buildings

MDPI

Article

Ensuring Efficient Implementation of Lean Construction Projects Using Building Information Modeling

Svetlana S. Uvarova [1], Alexandr K. Orlov [2] and Vadim S. Kankhva [2,*]

[1] Department of Economics, Management and Information Technology, Voronezh State Technical University, 20-Letiya Oktyabrya Street, 84, 394006 Voronezh, Russia
[2] Institute of Economics, Management and Communications in Construction and Real Estate, Moscow State University of Civil Engineering, Yaroslavskoe Shosse, 26, 129337 Moscow, Russia
* Correspondence: kanhvavs@mgsu.ru

Abstract: Modern economic dynamics makes it more expedient to introduce lean construction tools into the activities of all value chain participants in construction. The need to take into account digitalization processes in construction entail an increase in the urgency of the problem related to the integration of digital technologies into the concept of lean construction. Many studies have been devoted to the problems of integrating lean construction with building information modeling (BIM) tools, which have proved their effectiveness and substantiated obstacles to their active implementation. However, issues related to assessing the cost-effectiveness of integrating lean construction with BIM and other digital technologies (if companies refuse to introduce BIM), which allow for improving the interaction of investment and construction project participants, have not been actively studied. This article examines the effectiveness of using digital tools and technologies that will contribute to the development of lean construction and reduce the corresponding losses of investment and construction projects in the example of Russia. A literature review, interviews with experts aimed at summarizing the results, as well as practical calculations taken from the existing project, were used for the purposes of this study. The main losses at each stage of an investment and construction project arising from problems in the interaction of participants in Russian construction were identified, the effects of integrating lean construction with BIM and other digital technologies were determined, an algorithm for selecting digital technologies to be integrated with lean construction was developed. The methodology for calculating the effect of the implementation of tools and principles of lean–digital interaction technologies, as well as recommendations for the implementation of tools in construction practice, were discussed.

Keywords: lean construction; digitalization; efficiency; interaction

check for updates

Citation: Uvarova, S.S.; Orlov, A.K.; Kankhva, V.S. Ensuring Efficient Implementation of Lean Construction Projects Using Building Information Modeling. *Buildings* **2023**, *13*, 770. https://doi.org/10.3390/buildings13030770

Academic Editors: Agnieszka Leśniak and Ahmed Senouci

Received: 10 January 2023
Revised: 10 February 2023
Accepted: 13 March 2023
Published: 15 March 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In the context of a highly turbulent economic situation, the basis for the survival of a company is cost reduction and elimination of unproductive losses, which is the focus of lean manufacturing. Accordingly, it becomes relevant to improve the methodology and philosophy of lean manufacturing, taking into account the impact of key challenges of modern economic reality, which includes the impact of the coronavirus pandemic, import substitution under sanctions, changes in the geopolitical situation [1], and development trends, such as changes in the technological mode and Industry 4.0 and 5.0, digital economy formation and development, sustainable development [2–4]. The necessity and relevance of applying the concept of lean manufacturing in modern Russian construction are also reflected in the adopted Strategy for the Development of the Construction Industry and Housing and Public Utility Sector until 2030 [5].

When studying lean manufacturing, one should understand that manufacturing as the process of value generation is its fundamental basis [6,7]. Considering lean manufacturing in construction, it is necessary to take into account modern studies of value

chains, in which the use of advanced technologies [8,9], sustainable development [10,11], the interaction of participants [8,12,13], and the impact of digital transformation on the efficiency of these chains by improving management and performance [3,8,11,14] are shown as promising areas.

Analyzing the scientific literature devoted to the general problem of value chain digitalization and the digitalization of lean construction principles and tools, one can conclude that there is a certain dualism of opinions. A number of scientists [15–18] believe that the curve of added value distribution in value chains in the conditions of digital transformation demonstrates upward dynamics if lean manufacturing is combined with digital tools for studying consumer demand. Other researchers tend to separate lean manufacturing and digitalization, considering that fixing the processes by their digitization is not only inefficient but also results in losing financial and time resources [19].

The possibility of analyzing big data using digital platforms and the Internet of Things leads to an increase in the profitability of the product sales segment in the value chain [20]. This trend is also typical for construction products, given the limited information about needs and the corresponding high risks compensated by the high profitability of these value chain links. The use of digital technologies for collecting and analyzing data on consumers will reduce risks related to construction product selling and decrease the number of intermediaries thanks to digital platforms and services ensuring communication between manufacturers and consumers (similar to other value chains as specified in [21]).

Active discussion of the impact of various digital technologies on value chains often focuses on analyzing the impact of digitalization on employment and world trade, ignoring the relationships and communication of value chain participants [2,22]. Regarding the digitalization of value chains, the authors note the key possibility of tracking the movement of a product along the entire chain with the control of all material flows and financial calculations, which makes processes more transparent and also ensures lean manufacturing effective use at various stages of the value chain [8,16,23,24]. We agree with the opinion of a number of scientists who believe that at the current stage of digital transformation, digital solution providers should stop competing to retain consumers of these solutions and focus on cooperation with these consumers to take the lead in the markets of final products, i.e., the value chain exit [24–26]. The study [27] notes that in the context of the digital economy, management makes it possible to obtain reliable information about the actions of every value chain participant in order to coordinate actions and make correct managerial decisions when there are means for online information sharing and binding to a single model of the object [27].

Another crucial point, even a key one for the implementation of digital technologies, is the high turbulence of the socio-economic and political environment that has existed since the beginning of the pandemic in 2020. Researchers [4,25,28] note the need to increase the adaptability of value chains to various shocks [4]. In this context, digitalization creates opportunities to analyze the results of monitoring the entire supply chain in real-time and allows one to respond quickly to changes in consumer preferences and the dynamics of the external environment [29]. The problem of adapting value chains to various types of risk situations is of paramount importance in the relevant areas of research today [4,28,30]. The lean manufacturing system allows companies that are value chain participants to increase efficiency, eliminate losses, and reduce the working capital requirement [17,30,31].

To a certain extent, this allows the implementation of new digital technologies, which at the same time are a tool to support making decisions on a prompt response to changes in consumer preferences.

However, the limited number of resources at various levels of the economy during the crisis led to the need to select such principles of lean construction and digitalization tools integrated with lean construction that will, in practice, allow for increased efficiency in modern conditions, including the Russian construction management system and the corresponding interaction of value chain participants.

Despite the high level of development of the BIM and lean construction integration issue, there is little research on the effective use of other digital technologies since companies are reluctant to implement BIM; the same applies to the gradual transition to the use of BIM in lean construction. Moreover, the problem of assessing the effectiveness of lean construction tools' digitalization in the interaction of value chain participants remains underinvestigated.

Accordingly, the purpose of this study is to determine efficiency and identify the digital tools and technologies that will contribute to improving the efficiency of lean construction and reducing losses from the interaction of value chain participants.

The structure of the article is as follows. Section 1 provides an overview of the main current areas of research in the field of value chains in construction, the concept of lean construction and its interaction with digital technologies, and the purpose of this research. Section 2 presents the sources of theoretical and empirical data for the research, a detailed review of literature dedicated to interaction within the framework of lean–BIM, and empirical data from the Russian practice of value chain interactions in construction. A new approach to the selection of digital tools to implement the principles of lean construction in the value chain in construction is presented in Section 3. The results of the evaluation of the effect of the proposed approach on the example of a real construction project in Russia are given in Section 4. Prospects for wider application of the research results and its further development are presented in Section 5.

2. Materials and Methods

The logic of using the methodological framework and the research materials are given below, as well as the scientific justification of the possibility and feasibility of their use (Figure 1).

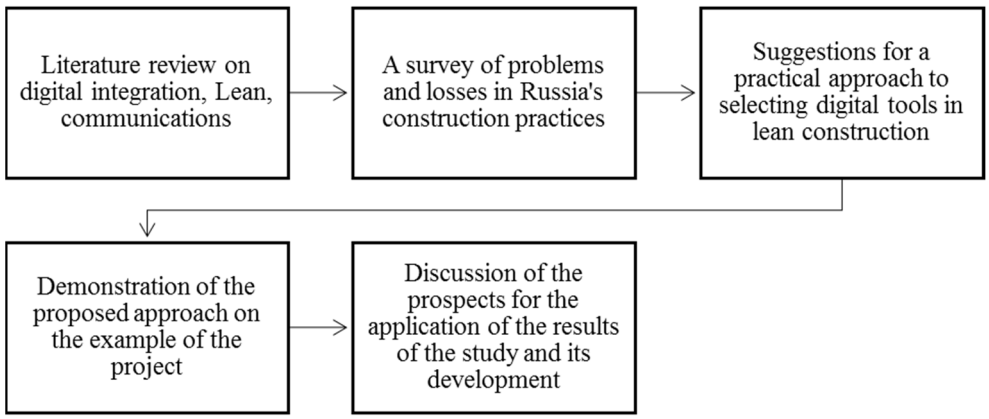


Figure 1. Research methods.

In the first stage, the literature is scanned to identify existing challenges, prospects, and areas for integrating lean construction with digital technologies in the value chain. Particular attention is paid to the study of the interaction of participants in the value chain in lean construction and their information component.

2.1. Lean Construction in the Value Chain

The purpose of lean manufacturing is to generate value for the consumer [6,32]. Modern economic science shifts the focus from the value-based approach studying the usefulness and consumer value towards value-based management, i.e., the approach to generating new value for stakeholders. Such an interpretation is typical for value-based management, to which the concept of lean construction refers [33–35].

Based on the multi-subject specificity and the need to combine and cooperate a number of specialized organizations in the process of the project life cycle and the life cycle of a real estate object, the process of generating consumer value in construction in-

cludes the consolidation of actions of all the listed subjects in the process of creating construction products [36].

Participants in the value chain in the construction of Russia are customers and investors of construction that create the basis for the implementation of investment and construction projects and the formation of resulting construction products. At the same time, standards and basic requirements both for the process of communication of project participants and the value generated for the consumer are developed under the influence of leaders in the process of self-regulation. The participants of the construction are both subjects of investment and construction design, including technical customers, contractors, project designers and surveyors, operating organizations, standardization and certification organizations, organizations producing construction materials, small innovative enterprises and PropTech startups, and consulting firms. Every participant, in turn, creates a complementary product or its part used to generate value or construction products.

The composition of participants in the value chain in Russian construction differs from the similar one in Europe due to the specifics of the legislation [37] and the absence of a number of types of contracts, for example, IPD [16]. A special group of participants consists of executive bodies of the Russian Federation and its subjects, including supervisory and controlling bodies. Functions in the field of urban planning or spatial environment reconstruction, including the development of urban development plans, ending with the issue of construction permits [37], are within the competence of the authorities of the constituent entities of the Russian Federation.

Sources [17,38] describe a combination of process and project approaches in management; therefore, participants in the value chain in construction and investment and construction project participants are synonyms.

The main trends in value chain research are the application of digital technologies to optimize supply chains; manage resources; ensure the sustainable management of green supply chains, system integration with partners and other participants, and creation of information platforms for uniting participants; and make joint decisions [8].

To increase value in the chain, we must remove communication and coordination barriers, which will also result in higher productivity, lower costs, and losses in construction [33].

2.2. Lean Construction and Digitalization

The use of lean manufacturing and principles in construction projects to improve efficiency has been developing. However, most of these principles and tools are not integrated with modern digital technologies, such as BIM [39,40]. The integrated application of lean–BIM in a construction project will significantly increase the value of the construction product and process [41]. Improving productivity and efficiency and reducing costs and losses as a result of integrated application of BIM and lean are confirmed by many studies [42–44]. The introduction of lean and BIM in project implementation has become a new area of research in the field of information technology development in architecture, design, and construction [42,44–46].

Opinions Differ Slightly on the Methods and Timing of Integration

Research [47] contrasts the lean construction approach and the digital transformation of management. Indeed, digitalization by itself will neither reduce losses nor optimize processes according to the principles of lean construction [48]. Accordingly, the digitization of business processes is one of the last stages of the life cycle of changes in the context of lean construction concept introduction. On the other hand, a number of researchers consider it necessary to introduce lean construction and digitalization tools simultaneously [44,45,49,50].

Regarding the significance of digitalization processes for value chains and the relation between Industry 4.0 tools and lean construction, the team of authors adheres to the position of R. Basso and other researchers [17,18,24,44,45,50] defining in modern conditions “Lean Manufacturing 4.0” or “Operational Excellence 4.0” [24,49,51]. The tools of lean production

and digitalization are not mutually exclusive and should be complementary tools that allow the implementation of complementary parallel processes.

Recently, researchers and practitioners have become interested in lean digital tools that support production planning and control [40,42]. BIM is the leader in this process, but there are problems both with the safety of the model and with data compatibility [40].

In any case, it is necessary to give priority to the involvement of employees, competencies, processes, and operating models [7,52]; combine digital technologies with lean manufacturing processes; and obtain, as a result, the trinity of processes, technologies, and people involved in the process. Two-thirds of the lean manufacturing program focuses today on talents and competencies, one-third on processes, and only 10% on technologies [49,53]. Lean manufacturing 4.0 connects technology with processes and people [40]. The introduction of digital technologies in the implementation of lean manufacturing processes, in particular, lean construction, will reduce the time spent by employees to fill in and prepare all documentation within the framework of lean construction activities as well as the time spent for meetings, for traveling to the place of meetings and the place of construction, for information processing, and the time needed to carry out various comparisons and present results visualization. Given the remoteness of construction facilities from the back office and the large number of participants in a construction project, digital technologies will reduce the time spent on data consolidation and aggregation, meetings, and status update meetings. Digitalization contributes to saving time, increasing the availability of knowledge and information, and improving decision-making processes [54]. Working in a digital environment is a new way of accomplishing existing lean construction tasks with certain advantages. Digitalization and technology should be integrated into lean construction programs not as an additional tool, but as consolidated information in an appropriate dashboard ensuring continuous progress in the level of sustainability of the company and its construction projects.

The recommendations for the integration of lean construction and digitalization tools include the leadership initiative, the introduction of educational programs, and the improvement of communication between project stakeholders, including through the change of contracts [55], high-quality training, partnership of all project participants, and state support [44].

2.3. Lean Construction, Communication, and Information

The philosophy and methodology of lean construction are based on the fact that at all stages of the life cycle of manufacture of a product, i.e., a capital construction project (CCP), various production losses are eliminated, as well as everything that does not generate consumer value, but only contributes to an increase in the price of the product is reduced to the maximum, and a system aimed at meeting customer needs and generating value is formed [6,55]. The concept includes a number of methodological tools and approaches to ICP management [6,19,32,42].

However, it is necessary to take into account not only material flows but also information flows arising in the process of construction [56]. The need for information management leads to the establishment of a relevant process as one of the components of the overall process of managing an ICP.

A number of researchers [45,57–59] note the importance of obtaining reliable information on time in the project. It is especially important that errors in design information lead to a huge number of improvements at the construction stage [58]; outdated information about the object leads to the complexity of its maintenance [59]. The study [60] calculated that more losses are accounted for the verification of information, while the inefficiency of business processes and downtime of employees account for 15%. The lack or insufficiency of information leads to losses [57], which require elimination within the framework of the concept of lean construction.

The toolkit for solving the problem of inefficient information is provided by digitalization, and the best solution is BIM [53,54]. Moreover, BIM "is a collaborative concept that

involves more integrated planning and interaction between team members" [17]; that is, digital technologies not only allow solving the problem of inefficient information but also ensure the interaction of project participants promptly. However, the application of BIM at the stage of object management, i.e., operation, is difficult due to problems with data integration between different software solutions [17,61], which leads to losses [17]. One of the possible solutions is the use of the IFC data format [17,62], which is also determined by Russian legislation.

Given the fact that BIM implementation is rather costly, a phased transition is proposed. It involves a transformation from 2D to 3D models [17,54], and this transformation also results in losses [59]. It is necessary to introduce lean construction tools [17], and it is important to take into account the shortcomings of BIM and provide for a gradual transition to it through the introduction of other digital lean construction tools.

Qualitative and prompt exchange of information is typical for joint models of project implementation [46,63]. Lean project implementation also refers to joint models [46], including joint planning, design, and control, which eliminates many inter-operational losses.

The study [50] investigated the synergistic relationship between lean, BIM, and integrated IPD project implementation (also representing a model of joint project implementation). IPD is a process with the help of which project participants are in the project from the beginning to completion [50], and lean construction is a process aimed at improving the communication between construction participants to maximize value and minimize losses [64]; these approaches complement each other. Moreover, the use of BIM and IPD improve the results of lean construction [50].

The Russian practice of interaction mainly uses the traditional model of project implementation based on the implementation of stages related to certain contractual relations [37]. Therefore, interaction is often weak; there are many requests and clarifications in the project and high losses due to communication [56].

The article [65] presents quantitative evidence of increased team interaction through the application of lean management of design and BIM. Interaction was achieved through early involvement of participants, joint planning, and prompt resolution of issues in a common data environment (EDMS). Team interaction was assessed using social media analysis [65]. However, the effectiveness of projects was not evaluated. Therefore, it is important to assess the effectiveness of joint work of construction participants from an economic standpoint and justify the tools applicable in Russian practice that improve the interaction of participants.

2.4. Practice of Interaction and Losses in the Value Chain in Russian Construction

Modern Russian construction practice only fragmentarily applies BIM tools and other digital technologies. Paperwork is more developed [56,61]. In Russia, according to the Ministry of Construction, Housing and Utilities of the Russian Federation, 20% of companies use BIM [66], and the volume of the information modeling market slightly exceeds $60 million. Information accumulated in a number of created information systems, such as FGIS PC (Federal Government Information System for Pricing in Construction containing data on construction resources and their cost), SIS HUS (State Information System of Housing and Utilities Sector), and UDSIS (Urban Development Support Information System), are used in the process of construction. Digital technologies are also used fragmentarily in design, ERP, CRM, and electronic document management systems (EDMS) [61,66].

The assessment of losses arising from the usual interaction of project participants was carried out on the basis of the previous online brainstorm session [67,68], which united 10 leading specialists in the construction industry (including designers, investors, heads of contracting and operating organizations, customers, professors of Moscow State University of Civil Engineering, heads of state authorities). As a result, key problems of communication and coordination throughout the life cycle of the project were systematized, and ideas for reducing losses were proposed (Table 1).

Table 1. Expert assessment of the individual significance of communication problems faced by project stakeholders; points.

ICP stages	Description of operations in accordance with ICP stages	Interaction chain (responsible persons)	Deadlines	Recommendations for optimizing the operation
Pre-design stage	Development of a project business plan	Customer	Not regulated	The project should have a minimum payback period, parameters necessary to receive government subsidies, concessional loans, or be subject to national projects. Reduce inter-operational losses of time spent on meetings and obtaining approvals
	Land plot allocation	Customer–Municipal administration	Within 30 days from the date of application submission	
	Obtaining credit financing	Customer–bank	7 to 60 days or more, depending on the complexity of the project and its estimated cost	
	Obtaining technical conditions for connection to the supply system	Customer–networks owners	Not regulated	This operation is the most long-lasting and bureaucratically complex at the initial stage. Reduce inter-operational losses of time needed to obtain approvals
Design stage	Tender for design and survey works	Customer	14 to 30 days, depending on the tender conditions	The customer needs to pay attention not only to the cost of the project but also to the qualifications of the design staff
	Development of design and estimate documentation	Project designers	30 days to 1 year and more, depending on the complexity of the project	The heart of any facility is the project. Here, it is necessary to take into account all the assemblies, solutions, and desires to link all this to the existing legislation and regulations. That is why the choice of project designers is one of the first things to pay attention to. Reduce operational and inter-operational losses due to RFI and changes in the project
	Tender for technical customer determination	Customer	14 to 30 days, depending on the tender conditions	It is necessary to be very careful when choosing the technical customer since you entrust some of your responsibilities to it. Reduce inter-operational losses of time spent on meetings
	Project appraisal	Technical customer–Project designers–State or commercial expertise	Up to 60 days, provided that There are no comments	The speed and absence of comments from experts depend on the quality of the project Reduce operational and inter-operational losses due to RFI and changes in the project

Table 1. *Cont.*

Construction stage	Obtaining a building permit	Technical customer	Up to 7 days	
	Tender for general contractor determination	Customer technical customer	14 to 30 days, depending on the tender conditions	The customer needs to pay attention not only to the cost of work but also to the qualifications of the construction organization
	Construction and installation works	General contractor	Deadline according to the work schedule	It is necessary to control fluctuations in the cost of basic materials to quickly solve the issue related to an increase in the cost of the project if the cost of materials exceeds 10% of the estimated cost presented in the estimates. Reduce operational losses using pull scheduling and integrated management. Reduce operational and inter-operational losses due to RFI and changes in the project. Reduce inter-operational losses of time spent on meetings and obtaining approvals
	As-built documentation preparation process	Technical customer	Throughout the construction and installation works	
Commissioning	Facility commissioning according to Article 55 of the Town Planning Code	Customer–technical customer	1 to 2 months	

The developed questionnaire is based on the ideas of brainstorming and the results of analyzing scientific studies (clauses 2.1–2.3 hereof).

We conducted an expert survey among managers of construction ecosystem organizations performing various functions (Figure 2). The survey was dedicated the problem of assessing the significance of losses in the communication of ICP participants at all stages of the life cycle.

A link to the online survey created in Google Forms was sent to 50 construction professionals holding management positions (who are at least a job superintendent or a head of a department), having work experience of 8+ years and experience in applying digital technologies, including BIM and lean.

The developed questionnaire consists of a few sections: type of activity, digital tools used, main problems of interaction, and effects of the introduction of digital technologies. The questionnaire is developed in the format of the Likert scale with a semantic rating scale of 1–5, similar to [24,55,69]. Some questions require free responses. An example of the questionnaire is provided in Supplementary Material.

At this stage, we present the results of the survey related to problems and losses arising in the course of interaction in the Russian construction practice.

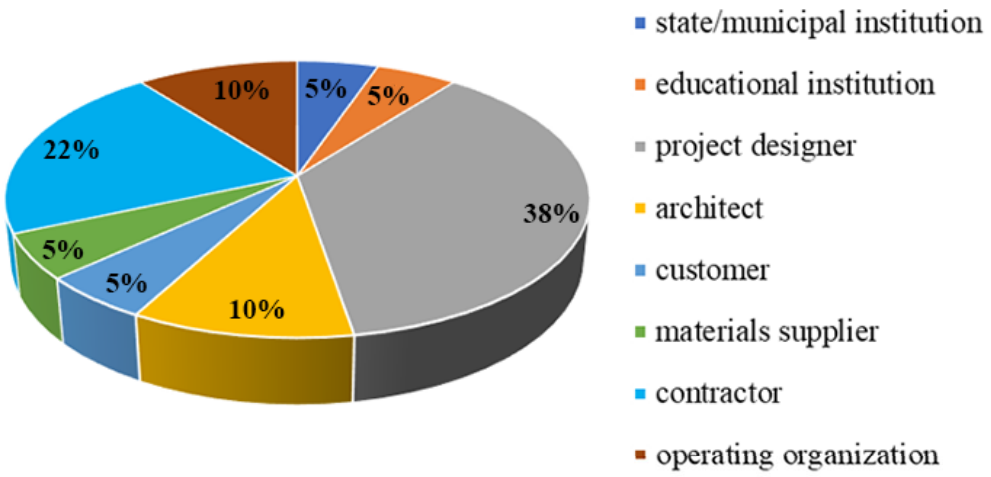


Figure 2. Structure of respondents by the type of activities of the organization; % (according to the results of the expert survey).

The quantitative results of the survey can be analyzed in terms of statistics and consistency. Average scores by points, simple percent, standard deviation, and coefficient of variation were used for data analysis [16,24,55]. According to the literature, a standard deviation below 1 on the five-point Likert scale is mainly taken as a low level of variance in the assessment [16,70]. The standard deviation was below 1 for all scores. The average value is also used to determine the importance of problems and losses [16]. The higher average reflected the greater importance of the problem from the experts' point of view. The assessment results are shown in Table 2.

The above calculation of the standard deviation and coefficient of variation proves the consistency of experts on each problem. Moreover, the consistency was assessed using Kendall's coefficient of concordance W = 0.78. Kendall's W ranges from 0 (no concordance) to 1 (complete concordance), and any value above 0.7 proves a high level of concordance [50,71]. The consistency of respondents' responses is high.

Table 2. Expert assessment of communication problems faced by project; points.

Stage	Communication	Problems	Arising Losses	Average Score	Variance	Standard Deviation	Coefficient of Variation
Pre-design	E-Cu, Cu-O	Low accuracy of project cost estimation	Losses due to the fact that the actual cost exceeds the estimated cost; losses due to low demand	2.60	0.49	0.70	0.27
		Insufficient visualization of CCP	Inter-operation losses due to inaccurate technical specifications provided by the investor and customer	2.60	0.49	0.70	0.27
	EA-Cu	Duration of procedures	Inter-operational time losses	1.90	0.32	0.57	0.30
	Cu-Pd	No front-end engineering design; ambiguous technical specifications; impossibility of taking into account operating parameters during the feasibility study and justification of investments; complexity of solutions for the reconstruction of the environment	Inter-operational losses due to inaccurate technical specifications provided by the investor and customer; time and operational losses due to RF clarifications	4.50	0.50	0.71	0.16

Table 2. *Cont.*

Stage	Communication	Problems	Arising Losses	Average Score	Variance	Standard Deviation	Coefficient of Variation
Design	Cu-Pd	Ambiguous nature of technical specifications; lack of information on the current cost; design documentation revision or alteration	Time and operational losses due to collisions and re-design; time and operational losses due to RFI clarifications; time losses due to the long-lasting document flow; losses due to the fact that the actual cost exceeds the estimated cost	4.60	0.49	0.70	0.15
	OO-Cu	Lack of information on the current cost; lack of statistics on resources and deadlines; design documentation revision or alteration; a large number of collisions; difficulty in obtaining the opinion	Time and operational losses due to collisions and design changes; time losses due to the long-lasting document flow; losses due to the fact that the actual cost exceeds the estimated cost	4.50	0.50	0.71	0.16
	EA-Cu	Duration of procedures	Inter-operational time losses	1.90	0.32	0.57	0.30
Construction	Co-Cu	Lack of a unified environment for interaction; the need to make changes to the project; non-compliance with the construction deadlines; overstatement of the estimated cost; non-compliance with the quality of the CCP	Time inter-operational and operational losses due to collisions and re-design; time and operational losses due to RFI clarifications; time losses due to the long-lasting document flow; losses due to the fact that the actual cost exceeds the estimated cost; losses due to the extension of the estimated construction period; operational losses due to the reduction in the quality of works and elements	4.50	0.50	0.71	0.16
	OO, E-Cu, Co	Lack of a unified interaction environment; the need to make changes to the project	Time and operational losses due to collisions and re-design; time and operational losses due to RFI clarifications; time inter-operational losses	3.90	0.54	0.74	0.19
	Co-Su	Lack of accurate data on the cost of resources; overstatement of the construction cost; supply risks; poor quality of materials	Time and operational losses due to disruption of resources supplies and an increase in the duration of operations; losses due to the fact that the actual cost exceeds the estimated cost; operational losses due to the reduction in the quality of works and elements; time inter-operational losses	4.10	0.32	0.57	0.14
	CS-Co, Cu	Non-compliance with the construction quality; many collisions; complexity of the document exchange process	Operational losses due to the reduction in the quality of works and elements; time and operational losses due to collisions and design changes; inter-operational losses of time	3.50	0.50	0.71	0.20
	B-Cu	Complex contractual system; complexity of the document exchange process	Inter-operational time losses	3.10	0.54	0.74	0.24
	EA-Cu	Duration of procedures	Inter-operational time losses	2.00	0.22	0.47	0.24
Operation	Cu, O-OO	No operation parameters are taken into account in the project; complexity of the document exchange process; lack of communication with operation systems	Time inter-operational losses; operational losses due to loss of value for buyers; direct losses due to the overrun of costs for CCP operation	2.60	0.49	0.70	0.27

Cu—customer; EA—executive authorities (regional, municipal); TPA—expert organizations carrying out technological and price audits of projects; Pd—the project designer; Co—the contractor; Ex—bodies of state or non-state expertise of design and estimate documentation; E—engineering, expert organizations; Su—suppliers of construction materials, structures, equipment; CO—bodies of state construction supervision, construction oversight, and audit organizations; B—bank; OO—operating organizations; O—owner (user) of the facility.

Based on the results of the expert survey, the duration of the procedures for approving and signing documentation was determined as the main problem of interaction between ICP participants. It results in a delay in introducing changes in the project and an increase in the time lag between the actual performance of works and the receipt of funds. In turn, these facts increase the time for correcting the comments and, ultimately, the construction duration. Failure to meet construction deadlines entails not only numerous inter-operational and operational losses resulting in an increase in financial costs but also the failure to implement investment programs. Accordingly, the need to eliminate and minimize identified losses involves solving a large number of problems and processing a large amount of information, which, in turn, necessitates the use of digital technologies.

The survey conducted among Russian specialists in construction is supported by the conclusions of the scientific research given in clauses 2.1–2.3. It is necessary to integrate digital technologies with lean construction tools to reduce losses arising from the interaction of investment and construction project participants.

Since one of the obstacles to the introduction of BIM and other digital technologies is their high cost [39,44,72,73], it is necessary to determine the effects that arise when integrating lean–digital technologies. This will help create an incentive for the introduction of lean–BIM.

2.5. The Effects of Integrating Lean Construction with BIM Regarding the Improvement of the Interaction between Participants

A number of studies are devoted to the problems of analyzing the effects of lean–BIM implementation (for example, [17,46,50,73,74]. The article [46] systematizes the effects on the basis of bibliographic analysis. The effects are divided into three main groups: process, people (interaction), and tools. Regarding the process parameter, there is an effect on project planning and implementation, increasing productivity, efficiency, and created value, reducing losses and costs, improving the interaction and information exchange, and reducing and distributing risks [46]. Regarding the people parameter, an increase in the involvement and effectiveness of teamwork is determined; the tools parameter includes the integration of participants in the process of work, data storage, and exchange. In [46], three main effects are distinguished: productivity, communication, and loss reduction.

Based on an extensive review of the literature, the work [17] notes such effects of the introduction of lean construction and value chains as productivity, reduction of time and costs, and reduction of losses from paperless workflow.

Regardless of the stage of lean construction technologies introduction, the processes of managing meetings, informing about the conditions of occupational safety, training and implementation of certain procedures, identification of problems during the operation of construction machines, mechanisms, logistics management, and so on are implemented on a daily basis (for example, [75]). Often, the implementation of such actions requires not only a large amount of time but also entails costs for the office, as well as losses due to distortion or slow receipt of information. In this interpretation, the above processes do not add value, which can be changed by automating these processes through digitalization. The possibility to work in a paperless environment, in a common data environment, allows for increasing not only the speed of processes implementation but also their consolidation, taking into account the possibility of making quick clarifications to the project and solving other production issues.

Based on the results of the expert survey, the following information on the main expected effects of digital paperless interaction in the construction process was obtained (Figure 3).

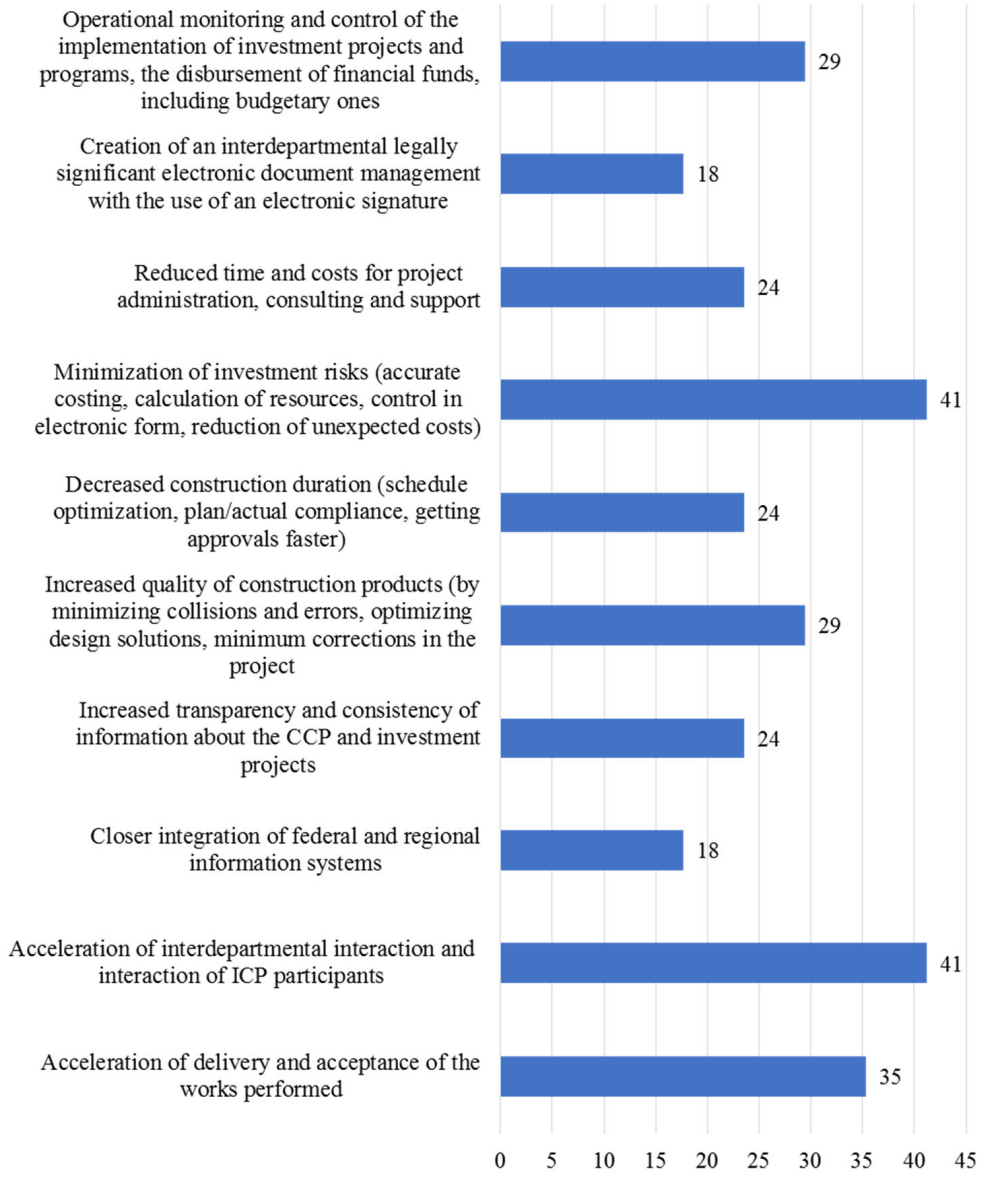


Figure 3. Results of the assessment of the main effects of processes digitalization and the creation of the electronic document management system (EDMS) in construction, % of respondents.

Consistency criteria calculations prove the validity of the conclusions. Based on the survey, the main types of effects that reflect the reduction of losses according to lean construction and are consistent with the results of the analysis of scientific research [17,46,50] were determined. Next, it is necessary to conduct a numerical assessment of the effects of the example of an implemented construction project. Moreover, based on the results of the survey, we can conclude that it is an effective decision to create an EDMS for project participants as the first step of digitalization in BIM implementation.

3. Results

A comprehensive review of the literature described in clauses 2.1–2.5 hereof showed the feasibility of integrating lean–digital technologies (lean Construction 4.0) in construction to improve the communication between participants, increase the value they create, as well as reduce losses.

A survey conducted among construction professionals in Russia showed that there are many problems in the interaction of project participants that result in operational and

inter-operational losses. The low use of BIM in Russia proves the need for the use of digital technologies that facilitate interaction and allow obtaining operational information in the project. The results of the literature review and the survey also showed a number of effects in the form of reducing losses from minimal digitalization (the use of an EDMS in the project), as well as from BIM.

Focusing on the identified key tasks of lean Construction 4.0 adopted within the framework of this study, we would like to present a new approach to the communication between ICP participants at the pre-design stage, design stage, construction stage, and operation stage in Russian construction practice (Figures 4–7).

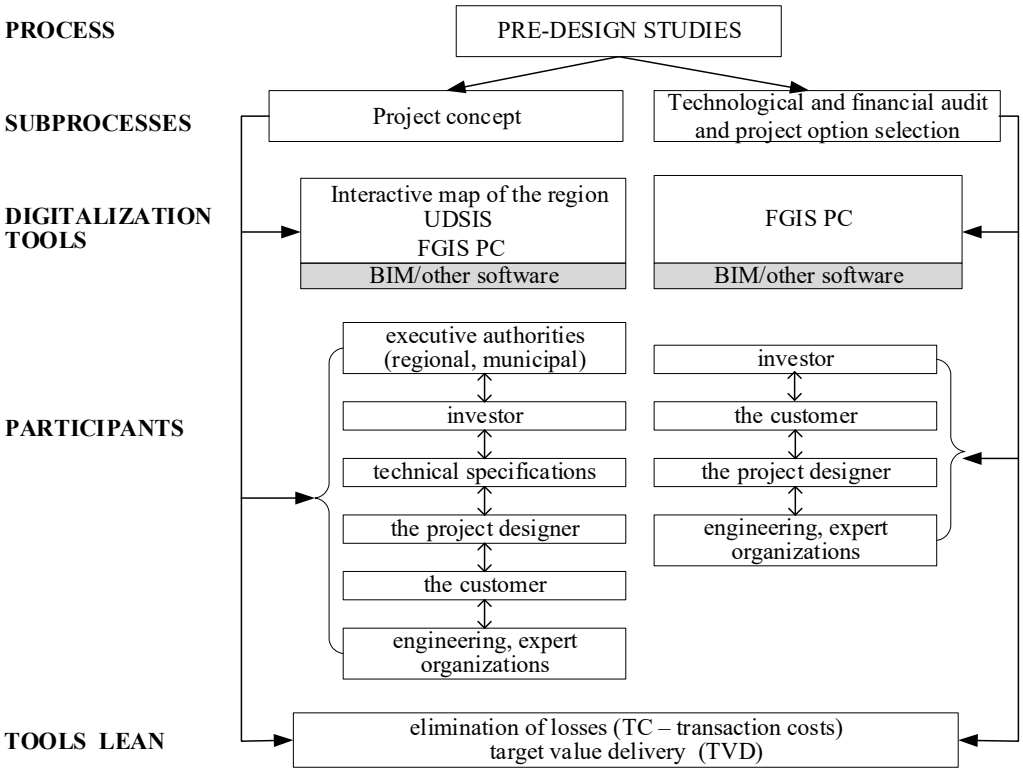


Figure 4. A new approach to the communication between participants of the ICP pre-design stage based on lean Construction 4.0. where: UDSIS—urban development support information system, FGIS PC—federal government information system for pricing in construction.

Considering digital tools as the basis of the target image of the lean construction process and noting that the maximum reduction in losses will be observed when a BIM model is created and the process of real estate creation and functioning becomes digitalized [40,72,74,76], it is necessary to adhere to the principle of pragmatism. According to this principle, the scope and methods of digitalization should clearly correspond to the solution of the set task [54]. Therefore, it is necessary not only to determine the target image of the lean construction process and its efficiency criteria, analyze the conditions for the efficiency of digital process transformation, and calculate the necessary costs but also to create an algorithm for determining the optimal tools depending on the specifics of projects and companies implementing them.

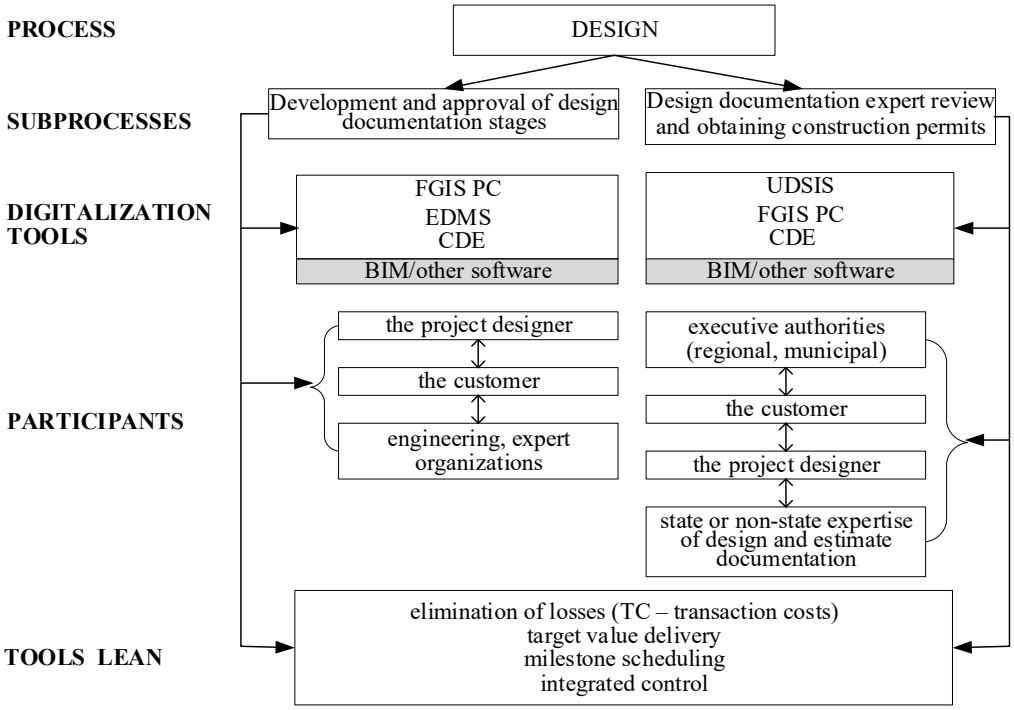


Figure 5. A new approach to the communication of participants of the ICP design stage based on lean Construction 4.0. where: FGIS PC—federal government information system for pricing in construction, EDMS—electronic document management system, CDE—common data environment, UDSIS—urban development support information system.

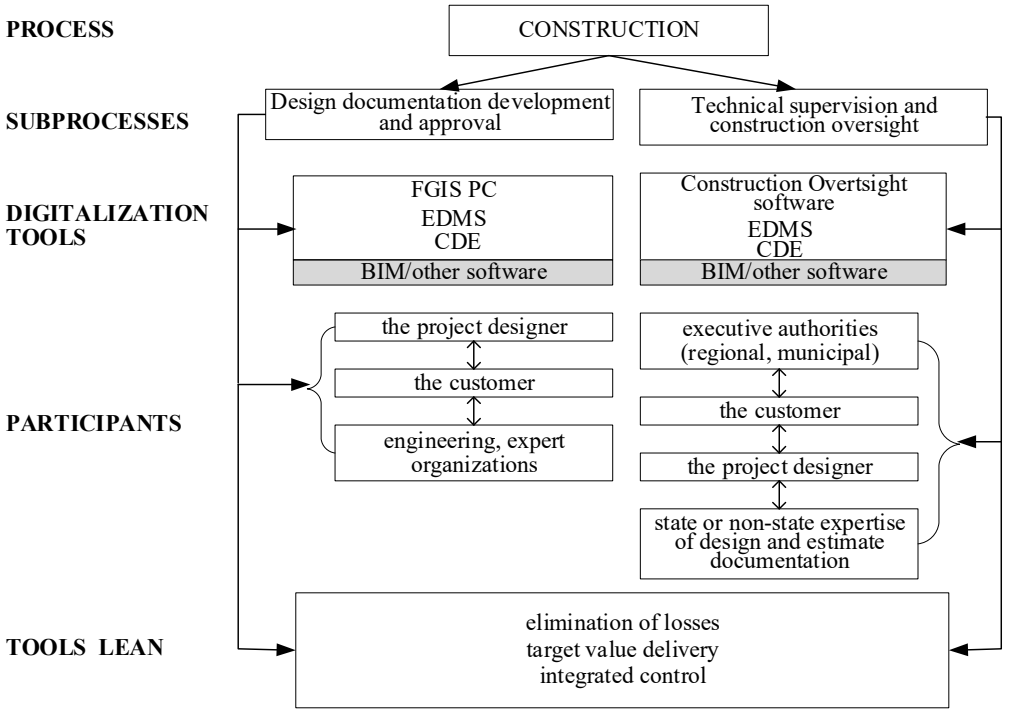


Figure 6. A new approach to the communication of participants of the construction stage based on lean Construction 4.0. where: FGIS PC—federal government information system for pricing in construction, EDMS—electronic document management system, CDE—common data environment.

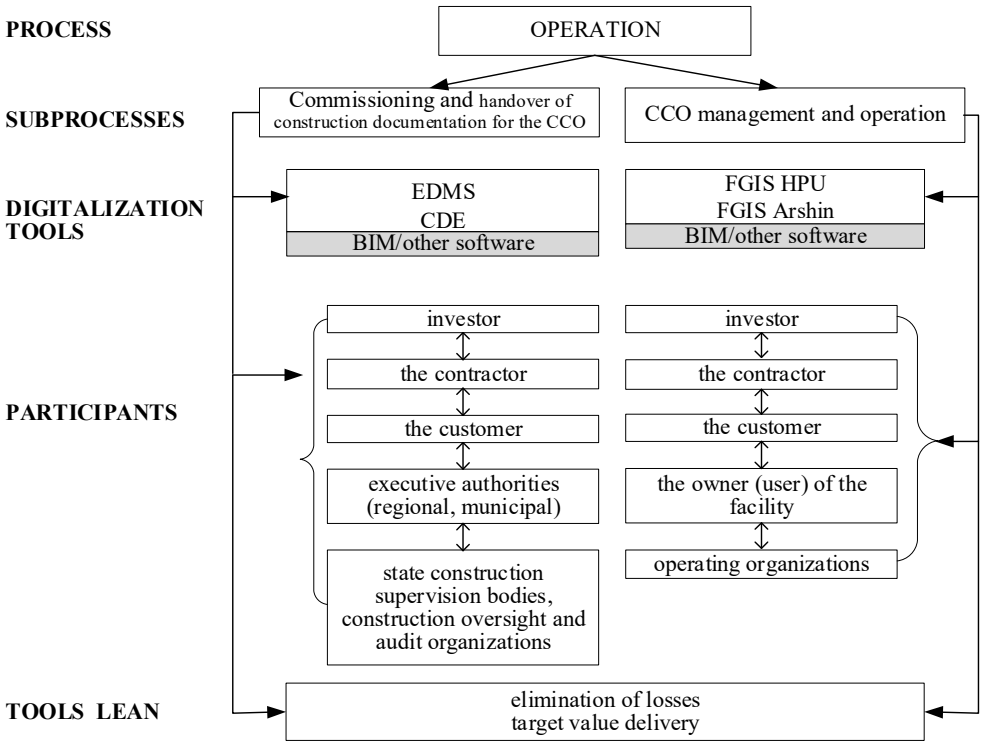


Figure 7. A new approach to the communication of participants of the construction stage based on lean Construction 4.0. where: EDMS—electronic document management system, CDE—common data environment, FGIS HPU—Federal Government Information System for the Housing and Public Utility Sector, FGIS Arshin—federal government information system for ensuring the unity of measurements of the State Committee for the Russian Federation for Standardization and Metrology.

However, it should be borne in mind that full digitalization of lean construction processes is not always necessary and effective.

When determining the feasibility of introducing a certain digital service or technology into the processes that implement the concept of lean construction, we consider it necessary, firstly, to determine the direct possibility or impossibility of introducing a specific element of digital transformation due to the presence or absence of conditions for its implementation; secondly, to prioritize the digital tool, which provides for the choice of appropriate goals and a set of changes in the process of lean construction when introducing a certain element of digital transformation, depending on the effect indicators that have the highest impact on the effectiveness criteria of this element.

The proposed algorithm for selecting digital tools and technologies for implementation in the process of lean construction is presented in the form of a flowchart (Figure 8).

Further development of the digital environment and information infrastructure as a result of the digital tools introduction will increase not only the efficiency of project implementation but also the volume of relevant and reliable information about problems, losses, and the results of their dynamics through the use of lean methods. So, lean principle digitalization forms a base containing the statistics related to problems, their systematic discussion, and options for their solution. Accordingly, digitalization allows not only to reduce of inter-operational losses but also to quickly and reliably implement one of the most important aspects of the lean concept—continuous improvement. One cannot stop at a one-time reduction in losses, costs, and quality.

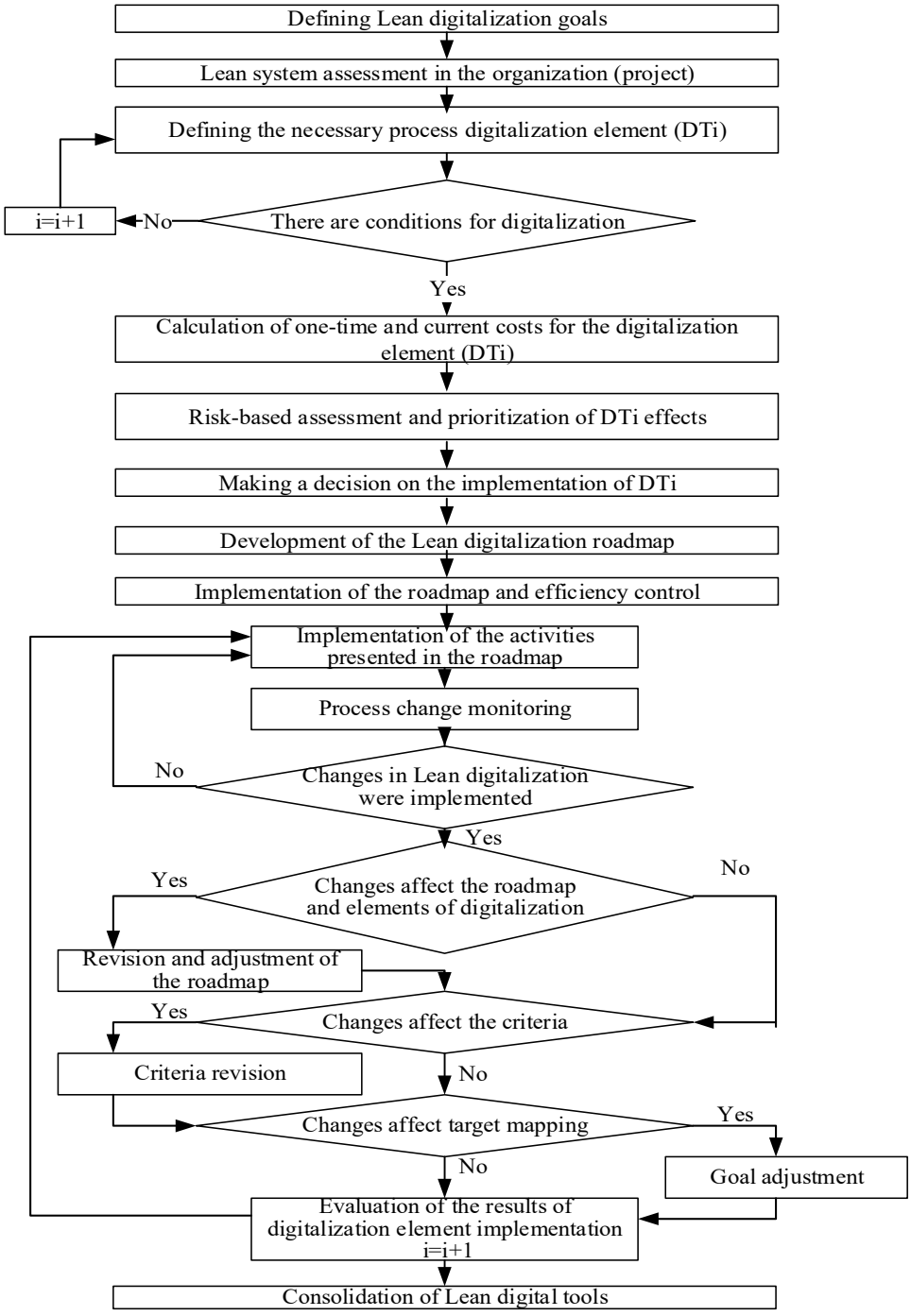


Figure 8. Flowchart of the algorithm for selecting digital tools and technologies for implementation in the process of lean construction.

4. Discussion of the New Approach Effects

The proposed lean–digital technologies approach with a focus on the communication between project participants was applied in practice for phase 2 of the project for the construction of a hospital with a birth center with a total area of 80,000 m^2. The total cost of construction is 9500 million rubles. Design is carried out in two stages. The first stage includes a multidisciplinary unit with a patient capacity of 606 beds consisting of three buildings—a diagnostic and treatment building, an auxiliary building, a ward building, and a pathoanatomical building with a laboratory and checkpoints. The second stage includes an outpatient department, a maternity hospital for 130 people, a children's hospital for

180 beds, an infectious building for children and adults for 100 beds, a first-aid station for 6 cars, a ground helipad, as well as transitions between the buildings.

Facility design in BIM was implemented, and an electronic document flow and a common data environment based on CDM Matrix software were created. They will allow the implementation of both integrated project management in the common data environment and pull scheduling.

The effect of applying the lean concept using digital tools is the reduction of losses (for example, [7,17,61], resulting in a reduction of both explicit and transactional costs.

The remarkable thing is that it is necessary to decide on the calculation tools that will be used to determine losses and the corresponding effects of digitalization, i.e., it is necessary to systematize the criteria for achieving the proposed target image of the process of ICP implementation based on the principles of lean manufacturing. We presented the proposed methods for formalizing the assessment of operating losses in a number of publications [7,31,61].

Inter-operation losses are reduced in most cases by reducing the number of RFIs and speeding up the processing of information requests. The communication nature of inter-operational losses postulated in this study allows referring to the category of transaction costs [56,77]. In the vast majority of cases, the assessment is expert-based due to the specifics of transaction costs. However, we consider it more expedient to use the calculation and expert method, which allows for calculating transaction costs based on the additive and multiplicative model:

$$TC = \sum_{j=1}^{n} t_j \cdot Cv_j + \sum_{j=n+1}^{m} Kt_j \cdot Ct_j + \sum_{j=m+1}^{l} Ce_j \quad (1)$$

where

1. TC—total transaction costs;
2. Kt_j—the number of transactions of j-th type;
3. Ct_j—the cost of one transaction of the j-th type;
4. t_j—time spent for the execution of transactions of the j-th type;
5. Cv_j—the cost of a time unit of transactions of the j-th type;
6. Ce_j—costs of the j type determined by expertise.

Calculations of effects resulting from the elimination of time losses elimination determined on the basis of the category of transaction costs are shown in Figures 9 and 10.

The results of the effect calculation for the organization of a conventional paper workflow are presented in Table 3.

In the example of the project for the construction of a hospital, we calculated the effects of full digitalization of lean construction processes based on the application of building information modeling (BIM). These effects lead to savings on loan payments to the bank (by reducing the amount of interest for the use of financial resources), which results in a reduction in project costs. The corresponding value of the effects of using BIM in the project is presented in Figure 11.

In general, the model of efficiency of digital tools introduction for lean construction concept practical implementation created on the basis of the literature analysis and a survey conducted among specialists, as well as calculations for a real project, is presented in Figure 12.

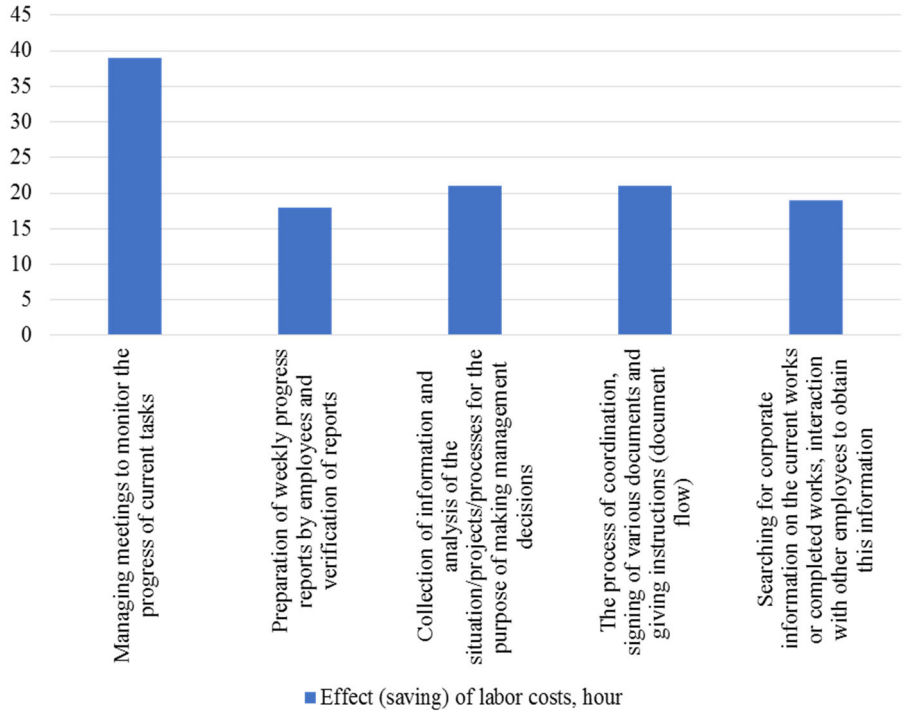


Figure 9. Saved labor costs at the facility per month after the introduction of an EDMS; hour.

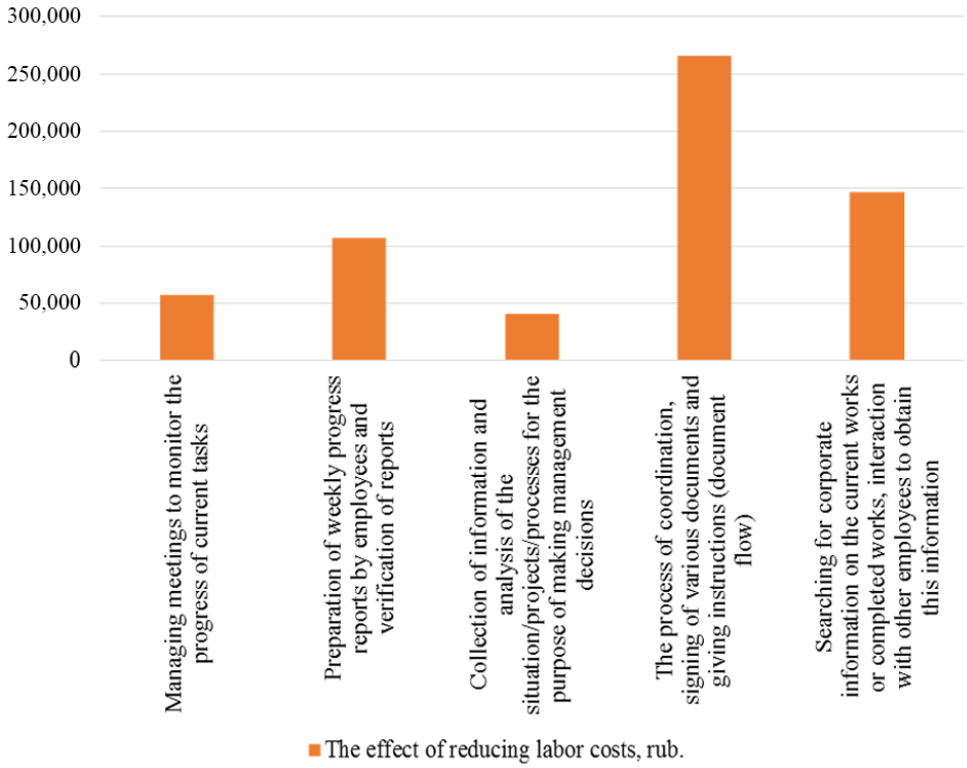


Figure 10. The result of calculating the monthly effect of eliminating time losses at the facility under consideration; rub.

Table 3. Calculation of costs for the organization of a conventional paper workflow for phase 2 of facility construction.

ICP Life Cycle Stage	Calculation Parameters						
	Number of Reports, pcs.	Number of Pages per Report, pcs.	Total Number of Pages in the Documentation	Number of Documentation Revisions	Total Number of Pages in the Documentation Considering Revisions	Number of Report Copies	Total Pages of Documentation for the Facility
Design and survey works	60	50	3000	5	15,000	4	60,000
As-built documentation	2000	24	48,000	2	96,000	4	384,000
Acts on improvement	1552	24	37,248	4	148,992	4	595,968
Acts for outdoor networks	1552	24	37,248	4	148,992	4	595,968
Conclusion on commissioning	40	24	960	1	960	4	3840

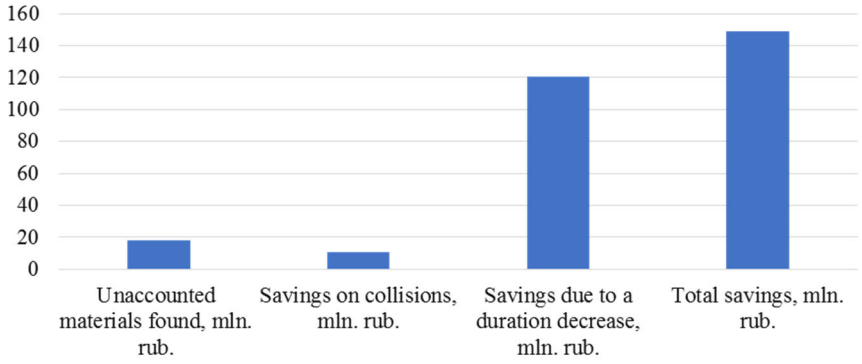


Figure 11. Effectiveness of using lean 4.0 in the project for the construction of a hospital.

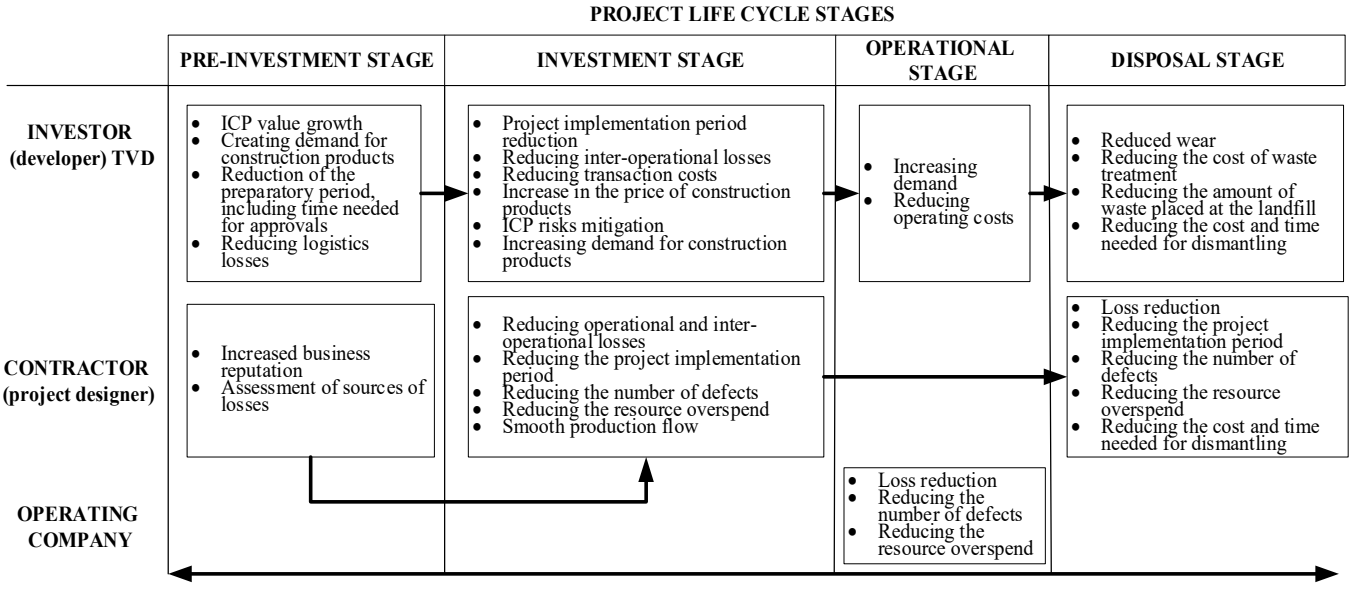


Figure 12. Generation of lean 4.0 effects for the participants of the manufacturing pool of the ICP.

At the micro level, the motivation for the transition to information modeling, particularly in digital transformation, should not only be used to meet the existing innovative technological trends of the modern construction market but also to meet business goals while solving existing problems at each stage of the life cycle of an ICP.

The main results and effects of lean construction processes and tools digitalization are the reduction of construction time due to the optimization of administrative procedures and digital integrated construction management, attraction and turnover of investments, transparent management and analysis of projected construction volumes, including construction in progress, analysis of resource needs, operational pull scheduling with the possibility to instantaneously analyze and respond to changes in dynamics, assessment of the regional urban planning potential, tracking the quality and supply of material resources in real-time.

Taking into account the value chain in lean construction, based on the conducted survey (Supplementary Material) value of lean construction digitalization effects for each ICP participant was determined (Figure 13).

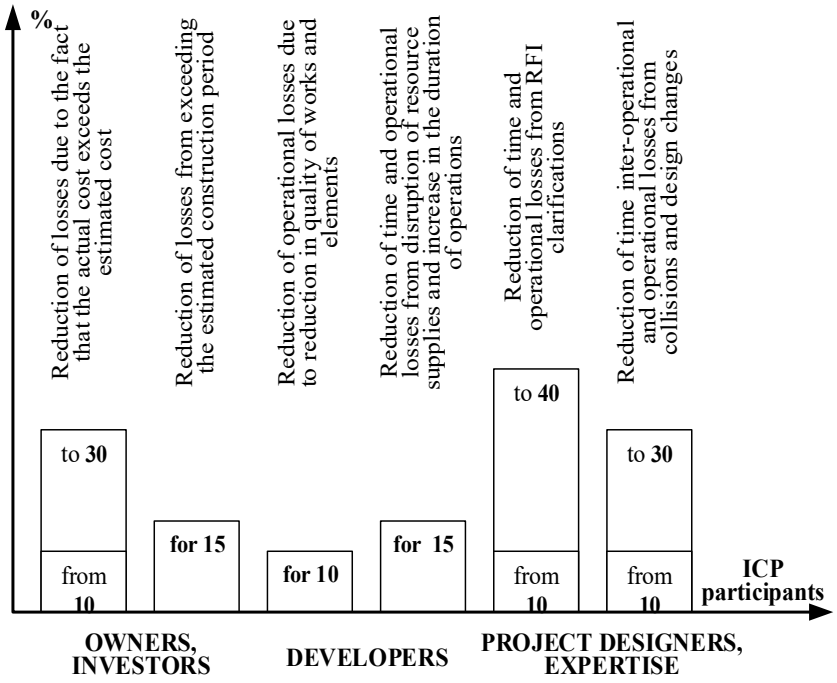


Figure 13. Average calculated value of lean digitalization effects for each ICP participant (according to the results of the conducted marketing analysis and analysis of data on implemented projects), %.

5. Conclusions

In the course of research based on a three-step procedure involving an extensive literature review, an expert survey, and project-specific calculations, it was found that the use of digital tools and technologies in lean construction contributes to the even greater economic efficiency of investment and construction projects, including the following:

- Increasing the speed of construction by optimizing the interaction of ICP participants and stakeholders and reducing time inter-operational losses;
- Reduction of time and operating financial losses during construction by improving the accuracy of cost estimates; reducing the number of collisions, clarifications, requests for information, changes in the project; and introducing electronic document management, pull scheduling, and integrated management in real-time;
- Increasing labor productivity by reducing time losses and shifting the time employees spend for the preparation for meetings and participation in the workflow to the implementation of kaizen, training, etc.;
- Improving the quality of works and facilities by monitoring the quality and supply of materials in real-time, monitoring hidden works in real-time, continuous monitoring of the Gemba in real-time, etc.

The research proposes a new approach to determining the target image of lean–BIM integration: the choice of digital technologies for gradual integration, taking into account obstacles to the introduction of BIM and calculation of effects.

The research recommends all stakeholders, not only the ones from Russia, determine the feasibility of using certain digital technologies in the lean construction system on the basis of prioritization of effects, development, and monitoring of a digitalization roadmap for relevant projects and processes of lean construction, taking into account external changes, analysis of the communication–cost–time–quality ratio, optimization of the cost-effect ratio customized for each ICP participant and the corresponding level of implementation of lean construction principles.

It can be concluded that there are a number of key effects common to all participants in the construction ecosystem: increasing the quality of the facility at each stage of the project life cycle and reducing the time, cost, and transaction costs. Digitalization also contributes to the formation of a base of data on the occurrence and ways to solve problems related to milestone scheduling of the investment and construction process, the possibility of online training of employees based on the case system, which fully corresponds to the thesis about the need for continuous improvements and involvement in lean construction.

The presented research has limitations. Firstly, the introduction of lean construction as a whole was considered without considering individual tools or principles. Accordingly, the following studies are needed to determine the effects of specific instruments. Secondly, BIM and EDMS were considered digital technologies. Other digital technology options, such as construction oversight software, need to be considered in future studies. Thirdly, it is necessary to calculate not only effects but also costs to be able to use the given conceptual scheme for the development of digital transformation effectiveness criteria. In future studies, costs for software, training, and retraining of personnel; changing business processes; and project support should be considered as the key costs necessary for the implementation of digital transformation of construction at the micro level. Moreover, this study did not investigate the risks of introducing lean–BIM to improve the communication between project participants. Finally, the study is limited to a survey of specialists and consideration of the situation in Russia, which has its own regional and cultural characteristics. Accordingly, it is necessary to compare the results with the results of lean–BIM effects calculation in other countries.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings13030770/s1.

Author Contributions: Conceptualization, A.K.O.; methodology, S.S.U. and V.S.K.; software V.S.K.; validation, S.S.U. and V.S.K.; investigation, A.K.O. and S.S.U.; writing—original draft preparation, A.K.O.; writing—review and editing, A.K.O., S.S.U. and V.S.K.; project administration, A.K.O. and S.S.U.; funding acquisition, A.K.O., S.S.U. and V.S.K. All authors have read and agreed to the published version of the manuscript.

Funding: The grant was made with the financial support of the Moscow State University of Civil Engineering within the framework of conducting fundamental and applied scientific research by scientific collectives of member organizations of the Industry Consortium "Construction and Architecture".

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors gratefully acknowledge the support of the Moscow State University of Civil Engineering.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Bank. *Annual Report 2022: Helping Countries Adapt to a Changing World*; World Bank: Washington, DC, USA, 2022.
2. World Bank. *World Development Report 2020: Trading for Development in the Age of Global Value Chains*; World Bank: Washington, DC, USA, 2020.

3. Rodrik, D. *New Technologies, Global Value Chains, and the Developing Economies*; Pathways for Prosperity Commission Background Paper Series, No. 1. University of Oxford: Oxford, UK, 2018.
4. Shih, W. Is it time to rethink globalized supply chains? In *MIT Sloan Management Review*; MIT Press: Cambridge, MA, USA, 2020.
5. Kankhva, V.; Uvarova, S.; Belyaeva, S. Development of the Scientific and Methodological Assessment Tools of Sustainability of the Investment and Construction Complex in Russia and its Structural Elements in Terms of Organizational and Economic Changes. *Procedia Eng.* **2016**, *165*, 1046–1051. [CrossRef]
6. Koskela, L. *Application of the New Production Philosophy to Construction*; Tech Report 72; Center for Integrated Facility Engineering: Stanford, CA, USA, 1992.
7. Orlov, A.K.; Kankhva, V.S. Lean Construction Concept Used to Develop Infrastructure Facilities for Tourism Clusters. *Buildings* **2022**, *12*, 23. [CrossRef]
8. Wen, S.; Tang, H.; Ying, F.; Wu, G. Exploring the Global Research Trends of Supply Chain Management of Construction Projects Based on a Bibliometric Analysis: Current Status and Future Prospects. *Buildings* **2023**, *13*, 373. [CrossRef]
9. Ergen, E.; Akinci, B.; Sacks, R. Tracking and Locating Components in a Precast Storage Yard Utilizing Radio Frequency Identification Technology and GPS. *Autom. Constr.* **2007**, *16*, 354–367. [CrossRef]
10. Wong, C.K.; Fung, I.W.H.; Tam, C.M. Comparison of Using Mixed-Integer Programming and Genetic Algorithms for Construction Site Facility Layout Planning. *J. Constr. Eng. Manag.* **2010**, *136*, 1116–1128. [CrossRef]
11. Albuquerque, A.T.; Debs, M.K.; Melo, A.M.C. A Cost Optimization-Based Design of Precast Concrete Floors Using Genetic Algorithms. *Autom. Constr.* **2012**, *22*, 348–356. [CrossRef]
12. Singh, S.; Dixit, S.; Sahai, S.; Sao, A.; Kalonia, Y.; Kumar, R.S. Key Benefits of Adopting Lean Manufacturing Principles in Indian Construction Industry. *MATEC Web Conf.* **2018**, *172*, 05002. [CrossRef]
13. London, K.; Pablo, Z. An Actor–Network Theory Approach to Developing an Expanded Conceptualization of Collaboration in Industrialized Building Housing Construction. *Constr. Manag. Econ.* **2017**, *35*, 553–577. [CrossRef]
14. World Bank. *World Development Report 2019: The Changing Nature of Work*; World Bank: Washington, DC, USA, 2019.
15. Ustyuzhanina, E.V.; Dementiev, V.E.; Evsukov, S.G. Distribution of power and economic rent in value networks. *Econ. Math. Methods* **2020**, *56*, 5–17. (In Russian) [CrossRef]
16. Dixit, S.; Mandal, S.N.; Sawhney, A.; Singh, S. Area of linkage between lean construction and sustainability in Indian construction industry. *Int. J. Civ. Eng. Technol.* **2017**, *8*, 623–636.
17. Terreno, S.; Asadi, S.; Anumba, C. An Exploration of Synergies between Lean Concepts and BIM in FM: A Review and Directions for Future Research. *Buildings* **2019**, *9*, 147. [CrossRef]
18. Moradi, S.; Sormunen, P. Lean and Sustainable Project Delivery in Building Construction: Development of a Conceptual Framework. *Buildings* **2022**, *12*, 1757. [CrossRef]
19. Lemans Manufacturing Systems of the Future Experience in the Implementation of LEAN and IT Solutions. *Digitalization of Manufacturing Experience in the Implementation and Cost-Benefit Analysis—Moscow*. 2022. Available online: https://dtmis.spbstu.ru/userfiles/files/pdf/program.pdf?v=2 (accessed on 10 December 2022).
20. Porter, M.E.; Heppelmann, J.E. Wie smarte Produkte den Wettbewerb verandern. *Harv. Bus. Manag.* **2014**, *36*, 34–60.
21. Rungi, A.; Del Prete, D. *The «Smile Curve»: Where Value is Added along Supply Chains*; IMT Lucca EIC Working Paper Series #05/2017; University of Milano: Milan, Italy, 2017.
22. Mytenkov, S.S.; Zhelenkov, B.A. Digitalization in Russia and the world through the prism of interaction between the state, business and the population Business. *Society. Authorities.* **2022**, *44–45*, 141–155.
23. Abdikeev, N.M.; Moreva, E.L. The main trends in the development of methods and models for the use of digital technologies in the creation of value chains. *World New Econ.* **2019**, *13*, 71–80. (In Russian) [CrossRef]
24. Lekan, A.; Clinton, A.; Fayomi, O.S.I.; James, O. Lean Thinking and Industrial 4.0 Approach to Achieving Construction 4.0 for Industrialization and Technological Development. *Buildings* **2020**, *10*, 221. [CrossRef]
25. Bar Am, J.; Furstenthal, L.; Jorge, F.; Roth, E. *Innovation in a Crisis: Why It Is More Critical than Ever*; McKinsey Global Institute, 2020.
26. Banihashemi, S.; Tabadkani, A.; Hosseini, M.R. Integration of Parametric Design into Modular Coordination: A Construction Waste Reduction Workflow. *Autom. Constr.* **2018**, *88*, 1–12. [CrossRef]
27. Dossick, C.S.; Neff, G. Messy talk and clean technology: Communication, problem-solving and collaboration using Building Information Modelling. *Eng. Proj. Organ. J.* **2011**, *2*, 83–93. [CrossRef]
28. MGI. *Risk, Resilience, and Rebalancing in Global Value Chains*; McKinsey Global Institute: Washington, DC, USA, 2020.
29. Senthil, J.; Muthukannan, M. Development of lean construction supply chain risk management based on enhanced neural network. *Mater. Today Proc.* **2021**, *56*, 1752–1757. [CrossRef]
30. Forno, A.J.D.; Pereira, F.A.; Forcellini, F.A.; Kipper, L.M. Value Stream Mapping: A study about the problems and challenges found in the literature from the past 15 years about application of Lean tools. *Int. J. Adv. Manuf. Technol.* **2014**, *72*, 779–790. [CrossRef]
31. Orlov, A.K.; Solovieva, E.S. Effectiveness of lean construction methodology application for the implementation of infrastructure projects in tourism clusters. *Econ. Entrep.* **2021**, *129*, 446–450.
32. Bajjou, M.S.; Chafi, A.; Ennadi, A. Development of a Conceptual Framework of Lean Construction Principles: An Input-Output Model. *J. Adv. Manuf. Syst.* **2019**, *18*, 1–34. [CrossRef]

33. Giménez, Z.; Mourgues, C.; Alarcón, L.F.; Mesa, H. Exploring Value Generation in Target Value Design Applying a Value Analysis Model. *Buildings* **2022**, *12*, 922. [CrossRef]
34. Bølviken, T.; Rooke, J.; Koskela, L. The Wastes of Production in Construction—A TFV Based Taxonomy. In Proceedings of the 22nd Annual Conference of the International Group for Lean Construction, Oslo, Norway, 25–27 June 2014; pp. 811–822.
35. Salvatierra, J.; Pasquire, C.; Miron, L. Exploring Value Concept through the IGLC Community: Nineteen Years of Experience. In Proceedings of the 20th Annual Conference of the International Group for Lean Construction, San Diego, CA, USA, 18–20 July 2012.
36. Ballard, G. Target Value Delivery. In *Lean Construction Core Concepts and New Frontiers*; Tzortzopoulos, P., Kagioglou, M., Koskela, L., Eds.; Routledge: London, UK, 2020; pp. 149–161.
37. Urban Planning Code of the Russian Federation.
38. Belov, M.V.; Novikov, D.A. *Methodology of Complex Activity: Foundations of Understanding and Modelling*; Springer: Berlin/Heidelberg, Germany, 2020.
39. Sacks, R.; Korb, S.; Barak, R. *Building Lean, Building BIM: Improving Construction the Tidhar Way*; Routledge: London, UK, 2017; p. 420.
40. Sbiti, M.; Beddiar, K.; Beladjine, D.; Perrault, R.; Mazari, B. Toward BIM and LPS Data Integration for Lean Site Project Management: A State-of-the-Art Review and Recommendations. *Buildings* **2021**, *11*, 196. [CrossRef]
41. Tennakoon, T.; Kulatunga, U.; Jayasena, H.S. Influence of organizational culture on knowledge management in BIM-enabled construction, environments. *VINE J. Inf. Knowl. Manag. Syst.* **2021**, *52*, 224–242.
42. Wu, H.; Lin, X.; Li, X.; Zhang, B.; Li, C.Z.; Duan, H. A Data-Driven Approach to Trace the Development of Lean Construction in Building Projects: Topic Shift and Main Paths. *Buildings* **2022**, *12*, 616. [CrossRef]
43. Afolabi, A.; Ibem, E.; Aduwo, E.; Tunji-Olayeni, P.; Olawumi, O. Critical success factors (CSFs) for e-Procurement adoption in the Nigerian construction industry. *Buildings* **2019**, *9*, 47. [CrossRef]
44. Likita, A.J.; Jelodar, M.B.; Vishnupriya, V.; Rotimi, J.O.B.; Vilasini, N. Lean and BIM Implementation Barriers in New Zealand Construction Practice. *Buildings* **2022**, *12*, 1645. [CrossRef]
45. Ghosh, A.; Chasey, A.D.; Mergenschroer, M. Building Information Modeling for Facilities Management: Current Practices and Future Prospects. In *Building Information Modeling*; American Society of Civil Engineers (ASCE): New York, NY, USA, 2015; pp. 223–253.
46. Moradi, S.; Kähkönen, K.; Sormunen, P. Analytical and Conceptual Perspectives toward Behavioral Elements of Collaborative Delivery Models in Construction Projects. *Buildings* **2022**, *12*, 316. [CrossRef]
47. Gorelik, P.I. Lean building as an innovative method of construction management. *Constr. Unique Build.* **2014**, *27*, 40–48.
48. Erol, H.; Dikmen, I.; Birgonul, M.T. Measuring the impact of lean construction practices on project duration and variability: A simulation-based study on residential buildings. *J. Civ. Eng. Manag.* **2017**, *23*, 241–251. [CrossRef]
49. Eroshkin, S.Y.; Kallaur, G.Y.; Papikyan, L.M. Lean construction and BIM model: Complementing each other for better project management. *Rev. Bus. Econ. Stud.* **2016**, *4*, 17–22.
50. Rashidian, S.; Drogemuller, R.; Omrani, S. Building Information Modelling, Integrated Project Delivery, and Lean Construction Maturity Attributes: A Delphi Study. *Buildings* **2023**, *13*, 281. [CrossRef]
51. Shildt, L.A. Use of lean construction technology in information modeling of buildings. *Econ. Manag. Sci. Pract. J.* **2018**, *141*, 36–41.
52. Wong, L.S.; Ahmed, M.E.A.M. A critical review of lean construction for cost reduction in complex projects. *Jordan J. Civ. Eng.* **2018**, *12*, 707–720.
53. Eldeep, A.M.; Farag, M.A.M.; El-hafez, L.A. Using BIM as a lean management tool in construction processes—A case study. *Ain Shams Eng. J.* **2021**, *13*, 101556. [CrossRef]
54. Kankhva, V.; Andryunina, Y.; Belyaeva, S.; Sonin, Y. Construction in the digital economy: Prospects and areas of transformation. *E3S Web Conf.* **2021**, *244*, 05008. [CrossRef]
55. Popova, E.S. Lean construction methodology as an innovative approach to management in the construction industry. *Masters J.* **2016**, *1*, 141–146.
56. Panenkov, A.; Lukmanova, I.; Kuzovleva, I.; Bredikhin, V. Methodology of the theory of change management in the implementation of digital transformation of construction: Problems and prospects. *E3S Web Conf.* **2021**, *244*, 05005. [CrossRef]
57. Alexander, K. *Facilities Management: Theory and Practice*; Routledge: London, UK, 2013.
58. Love, K.; Pritchard, C.; Maguire, K.; McCarthy, A.; Paddock, P. Qualitative and quantitative approaches to health impact assessment: An analysis of the political and philosophical milieu of the multi-method approach. *Crit. Public Health* **2005**, *15*, 275–289. [CrossRef]
59. Volk, R.; Stengel, J.; Schultmann, F. Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Autom. Constr.* **2014**, *38*, 109–127. [CrossRef]
60. Gallaher, M.P.; O'Connor, A.C.; Dettbarn, J.J.L.; Gilday, L.T. *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*; National Institute of Standards and Technology (NIST): Gaithersburg, MD, USA, 2004.
61. Belyaeva, S.V.; Uvarova, S.S.; Kankhva, V.S.; Galeev, K.F. Digitalization of construction: Problems and key areas in modern conditions of import substitution. *J. Econ. Entrep.* **2022**, *140*, 1283–1289. (In Russian)
62. Kensek, K. BIM Guidelines Inform Facilities Management Databases: A Case Study over Time. *Buildings* **2015**, *5*, 899–916. [CrossRef]

63. Moradi, S. Project Managers' Competencies in Collaborative Construction Projects. Ph.D. Thesis, Tampere University, Tampere, Finland, 2021. Available online: http://urn.fi/URN:ISBN:978-952-03-2002-7 (accessed on 10 January 2022).
64. Albalkhy, W.; Sweis, R. Barriers to adopting lean construction in the construction industry: A literature review. *Int. J. Lean Six Sigma* **2020**, *12*, 210–236. [CrossRef]
65. Herrera, R.F.; Mourgues, C.; Alarcón, L.F.; Pellicer, E. Comparing Team Interactions in Traditional and BIM-Lean Design Management. *Buildings* **2021**, *11*, 447. [CrossRef]
66. Report on the Study "The Level of BIM Application in Russia 2019". Available online: http://concurator.ru/information/bim_report_2019/?fbclid=IwAR2OVYWwWqYXgNAC8MJeyNK_kg--bboku_TyYuRwefgj4OQ7LAvM-EeQC8Y (accessed on 15 December 2022). (In Russian)
67. Arslanbaeva, G.D. Analysis of methods of psychological activation of thinking: Brainstorming and coaching. Their application in business. *Acad. J.* **2021**, *7*, 247–252. (In Russian)
68. Seliverstov, A.S.; Utkin, D.Y.; Postnov, V.V.; Semidotchenko, A.R.; Nikolaeva, K.A.; Polyakova, T.V. Brainstorming as a quality management tool at the enterprise. *Young Sci.* **2019**, *280*, 225–227. (In Russian)
69. Yehuda, B.; Brooks, C.H. Survey response rate levels and trends in organizational research. *Hum. Relat.* **2008**, *61*, 1139–1160.
70. Julsrud, T.E.; Priya Uteng, T. Technopolis, shared resources or controlled mobility? A net-based Delphi-study to explore visions of future urban daily mobility in Norway. *Eur. J. Futur. Res.* **2015**, *3*, 10.
71. Heiko, A. Consensus measurement in Delphi studies: Review and implications for future quality assurance. *Technol. Forecast. Soc. Chang.* **2012**, *79*, 1525–1536.
72. Georgiadou, M.C. *An Overview of Benefits and Challenges of Building Information Modeling (BIM) Adoption in U.K. Residential Projects*; Construction Innovation: Bradford, UK, 2019; Volume 19, pp. 298–320.
73. Al-Saeed, Y.; Edwards, D.J.; Scaysbrook, S. *Automating Construction Manufacturing Procedures Using BIM Digital Objects (B.D.O.s): Case Study of Knowledge Transfer Partnership Project in the UK*; Construction Innovation: Bradford, UK, 2020; Volume 20, pp. 345–377.
74. Evans, M.; Farrell, P. Barriers to integrating building information modeling (BIM) and lean construction practices on construction mega-projects: A Delphi study. *Benchmarking Int. J.* **2020**, *28*, 652–669. [CrossRef]
75. Solaimani, S.; Sedighi, M. Toward a holistic view on lean sustainable construction: A literature review. *J. Clean. Prod.* **2020**, *248*, 119213. [CrossRef]
76. Brydea, D.; Broquetasb, M.; MarcVolmc, J. The project benefits of Building Information Modelling (BIM). *Int. J. Proj. Manag.* **2013**, *31*, 971–980. [CrossRef]
77. Revunova, S.; Vlasenko, V.; Bukreev, A. Modeling the sustainable development of innovation in transport construction based on the communication approach. *IOP Conf. Ser. Earth Environ. Sci.* **2017**, *90*, 012164. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.