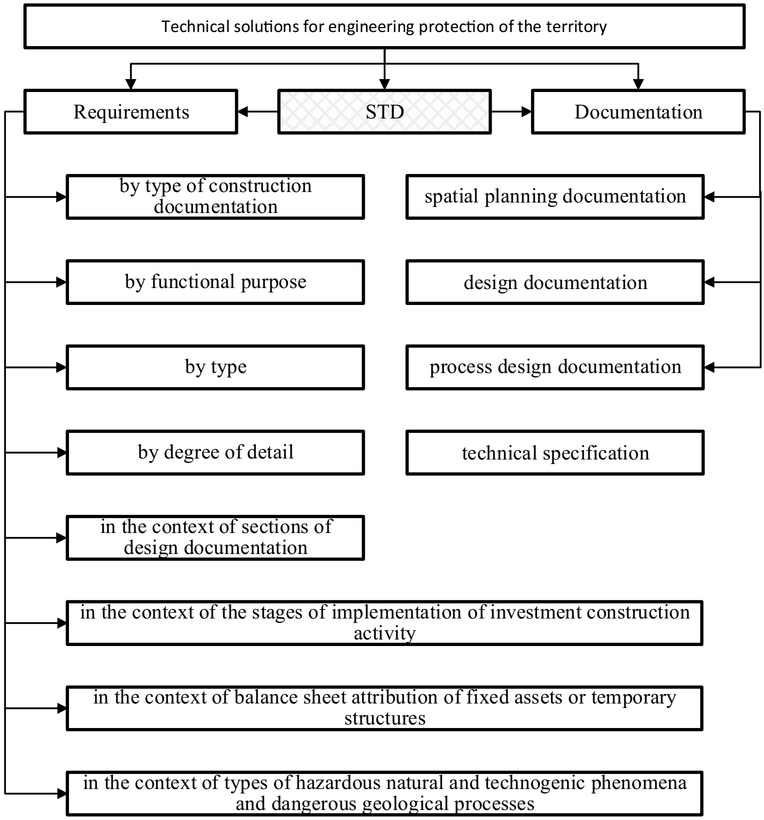

Fig. 1 Requirements for the formation of technical solutions to ensure engineering protection and their documentary representation

I. By type of construction documentation:

1) spatial planning documentation;
2) design documentation.

II. By functional purpose and features of construction objects:

1) industrial objects, excepting linear facilities;
2) non-industrial objects;
3) linear facilities (pipelines, roads and railways, power lines);

III. By type:

1) engineering protection of territories;
2) engineering protection of buildings and structures.

IV. By degree of detail of the technical solutions for construction:

1) constructions of engineering protection of territories from hazardous geological processes;
2) constructions of engineering protection of buildings and structures;
3) measures of engineering protection of territories from hazardous geological processes;
4) measures of engineering protection of buildings and structures.

V. In the context of sections of design documentation:

1) engineering construction site investigations;
2) Sect. 1 “Explanatory note”;
3) Sect. 2 “Planning of the land plot”;
4) Sect. 4 “Design and space-planning solutions”;
5) Sect. 6 “Project of construction organization”;
6) Sect. 8 “List of measures for environmental protection”;
7) Sect. 12 “Other documentation, stipulated by federal laws”.

VI. In the context of the stages of implementation of investment construction activity:

1) at the stage of construction site preparation;
2) at the erection stage;
3) at the operation stage.

VII. In the context of balance sheet, attribution of fixed assets or temporary structures:

1) engineering protection structures put into operation as a part of capital construction objects;
2) engineering protection structures related to temporary structures and subject to dismantling.

VIII. In the context of types of hazardous natural and technogenic phenomena and dangerous geological processes, which include floods, inundations, mudflows, landslips and avalanches, karst, erosion of seashores, reservoirs, lakes and rivers, frost heave, ice formation, thermokarst, hurricanes, tornadoes and others.

The necessity of an integrated approach to the engineering protection arrangement at each stage of the territory planning, design and development requires preparation of an engineering protection project, including general layouts, detailed and specified plans, to develop various project solutions, optimize the design process, assess the prevented damage, justify the investment and estimate the consolidated approximate cost.

3 Results

The list of documents, which may be grouped in a following way, must comply with the above requirements:

1) spatial planning documentation;
2) urban planning and design documentation;
3) process design documentation;
4) technical specifications (including special ones).

As it was already mentioned, the substantive basis of these types of documentation consists of engineering (technical) solutions. According to the chosen area of research, organizational and technological solutions to ensure engineering protection of the territory, directly related to the erection works, are of the greatest interest. They are formed sequentially at all stages of the life cycle, but they have their own specific features.

Organizational and technological solutions for ensuring engineering protection of the territory, by its definition, are the result of the professional activity of the relevant specialists with certain competencies. Moreover, the professional and qualification composition of these specialists changes due to a change in the set of tasks to be solved at the stages of the life cycle of a capital construction object (CCO).

In this regard, the following main stages may be established (Fig. 2) whereas distinctive engineering results may be determined for them:

1) Spatial planning stage. The result of this stage are plans and documents of a certain level of spatial planning (regional, local, etc.);
2) Design stage. Depending on the scale and level of the tasks, the result of professional activity of this stage may be urban planning documentation (general layouts, development schemes, town-planning regulations) or design documentation for engineering protection of the specific area;
3) Erecting stage. Understanding the tasks of direct erection of the designed structure, the ability and preparedness to perform these works are indissolubly

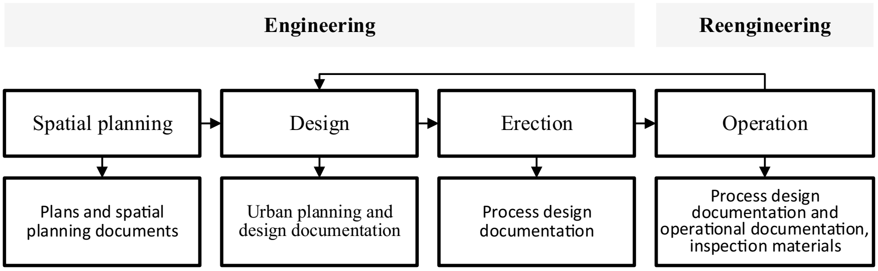

Fig. 2 Stages of formation of engineering solutions for the protection of the territory

connected with the development of process design documentation (project of work production, flow diagram, plan of organization of work), allowing achievement of the planned technical-economical indexes and ensuring the required quality of engineering protection;

4) Operation stage. The result of the tasks, solved within this stage may be operational documentation, that determines the technical condition of the capital construction object, and process design documentation, required to carry out repair and restoration works.

Considering the proposed stages of solving technical (engineering) problems, the first three stages and partially the 4th stage (in relation to repair and restoration and construction works) may be attributed to the research area of engineering. And the 4th stage in terms of amending existing engineering solutions of the capital construction object to improve its technical and economic indexes on the basis of the objectively formed necessity for the transformation of the territory, development may be attributed to the research area of reengineering. Following the logic of the discourse, reengineering may be applied to technical solutions of the territory (land plot), development and objects of engineering protection themselves [9, 10].

Some regularities and features of these types of reengineering should be noted. So, reengineering is almost all cases considered as an alternative to decommissioning, object liquidation and disposal of teardowned constructions for the CCO (and their complex, which is development). However, this principle does not make sense for the territory, in this case, reengineering is the only acceptable option. It may be implemented in the form of the territory renovation or its reclamation.

Taking into account the definition of reengineering [9, 10] as a qualitative transformation of the territory, development, CCO, it is necessary to establish the reasons for its implementation (Fig. 3).

As it was noted above, reengineering is an uncontested development of the land plot, along with which technical solutions of engineering protection are being transformed. Such development is caused, on the one hand, by scientific and technological progress, inducing the appearance of new materials and technologies with higher technical and economic characteristics or even unparalleled ones at the moment. On the other hand, the driving motive is convergence, which has a certain grouping and hierarchy of manifestation. In the context, considered in the article,

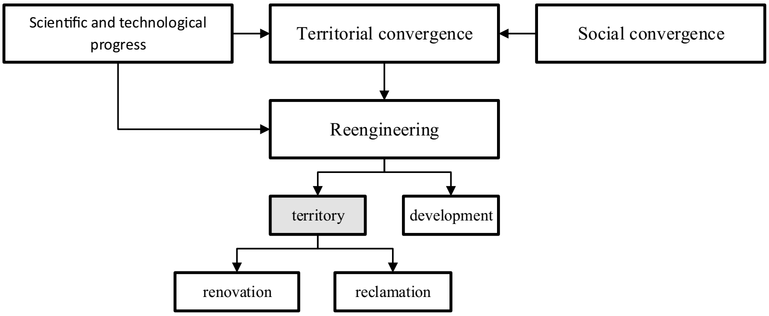

Fig. 3 Scheme of the reasons for implementation of reengineering the territory and development

it seems appropriate to note its social and territorial varieties. As a result, these phenomena determine the appearance of new requirements, which sometimes may be legislated [11–26].

4 Discussion

A qualitative change in technical solutions for engineering protection of the territory is becoming an objective necessity for the above reasons, and their implementation is connected with the reengineering measures, aimed not only directly at the land plot, but also at its development or even at a separate CCO. It is obviously necessary to ensure a single vector in the implementation of reengineering measures due to their diversity, it should be plotted at the stage of spatial planning and enshrined in the urban planning regulations.

In this regard, reclamation and renovation should be determined as possible options of reengineering of the territory. If in the first case, the terminological identification of reclamation, as well as its order, stages and composition, are legislated, then in the second case, there is nothing of the kind, that requires additional regulations.

The following definition of renovation of the territory (land plot) may be proposed, which means a qualitative transformation of planning, engineering and infrastructure solutions, as well as changes in the functional purpose of a land plot. Unlike renovation, reclamation is defined as restoration of a land plot, while its functional purpose remains unchanged.

Reengineering of a territory may involve sequential implementation of reclamation measures and then renovation ones. This statement may become a direction of further researches within the chosen subject area.

As a conclusion, the following statements may be noted. Technical solutions for the engineering protection of the territory and managerial aspects of their formation at different stages of the life cycle have their own features in of the content and procedural sides. One such aspect is the necessity for engineering measures, aimed at the qualitative transformation of existing technical solutions. They are motivated by scientific and technological progress and convergence. Regardless of the motivation, the result of reengineering of the territory should be the creation of a comfortable and safe living environment, which is based on the principles of the concept of spatial sustainability.

5 Conclusions

The features of providing engineering protection of settlements at the stage of spatial planning are described.

The analysis of statistics, main reasons and factors, requiring consideration and affecting the integrated (spatial) development of the territories of future construction, is carried out.

Engineering protection has an influence (mutual one) on the designed buildings and structures, as it significantly exceeds the established design boundaries of the objects. So that the problematic issues, preventing the implementation of sustainable development of territories due to spatial planning and urban planning zoning and forcing to consider the requirements of technical regulations, ensuring engineering protection of territories, at the design stage of capital construction, are stated.

The list of measures, as part of the engineering protection of the territory, for the preparation of the land plot for construction and organization of the erection works, accounting the characteristics of the territory (site) of construction is generalized.

The list of requirements for making managerial and technological decisions when arranging engineering protection at the stages of spatial planning and architectural and construction design is generalized.

Execution of the formulated principles (conditions) and requirements when making decisions on the arrangement of engineering protection of the territory and construction objects will ensure the implementation of reengineering of the spatial organization (development) of the territory.

The necessity for an integrated approach to the engineering protection at each stage of planning, design and development of the territory is noted, this approach is based on the development of various design solutions, optimization of the design process, assessment of the prevented damage, justification of the investment and estimation of the consolidated approximate cost.

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