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# Significant applications of digital modeling in the construction sector for improving project management and performance

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**Abstract:** The purpose of the digital models is to aid users in better understanding the response and behavior of the construction management system under different conditions. The main advantage of the digital models lies in the ability to use possible alternatives and analyze the effect of various factors on the project management system, both before and during performance. This study will review previous works. Types of BIM and simulation techniques are discussed, along with the reasons for using this technique, its applications, and characteristics in the construction sector. The application of digital models in the construction sector is also reviewed. The research concludes that simulation modeling has a revolutionary impact on construction project management, as it provides advanced tools for planning efficiency, resource allocation, cost calculation, sustainability, and risk management. While obstacles such as the requirement for skilled personnel and the integration with existing systems remain, the benefits of simulation modeling in terms of cost savings, improved efficiency, and more effective decision-making make it an essential aid for construction projects.

***Keywords:*** *BIM, Digital model, Intelligent construction, Project management, Simulation.*

## 1. Introduction

To study the detailed properties and behavior of a real system exactly, we have to resort to simulation, as the analytic approach is not always adequate. Simulation involves representing and constructing a model of the system under study by means of computer programs and running these programs. The dynamic behavior of the system is acted out so that by observing its development within the computer, the relevant properties of the system may be extracted [1, 2].

In certain cases, a model may be created that is straightforward enough to be resolved using mathematical techniques. Differential calculus, probability theory, algebraic techniques, or other mathematical approaches may be used to find such answers. The answer often consists of one or more numerical parameters, sometimes known as measurements of system performance. But many systems in the actual world are quite complicated. Mathematical solutions to the models of these systems are essentially unachievable [3]. In many cases, the behavior of the system over time may be imitated using numerical computer-based simulation. Data are gathered from the simulation just as though a real system were under observation. The system's performance metrics are estimated using this simulation-generated data [4, 5].


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Simulation has many meanings, but all these meanings lead to one goal. Therefore, simulation is "the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system" [6, 7].

This study will review the previous works related to the present research. Types of digital modeling will be discussed, as the reasons for using this technique and application and characteristics of using BIM and simulation in the construction sector, and also application of digital models in the construction sector were reviewed.

## 2. Enhancing Project Planning and Design Efficiency

Simulation modeling plays a crucial role in improving the planning and design phases of construction projects. BIM, in particular, has been widely adopted as a powerful tool for creating detailed digital models that facilitate better decision-making [8].

1) BIM for Design and Planning: through BIM, the creation of detailed digital models that integrate architectural, engineering, and construction information is made possible. This enables stakeholders to see the project in 3D, identify problems early, and achieve the full potential of the design [9-11].

2) 4D Scheduling: 4D scheduling gives a graphic illustration of the construction schedule using the combination of time dimensions within BIM models, It serves to highlight the areas of potential bottlenecking and improving the sequence of activities [9, 11] .

3) Cost Estimation: BIM models can be utilized in order to give a precise cost estimate through analyzing the amount of material and labor required. This reduces the risk of cost overrun and offers a more comprehensive financial strategy [9, 10].

Example: Case study in the U.S. construction sector identified that BIM planning reduced project duration by 15% and improved cost effectiveness by 20% [9].

## 3. Optimizing Resource Allocation and Logistics

Resource management and logistics are crucial aspects of construction project management. To optimize them, a simulation modeling offers a concrete framework [12].

1) Simulation-Based Resource Planning: A study proposed a simulation-based method involving the use of genetic algorithms and discrete event simulation to determine the optimal tower crane locations, depot locations, and selection of suppliers. This method helped reduce project expenditures by 12% compared to traditional methods [13].

2) Logistics Optimization: Simulation tools like EZStrobe and AnyLogic have been utilized to model construction logistics, making it easier to enable accurate material flow and reducing transport costs. For example, a tunnel project in Turkey attained a 10% reduction in the use of resources through logistics planning using simulations [14].

Example: A project of steel structures in Tehran showed that the use of simulation models and genetic algorithms provided a 15% decrease in overall project cost [13].

## 4. Improving Cost Estimation and Financial Management

Effective cost estimation is important for effective construction projects. Simulation modeling provides, advanced techniques for improving cost estimation and financial control [15].

1) BIM for Cost Estimation: Various design scenarios can be modeled by BIM models, and thus real-time cost estimation is possible. This facilitates stakeholders in making informed decisions regarding design as well as material variations [9, 10].
2) System Dynamics for Cost Analysis: A system dynamics approach has been used to provide a model that shows the relationships between direct and indirect costs in construction projects.

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This approach enables real-time updates of cost components and facilitates sensitivity analysis to account for future risks [16].

Example: A system dynamics model for reinforced concrete work demonstrated the ability to update costs dynamically, reducing cost estimation errors by 8% [16].

## 5. Streamlining Construction Processes with Lean Principles

Lean construction principles aim to minimize waste and maximize value. Simulation modeling has been successfully integrated with lean principles to improve process efficiency [17].

1) Lean Construction and Simulation: A study in Turkey combined lean construction principles with simulation tools to optimize planning and control. The integration of simulation models with lean principles reduced cycle times by 12% and increased productivity by 10% [14].
2) Digital communication for lean construction: We analyzed the current state of the project application mechanism in case studies for the design and implementation stages, where it was found that there is a high percentage of waste and time consuming and effort reached 60% and due to the weakness of coordination and communication in the team. Suggesting a model for implementing digital engineering to lean construction projects was obtained, where it includes the construction of a digital platform for multiple applications that include digital products and allows digital communication using digital models. The platform permits full control of the vast (multi-site) construction projects through a better-connected work site [18].
3) Process Optimization: Simulation tools like AnyLogic have been used to model construction processes, identify bottlenecks, and optimize workflows. For example, a tunneling project achieved a 15% reduction in cycle times through simulation-based process optimization [14].

Example: In a large-scale tunneling project, the use of simulation tools reduced resource consumption by 10% and improved overall efficiency [14].

## 6. Enhancing Safety and Risk Management

Simulation modeling also plays a role in improving safety and risk management in construction projects.

1) Safety Simulation: A virtual simulation platform integrating machine learning and statistical modeling has been used to predict safety outcomes in construction projects. The platform achieved an accuracy of 90% in safety ratings, enabling proactive risk management [19].
2) Risk Assessment: System dynamics models have been used to simulate the impact of potential risks on project outcomes. For example, a model for reinforced concrete work analyzed the impact of material price fluctuations on project costs, enabling better risk mitigation strategies [16].
3) Risk management: The Role of BIM in Managing Risks in Sustainability of Bridge Projects was conducted through a systematic review, where the relevant literature was collected and studied. The findings stated that the correct implementation of BIM significantly improves the efficient management of risks in bridge projects. Hence, this has a progressive result on the development of the three essential (environmental, economic, and social) traits of sustainability. The influence mentioned is particularly apparent in improving the management of information throughout the whole lifespan of a bridge project. This, in turn, simplifies precise decision-making in the design phase, aligns with assessments of environmental impact, enables real-time monitoring during execution, efficiently manages the maintenance of the structure, assists efficient allocation and utilization of resources, and improves design practices by providing designers with the correct information [20].

Example: A simulation-based platform predicted safety ratings with high accuracy, reducing workplace accidents by 20% in a construction project [19].

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## 7. Optimizing Workforce Management

Effective workforce management is critical for the success of construction projects. Simulation modeling provides tools for optimizing manpower allocation and reducing working hours [21].

1) Manpower Simulation Models: A study in Japan proposed a simulation model to estimate the appropriate allocation of engineers and assess the impact of ICT systems on workforce productivity. Working hours for site management engineers have been reduced by 10% [22].
2) Workforce Allocation: Simulation tools have been used to give an accurate model that shows the impact of strategies related to allocating the workforce on the project outcome. For instance, a steel structure project achieved accurate engineer allocation using simulation models, which reduced project timeline by 8% [13].

Example: Use of manpower simulation models in a Japanese building project helped reduce the working hours of engineers on-site by 12% [22].

## 8. Integrating Emerging Technologies for Intelligent Construction

The incorporation of new technologies such as virtual reality (VR), machine learning, and statistical modeling facilitated more creative approaches in management of building projects [23].

1) Virtual Simulation Platforms: For predicting project outcomes, there has been the creation of a virtual simulation platform that integrates VR, machine learning, and statistical modeling. This helped in achieving maximum resource utilization, and in assessing project risks. The platform achieved high precision in predicting project duration, cost, and safety ratings [19].
2) Machine Learning-based Project Estimation: The platform unveiled the capability to make a very precise estimation of project parameters [19].

Example: Virtual simulation platform made high-accurate estimation of project results that supported data-driven decision-making as well as helped in achieving the efficiency of the project. [19].

## 9. Sustainability and Environmental Management

Simulation modeling has also shown potential to aid sustainability and environmental management intervention in construction practices.

1) Sustainability Simulation: The use of simulation tools was shown to reduce material wastage as well as environmental degradation. For instance, a simulation model for a steel structure project had saved 15% of wastage of material [13].
2) Environmental Impact Assessment: System dynamics models have been used to assess the environmental impact of construction projects and identify carbon reduction strategies [16].
3) Reducing energy costs: this study focuses on the ability to control energy cost in building's life cycle. Revit software was obtained for the alternate designs to building insulation and their impact on energy consumption. Green Building Studio was used for energy analysis of the building for the isolated building and the traditional performance comparison. The result showed that BIM assists to implement energy analysis at a high speed and the use of insulation materials according to particular selections will permit to reach significant savings: 2.8$ per square meter lead to reduce energy cost and thus reduce the total costs of the building during the project life-cycle stages to have more sustainable buildings [24].

Example: A simulation-based approach reduced material waste by 15% in a steel structure project, contributing to sustainability goals [13].

## 10. Facilitating Education and Training

Simulation modeling also serves as a valuable tool for education and training in construction project management [25].

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1) Training Simulations: Virtual simulation platforms have been used to train construction professionals in project management, enabling them to practice decision-making in a risk-free environment [19].
2) Skill Development: A study showed the importance of training in BIM adoption, which emphasizes the importance of skilled personnel to achieve the full benefits of simulation modeling [9, 26].

Example: A learning platform for construction professionals was provided by using virtual simulation platform, which helped them improve their decision-making and capability to manage the project [19].

## 11. Addressing Challenges in Simulation Adoption

While simulation modeling holds great benefits, there are challenges in its application within the construction sector [27].

1) Trained Staff: Lack of trained staff is a major drawback in the application of simulation modeling. Research was targeted towards the role of training programs in resolving this challenge and creating a competent workforce [9, 26].
2) Existing Systems Integration: Incorporation of simulation tools within current project management systems must be scheduled and carried out with utmost standards. Some approaches to addressing such challenges were outlined in a study, including developing standardized protocols [9].
3) Legal and Contractual Implications: Legal and contractual implications may be raised due to the use of simulation modeling, particularly in terms of data sharing and collaboration. A study highlighted the need for clearly defined contractual frameworks to address these issues [9].

Example: A U.S. construction industry study highlighted the need for standardized protocols to facilitate the integration of BIM with current project management systems [9].

## 12. Previous Studies and Researches in the Constructive Sector

Many studies were utilized in the construction sector, which utilized the simulation method [13]. The studies aim to overcome the poor decision-making challenges in site layout planning, and also resource allocation in construction projects. Existing approaches often rely on mathematical models that produce unrealistic results or encounter limitations confined to the site itself. To overcome these constraints, this study proposes a simulation-based approach with a focus on automatically optimizing tower crane placement, depot locations, and supplier selection. The primary objective is to minimize project costs while enhancing overall efficiency and productivity. AKSÜLLÜ et al, 2024 examine the significance of effective resource management in large-scale construction projects, with a particular focus on regions such as Turkey. It proposes the integration of lean construction principles with simulation techniques to enhance planning and control. Field observations and simulations were conducted on construction sites. EZStrobe and AnyLogic software were used. Initial simulations were conducted with EZStrobe, followed by sensitivity analysis and comparison with AnyLogic software. Zhang, 2024 developed the VS-ML platform to accurately estimate construction project parameters, optimize resource utilization, schedule tasks efficiently, and classify project outcomes with high accuracy, leading to improved project management, cost savings, and enhanced safety standards in the construction industry [22]. Building a simulation model that can be used to improve construction management of buildings by identifying tasks and parametrically describing the manpower required is proposed, which will enable an estimation of the appropriate allocation of engineers, effects of ICT systems, and effects of various other measures.

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## 13. Conclusion

Simulation modeling has facilitated novel solutions to the management of construction projects with the use of modern tools that enhance planning, resource allocation, cost estimation, and risk management. The incorporation of new technologies such as BIM, machine learning, and system dynamics has enhanced the potential of simulation modeling even further. Although concerns such as the need for skilled practitioners and integration with existing systems remain, the benefits of simulation modeling in terms of cost savings, enhanced efficiency and decision-making make it a tool worth having for the construction industry. As the industry progresses, the application of simulation modeling is expected to have an increasingly important part to play in the delivery of successful projects.

## Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

## Copyright:



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