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OPTIMISING TIME AND RESOURCES IN CONSTRUCTION MANAGEMENT: EFFECTIVE PLANNING AND TASK ALLOCATION STRATEGIES

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INTRODUCTION. The increasing complexity of construction projects and growing competitive pressure in the industry have created a critical need to enhance planning methods and resour ce allocation in construction management.

RESEARCH HYPOTHESIS. The introduction of integrated digital technologies, such as digital twins, artificial intelligence, the Internet of Things, and advanced planning methods, will significantly increase the efficiency of construction process planning, reduce costs and project execution time, while reducing risks and improving forecasting accuracy.

THE AIM The purpose of this study was to develop a methodology for improving the efficiency of construction process planning through the integration of digital technologies and algorithmic optimisation methods.

METHODS. The study was based on an analysis of the implementation of digital planning methods in seven leading international construction companies in 2023–2024, using data from technical documentation for deployed systems and financial statements.

FINDINGS. The adoption of integrated digital platforms reduced planning time by 45–52% and minimised equipment downtime by 38–40%. The use of graph databases optimised the sequencing of construction operations, while predictive analytics improved forecasting accuracy for work deadlines to 92%. The integration of artificial intelligence (AI) and Internet of Things (IoT) technologies lowered logistics costs by 25–33% and reduced modelling (BIM) technologies, combined with collaborative planning systems, increased productivity by 25% and reduced schedule deviations by 32%. Furthermore, the development of a digital twin system enabled process modelling at the planning stage, facilitating early detection of potential issues and reducing error correction costs by 28%. The application of predictive analytics allowed a shift from reactive to proactive resource management through risk forecasting and automatic plan adjustments.

CONCLUSION. The proposed phased methodology for digital solution implementation, incorporating a technology audit and personnel development programmes, can be applied by construction companies of various sizes to optimise planning processes and enhance operational efficiency.

KEYWORDS: digital twins; intelligent systems; graph databases; manufacturing processes; collaborative planning.

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ОПТИМІЗАЦІЯ ЧАСУ ТА РЕСУРСІВ В УПРАВЛІННІ БУДІВНИЦТВОМ: ЕФЕКТИВНІ СТРАТЕГІЇ ПЛАНУВАННЯ ТА РОЗПОДІЛУ ЗАВДАНЬ

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ВСТУП. Зростаюча складність будівельних проектів та посилення конкурентного тиску в галузі створили гостру потребу в удосконаленні методів планування та розподілу ресурсів в управлінні будівництвом.

ГІПОТЕЗА ДОСЛІДЖЕННЯ. Впровадження інтегрованих цифрових технологій, таких як цифрові двійники, штучний інтелект, Інтернет речей, та передові методи планування, дозволить значно підвищити ефективність планування будівельних процесів, скоротити витрати та час виконання проектів, знижуючи рівень ризиків та покращуючи точність прогнозування.

МЕТА. Метою даного дослідження була розробка методології підвищення ефективності планування будівельних процесів шляхом інтеграції цифрових технологій та алгоритмічних методів оптимізації.

МЕТОДИ. Дослідження ґрунтувалося на аналізі впровадження методів цифрового планування в семи провідних міжнародних будівельних компаніях протягом 2023–2024 років з використанням даних технічної документації на розгорнуті системи та фінансових звітів.

РЕЗУЛЬТАТИ. Впровадження інтегрованих цифрових платформ скоротило час планування на 45–52% та мінімізувало простої обладнання на 38–40%. Використання графових баз даних оптимізувало послідовність будівельних операцій, а предиктивна аналітика підвищила точність прогнозування термінів виконання робіт до 92%. Інтеграція технологій штучного інтелекту (ШІ) та Інтернету речей (IoT) знизила логістичні витрати на 25–33% і скоротила складські запаси на 42%. Впровадження технологій інформаційного моделювання будівель (BIM) у поєднанні з системами спільного планування підвищило продуктивність на 25% і зменшило відхилення від графіка на 32%. Крім того, розробка цифрової системи-двійника уможливила моделювання процесів на етапі планування, що сприяло ранньому виявленню потенційних проблем і скоротило витрати на виправлення помилок на 28%. Застосування предиктивної аналітики дозволило перейти від реактивного до проактивного управління ресурсами завдяки прогнозуванню ризиків та автоматичному коригуванню планів.

ВИСНОВКИ.
Запропонована поетапна методологія впровадження цифрового рішення, що включає технологічний аудит та програми розвитку персоналу, може бути застосована будівельними компаніями різного розміру для оптимізації процесів планування та підвищення операційної ефективності.

КЛЮЧОВІ СЛОВА: цифрові двійники; інтелектуальні системи; бази даних графів; виробничі процеси; спільне планування.

Introduction. In the modern construction industry, effective planning and the rational assignment of tasks are becoming increasingly relevant due to the growing complexity of projects and rising competitive pressure in the market. The industry's development necessitates the active adoption of innovative approaches to resource management, aimed at optimising work processes, ensuring timely project execution, and achieving planned financial targets. The digitalisation of the construction sector presents new opportunities for enhancing management efficiency through the integration of automated planning and monitoring systems.

One of the key areas of research in modern project management is multi-criteria optimisation, which has been analysed in detail by K. Guo & L. Zhang (2022). Drawing on an extensive phase of empirical experiments and practical case studies, they proposed an innovative methodology for evaluating project solutions. This methodology is based on a comprehensive analysis of the interrelationships between time, resource, and financial parameters. A significant outcome of their research was the development of a system of performance metrics that quantitatively measure the quality of management decisions and predict their impact on construction project implementation, regardless of scale or complexity.

A significant contribution to the development of automated planning methods was made by F. Amer *et al.* (2021). Their study focused on a retrospective analysis of the technological evolution in construction management over the past three decades. In particular, the authors outlined the key stages of technological transformation, identified factors that contributed to the successful implementation of automated systems, and systematised the reasons for the failures of early automation approaches. The study’s practical conclusions included recommendations for overcoming common barriers to the integration of modern construction project management systems. Another rapidly developing area of research concerns the mathematical modelling of spatial optimisation in construction sites. This topic was explored by M. Xu *et al*. (2020), who proposed an innovative model that considers the complex network of interdependencies between equipment location, logistical routes, and safety requirements. The practical value of this research is demonstrated by the implementation of the methodology on real construction sites, where the results showed a significant reduction in time costs, as well as a marked increase in the efficiency of space and resource utilisation.

The concept of intelligent construction has also seen substantial development in the study conducted by N. Rane (2023). Through a comprehensive analysis of the potential integration of building information modelling (BIM) and artificial intelligence (AI) technologies, the author proposed a holistic system for automated construction process management.

Particular emphasis was placed on big data processing mechanisms and the application of machine learning algorithms to enhance planning, quality assurance, and resource management processes in real time.

The practical aspects of implementing BIM technologies were thoroughly examined in the study by M. Parsamehr *et al*. (2023). As part of their research, a multi-level system was developed to assess the effectiveness of modern technology implementation, covering technical, organisational, and economic aspects. The proposed methodology includes quantitative indicators for evaluating the impact of BIM on labour productivity, construction quality, and the financial performance of construction projects. Progress in the application of digital twins is presented in the study by Y. Jiang *et al.* (2024). Their proposed algorithms enable continuous monitoring and optimisation of construction processes through real-time data analysis. A key contribution of this research is the development of a system for predicting potential problems, with the capability to automatically adjust operational plans in response to real-time conditions on the construction site. A comprehensive framework for dynamic resource planning in industrial construction was developed by M. Taghaddos *et al.* (2024), focusing on adapting plans to changing project conditions while accounting for the stochastic nature of construction processes. Particular emphasis is placed on methods for risk assessment and mitigation when reallocating resources under high uncertainty.

The integration of circular economy principles into construction management was the subject of research by L. Tang *et al*. (2024). Their study developed a holistic approach to optimising construction waste management, including methods for assessing material reuse potential and algorithms for streamlining logistics processes. The findings demonstrate significant potential for cost reduction and minimising the environmental impact of construction projects. The prospects for integrating BIM technology with the Last Planner System (LPS) for optimising construction site management were thoroughly investigated by M. Sbiti *et al*. (2021). The researchers proposed a comprehensive methodology that effectively integrates data from various management platforms, applying lean production principles to the construction sector. Special attention is given to synchronising information flows and ensuring data integrity when integrating different software systems. The practical significance of this study lies in its recommendations for overcoming technical and organisational barriers to the implementation of integrated management solutions.

An approach to planning optimisation based on bio-inspired algorithms was presented in the study by S. Maruthi *et al*. (2022). This research provides a detailed analysis of the potential applications of natural algorithms and AI in addressing complex construction planning challenges. The proposed automated planning methods have demonstrated significant potential for enhancing decision-making efficiency through the integration of modern machine learning technologies and optimisation tools. The systematisation of existing approaches and the development of recommendations for implementation in various types of construction projects are of considerable value. The integration of AI technologies into data engineering is becoming increasingly relevant due to the growth in data volume and complexity, which requires innovative approaches to data processing and analysis. The study by V. Nesterov (2023) highlights key challenges, including data variability, the need for standardisation and security concerns, and outlines the prospects for automation and predictive analytics, which are essential for optimising planning and decision-making processes.

Advancements in the optimisation of production processes in prefabricated construction were achieved by L. Wang *et al.* (2023). Based on an in-depth examination of current practices and challenges, the researchers developed an innovative methodology for planning the production of prefabricated structures, specifically tailored to off-site construction. The proposed approach included a system of performance indicators and algorithms for optimising production schedules, aimed at minimising time and resource losses during the manufacture of building components. Practical testing of this methodology demonstrated significant potential for increasing productivity and ensuring high-quality prefabricated structures.

However, previous studies have certain limitations, particularly regarding insufficient attention to the integration mechanisms of the proposed solutions into existing construction project management systems. The aim of this study was to develop a holistic approach to optimal planning and task allocation in construction management by analysing modern methods for optimising time and resource utilisation. To achieve this objective, the following tasks were identified: to analyse existing approaches to planning and task allocation in construction management; to assess the potential for improving resource utilisation through modern innovative technologies; and to formulate practical recommendations for the implementation of enhanced methods in construction management.

Materials and Methods. The research methodology was based on the analysis of the implementation of digital planning and task distribution methods in construction management. The study was conducted through a comprehensive analysis of data from seven international construction companies: Skanska (2025), Balfour Beatty (2025), Hochtief (2025), Bouygues Construction (2025), Strabag (2025), Vinci Construction (2025), and Royal BAM Group (2025), covering the period 2023–2024. The selection of these companies was based on their experience in executing projects of varying complexity and scale – from residential developments to industrial facilities – ensuring the representativeness of the sample. Empirical data were collected through an examination of technical documentation related to the implemented systems, as well as annual company reports, corporate financial statements (Form 20-F), sustainability materials, and independent audit reports (Deloitte, 2025). Additionally, an analysis of data from the internal information systems of these enterprises was conducted, focusing on the duration of construction operations.

The study analysed the technical parameters of the implemented systems in each company. By Skanska, a resource allocation system was examined, incorporating criteria for optimising work duration, costs, personnel qualifications, technical constraints, logistics, risks, energy efficiency, and environmental sustainability, as well as the use of machine learning (ML) models. At Balfour Beatty, a digital platform integrating Internet of Things (IoT) sensors was analysed. At Hochtief, a 6D BIM system with automated calculations was studied. Bouygues Construction's implementation of a neural network, trained on data from 120 projects, was examined. Strabag's integrated ERP-BIM system, incorporating digital twin technology, was evaluated. At Vinci Construction, a network of 500 sensors alongside a predictive maintenance system was assessed. Finally, at Royal BAM Group, a graph database (Graph DB) with 12,000 nodes for distributed planning was analysed.

The Graph DB Neo4J was used to systematise data, enabling the modelling of relationships between planning processes. The impact of the implemented methods on enterprise operations was assessed using key performance indicators, including the reduction of equipment and personnel downtime, minimisation of deviations from established schedules, optimisation of material resource utilisation, and improved accuracy in forecasting work completion. These indicators were evaluated based on data from the 2023–2024 period, following the technical audit methodology developed by Deloitte (2025) and in accordance with industry standards: ISO 29481-1:2016 "Building Information Models – Information Delivery Manual. Part 1: Methodology and Format" (2016) and ISO/IEC/IEEE 15288:2015 "Systems and Software Engineering – System Life Cycle Processes" (2015).

The reliability of the results was ensured through the use of standardised analytical approaches, allowing for a comparative assessment of the effectiveness of digital transformation in planning processes across the studied companies. All stages of the study were documented in accordance with corporate standards for maintaining technical documentation and the requirements for conducting independent audits of construction companies. The formulation of conclusions was based on a comprehensive analysis of the results, taking into account the specific characteristics of each enterprise and the nature of the implemented projects. To ensure the objectivity of the assessment, factors such as project scale, technological complexity, and the degree of process automation were considered. The proposed methodology facilitated the identification of patterns between the characteristics of the implemented systems and the achieved performance indicators.

Results.

Modern methods and tools for task planning in construction management. The development of the methodological framework for planning construction processes has progressed through the gradual integration of classical management theory with the mathematical foundations of operations research and modern information technologies. To systematise the theoretical and methodological foundations, a classification has been developed, illustrating the transition from basic algorithmic methods to complex integrated management systems (Table 1). The classification structure encompasses the theoretical foundations of each method, its methodological principles, and its conceptual characteristics, providing a comprehensive understanding of the evolution of planning approaches.

Table 1

Methodological principles of planning in construction management

Method	Theoretical background	Methodological principles	Conceptual features
Greedy algorithms	Decision theory, mathematical optimisation	Local optimality, problem decomposition	Step-by-step analysis of states, priority matrices
LPS	Lean production, theory of constraints	Cascade planning, collective responsibility	Hierarchical structure of plans, review cycles
BIM integration	Information modelling, systems engineering	Process parameterisation, digital prototypes	Multidimensional models, topological relationships
AI optimiiation	Machine learning, probability theory	Adaptive learning, stochastic modelling	Neural network architectures, gradient methods
ERP+BIM	Process approach, systems analysis	Data integration, end-to-end planning	Unification of processes, matrix structures
IoT+AI	Automatic control theory, distributed systems	Reactive management, predictive analytics	Sensor networks, streaming data processing
Graph DB+LPS	Graph theory, relational algebra	Topological analysis, graph algorithms	Directed acyclic graphs, path finding

Note: theoretical and methodological principles of planning methods are systematised without considering the specifics of particular software implementations.

Source: *created by the author based on* Y. Jiang *et al.* (2024), M. Sbiti *et al*. (2021), S. Maruthi *et al*. (2022).

Greedy algorithms are based on decision theory and mathematical optimisation. They apply the principles of local optimality and problem decomposition, thereby enabling rapid identification of approximate solutions. Conceptually, this method involves a step-by-step analysis of system states, utilising priority matrices to make optimal decisions at each stage. This approach is employed in construction to optimise work schedules, resource management, and logistics route planning. The LPS methodology is based on the concepts of lean production and the theory of constraints, which ensure effective management of construction processes. The principles of cascade planning and collective responsibility enable the creation of a coordinated system for task distribution. Conceptually, LPS has a hierarchical structure that includes long-term, medium-term, and short-term plans, supplemented by cycles of verification and adjustment. This structure facilitates rapid adaptation to changes in the construction environment and minimises the loss of time and resources.

BIM integration is based on information modelling and systems engineering, which provide process parameterisation and the creation of digital prototypes of construction objects. Methodological principles facilitate multidimensional data representation and spatio-temporal synchronisation of construction processes. Conceptual features of BIM include the use of topological relationships to manage interdependent project elements, thereby improving the accuracy of forecasting work timings and controlling costs at all stages of the building life cycle.

AI optimisation methods are based on machine learning and probability theory. They utilise the principles of adaptive learning and stochastic modelling to improve decision-making processes. Conceptually, this includes neural network architectures that analyse large amounts of data and optimise construction processes using gradient methods to find optimal solutions. The implementation of AI optimisation increases the efficiency of resource management, automatically adjusts construction schedules, and predicts possible risks.

The integration of ERP systems with BIM is based on a process approach and systems analysis, ensuring end-to-end planning of construction processes. The main methodological principle is the integration of data between different stages of the project, which synchronises the financial, material, and production aspects of management. Conceptually, this is implemented through the unification of processes and matrix management structures that allow for the effective coordination of large infrastructure projects with many participants.

The combination of IoT and AI in construction is based on the theory of automatic control and distributed systems, allowing the implementation of the principles of reactive control and predictive analytics. Conceptually, this includes the use of sensor networks to collect information in real time and data streaming, which permits rapid responses to changes in the construction environment. These technologies are used to monitor the safety of construction sites, assess the condition of structures, and automate decision-making processes. Using Graph DB in combination with LPS is based on graph theory and relational algebra, which provides topological analysis of construction processes. Methodologically, this involves the use of graph algorithms to model complex relationships between construction elements. Conceptually, directed acyclic graphs are used to represent interdependencies between tasks, which optimises work planning and facilitates rapid adaptation of the project to changes. This is especially effective in complex construction projects, where dynamic restructuring of work schedules is required depending on the current state of the project.

Optimising the use of resources in construction projects. A study conducted between 2023 and 2024 on the optimisation of resources in construction projects identified planning and management approaches that significantly affect the efficiency with which time and resources are utilised. The analysis focused on seven leading international companies that successfully implemented technologically sophisticated solutions to rationalise the use of material, labour and energy resources, demonstrating varying degrees of management system integration. The use of standardised assessment approaches enabled a comparative analysis of the outcomes of the digital transformation of planning processes. The summarised results were presented in Table 2. The main performance metrics of the new methods included reduced equipment and personnel downtime, reduced deviations from the work schedule, optimised use of material resources and increased accuracy in predicting task completion dates.

Table 2

Implementation of digital planning methods in construction companies

Company	Planning method	Technical implementation parameters	Results obtained
Skanska	Greedy algorithms	Resource allocation system with defined optimisation criteria (work duration, costs, personnel qualifications, technical limitations, logistics, risks, energy efficiency, and environmental friendliness) and ML forecasting models	Reduced planning time by 45%, reduced downtime by 38%
Balfour Beatty	LPS	Digital collaborative planning platform with IoT sensor integration	Productivity increase by 25%, deviation reduction by 32%
Hochtief	BIM integration	6D BIM with automated calculation of cost and work deadlines	230 collisions detected, saved 18% of the budget

End Table 2

Company	Planning method	Technical implementation parameters	Results obtained
Bouygues Construction	AI optimisation	Neural network based on a database of 120 completed projects with predictive analytics	Forecast accuracy 92%, resource optimization by 35%
Strabag	ERP+BIM	Integrated system with digital twins of objects	Inventory reduction by 42%, delivery acceleration by 48%
Vinci Construction	IoT+AI	A network of 500 sensors and a predictive maintenance system	40% reduction in downtime, 25% fuel savings
Royal BAM Group	Graph DB+LPS	12,000-node database and distributed scheduling system	52% faster planning, 38% more accurate

Note: averaged indicators for the implementation period 2023–2024 are given.
Source: *created by the author based* on Skanska (2025), Balfour Beatty (2025), Hochtief (2025), Bouygues Construction (2025), Strabag (2025), Vinci Construction (2025), Royal BAM Group (2025), Deloitte (2025).

The transformation process began with the use of basic optimisation algorithms. One of the main problems that Skanska AB faced was insufficient efficiency in resource allocation between parallel projects, which caused excessive downtime for both equipment and personnel. To solve this problem, the company implemented a system based on greedy algorithms that accumulated data from 1,200 sensors installed on construction sites and integrated them with corporate databases. The algorithm performed a multi-criteria analysis of tasks, taking into account parameters such as execution duration, costs, worker qualifications, technological limitations, logistics, and the likelihood of risks. As a result of implementing this system, the time required for planning was reduced by 45%, while downtime was reduced by 38%. Automation of resource allocation processes using sensor systems further reduced logistics costs by 25%.

In contrast, Balfour Beatty faced a key challenge in coordinating the activities of the many participants in the construction process. To address this issue, the company implemented a digitally based LPS system that supported remote collaboration. Electronic planning tools were synchronised with the information systems of suppliers and subcontractors, and periodic weekly meetings were held in a hybrid format with the function of automatic recording of decisions. Thanks to the implementation of the new system, productivity increased by 25%, and discrepancies between plans and actual implementation were reduced by 32%. The decisive factor in success was the active involvement of contractors in the planning process, as well as the development of a transparent system for monitoring the implementation of tasks. The implementation of a digital platform for coordinating plans further reduced the costs of organising work by 28%.

Hochtief, unlike previous companies, faced the challenge of comprehensively integrating data on costs, deadlines, and construction technologies. The solution to this issue was the adoption of 6D BIM technology, which significantly enhanced planning capabilities by integrating all key parameters into three-dimensional digital models. The system supported twelve data exchange standards and enabled two-way communication with project management software. The accuracy of resource planning improved by 85% due to the ability to virtually forecast construction processes. Optimisation of procurement and warehouse management resulted in a 45% reduction in construction waste. The implementation identified 230 potential conflicts at the planning stage, leading to budget savings of 18%. The applied technological innovations demonstrated their effectiveness, confirming the importance of comprehensive optimisation in enhancing the efficiency of construction projects.

The next stage of evolution involved the implementation of artificial intelligence. Bouygues Construction encountered challenges in forecasting construction project deadlines due to the significant influence of external factors. Traditional planning approaches were unable to effectively account for seasonality, climate conditions, and the varying productivity of different teams. To address this issue, the company introduced a neural network-based system trained on data from 120 completed projects. The system analysed 85 key parameters, including historical weather data, logistical barriers, and team performance. Neural network algorithms, incorporating forecasting modules, schedule optimisation, and predictive maintenance, formed a comprehensive resource and time management system. These algorithms uncovered hidden dependencies between these factors and the duration of the work. Integration with external weather services enabled real-time adaptation of plans to changing climate conditions. As a result, forecasting accuracy reached 92%, and resource efficiency improved by 35%. Additionally, this approach increased the operational efficiency of construction equipment by up to 55%.

The implementation of integrated planning systems of medium complexity represents a significant shift from the localised optimisation of individual processes to a systemic approach to resource management. At Strabag, the integration of ERP and BIM facilitated the development of a unified project lifecycle management system. The synergy between BIM and ERP enhanced planning accuracy and significantly reduced unproductive time at all stages of construction. The implementation of digital twins provided access to detailed information on material specifications, installation methods, and operational parameters. By adopting the just-in-time supply principle, warehouse stock levels were reduced by 42%. Automated logistics planning increased the speed of material deliveries by 48%, while the optimisation of transport routes and loading significantly lowered overall logistics costs by 33%.

The next stage involved the full integration of IoT technologies. Vinci Construction implemented a network of IoT sensors to monitor construction processes in real time. These sensors recorded data on the location and technical condition of equipment, material consumption, and microclimate parameters at construction sites. The application of neural networks to analyse data flows enabled the detection of anomalies and the prediction of potential issues. Predictive maintenance of equipment was based on the analysis of key operational parameters for each unit. The integration of this system with planning platforms automated work schedule adjustments in response to deviations from normal operating conditions. As a result, equipment downtime was reduced by 40%, fuel consumption decreased by 25%, and the productivity of construction crews increased by 35%.

The most comprehensive approach was demonstrated by Royal BAM Group, which utilised the Graph DB Neo4J to model complex technological and organisational relationships in construction projects. The system stored data on technological dependencies, resource constraints, and logistical processes in a graph format consisting of 12,000 nodes. Algorithms for traversing this graph optimised the sequence of work execution, accounting for 45 types of relationships between tasks. Integration with the Last Planner System (LPS) enabled the coordination of short-term planned activities with the overall project schedule. As a result, the speed of plan formation increased by 52%, planning accuracy reached 88%, and resource allocation efficiency improved by 38%.

An analysis of the practical experience of leading construction companies highlights a clear trend towards the integration of multifunctional technological solutions. The highest levels of efficiency were achieved by combining resource optimisation systems with collaborative planning tools and analytical predictive models. The outcomes of digital transformation confirm the feasibility of such approaches: the accuracy of forecasting work deadlines increased by 35–92%, resource use optimisation resulted in savings of 25–42%, while improved coordination between participants reduced deviations in work by 32–38%.

The collected results of various approaches to resource optimisation in construction projects have been systematised according to the main resource categories and the corresponding methods for their improvement. A comprehensive assessment of effectiveness considers not only economic aspects but also the impact on project implementation timelines and additional performance indicators. Particular emphasis is placed on analysing the relationships between selected optimisation methods and their impact on the efficiency of different types of resource utilisation. Table 3 presents a comparative analysis of the results of implementing resource management systems, using leading construction companies as examples. This allows for an assessment of the effectiveness of various optimisation approaches and their overall impact on the productivity of construction projects.

Table 3

Comprehensive assessment of the effectiveness of implementing resource management systems in construction projects

Resource category	Optimisation measures (method/tool)	Enterprise	Economic effect	Impact on project duration	Additional performance indicators
Building materials	Automated accounting and supply planning (BIM integration)	Hochtief	Saving 18% of the budget	230 collisions detected	Reducing logistics costs
	Intelligent graph databases (Graph DB+LPS)	Royal BAM Group	Acceleration of planning by 52%	38% accuracy improvement	Supply optimisation
Construction machinery	Predictive maintenance (IoT+AI)	Strabag	Inventory reduction by 42%	Acceleration of deliveries by 48%	Reduction of downtime
	Task scheduling using AI optimisation	Bouygues Construction	92% forecast accuracy	Resource optimization by 35%	Reduced operating costs
Labor resources	Qualification matrices and flexible schedules	Balfour Beatty	25% productivity increase	32% reduction in deviations	Improving work coordination
	Greedy algorithms for task distribution	Skanska	Reduction of planning time by 45%	38% reduction in downtime	Workflow optimisation
Energy resources	Intelligent energy management systems (IoT+AI)	Vinci Construction	Fuel savings by 25%	40% reduction in downtime	Reducing energy consumption

Note: figures are averaged over the implementation period 2023–2024.
Source: *based on financial statements o*f Skanska (2025), Balfour Beatty (2025), Bouygues Construction (2025), Strabag (2025), Vinci Construction (2025), Royal BAM Group (2025), sustainability reports and independent audit results by Deloitte (2025).

The implementation of material resource management systems demonstrates significant potential for optimising construction processes. In particular, BIM integration at Hochtief led to an 18% reduction in project budgets and enabled the identification of 230 technical conflicts at the planning stage. This helped to minimise material resource losses and prevent delivery delays. The use of Graph DB at Royal BAM Group significantly transformed planning processes, reducing the duration of work by 52% while simultaneously increasing accuracy by 38%. This approach ensured the optimisation of supply chains and a reduction in warehouse inventories.

The integration of ERP systems for construction equipment management at Strabag provided comprehensive optimisation. Through automated planning and predictive maintenance, warehouse inventories were reduced by 42%, and the delivery process was accelerated by 48%. Meanwhile, the application of AI technologies at Bouygues Construction significantly increased forecast accuracy to 92%, optimised equipment uses by 35%, and reduced operating costs. The use of the Last Planner System (LPS) in Balfour Beatty's workforce management formed the foundation for system-wide transformations. This enabled a 25% increase in productivity and a 32% reduction in deviations from initial plans, particularly due to improved coordination and communication between work teams. Greedy task distribution algorithms implemented at Skanska provided significant optimisation of planning processes: task execution time was reduced by 45%, and downtime decreased by 38%. In the area of energy management, the application of intelligent systems at Vinci Construction had a substantial impact on the environmental efficiency of construction. Fuel savings reached 25%, and downtime was reduced by 40%, leading to a decrease in CO_2 emissions and an overall improvement in energy efficiency. The digitisation of the monitoring process has laid the foundation for further optimising energy consumption and minimising the environmental impact of construction processes.

A comprehensive analysis of the application of various resource optimisation methods indicates that the highest results can be achieved through a balanced combination of technological solutions and the improvement of planning processes, particularly in relation to working time. For large enterprises, the implementation of integrated systems based on AI and IoT is recommended, as these technologies provide the highest level of automation and predictability. For medium-sized companies, it is advisable to begin by adopting BIM technologies in combination with ERP systems to achieve an optimal balance between efficiency and costs. Smaller enterprises can focus on fundamental methods, such as the Last Planner System (LPS) or greedy algorithms, which offer significant productivity gains with moderate investment.

The key factor in selecting optimisation methods is the specificity of the projects. For multi-level and complex projects, the integration of all planning systems is critically important, whereas for standardised projects, a basic level of automation is sufficient. The transition from fragmented, localised solutions to integrated planning platforms has established the foundation for the systemic optimisation of material, energy, and labour resource utilisation in the construction industry.

Practical recommendations for the implementation of optimisation methods in construction management. The practical implementation of optimisation methods in construction management requires a clear and systematic approach based on algorithmically defined implementation stages. The first stage involves conducting a detailed technological audit, which includes a comprehensive assessment of the enterprise's existing infrastructure, a qualitative evaluation of personnel competence, and an analysis of the effectiveness of current planning tools. Based on the audit results, it is advisable to develop a transformation roadmap with structured phases for innovation implementation, including the automation of fundamental processes, the integration of specialised software, and the adoption of BIM technologies. The transformation schedule should account for a planning horizon of three to five years, considering the organisation's level of digital maturity to enhance the consistency and sustainability of changes.

During the formation of the implementation team, it is essential to ensure the involvement of specialists from various fields, including project management experts, construction engineers, and IT professionals. Special emphasis should be placed on training initiatives: personnel should undertake courses lasting between two and six months, focusing on the practical application of new technological solutions. The primary performance metrics should include factors such as reducing the time required for plan development, minimising deviations from approved schedules, and optimising overall resource utilisation. The practical experience of companies such as Skanska and Balfour Beatty have demonstrated significant improvements, including a 38–40% reduction in downtime and a 25–35% increase in productivity.

To develop technical requirements for information systems, the principle of an optimal cost-to-functionality ratio should be followed. The core functionality should include calendar planning, resource management, and task performance monitoring. Advanced modules may incorporate predictive analytics, integration with IoT sensors, and logistics process optimisation. The estimated budget for implementing an innovative system should range between 2% and 5% of the total project cost. Before large-scale deployment, it is essential to test the developed solutions at pilot sites to identify potential shortcomings.

The standardisation of processes involves creating standardised templates and regulatory documentation for project management. Additionally, tools for regular monitoring of the effectiveness of the implemented methods must be developed. Furthermore, establishing a knowledge base is crucial to preserve accumulated practical experience and analyse any errors encountered during implementation. The integration of modern planning solutions should include the development of a centralised data management platform to collect information from over 1,200 sensors on construction sites. The collected data should be processed using Graph DB and integrated with supplier systems. To protect critical data, backup mechanisms should be implemented alongside recovery procedures designed to minimise the risk of losing strategic plans.

A modular approach is recommended for implementing planning systems, with a gradual increase in functionality. For small projects, it is advisable to begin with basic calendar planning tools that automate calculations and synchronise schedules. For medium-scale projects, specialised software should be used to add resource planning and cost optimisation capabilities. For large and complex projects, integrated BIM platforms are the optimal choice, as they consolidate all necessary information into three-dimensional models, ensuring efficient collaboration among all project participants.

The automation process required the standardisation of data exchange using IFC and API REST protocols. Structuring information models in accordance with the ISO 29481 (2016) standard established the foundation for unified management. The integration of blockchain technologies facilitated secure and transparent data exchange within the framework of distributed planning. To scale planning systems, the implementation of cloud platforms was recommended, as they offer flexible pricing and adapt to fluctuations in workload. To address the challenges of optimising complex schedules, it is worth exploring the potential of quantum computing. A key aspect of successful implementation is the gradual introduction of new functions in alignment with the increasing competency levels of personnel.

In practice, the implementation of these recommendations in construction companies has delivered significant results. The integration of BIM and Graph DB accelerated planning processes by 52% while improving accuracy by 38%. The use of predictive analytics based on neural networks enabled forecasting with an accuracy of up to 92% and optimised resource utilisation by 35%. The integration of IoT sensors reduced downtime by 40% and fuel consumption by 25%. The combination of ERP systems with digital twins contributed to a 42% reduction in inventory and a 48% acceleration in deliveries. The implementation of a digital platform for the Last Planner System (LPS) increased work productivity by 25% and minimised deviations from the schedule by 32%. A comprehensive approach to optimisation has established a robust technological foundation for the continued enhancement of planning systems in construction management.

Discussion. A study by P. Bründl *et al*. (2024) confirmed the high effectiveness of Graph DB in optimising planning processes. Their research demonstrated that using Neo4J to model relationships in construction projects reduced decision-making time from four hours to 45 minutes and increased planning accuracy by 22%. The present study extends P. Bründl's *et al.* approach by incorporating an analysis of the impact of human factors on planning processes. L. Tang *et al.* (2024) analysed resource optimisation in construction projects and found that inefficient resource management could increase operational time by up to 49.6%. The present study complements these findings by demonstrating that the application of structural modelling methods to analyse resource flows enables the identification of key optimisation points and facilitates the implementation of appropriate management decisions.

F. Althoey *et al.* (2024) investigated the impact of IoT on resource management, confirming the necessity of integrating digital technologies into planning processes. However, while F. Althoey *et al.* primarily focused on the technical aspects of IoT implementation, the present study examines the organisational changes and staff adaptation required for successful technology adoption. O. Ghandour *et al*. (2024) proposed an adaptive workload management model, which aligns with the findings of the present study regarding the need for a flexible approach to resource management. Both studies demonstrated the effectiveness of predictive analytics in mitigating the risks of resource overload and enhancing overall construction project productivity.

K. Radwan *et al.* (2024) developed a model for optimising resource allocation based on a greedy algorithm, confirming the effectiveness of algorithmic methods in planning, as indicated in the present study. This approach was further extended by analysing the potential long-term consequences of implementing such algorithms on the organisational culture of construction companies. The study by Z. Wang and H. Xu (2024) on the optimisation of production planning for prefabricated structures made a significant contribution to expanding knowledge in the field of production process management. Their conclusions regarding the importance of accounting for potential failures in the planning process align with the findings of the present study, which emphasise the necessity of developing flexible and adaptive management systems.

The work of H. Bakker *et al.* (2020) focused on multi-stage optimisation under uncertainty, further supporting the feasibility of the adaptive planning approach highlighted in this study. However, the present research advances these theoretical concepts by integrating practical tools for implementing adaptive planning, specifically tailored to the context of construction projects. In the field of information technology applications in project management, this study corroborates the findings of J.C.-W. Lin *et al.* (2022) regarding the effectiveness of algorithmic optimisation methods for balanced resource allocation. However, in contrast to their predominantly technocentric perspective, the present results highlight the importance of achieving a harmonious integration of automated systems with the human factor in managerial decision-making.

In the context of human resource management, the work of F. Pariafsai and A.H. Behzadan (2021) highlighted the need to expand the managerial competencies of project managers. The present study builds on this thesis by demonstrating the necessity of systematically developing the competencies of all project team members, including personnel at different organisational levels. The application of AI in human resource management was explored in the study by T. Aizenberg (2024), which outlined the general advantages of such technologies. However, the present study provides a more detailed examination of AI tools specifically within the construction industry, taking into account the unique significance of workers' physical presence on construction sites.

The analysis of planning processes corroborated the conclusions of O.V. Bugrov (2024) regarding the importance of a structured approach to project management. At the same time, this study identified new optimisation perspectives related to enhancing planning flexibility and adapting to the constantly changing conditions of construction projects. Y. Polusmiak *et al.* (2024) investigated the logistics aspects of the construction industry, focusing on supply chain optimisation. The present study expands on this perspective by revealing the close relationship between logistics efficiency and overall project management performance, particularly through the integration of supply planning systems with work schedules. Regarding technological aspects, the research by E. Sarker *et al.* (2021) highlighted the benefits of implementing intelligent systems for resource management. The findings of the present study confirm these advantages while also emphasising the specific requirements of such systems in the context of the construction industry.

A study conducted by O.S. Hachaturyan (2020) confirms that the implementation of information systems, such as Enterprise Asset Management, significantly enhances the efficiency of resource utilisation in the construction industry. The results obtained align with scientific conclusions regarding the integration of modern digital technologies into construction project management processes. In particular, it is emphasised that the use of digital tools not only improves planning and control over resource usage but also minimises downtime and increases forecasting accuracy. However, O.S. Hachaturyan’s work primarily focuses on aspects of human resource management and the need to enhance personnel skills. These aspects are further analysed in the present study from the perspective of applying algorithmic approaches to task planning and distribution.

The study by H. Yu *et al.* (2021) examines task planning mechanisms within fog computing systems, highlighting the importance of optimal resource allocation to reduce delays and enhance task performance efficiency in real time.

This approach aligns with the broader principles of applying algorithmic methods, particularly greedy algorithms, in the field of construction management. The use of such methods facilitates optimal resource allocation and ensures adaptability in task execution. Both studies underscore the critical role of automated systems in accelerating responses to project changes and adapting management strategies in real time. The findings of this study significantly contribute to the existing theoretical and practical foundations for optimising planning in construction management through the integration of digital technologies, algorithmic approaches, and adaptive management solutions. The demonstrated practical value of an integrated approach – combining technological innovations with organisational changes and human resource development – further confirms its effectiveness in ensuring the sustainable development of the construction industry.

Conclusions. The study demonstrated that the efficiency of construction planning is largely dependent on the digitalisation of processes, algorithmic optimisation, and adaptive resource management. The integration of modern technologies has enabled a 25–30% reduction in work organisation time, a 40% decrease in errors related to resource allocation, and an increase in forecasting accuracy for task deadlines of up to 85%. A transition is underway from localised systems to comprehensive platforms that integrate calendar, resource, and financial planning. This shift has led to increased operational efficiency, minimised downtime, and more rational use of material and human resources.

Algorithmic optimisation methods, combined with AI and IoT, have significantly transformed construction management approaches. The use of Graph DB for modelling technological dependencies has improved the sequencing of operations, while predictive analytics and automated monitoring systems have enabled the early detection of potential risks. This has facilitated the transition from reactive to proactive management, allowing for the prediction of potential deviations and the automatic adjustment of plans.

Based on the findings, a phased methodology for digital transformation was developed, encompassing a technological audit, the establishment of digital infrastructure, and staff training. A differentiated approach to the integration of optimisation methods was proposed, tailored to the scale of enterprises and the complexity of their projects. Integrated management systems have enabled the optimisation of the entire lifecycle of construction projects, from documentation development to the commissioning of facilities. The introduction of digital twins has been identified as a key factor in modelling construction operations and identifying potential risks at the planning stage.

The practical significance of this study lies in the development of a methodology for implementing technological solutions while accounting for the specific characteristics of construction projects. A system of metrics has been devised to assess the effectiveness of digital transformation, along with a methodology for calculating its economic benefits. A key limitation of this study is its focus on large international companies, which makes it challenging to extrapolate conclusions to small and medium-sized enterprises. Future research could explore the integration of quantum computing and AI to further enhance construction planning and optimise complex project schedules.

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