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The Role of BIM Technologies in Capital Construction Project Management

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Abstract— *The article is devoted to the study of the role of BIM technologies in the management of capital construction projects. The relevance of the question is due to the need to increase the capacity of the construction industry in relation to the increasing complexity of projects and complex requirements for time and quality of implementation. The purpose of the study is to analyze the impact of BIM on various aspects of construction project management and identify mechanisms to overcome existing industry problems through the introduction of these technologies. The study revealed contradictions between the potential advantages of BIM and the difficulties of their practical implementation, associated with technological, organizational, and regulatory barriers. It is concluded that BIM technologies play a transformational role in project management, providing increased efficiency at every stage of the life cycle of objects, but require an integrated approach to implementation. The article will be useful for specialists in the field of construction project management, researchers developing innovative approaches in construction, as well as decision-makers on the introduction of digital technologies.*

Keywords— *BIM technologies, object lifecycle, information modeling, capital construction, design, project management, digital transformation.*

I. Introduction

In the modern realities of the construction industry, a rapid digital transformation is underway. One of the key drivers of this process is Building Information Modeling (BIM) technology, which is transforming the approach to managing capital construction projects. The scientific works of many researchers are devoted to a comprehensive analysis of the role of BIM in optimizing design, construction, and operational processes.

The construction industry faces several significant challenges, including low labor productivity, considerable time and financial losses due to design and coordination errors, and inefficient information management throughout the life cycle of projects. Traditional methods often fail to cope with the increasing complexity of projects and the growing demands for speed and quality in their execution.

In this context, the key research problem is to determine the extent of BIM technology's impact on the efficiency of capital project management and to identify the mechanisms by which the implementation of BIM will help overcome existing industry limitations.

II. Methods and Materials

The methods of comparison, system-logical analysis, systematization, and generalization were used. Scientific publications and materials pay close attention to the integration of BIM with the concept of Lean Construction. H.G. Bayhan and co-authors developed a model of interaction between BIM and Lean Construction aimed at increasing industry efficiency [1]. A. Eldeep analyzed the advantages of such integration at the design and construction stages, identifying key lessons for practical application [3]. İ. Karataş and A. Budak studied the combined influence of Lean Construction and BIM on waste reduction in the construction industry, highlighting the environmental aspect of this approach [7].

Several researchers focus on the application of BIM in specific areas of construction. A. Juszczyk examined the challenges of implementing BIM in Poland's construction industry, identifying particular issues for this sector [6]. I. Hermawan and S. Sudirman explored the integration of BIM with 3D machine control systems to improve the efficiency of capital construction projects, demonstrating the potential of BIM in automation [5].

Quality and safety management issues in the context of BIM are discussed in the works of P. Chen, who proposed a corresponding control system [2], and A.V. Ginzburg and S.I. Kozminykh, who studied the information support for comprehensive safety of capital construction objects using BIM technologies [4].

Particular attention is paid to the application of BIM in project management. T. Ye and co-authors developed a method for managing project documentation based on BIM and a precedent approach [9], while Sh. Yin proposed a methodology for working with construction schedules of large-scale projects relying on BIM models [10].

Environmental aspects are explored by J.S. Sudarsan and H. Gavali, who considered the possibilities of using BIM in combination with circular economy principles to ensure sustainable construction [8].

Thus, researchers use various approaches to studying the role of BIM in capital construction project management. Methods of modeling, case studies, comparative analysis, and empirical research are employed. Many authors focus on the integration of BIM with other advanced concepts and technological developments, reflecting the interdisciplinary nature of modern research in this area. A common trend is the recognition of BIM's transformative potential for all stages of the construction project's life cycle. At the same time, specialists note the need to overcome several technical, organizational, and regulatory barriers for the full realization of BIM technology's advantages.

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III. Results and Discussion

Addressing the essential characteristics, it should be noted that BIM represents a comprehensive approach to creating and managing information about a construction object throughout its entire life cycle. At its core is the conceptual framework of a unified digital model, containing exhaustive data on:

- geometry;
- physical properties;
- functional characteristics;
- relationships between all elements of the structure [2, 8, 10].

A key feature of BIM is parametric modeling, which allows for the automatic adjustment of all interconnected elements when any parameter is changed. This ensures the consistency and relevance of data at all stages of the project implementation.

Thus, the conceptual basis of BIM technologies in capital project management lies in the creation and use of digital models that consolidate information on all aspects of a building throughout its life cycle, from design to operation. BIM enables the integration of architectural, engineering, and construction data into a unified information environment, ensuring interdisciplinary coordination, improving project quality, and significantly reducing risks. The main principles include:

- 3D modeling;
- data management;
- collaborative work among participants;
- efficiency analysis at each project stage [6].

The diagram (Fig. 1) illustrates the basic aspects of BIM's impact on project management.

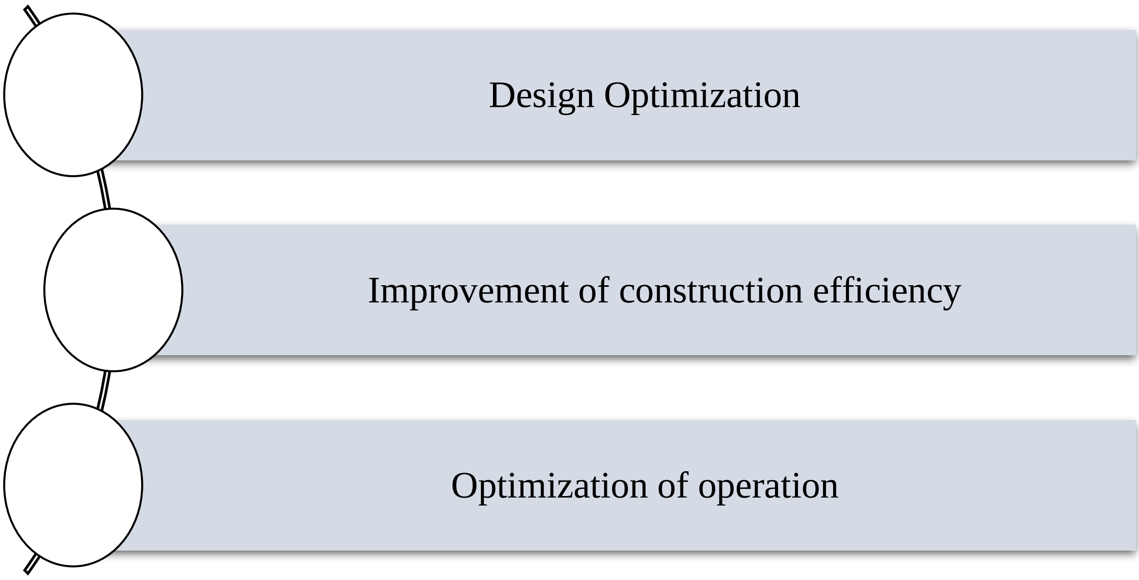

Fig. 1. The impact of BIM on project management [1, 5, 7]

Thus, BIM technologies have the potential to radically transform the design process by providing tools for creating highly accurate digital prototypes. Specifically, they enable the following:
- detecting clashes and discrepancies at early stages, minimizing the risk of costly errors during construction;
- conducting multi-variant designs, quickly evaluating the effectiveness of various architectural and engineering solutions;
- automating routine tasks (such as generating specifications and work volume lists).

During the construction phase, BIM ensures:
- precise planning of work sequences and logistics;
- real-time monitoring of compliance between actual work and design decisions;
- effective coordination of all participants in the construction process.

The BIM model becomes a valuable asset during the operation phase of the facility, providing:
- comprehensive information on engineering systems and equipment for maintenance planning;
- the ability to model various scenarios for renovation and modernization;
- tools for effective management of energy consumption and resource bases.

Next, it is necessary to address the economic aspects of BIM implementation. It requires substantial initial investments in software, staff training, and business process reorganization. However, these costs are offset by significant efficiency improvements (Fig. 2):

Regarding the technological aspects, a key factor for the successful implementation of BIM is ensuring interoperability — the seamless exchange of data between different software systems. The IFC (Industry Foundation Classes) standard plays a fundamental role in this process, providing a universal format for exchanging BIM models.

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Integrating BIM with cloud platforms provides more opportunities for collaboration and data management. This provides:
- real-time access to up-to-date information for all project participants;
- the ability to work effectively on large-scale projects with distributed teams;
- reduced costs for IT infrastructure.

The application of AI algorithms in conjunction with BIM enables the automation of model compliance checks with regulatory requirements, optimization of design solutions based on the analysis of large data sets, and the prediction of potential risks and issues based on historical data.

The challenges and prospects of BIM development are best viewed through the following lenses (Fig. 3):

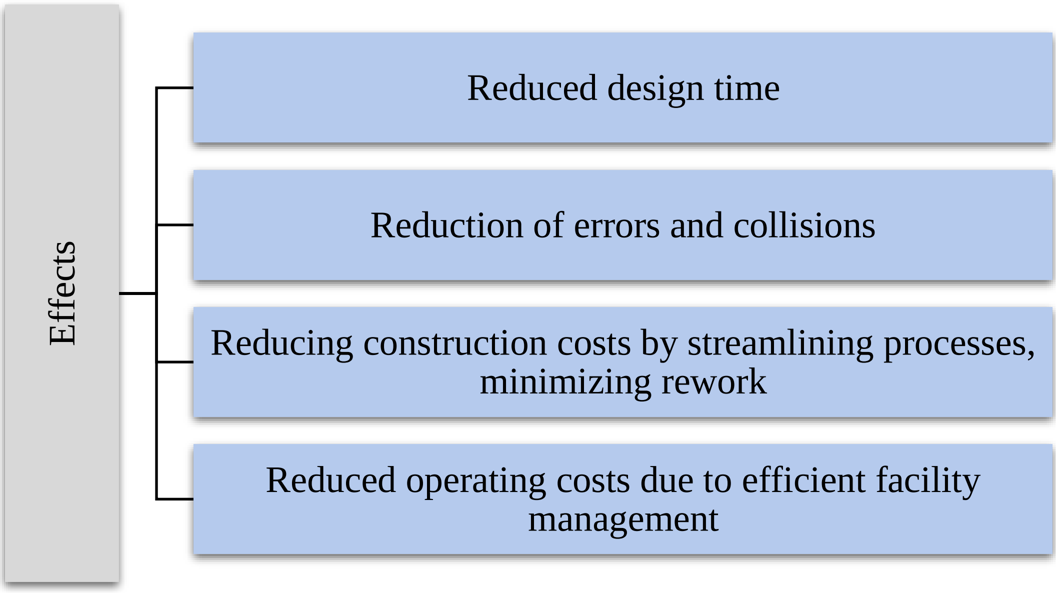

Fig. 2. Systematization of the economic effects of the introduction of BIM technologies in the management of capital construction projects [5, 6]

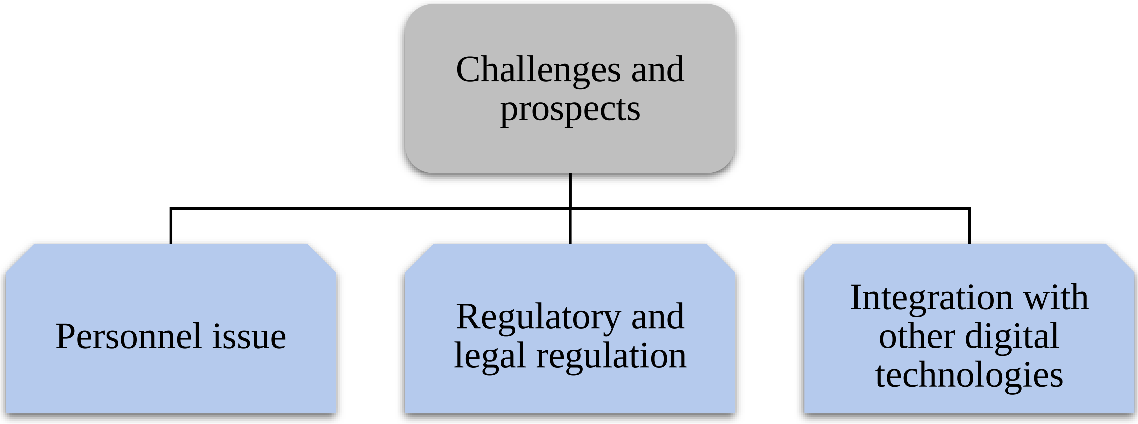

Fig. 3. Perspectives of the analysis of challenges and prospects of using BIM technologies in capital construction project management [3, 9]

The widespread adoption of BIM technologies highlights the issue of a shortage of qualified specialists. This necessitates the development of new educational programs and training standards in the field of digital construction.

BIM advancements are outpacing the formation of an appropriate regulatory framework. There is a need for the development of guidelines and regulations that define the use of BIM at all stages of the life cycle of capital construction projects.

A promising direction for future development is the integration of BIM with virtual and augmented reality technologies, the Internet of Things, and 3D printing. This opens new possibilities for visualization, monitoring, and optimizing construction processes.

To conduct a conclusive analysis of the advantages and limitations of BIM technologies in managing capital construction projects, the following categories were identified:
- design efficiency (important for assessing accuracy and coordination between project participants);
- visualization and coordination;
- economic efficiency (impact on budget management and project timelines);

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- data management (reflects the ability to collect, store, and use information during the design and construction process);
- training and technology adaptation (related to the process of implementing and mastering BIM by specialists).

Based on the analysis, a summary of Table 1 was compiled, systematizing the advantages and limitations.

TABLE 1. Justification of the role of BIM technologies in capital construction project management (compiled by the author)

Category	Advantages	Limitations
1. Design efficiency	Precise coordination, reduced errors, clashes	High initial implementation costs
2. Visualization, coordination	Improved project visualization	Need for powerful computational resources
3. Economic efficiency	Cost reduction through accurate planning	Difficulties with integration in smaller projects
4. Data management	Centralized storage and management of information flows	Requires standardization of formats and interaction protocols
5. Training and adaptation	Opportunities for professional growth	Need for additional staff training

Commenting on the table, it should be noted that BIM technologies provide significant advantages in project management in the field of capital construction, by improving design accuracy, enhancing coordination, and optimizing costs.

At the same time, it is important to emphasize that their practical implementation involves high initial costs, the need for training, and technical adaptation, which often complicates the application of these technological developments in smaller projects or organizations with limited resources.

IV. Conclusions

BIM technologies play a transformative role in managing capital construction projects, providing a qualitatively new level of efficiency, accuracy, and transparency at every stage of the life cycle of assets. Despite existing challenges, the potential of BIM for optimizing the construction industry is immense. Further development and integration of BIM with advanced digital technologies will facilitate the transition to a new paradigm of "smart construction," characterized by a high degree of automation, predictability, and sustainability.

It seems advisable to deepen the study of the mechanisms for integrating BIM with other advanced technologies—such as artificial intelligence, the Internet of Things, etc.—to create more effective and intelligent construction project management systems. Special attention should be paid to developing methodologies for assessing the economic efficiency of BIM implementation at various stages of a project's life cycle, considering both direct and indirect effects. A relevant area of research is the analysis of the socio-psychological aspects of BIM, including the study of resistance to change and the development of strategies to overcome organizational barriers.

It is also important to focus on studying the impact of BIM on the sustainable development of the construction industry, particularly regarding opportunities for optimizing the energy efficiency of buildings during the design phase. A promising direction involves the development of standardized approaches to assessing BIM maturity levels within organizations and the industry as a whole.

Implementing these research objectives will not only expand the theoretical foundation for the use of BIM but also create practical tools for improving the management of capital construction projects in the context of digital transformation.

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