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Assessing the Benefits and Challenges of Implementing 4D Modeling in Construction

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Abstract

Introduction. Improved visualization is one of the results of the implementation of information modeling technology. Information modeling technology was mainly used by designers when developing a digital 3D model of an object. 4D modeling combines the organizational and technological sequence of works in the project with a parametric digital 3D model of the object under construction. 4D modeling can potentially contribute to the effective implementation of the project, but data on the scale of 4D implementation are limited, there is no empirical data in practice on the possibilities and problems of using this technology. The purpose of the study is to study the state of implementation of 4D modeling, the advantages of use, the main problems that hinder effective implementation, as well as incentives for implementation in the construction sector.

Materials and Methods. The article used a qualitative analysis of the functionality of 4D modeling to form a questionnaire for a survey among specialists in the construction industry. Based on the analysis of the array of data obtained, a statistical analysis was carried out to identify key problems and incentives for the implementation of 4D modeling in the activities of construction organizations.

Results. The main reasons for the insufficient implementation of 4D modeling technology in construction organizations are identified along with high awareness of the benefits of use. Critical problems that hinder the implementation of this technology are identified, as well as key factors that can stimulate the implementation of investment and construction projects using 4D modeling.

Discussion and Conclusion. The results of the study provide a basis for theoretical analysis to solve the problems of implementing 4D modeling in the construction industry. The study uses the theory of sustainable development and the theory of the full life cycle as a theoretical basis, combines qualitative and quantitative research methods, and conducts an in-depth study of various factors that affect the management of investment and construction projects using 4D modeling technology.

Keywords: 4D modeling; information modeling technology; implementation of BIM technologies

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Оригинальное эмпирическое исследование

Оценка преимуществ и проблем внедрения 4D-моделирования в строительство

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Аннотация

Введение. Усовершенствованная визуализация — один из результатов внедрения технологии информационного моделирования. Технология информационного моделирования в основном использовалась проектировщиками при разработке цифровой 3D-модели объекта. 4D-моделирование объединяет организационно-технологическую последовательность работ в проекте с параметрической цифровой 3D-моделью строящегося объекта. 4D-моделирование потенциально может способствовать эффективной реализации проекта, но данные о масштабах внедрения 4D ограничены, в практической деятельности отсутствуют эмпирические данные о возможностях и проблемах использования данной технологии. Целью исследования является изучение состояния внедрения 4D-моделирования, преимуществ при использовании, основных проблем, мешающих эффективной реализации, а также стимулов для внедрения в строительном секторе.

***Материалы и методы*.** В статье был использован качественный анализ функционала 4D-моделирования для формирования анкеты в целях опроса среди специалистов строительной отрасли. На основании анализа массива полученных данных проведен статистический анализ для выявления ключевых проблем и стимулов внедрения 4D-моделирования в деятельность строительных организаций.

На основании разработанной анкеты был проведен опрос среди заказчиков и подрядчиков строительной отрасли, которые были отобраны выборочным методом. Для анализа полученных данных использовались методы описательной статистики. Индекс относительной важности использовался для ранжирования показателей, чтобы понять относительную важность, как они воспринимаются респондентами. *Т*-тест использовался для проверки статистической значимости предполагаемых различий между клиентами и подрядчиками. Коэффициент Альфа Кронбаха использовался для обеспечения внутренней согласованности и надежности данных для анализа.

Результаты исследования. Определены основные причины недостаточного внедрения в строительных организациях технологии 4D-моделирования наряду с высокой осведомленностью о преимуществах использования. Выделены критические проблемы, препятствующие реализации данной технологии, а также ключевые факторы, которые могут стимулировать реализацию инвестиционно-строительных проектов с применением 4D-моделирования.

***Обсуждение и заключение*.** Результаты исследования обеспечивают основу теоретического анализа для решения проблем внедрения 4D-моделирования в строительной отрасли. Исследование использует теорию устойчивого развития и теорию полного жизненного цикла в качестве теоретической основы, сочетает в себе качественные и количественные методы исследования и проводит углубленное изучение различных факторов, которые влияют на управление инвестиционно-строительными проектами с использованием технологии 4D-моделирования.

Ключевые слова: 4D-моделирование, технология информационного моделирования, внедрение BIM технологий

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Introduction. Construction is an important industry in Russia’s economy and ranks 5th among the branches of the national economy according to its contribution to the gross domestic product. The industry is witnessing a rapid growth [1] (Fig. 1).

The level of complexity of investment and construction projects is extremely high due to customers’ increasing demands. Traditional project implementation systems are largely focused on project completion dates and costs. Unfortunately, under the current conditions, designers, contractors and manufacturers of building materials are not always capable of completing their tasks on time, within a set budget and cater for their customers’ needs. What is more, many fail to achieve the desired outcome [1].

Building information modeling provides participants in investment and construction activities with a platform for collaboration in a shared data environment for increasing the efficiency and improve the outcome. The 3D model of the project documentation can be used for construction planning. When the "time" parameter is added to the model, 4D

[1] The statistical data were accessed from https://rosstat.gov.ru/

modeling is implemented. 4D modeling enhances the efficiency of processes by reducing unproductive costs and helps to complete projects on time within a set budget controlling the construction schedule and increasing value for customers [2]. However, despite these opportunities, 4D modeling is not commonly used by construction project participants. It is thus proposed that the degree of use is assessed and the point of view of key construction actors on the advantages, obstacles and motivational forces of 4D modeling is understood.

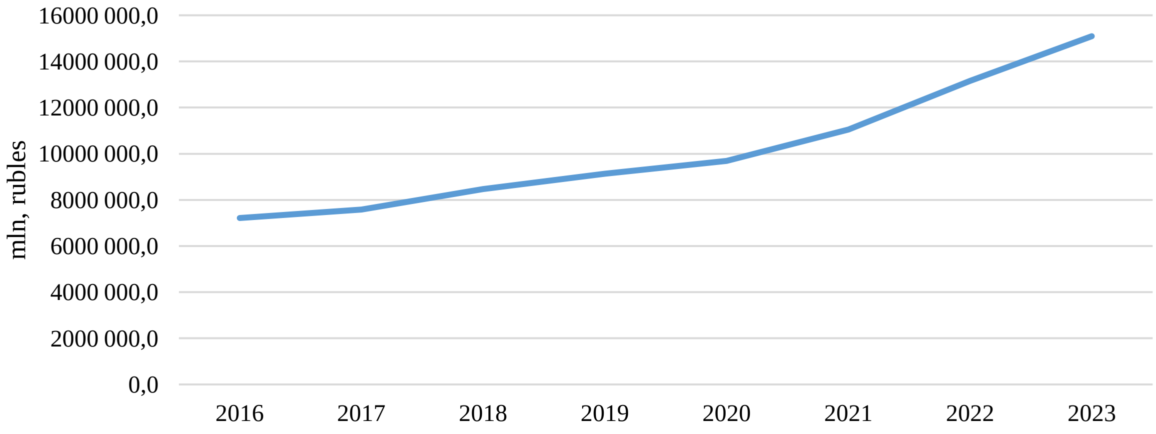


Fig. 1. Dynamics of the indicator "Amount of Work Performed Independently according to an activity type "Construction""

Traditional planning methods are not directly related to the design and construction model [3], the sections of the plans are not in complete synchrony with the project making it difficult for project participants to make sense of the plan and its impact on logistics management at the facility [4]. The lack of this connection causes alterations, unevenness and improper use of resources, which increases construction time and costs [5].

4D modeling is also instrumental in speeding up construction thus reducing the number of errors that are easily eliminated at the design stage, avoiding major problems that are rather expensive to resolve at a later stage of construction [6, 7].

4D modeling offers an expanded vision of planning, designing and building, developing or maintaining a single information model including all of the necessary information about the project lifecycle. 4D modeling plays a major role in the coordination between designers and customers during the planning phase. The experience of contractors is crucial while developing a 4D model for planning and is capable of providing valuable information about the feasibility of construction, the estimated construction costs and the sequence of work [4]. This helps project stakeholders to identify problems during the construction phase and keep track of work progress [2, 8]. 4D modeling helps to design virtual projects and stimulate them with various scenarios, which enables all stakeholders to gain a better insight into the risks of the project at an early stage and their reduction by taking corrective measures.

The major advantages and applicability of 4D modeling are visualization of the progress of construction at any time with possible forecasting [8, 9]; logistics planning (movement of resources on the construction site) [10]; site layout (reduces losses that might take place during construction, thus improving construction opportunities) [9, 11]; location-based planning [9]; a clear understanding of the construction process and construction methodology [9]; checking schedules using modeling [12]; discussing progress in meetings for a better insight [12]; safety planning (visual representation of hazards and a safety plan) [9, 11]; analysis of the documentation and claims (it is quite easy to prove which party is to be held accountable for the delay and what potential outcomes are to be expected) [12]; reducing risks in the project [9]; increasing customer satisfaction [10]; monitoring the project with modeling a schedule that helps to reduce the amount of necessary improvement [9].

Notwithstanding the advantages that 4D modeling offers to the construction industry, there are technical and non-technical problems preventing 4D modeling from being commonly adopted [8]. The widespread adoption of BIM and 4D modeling is more affected by non-technical barriers than technical ones. Information on the scale of 4D modeling implementation in Russia is rather limited. Hence the experience of using 4D modeling overseas where this method is most common was investigated. These countries are Great Britain, France, Slovakia, the USA, Iran, etc. Scholars and practitioners in all of these countries note the problems associated with the development of the 4D model (model volume, level of detail, time components, decomposition and aggregation) and the lack of proper implementation plans, guidelines and standards to be adhered for 4D modeling to be implemented. The inexpediency of spending time on training and the lack of time for employees' training is also noted. A major obstacle to implementation is the lack of 4D modeling experience in the market, the lack of standards for 4D modeling, difficulties in understanding the methods, and the longer process of creating a 4D model [9-13]. There is also insufficient customer demand for the use of the 4D model, high software investment as well as training costs, lack of knowledge of 4D modeling among the workforce, employees' resistance to abandoning traditional construction planning methods and switching to 4D modeling, as well as problems with data exchange between software related to software compatibility.

The construction industry has become somewhat aware of the value of BIM and started using it during the design phase, but the use of BIM during the planning and construction phases is growing at a slow rate. There have been no studies on the implementation of 4D modeling in Russia. There is thus a need to investigate the status of 4D modeling implementation in Russia as well as the perceived advantages and issues of various subjects of investment and construction activities in the construction sector. The aim of the study is to investigate the extent of the use of 4D modeling, the views of the main stakeholders on 4D modeling when it comes to the advantages, obstacles and motivational forces in the Russian construction.

Materials and Methods. The target audience of the study is customers and contractors of the construction industry. A sampling method was employed in order to select the respondents. In order to conduct the survey, a questionnaire was designed including information about the demographic data of the participants, as well as some questions on the applicability of 4D modeling, the advantages of 4D models as opposed to traditional approaches to construction planning, the challenges of implementing 4D modeling, and motivational efforts to implement 4D modeling.

Descriptive statistics methods were used in order to analyze the data. The relative humidity index is employed in order to rank the indicators for a better insight into the relative importance of how they are seen by the respondents. The T-test is used to verify the statistical significance of the perceived differences between the clients and contractors, if any. The Cronbach Alpha coefficient is used to ensure the internal consistency and reliability of the data for analysis.

The survey tool was designed digitally and requests were sent to customers-developers and contractors of the Southern Federal District by e-mail. 27 responses were received, including from 17 contractors and 10 from construction customers. Cronbach's Alpha is used to evaluate the internal consistency of the instrument and the reliability of the data collected for further analysis. The calculated values of Cronbach's Alpha are made in Excel and shown in Table 1. All the values are over 0.7 (the threshold for social research) making the data collected reliable and acceptable for further analysis.

Table 1

Reliability statistics

Name	Cronbach's Alpha	Number of the indicators
Possibility of use	0.906	12
ПAdvantages	0.925	12
Issues	0.812	14
Incentives for use	0.835	6
Total	0.894	44

Research Results. Information modeling technology functions are used to assess the feasibility of applying the advantages, obstacles, and driving forces of 4D modeling. According to the study of the used sources, indicators were designed that are to be further investigated (Table 2).

A quantitative approach based on a survey is used to examine construction professionals' views on applicability, advantages, obstacles and driving forces of using 4D modeling in implementing investment and construction projects.

There were 27 responses received, with most provided by large organizations (71.8%), whereas the remainde were medium-sized (10.8%) and small (17.4%) organizations. The respondents are the top management (23.9%), middle management (54.8%) and operational (21.3%) levels in their organizations. The respondents' work experience in construction is as follows: 35% have more than a 10- year work experience, 36% of the respondents have a 5–10 year work experience, 19% of the respondents have a 2–5 year work experience, and 10% of the respondents have less than a 2–year work experience.

Knowledge and use of 4D modeling. It was noted that most (74%) of the respondents know about 4D modeling, but have not used it, whereas 11% both know and use it, and 15% said that they did not know about 4D modeling (Fig. 2). Some of the respondents use the concept of 4D BIM, which is essentially equivalent to the concept of 4D modeling.

Table 2

BIM functions, challenges, and incentives for using 4D modeling

№ of the indicator	Name of the indicator
1. Functionality implemented during the introduction of 4D modeling	
1.1	Logistics planning
1.2	Planning the organization of the construction area
1.3	Interconnection of individual construction plans of the contractors involved in construction
1.4	Planning of the organizational and technological sequence of work
1.5	Construction process visualization
1.6	Planning accounting for the location
1.7	Checking the construction plan using modeling
1.8	Possible work meetings held during the construction
1.9	Safety planning
1.10	Documenting and analyzing claims
1.11	Risk management
1.12	Variant design with construction schedule modeling
2. Issues of introducing 4D-modeling	
2.1	Lack of customer demand for using the 4D model
2.2	High software investment costs
2.3	High training costs
2.4	Employees' insufficient knowledge of 4D-modeling
2.5	No experience of 4D-modeling in the market
2.6	Unnecessary time spent on training
2.7	Insufficient time for the employees' training
2.8	Employees' resistance to change
2.9	No 4D-modeling standards
2.10	Issues of developing the 4D-model
2.11	Challenges of understanding the 4D-modeling methods
2.12	Traditional methods of implementing the project/contract
2.13	A more lengthy process of designing 4D-modeling
2.14	Issues of data exchange between the software programs
3. Incentives for implementing 4D-modeling	
3.1	Developing local 4D-modeling standards
3.2	State support of 4D-modeling
3.3	Improving the software functionality
3.4	Software providers' support
3.5	Knowledge of the advantages of 4D-modeling and return on investment
3.6	Positive examples of the use of 4D-modeling in the market

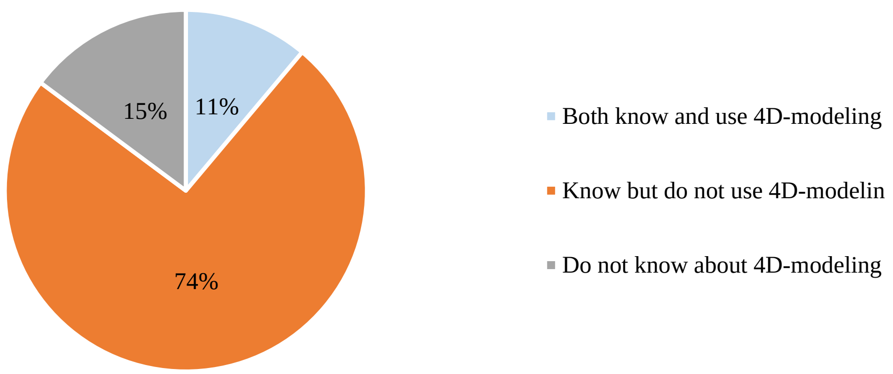


Fig. 2. Knowledge and use of 4D-modeling

The results indicate a higher level of awareness about 4D modeling and a much lower level of use. An attempt was made to make sense of the plan of the respondents who know about but did not use 4D modeling. Although some of the respondents indicated that they were planning to use 4D modeling in the foreseeable future (11% within a year and 31% within 1–3 years), a significant proportion (58%) of the respondents are planning to use 4D BIM only after 3 years (Fig. 3). This implies an expected lower spread of 4D BIM in the short term.

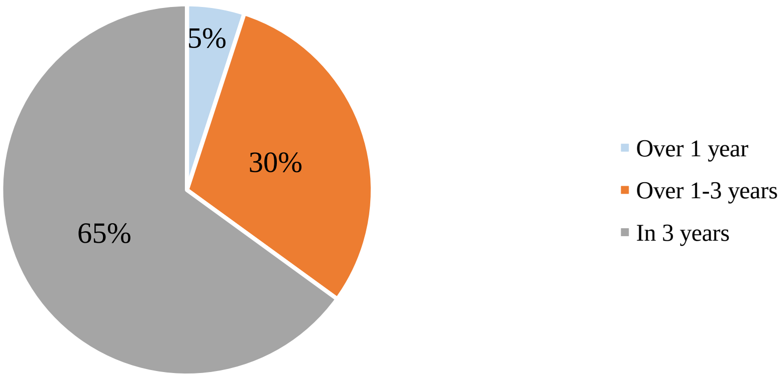


Fig. 3. Plans to implement 4D-modeling

Applicability of 4D BIM. The participants were asked to express their opinion on the possibility of using 4D modeling functionality on a five-point Likert scale (from "not applicable at all" to "very applicable") in relation to the various BIM functions according to the list provided in Table 2. The distribution of the responses is shown in Fig. 4. Their structure indicates that the respondents rated 4D modeling as applicable. Among the BIM functions, "Visualization of the Construction Process" (1.5), "Interconnection of Individual Construction Plans of Contractors Involved in Construction" (1.3) and "Verification of the Construction Plan Using Modeling" (1.7) turned out to be the most preferred ones. Although "Planning of the Construction Site Organization" (1.2) and "Logistics Planning" (1.1) were ranked low, they can be considered applicable. On top of that, the clients rated "Variant Design with Construction Schedule Modeling" (1.12) as very applicable.

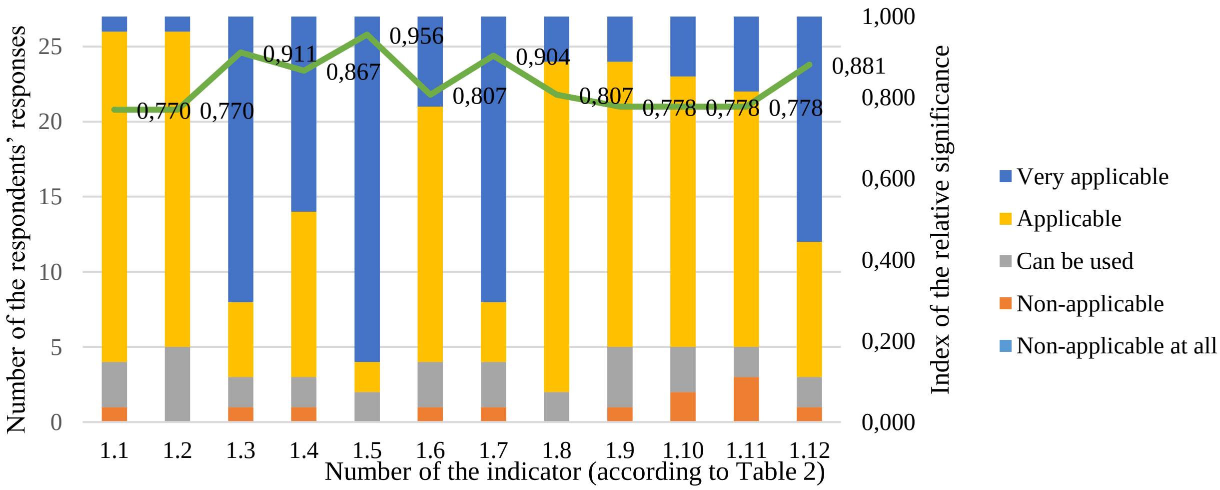


Fig. 4. Possibility of using the 4D-modeling functional

Advantages of using 4D modeling. In response to a question about the advantages and usefulness of 4D modeling, participants rated the various BIM functions listed in Table 2 on a five-point Likert scale (from "not profitable at all" to "very profitable"). The distribution of the responses is shown in Fig. 5.

It can be noted that the response pattern is similar to the one shown above (Fig. 4). "Visualization of the construction process" (1.5), "Interconnection of individual construction plans of contractors involved in construction" (1.3) and "Verification of the construction plan using modeling" (1.7) were evaluated as the main advantages of 4D modeling. However, respondents believe that "Variant design with modeling of the construction schedule" (1.12) is more useful than "Interconnecting individual construction plans of contractors" (1.3). It should be noted that high scores on other indicators indicate the very beneficial nature of 4D modeling.

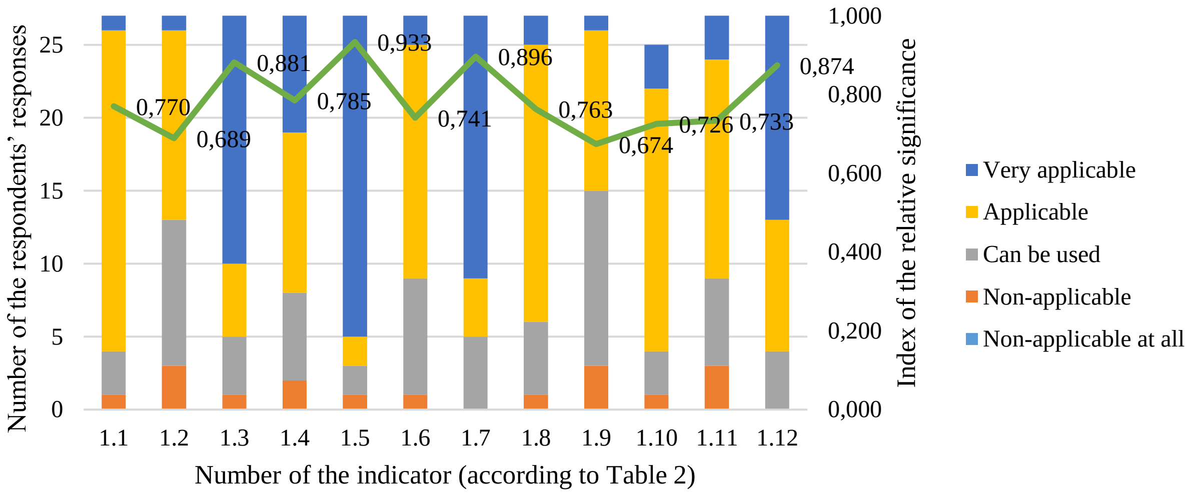


Fig. 5. Advantages of using 4D-modeling

Issues of 4D modeling implementation. The respondents believe that "Lack of knowledge of 4D modeling among employees" (2.4), "Traditional methods of project/contract implementation" (2.12) and "Lack of 4D modeling experience in the market" (2.5) are the major obstacles to the introduction and use of 4D modeling (Fig. 6). "Unjustified costs time for training" (2.6) and "Lack of time for employee training" (2.7) were assessed as minor issues for implementation.

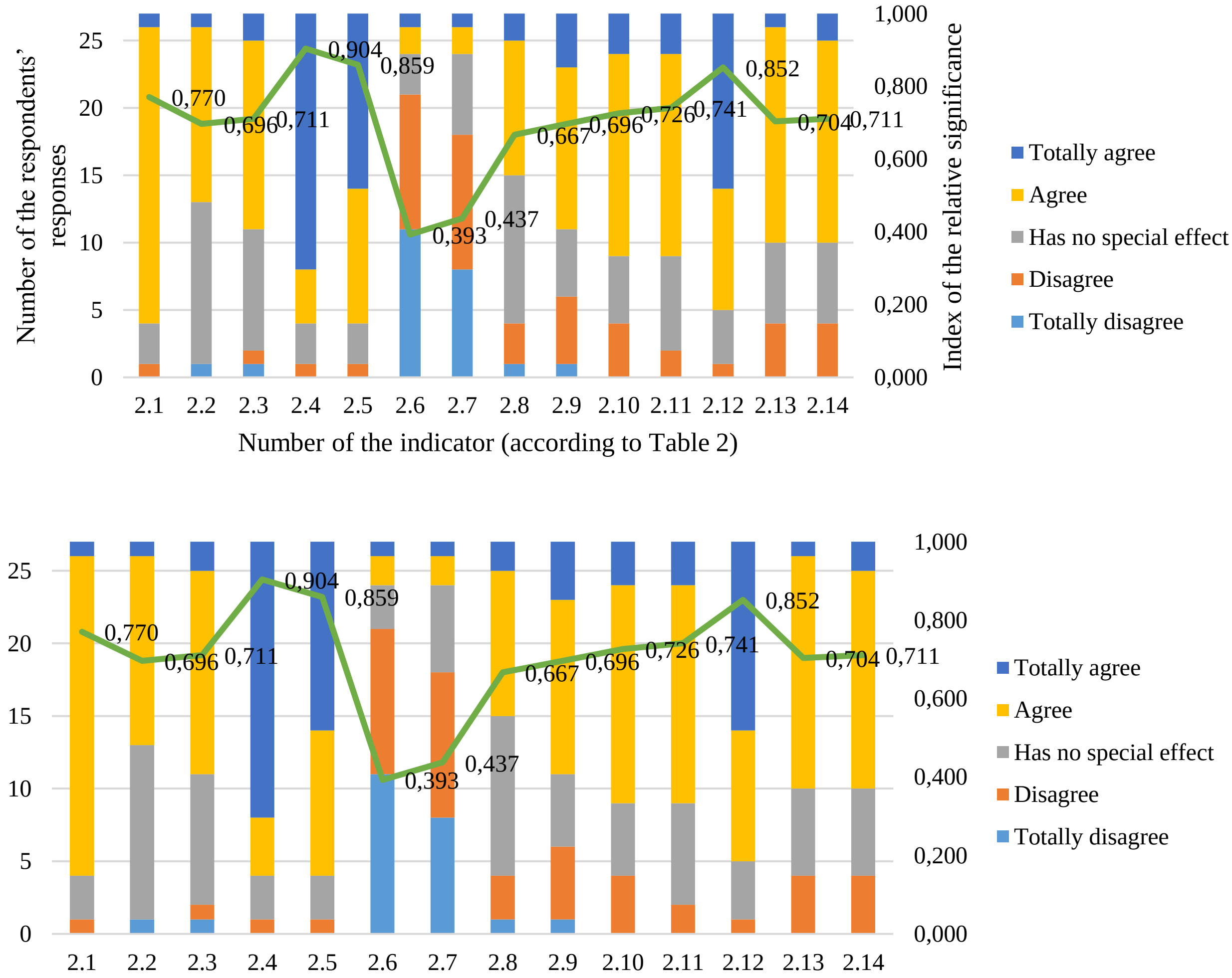
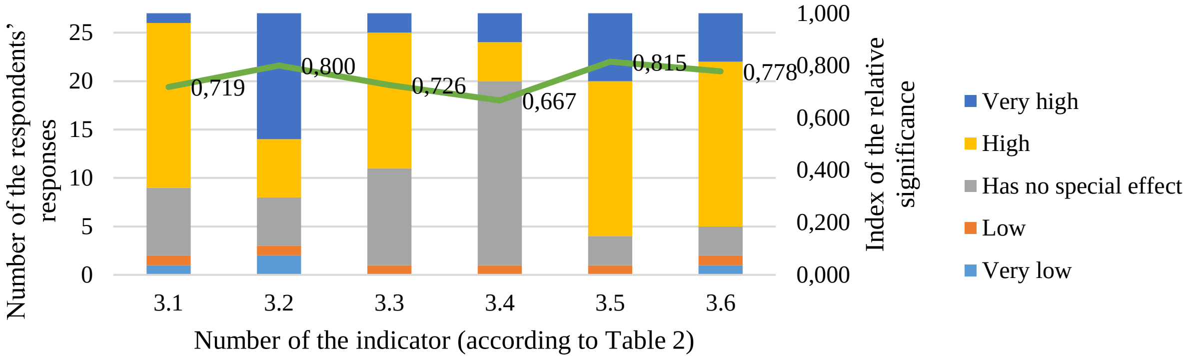


Fig. 6. issues of implementing 4D-modeling

Incentives for using 4D modeling. In response to a question about the driving forces contributing to the implementation of 4D modeling in organizations, on a five-point Likert scale (from "very low" to "very high"), the respondents rated "Knowledge of the benefits of 4D modeling and return on investment" (3.5) as the major criterion (Fig. 7).



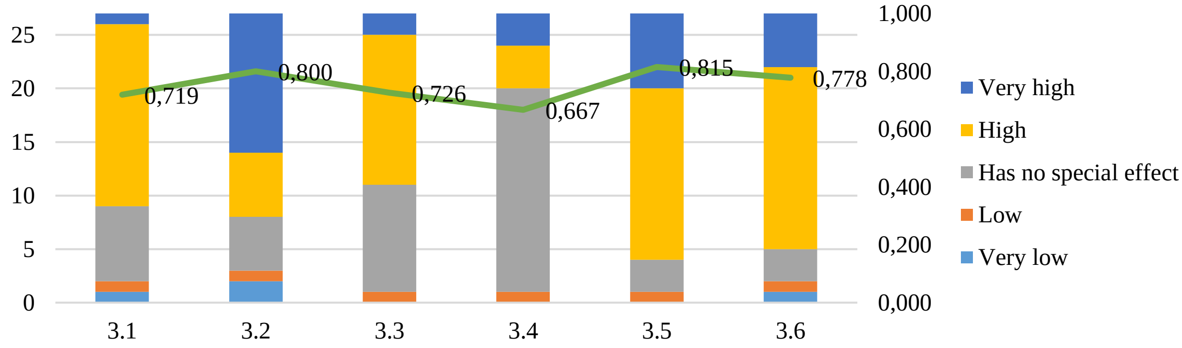


Fig. 7. Incentives for using 4D-modeling

Along with 3.5, "Government support" (3.2) and "Accessibility of 4D modeling experience in the market" (3.6) are also considered as the major factors. It can be noted that "Support from software vendors" (3.4) was ranked the lowest.

Hypothesis testing. Although there was generally agreement among the construction customers and contractors on their responses, an attempt was made to test that statistically to ensure that this was not by chance. The independent *t*-test is a statistical test that is used to identify the difference in averages.1 In addition, the t-test is applicable when only two groups are compared, and the sample size is very small. The following hypotheses are tested using the t-test for two independent samples assuming equal variance at a significance level of 5%.

Null hypothesis H_0: There is no significant difference in the perception by the customers and contractors of the applicability, advantages, challenges, and incentives of implementing 4D modeling.

Alternative Hypothesis H_1: To test the null hypothesis, there is a significant difference in the perception of the customers and contractors regarding the applicability, benefits, challenges, and incentives of implementing 4D modeling in the construction industry.

The test results are shown in Table 3. The p-value indicator was used to verify the test results, which indicates the probability of obtaining the observed results if the null hypothesis is correct, or the probability of error if the null hypothesis is rejected. As the p-value for all of the four variables is over 0.05, there is no sufficient evidence to reject H_0, and H_0 is thus accepted. This means that there is no significant difference in the perception by the customers and contractors of the applicability, advantages, challenges, and incentives of implementing 4D modeling.

Table 3

Results of the *t*-criterion for the null hypothesis

Variables	*p*-value
Applicability	0.134
Advantages	0.707
Issues	0.367
Incentives	0.132

Discussion and Conclusion. According to the study, it can be noted that there is a high level of knowledge knabout 4D modeling in construction. However, the task is to turn this knowledge into practice. Despite the increased knowledge and willingness to use 4D models, most of the respondents do not plan to use this information modeling technology in the next three years. In order to be competitive in the market and successfully implement investment and construction projects on time, with proper quality and within a set budget, there is a significant need to implement 4D modeling in construction organizations as early as possible.

Reviews of the applicability and advantages of 4D modeling (1.5, 1.3, 1.7 and 1.12 of Table 2) emphasize the need for improved visualization for communication between the general contractor and subcontractors for timely transfer of the work, the possibility of preliminary organizational and technological modeling of a range of options for managing the construction process in order to complete the project on time as stipulated by the contract. Building capacity and opportunities through education and training is critical to meeting these expectations. Construction customers can predict various project implementation options with the modeling of the construction plan (1.12), which demonstrates a change in priority towards project quality and timely logistics.

It is also important to pay attention to the obstacles to the implementation of 4D modeling. "Lack of knowledge about 4D modeling tools among the employees of construction organizations" (2.4) calls for special attention to training and continuous professional development within organizations. In order to address these issues, it is necessary to change the "Traditional approach to project implementation" (2.12), apply innovative procurement methods such as integrated project implementation (IPD) and smart contracts using blockchain. "Lack of experience using 4D modeling in the market" (2.5) calls for educational institutions to review curricula to ensure that students graduate with the necessary digital skills. As "Unjustified time spent on training" (2.6) and "Lack of time for employees' training" (2.7) were assessed as minor issues, meaning that organizations and their employees are willing to accept these changes and implement modern modeling approaches.

While focusing on the incentives for using 4D modeling, it can be noted that it is necessary to promote information about the advantages of implementing 4D modeling, to prove the efficiency of investing in this stage of information modeling technology (3.5). Therefore "Government support for the use of 4D modeling" (3.2) plays a key role through the development of appropriate standards, training programs, and other incentive measures. Currently, there is no official set of rules reflecting approaches to the use of 4D modeling. It is only SP 331.1325800.2017 "Information Modeling in construction" that gives a definition of 4D.

It can be noted that the major advantages of using 4D modeling are found in studies conducted overseas. Certainly, there are a few differences. E.g., in the UK [8], "Logistics planning" (1.1) was ranked high, and the lack of knowledge of the project participants was attributed to crucial problems. The unavailability of qualified specialists has proved to be a critical factor in Qatar's construction industry. In India, the use of existing project implementation methods and lack of customer demand were identified as the major challenges facing 4D modeling.

Considering the relatively small sample size, the conclusions are to be trusted with some reservations. A wider study among customers and contractors with an increased sample size might shed more light. It is also worth exploring the role of visualization for communication in decision-making by all project participants in order to improve implementation of investment and construction projects.

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