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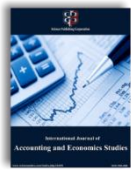

Assessment of The Development Project Management Efficiency Under Conditions of Uncertainty

Mykhailo Malykhin *, Ihor Dvornichen, Dmytrii Ziakhor, Aleksiy Tugay, Oleksandr Dubynka

Department of Organization and Business of Construction, Kyiv National University of Construction and Architecture, Kyiv, Ukraine
**Corresponding author E-mail: mykhailomalykhin@gmail.com*

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Abstract

The purpose of this study was to assess the effectiveness of various strategies for managing development projects under conditions of uncertainty and to develop practical recommendations for improving management efficiency. The methodology included system analysis, economic and mathematical modelling, expert assessments, and innovative digital technologies to evaluate project management effectiveness under uncertainty, incorporating a mathematical model with key performance indicators and expert insights on the impact of technologies like Building Information Modelling (BIM), Design for Manufacturing and Assembly (DfMA), and 3D printing on risk mitigation and efficiency. The findings of this study revealed that the introduction of innovative approaches to the management of development projects substantially improves their efficiency, especially in conditions of uncertainty. The analysis of modern methods revealed that the use of technologies such as DfMA, BIM, Agile, and Lean enables process optimisation, risk mitigation, and more accurate resource planning. Particular attention was paid to the effects of digital tools that facilitate better coordination between project participants. Furthermore, the introduction of innovations contributes to more effective management of risks associated with economic and regulatory fluctuations. A prominent aspect of the study was to examine the effects of these approaches on increasing the resilience of projects to external factors and the ability of teams to respond quickly to changes in market conditions. Based on the findings, recommendations were given to optimise the management of development projects.

Keywords: *Construction; Effectiveness; Development project; Management; 3D printing.*

1. Introduction

Development projects are defined in this study as extensive, capital-intensive endeavours that are mainly concerned with the building, enlargement, or modernisation of infrastructure for homes, businesses, or industries. These projects often have long implementation schedules, many stakeholders, and significant financial outlays. Due to their intricacy, development projects are extremely susceptible to outside factors, including changes in regulations, technical advancements, and economic volatility. As a result, its successful implementation requires the application of flexible management techniques as well as efficient scheduling, resource, and quality standard coordination.

Managing development projects requires effective strategies for adapting to ever-changing conditions, which is especially relevant in a global economy (Radzinska et al., 2024; Silagadze et al., 2024). Changes in legislation, economic fluctuations, political instability, and the growing need for sustainable development pose challenges to developers that must be addressed urgently. These external factors directly affect project financing and the regulatory framework governing construction activities, requiring companies to adopt environmentally friendly technologies and approaches. These market dynamics increase the risks and uncertainties that can greatly affect the success of projects.

Effective project management in an environment of uncertainty is becoming critical to success, as reducing risks and increasing flexibility help to maintain competitive advantage in the market (Buil et al., 2016; Voloshchuk et al., 2025). That is why it is relevant to develop new models for assessing the effectiveness of project management that factor in the specifics of development activities and integrate both conventional and innovative approaches. The new models will help not only to adapt to external changes but also to optimise internal processes, increasing the efficiency and competitiveness of development projects, ensuring transparency, and reducing risks in project processes.

Many scientists and practitioners in the field of project management have focused on improving the efficiency of project management, exploring the issues of classical project management. Banaitiene and Banaitis (2012) focused on risk management in the construction industry. The authors emphasized that it is a critical component of construction project success, as it enhances decision-making, improves productivity, and contributes to financial efficiency. They also argued that integrating both qualitative and quantitative methods into a unified risk management framework can substantially improve a company's ability to respond to uncertainties. Pialles (2017) considered the specific features of development projects, identifying the primary challenges associated with real estate management. Reality, modern reality, when markets are becoming more unpredictable and technologies are developing rapidly, requires considering novel approaches to project management. Digitalisation of project management processes plays a significant role in adapting to new challenges (Matskiv et al.,

2025). According to Tytok et al. (2022), the integration of digital technologies into construction companies contributes to the efficiency of management and process automation, which can considerably reduce the human factor and errors associated with it. In this context, it is vital to investigate how digital tools can improve the efficiency of development project management.

Another aspect that deserves attention is the use of Building Information Modelling (BIM) and its effects on management processes. According to Johansson and Roupé (2024), BIM not only simplifies the process of planning and visualisation of projects but also greatly reduces costs through effective management of resources and time. The introduction of BIM also reduces the number of errors at the project implementation stage, which is crucial in an environment of uncertainty (Annenkov, 2022; Lapshyn & Yaroshenko, 2024). At the same time, augmented reality (AR) and virtual reality (VR) technologies in construction greatly expand the possibilities for improving planning processes and interaction between stakeholders. According to Purushottam et al. (2021), the use of AR can significantly improve accuracy in design and construction, as well as reduce the risks associated with errors in the installation of structures. According to Abrishami and Martín-Durán (2021), the Design for Manufacturing and Assembly (DfMA) concept helps to optimise design and reduce construction costs by standardising and simplifying the manufacturing and assembly of components. This enables companies to manage resources and timelines more efficiently in an environment of high uncertainty.

3D printing technologies also help to reduce the cost and time of project implementation (Novak & Osaulenko, 2025). Zelentsov et al. (2022) noted that 3D printing can reduce waste and create complex architectural forms that could not be implemented using conventional methods. Digital solutions also contribute to increased transparency and interaction between project stakeholders (Piera et al., 2013). Al-Saffar et al. (2024) investigated the benefits of artificial intelligence for risk prediction and real-time scenario modelling, which enabled development projects to better meet construction goals. Ananth et al. (2023) examined the key factors that ensure successful project management and emphasised the need to develop professional skills in risk management and sustainable construction to ensure long-term results.

Although project management has received a lot of attention in the construction industry, most of the research that has been done so far is still dispersed, focusing on either specialised technological advancements or conventional management models without providing a comprehensive view. Numerous studies examine risk management or the application of specific technologies like Agile or BIM, but they frequently ignore the necessity of combining these strategies into a cohesive framework that is adapted to the reality of market volatility and uncertainty. Furthermore, although flexible techniques and digitisation are recognised as advantageous, their combined effects on overall project efficiency and adaptability in development contexts have not been thoroughly examined. This results in a significant research vacuum in the methodical assessment of how creative and flexible management techniques can be used to improve the resilience and success of development initiatives that operate in dynamic and uncertain environments.

Thus, the purpose of this study was to develop a comprehensive approach to assessing the effectiveness of development project management under conditions of uncertainty, which includes both financial and non-financial indicators, as well as factors in the specifics of development activities and risk factors. To fulfil this purpose, the following research objectives were formulated:

1. To analyse modern approaches to the management of development projects and methods of assessing their effectiveness.
2. To identify key uncertainty factors that affect the effectiveness of development projects.
3. To assess the effectiveness of innovative management methods.
4. To provide recommendations for improving the efficiency of development project management.

2. Materials and Methods

To meet the objectives of the study, a methodology was developed that includes several key stages and research methods, such as system analysis, economic, and mathematical modelling, expert assessments, and the use of innovative digital technologies to optimise project management. System analysis was employed to evaluate modern methods of managing development projects, such as Agile, Lean, BIM, DfMA, and 3D printing, in the context of working with a great level of uncertainty. The primary purpose was to identify the key factors affecting project management under conditions of uncertainty and to determine which innovative management methods are most effective in overcoming these challenges. The systematic approach also helped to structure project processes, identify key risks, and develop strategies to minimise them. Attention was paid to key management elements, such as control over time, costs, quality of project implementation, and coordination between multiple project participants.

To gain a deeper understanding of the effects of uncertainty on the efficiency of development projects, a survey was conducted among experts in the field of construction and project management. A total of 30 experts took part in the survey, including representatives of leading Ukrainian and international development companies such as Arricano Real Estate, Ukrainian Development Partners (UPD), KAN Development, Dragon Capital, City One Development, and researchers in project management and construction market analytics from leading Ukrainian universities such as Kyiv National University of Construction and Architecture and Lviv Polytechnic National University. The experts were asked to assess the effects of various risks on the success of development projects, including economic risks, changes in legislation, technological innovations, and market fluctuations. The experts also provided their assessments of the effectiveness of innovative technologies, such as BIM, DfMA, and 3D printing, in minimising the effects of these risks. The assessment was made on a scale from 1 to 10, where 1 meant negligible impact and 10 meant a critical impact on the project.

One of the key stages of the study was the creation of a mathematical model to assess the effectiveness of development project management under conditions of uncertainty. The model helped to assess how changes in market, economic, and regulatory conditions can affect the budget, implementation time, and ultimate project performance. To assess the effectiveness of project management, the following Equation (1) was developed and applied:

$$E=w_1F+w_2Q+w_3T\ w_4R+w_5S, \quad (1)$$

where E is the overall project efficiency, F is the financial indicator (calculated as the ratio of the net present value of the project to the volume of investment (I)), Q is the quality indicator (defined as the percentage of defects detected from the maximum permissible level), T is the time indicator (calculated based on the deviation of the factual implementation time from the planned one), R is the risk indicator (factors in the probability of risks and their impact on the project), S is the stakeholder satisfaction indicator (determined based on satisfaction ratings of different groups of project participants), w1, w2, w3, w4, w5 are weighting factors that determine the significance of each indicator.

This formula enabled a comprehensive assessment of project performance, considering both financial and non-financial indicators. The weighting factors were determined based on expert opinions obtained through a survey of industry experts.

The following scale was developed to interpret the results of the performance assessment: $E \geq 0.8$ – strong level of efficiency; $0.6 \leq E < 0.8$ – average level of efficiency; $0.4 \leq E < 0.6$ – satisfactory level of efficiency; $E < 0.4$ – low level of efficiency requiring urgent improvement measures.

This scale helped not only to quantify the effectiveness of each project but also to provide a qualitative interpretation of the results, which facilitated the development of recommendations for improving project management. The study also examined Agile, Lean, BIM, and DfMA methodologies on practical projects to determine how they help reduce risks and increase project efficiency. For this, the study employed real data from financial and audit reports of development companies, such as the report of the independent auditor AC Crowe Ukraine (2022), the developers of three development projects implemented in the period from 2019 to 2022:

1. Novopecherski Lypky Residential Complex: one of the largest residential projects in Kyiv, which faced economic and market risks due to changes in legislation and the real estate market. Lean and BIM methodologies were applied in the project, which helped to optimise construction costs and reduce the number of errors at the design stage.
2. UNIT.City office complex: an office park in Kyiv that integrated BIM and Agile approaches to improve coordination between contractors and reduce implementation time. The project was implemented during the COVID-19 pandemic, which helped to test the impact of uncertainty on the effectiveness of the implemented methods.
3. Respublika Park shopping and entertainment centre: a project that used the DfMA to standardise and modularise construction. This greatly reduced the time for construction and reduced the cost of construction materials. Furthermore, 3D printing was introduced to create complex architectural elements.

3. Results

In the current practice of development projects, various management strategies are used, which can be divided into conventional and innovative ones. Conventional management approaches, such as Waterfall and Critical Path Method (CPM), have the advantage of being structured and carefully planned. However, they do not factor in possible changes in the external environment that often arise during the implementation of projects.

Waterfall, or the cascade approach, is a clear structuring of the project with its division into successive stages (Zhangabay et al., 2023; Zotsenko & Vinnikov, 2016). This approach enables careful project planning and ensures that the project is implemented within the original plan (Fesenko and Seek Ali, 2018). The key advantage of this approach is its structured and predictable nature, which ensures reliable planning. However, in conditions of heightened market uncertainty, which is typical for the construction industry, this method loses its effectiveness due to its inflexibility. If market conditions or client requirements change during a project, the cascade approach does not enable quick adaptation to new circumstances, which leads to delays and added costs.

CPM, as a method of critical path management, also revealed its limitations in the face of uncertainty. While it enables the identification of critical project milestones and optimisation of resource use, its main weakness is that it does not provide sufficient flexibility to deal with unforeseen changes. For instance, in as of new regulatory requirements or the need to change suppliers, the CPM approach becomes less effective due to the difficulty of reallocating resources and adapting schedules (Slivka, 2024).

Unlike conventional approaches, innovative methods such as Agile and Lean are much more effective in the context of development projects operating in an unstable environment. Agile involves the implementation of a project in iterations, i.e., small stages that allow regularly reviewing the results and adjusting based on new requirements or external factors. The advantage of this management strategy is the ability to respond quickly to changes, which reduces the risk of non-compliance with initial requirements or market conditions. Research revealed that the implementation of Agile has reduced project delivery times by 15-20% compared to conventional approaches (Dybå et al., 2014). At the same time, Agile can be complicated to coordinate large projects with many stakeholders, as frequent changes can cause misunderstandings between project participants.

Lean management also provides flexibility, but it aims to reduce resource and time consumption, which is crucial in an uncertain environment where the risk of budget overruns is elevated. The purpose of this strategy is to ensure the efficient use of material, financial, and human resources by eliminating everything that does not add value to the project. This enables developers to optimise costs and minimise the effects of external factors, such as volatile prices for construction materials or changes in regulatory requirements. For instance, a 10-15% reduction in costs was achieved during the construction phase by implementing Lean principles to optimise the use of materials and labour (Herrera & Mares, 2023). Furthermore, Lean has helped to reduce delays in the supply of materials, which is a significant factor in the face of unpredictable changes in supply chains.

Each approach has its advantages and disadvantages (Table 1). In an environment of uncertainty, it is most reasonable to use flexible and mixed approaches that enable rapid adaptation to changes. At the same time, the choice of a particular approach depends on the specifics of the project, the organisational culture of the company, and the level of maturity of management processes.

Table 1: Comparative Characteristics of Approaches to Development Project Management

Approach	Key features	Advantages	Disadvantages
Waterfall (cascade approach)	Successive stages of project implementation	Clear planning, control over task execution	Inflexibility in the face of change
CPM	Identification of the critical path without delays	Visualisation of the entire project, identification of key tasks	Limited flexibility
Agile	Division of the project into iterations	Flexibility, quick response to changes	Complexity in coordination
Lean	Focus on eliminating costs	Efficient use of resources	Great demands on the team

Source: compiled by the authors of based on Herrera and Mares (2023), and Arifin et al. (2024).

One of the key objectives of this study was to identify the risks that affect the efficiency of development projects. The identified risks can be divided into several principal groups:

1. Economic risks. Currency fluctuations, inflation, and market instability have proven to be among the greatest threats to development projects. For instance, a sudden increase in prices for construction materials can lead to considerable budget overruns. As a result, developers often face the need to revise financial plans or even freeze projects until the market stabilises. Studies indicate that economic risks can lead to budget overruns of 10-20% of the planned amount (Edwards et al., 2019).

2. Regulatory changes. Development projects in many countries face changes in the legislation governing construction activities. For instance, new environmental requirements or energy efficiency standards may require extra investment in the project during its implementation. This may lead to delays in project implementation and budget overruns. Regulatory risks have a particular impact on large infrastructure projects, where any change in requirements can cause delays of several months.
3. Technological risks. The introduction of the latest technologies in construction, such as BIM, 3D printing, or DfMA, also carries certain risks, as these technologies require specialised staff training and process adaptation. For instance, the improper use of BIM can lead to design errors, which will require added costs to eliminate. The study revealed that technological risks can increase project delivery times by 10-15% if proper training and control over the implementation of the latest solutions are not provided.
4. Risks associated with the supply of materials. Development projects often face problems with the supply of materials due to market fluctuations or changes in international logistics. For instance, during the COVID-19 pandemic, many development projects experienced delays due to shortages of construction materials or delays in their supply. To mitigate the impact of this risk, developers have implemented material reserves or entered long-term contracts with suppliers, which minimize exposure to fluctuations in global supply chains.

All these risks can significantly affect the performance of development projects, especially in an uncertain environment. To mitigate their effects, developers are increasingly implementing risk management strategies that involve not only their identification but also active planning of measures to minimise them.

Based on the analysis and expert opinions, the key uncertainty factors and risks affecting the efficiency of development projects were identified and studied in detail. Economic risks, which have an average impact score of 8.5/10, include currency fluctuations (9/10). Development projects often depend on imported materials and equipment, and therefore, currency fluctuations can substantially affect the project budget. Experts noted that even minor changes in the exchange rate can lead to budget overruns of 5-10%. Other economic risks include changes in interest rates (8/10). Most development projects are implemented using borrowed capital. Changes in interest rates can substantially affect the financial model of a project. Experts estimate that a 1-2% increase in interest rates could reduce project profitability by 3-5%. Inflationary processes (8.5/10) also affect the cost of materials, labour, and overall project costs. Experts noted that even moderate inflation (5-7% per year) can lead to a 10-15% increase in the project budget during the construction period. Changes in the government's economic policy (8.5/10), such as the introduction of new taxes or changes in the business environment, could greatly affect the project's profitability. Experts estimated that such changes could lead to a 5-10% reduction in project profitability.

Regulatory changes (7.8/10) include changes in building codes (8/10), which may require extensive changes to the project, resulting in added costs and delays. According to experts, such changes can increase the cost of a project by 3-7% and delay its implementation by 2-4 months. Regulatory changes also include changes in tax legislation (7.5/10), which may affect the financial model of the project. Experts noted that the introduction of new taxes or an increase in existing ones could reduce the project's net profit by 5-15%. Changes in land legislation (8/10) may affect the feasibility of the project or change its parameters. Experts estimate that such changes could delay the project by 6-12 months or even lead to its complete termination. Changes in environmental legislation (7.5/10) may require further investment in the project. Experts estimated that such changes could increase the project cost by 2-5% and delay its implementation by 1-3 months.

Technological risks (6.9/10) include the emergence of new construction technologies (7/10) that could make the project obsolete before it is completed. Experts noted that this could reduce the competitiveness of the project and reduce its market value by 5-10%. Changes in energy efficiency standards (7.5/10) may require added investment, which may increase the cost of the project by 3-8%, but in the long term, increase its attractiveness to buyers. The development of digital technologies in construction (6.5/10), such as BIM, 3D printing, or DfMA, may require further investment, but also increase the value of the project. Experts estimate that such technologies can increase project costs by 2-5% but potentially increase their market value by 7-12%. The introduction of automation and robotics (6.5/10) can reduce labour costs but requires extensive upfront investment. Experts estimate that this could increase initial costs by 10–15% but reduce overall construction costs by 5-10% in the long term.

Market fluctuations (8.2/10) include changes in demand for property (8.5/10), which can substantially affect the success of a project. Experts noted that a 10% decline in demand could lead to a 5-15% reduction in the sale price and a 6-12-month extension of the project implementation period. Competition in the development market (8/10) may reduce the attractiveness of the project. According to experts, this could lead to a 3-7% reduction in the sale price and a 10-20% increase in marketing costs. Changes in consumer preferences (8/10) may require changes in the project. Experts estimated that such changes could result in further costs of 2-5% of the project budget and delay its implementation by 3-6 months. The effects of global economic trends (8.5/10), such as global economic crises or booms, can substantially affect the success of the project. According to experts, a global economic crisis could lead to a 20-30% reduction in project costs and a 1-2-year extension of the project implementation period. Experts also noted that these uncertainties and risks are often interrelated and can reinforce each other. For instance, the economic crisis may lead to changes in legislation, which may affect market demand.

To assess the effectiveness of managing development projects under uncertainty, a comprehensive mathematical model has been developed that considers both financial and non-financial indicators and risk factors. This model is based on the method of fuzzy logic and fuzzy set theory. Fuzzy logic offers a flexible approach to evaluating development project management by allowing imprecise and uncertain data to be expressed in degrees rather than fixed values (Allahverdiyev, 2023). This is especially helpful for evaluating qualitative metrics that are difficult to measure with conventional binary reasoning, like stakeholder satisfaction or risk levels. Fuzzy set theory supports this by enabling partial membership in categories, reflecting the gradational nature of project efficiency indicators. Expert evaluations were converted into fuzzy values and combined using a weighted formula in this study, enabling a more flexible and realistic assessment of project performance under uncertainty. The primary purpose of the model was to provide a more flexible approach to performance assessment, considering the various factors that may affect the success of a project.

For example, the management effectiveness of the Novopecherski Lypky project was analysed. For this project, the following indicators were collected: the financial indicator (F), which characterises the ratio of the net present value of the project to the volume of investment, was 0.85. The quality indicator (Q), which is determined by the percentage of defects detected compared to the maximum permissible level, was 0.90. The time indicator (T), which reflects the deviation of the factual implementation period from the planned one, was 0.80. The risk indicator (R), which factors in the probability of risks and their impact on the project, was estimated at 0.75. Finally, the Stakeholder Satisfaction (S) score, which is based on the satisfaction scores of different groups of project stakeholders, was 0.88.

Based on the collected data and the pre-established weighting factors (w) that determine the significance of each parameter, the final calculation of management effectiveness was made. The weighting factors for the financial indicator (w1) were 0.3, for the quality indicator (w2) – 0.2, for the time indicator (w3) – 0.2, for the risk indicator (w4) – 0.2, and for the stakeholder satisfaction indicator (w5) – 0.1. According to this methodology, the overall efficiency of the Novopecherski Lypky project was calculated using Equation (1):

$$E = (0.3 \times 0.85) + (0.2 \times 0.90) + (0.2 \times 0.80) + (0.2 \times 0.75) + (0.1 \times 0.88) = 0.833.$$

This result indicates a strong level of efficiency in the management of this project, as the overall indicator exceeds the threshold of 0.8, which corresponds to a prominent efficiency level.

An analogous calculation was made for the UNIT. City project. For this project, the financial indicator (F) was 0.82, the quality indicator (Q) was 0.87, the time indicator (T) was 0.78, the risk indicator (R) was 0.77, and the stakeholder satisfaction (S) was 0.85. Using the same weighting coefficients, the overall efficiency was calculated using Equation (1):

$$E = (0.3 \times 0.82) + (0.2 \times 0.87) + (0.2 \times 0.78) + (0.2 \times 0.77) + (0.1 \times 0.85) = 0.815.$$

This result suggests a strong level of efficiency in the management of this project, as the overall indicator exceeds the threshold of 0.8, which corresponds to a prominent efficiency level.

For the Respublika Park project, the financial indicator (F) was 0.88, the quality indicator (Q) was 0.92, the time indicator (T) was 0.81, the risk indicator (R) was 0.79, and the stakeholder satisfaction indicator (S) was 0.90. The overall management efficiency of this project was calculated using the same Equation (1):

$$E = (0.3 \times 0.88) + (0.2 \times 0.92) + (0.2 \times 0.81) + (0.2 \times 0.79) + (0.1 \times 0.90) = 0.858.$$

This result demonstrates an extremely strong level of management efficiency, as the overall indicator exceeds 0.85, which suggests the success of the project and its resilience to external risks.

Thus, using a mathematical model, a comprehensive assessment of the effectiveness of development project management under conditions of uncertainty was performed. This helped to demonstrate the achievement of key management performance indicators and highlight the benefits of applying modern innovative approaches in this process.

The introduction of BIM, DfMA, and 3D printing has become a significant innovation in the management of development projects (Trushaj & Xhelaj, 2024). BIM technology has greatly transformed approaches to development projects by offering more integrated and visualised management of construction processes (Bugaevsky et al., 2020; Kerimkhulle et al., 2023). It uses digital models of buildings that contain accurate geometric and technical data on all elements of the structure, enabling all project participants, from architects and engineers to builders and customers, to work together on one information platform. This contributes to better planning, coordination, forecasting of results, cost optimisation, and efficient management of resources at all stages of construction. The use of this technology not only reduces the number of errors at the physical implementation stage of projects, but also greatly reduces the time and costs associated with construction. Furthermore, BIM allows performing the comprehensive analyses of buildings, including energy efficiency, light flow analysis, and the interaction of infrastructure elements with the environment. This helps not only to improve the quality of projects but also to ensure their compliance with modern sustainability standards. BIM is not only a technology but also a strategic tool that allows development companies to approach construction in an innovative way, ensuring high return on investment and customer satisfaction (Shults & Annenkov, 2023; Mysak & Mysak, 2024). The use of BIM also contributes to the globalisation of the construction services market, enabling companies to easily adapt to international projects and standards, which is a great advantage in a globally competitive environment.

The DfMA methodology aims to standardise design processes and simplify the manufacture and installation of building components. This approach greatly reduces construction time by using prefabricated elements that can be easily assembled on site. This minimises dependence on external suppliers and avoids delays due to supply disruptions. In an uncertain market, where the supply of materials can be unpredictable, the implementation of this methodology enables projects to be implemented faster and with less risk. DfMA, as an innovative approach in construction, has demonstrated great efficiency in standardising construction processes. For instance, in a project to build a modular office complex, the use of DfMA reduced installation time by 25% and material costs by 10% (Montazeri et al., 2024). This methodology also helps to reduce construction waste and increases the efficiency of material resource management.

3D printing technology has become widespread in construction and has proven to be effective in reducing material costs and increasing flexibility in the design of facilities (Maripov, 1994; Maripov & Ismanov, 1994). The use of a 3D printer allows creation complex architectural forms with minimal material costs and a considerable reduction in construction waste (Azizov et al., 2019). In one of the projects studied, where this technology was used to create architectural elements, the use of 3D printing reduced material costs by 8% and the amount of construction waste by 15% (Zelentsov et al., 2022). This enables developers to increase environmental sustainability, deliver projects faster, and reduce overall construction costs, which is critical in an unstable economic environment.

The study also included an assessment of the effectiveness of digital tools, such as AR and VR, in development projects. These tools allow for the creation of virtual models of buildings, which helps both designers and customers to better understand construction processes before work begins. AR is used to visualise construction processes in real time, which helps to identify potential errors at an early stage (Babayev et al., 2017). In an office centre construction project, the introduction of AR reduced the number of technical errors by 20%, as all changes in the project could be quickly displayed on a real object model (Sahyoune et al., 2024). VR improves communication between developers, architects, and clients. The use of VR models in a residential complex project helped to identify problems with the placement of engineering systems at the design stage, which helped to avoid further costs for correcting these errors during construction. The effectiveness of VR in this project was to reduce costs by 9% by optimising planning and coordination between project participants (Johansson & Roupé, 2024; Shymko & Slipych, 2024). Overall, digital tools such as AR and VR have been shown to be effective in development projects by reducing the risk of errors at the design stage and improving communication between all project participants. They also help reduce the cost of correcting errors and ensure better adherence to project deadlines.

To illustrate these innovative methodologies and technologies, three real-life development projects were analysed (AC Crowe Ukraine, 2022). Novopecherski Lypky is a premium residential complex in Kyiv that has become one of the most successful development projects in Ukraine. One of the project's specific features was its scale and sheer complexity, specifically due to the economic challenges and market volatility that accompanied its construction.

To optimise processes and reduce costs, the company implemented the Lean methodology, which contributed to more efficient use of construction resources. The company also used the Just-in-Time principle, which substantially reduced the cost of construction materials and ensured prompt deliveries, reducing the risk of cost overruns and downtime at the site.

The introduction of BIM technology in the project helped to greatly reduce the number of collisions between different stages of design and construction. Thanks to the detailed digital model, more accurate planning and control over the execution of work were ensured, which

reduced the number of defects and improved the overall quality of construction. It also helped to reduce the cost of correcting errors that could have arisen due to factors not considered during the design.

The project had a complex architecture and required a great level of coordination between contractors and designers. The use of Lean and BIM helped to increase labour productivity by 25% and reduce construction waste by 30%, which was critical in a resource-constrained environment. At the same time, thanks to Agile elements in planning, the project managed to adapt to changing market conditions that arose during its implementation.

UNIT.City is one of the largest innovative development projects in Ukraine, designed to develop a business ecosystem that supports start-ups and innovation (Tkachenko et al., 2025; Turilo et al., 2024). The project faced numerous challenges related to economic and political changes, as well as uncertainty in the real estate market. Innovative approaches and methodologies were used to effectively manage the project, which considerably increased its efficiency and helped minimise risks.

The use of BIM technologies helped to create a digital model of the entire UNIT.City infrastructure, which included all stages of design and construction. This allowed optimising coordination between different project participants, improving cost and time control, and reducing the number of errors at the design stage. BIM also facilitated the process of managing changes that often arise due to regulatory and economic fluctuations, minimising the effects of these factors on the project.

The Agile methodology helped the team to work in short sprints, responding quickly to changes in project conditions and client requirements. Agile's flexibility helped to reduce the time to complete tasks and improve interaction between all stakeholders. Regular meetings and constant review of results contributed to the prompt resolution of problems that arose in the process. Lean approaches were also used, focusing on minimising waste and optimising resource use, which helped to reduce the cost of construction materials and labour.

The project's distinctive feature was a combination of innovative technologies and a focus on sustainable development. This is not just a commercial or residential complex – it is a high-tech business cluster that is set to become the main centre of innovation in Ukraine. Thanks to the use of modern technologies and approaches such as BIM and Agile, the project was implemented in the face of economic instability and risks, while maintaining great efficiency.

Respublika Park shopping and entertainment centre is one of the largest development projects in Kyiv, which includes the creation of commercial infrastructure and the use of the latest technologies in construction.

The project applied the DfMA methodology, which enabled standardisation of the manufacturing and installation of building components. This resulted in a 10% reduction in material costs and a reduction in construction time due to the use of prefabricated modular elements. 3D printing technology was used to create complex architectural elements, which considerably reduced labour and material costs. The use of 3D printing reduced the time for manufacturing architectural components by 20% and reduced the amount of construction waste, which improved the project's environmental performance.

The project was unique in its use of innovative approaches, such as DfMA and 3D printing, which minimised the effects of external risks on the project timeline. Thanks to the standardisation of processes and the use of innovations, the project was implemented with minimal cost and time.

Based on the analysis, some recommendations were made to improve the efficiency of managing development projects under conditions of uncertainty:

1. Implementation of flexible management methods. The use of such approaches as Agile and Lean is a key factor in ensuring flexibility in project implementation. Implementing Agile allows teams to respond quickly to changes in the environment by adapting the project to new requirements or market conditions. This helps to avoid delays and budget overruns, which is especially significant in projects with a great degree of uncertainty. Lean allows developers to focus on optimising resources and reducing losses, which increases the efficiency of project execution in cases of limited financial and material resources. It is suitable for the construction of large infrastructure projects where each stage of work can be optimised.
2. Active risk management. Proactive risk management is a significant element of successful project management in an uncertain environment. Regular monitoring of market conditions, economic trends, and changes in legislation allows companies to better prepare for possible problems and reduce their impact. For this, it is recommended to use specialised risk analysis tools, such as Monte Carlo Simulation or Scenario Analysis, which allow anticipating possible risks and developing alternative strategies to overcome them. Furthermore, it is significant to create financial contingency funds and have plans in place to deal with unforeseen circumstances, such as delays in the supply of materials or sudden cost increases.
3. Implementation of innovative technologies. Innovative technologies, such as BIM, DfMA, and 3D printing, greatly increase the efficiency of development projects. BIM allows creating a virtual model of a building that includes all stages of design, construction, and operation. This minimises errors at the design stage and significantly reduces the time required to fix problems during construction. The DfMA ensures standardisation of the processes of manufacturing and installation of building components, which reduces dependence on external factors and shortens project implementation time. 3D printing allows quick production of building elements with minimal material and labour costs, which makes this approach particularly effective for projects on a tight budget. The use of 3D printers to produce complex architectural forms or even entire building elements can reduce the amount of construction waste, shorten the time for the construction of buildings, and reduce dependence on human resources, which is a significant advantage in times of market uncertainty.
4. Optimisation of communications between project participants. One of the critical success factors for development projects is effective communication between all project participants: customers, designers, contractors, suppliers, and construction site workers. Late receipt of information or lack of coordination between different teams can lead to delays, errors, or budget overruns. In large development projects involving dozens of companies and hundreds of workers, it is essential to use modern digital project management platforms. Tools such as BIM, Microsoft Project, Trello, Procore, or PlanGrid enable real-time coordination of all activities. This helps to avoid misunderstandings, identify problems promptly, and adjust construction processes. To ensure transparency of processes and improve the quality of communications, it is also recommended to introduce regular team meetings, reviews, and adjustments to work schedules, and constantly update data on resources and project progress. The use of specialised project monitoring tools will allow project managers to receive prompt information on the status of the project, respond to problems promptly, and reduce the risk of delays or budget overruns. In the modern environment, remote working methods are especially significant, which makes the introduction of digital communication tools even more relevant.
5. Create contingency plans and financial reserves. One of the key aspects of managing development projects in an uncertain environment is the availability of contingency plans and financial resources to cover unforeseen expenses. Changes in the market situation, such as rising prices for construction materials or delays in deliveries, can lead to budget overruns or even construction stoppages. To avoid such situations, companies are recommended to have a contingency fund of 10-20% of the total project budget. This fund can be used to cover unforeseen costs related to delays, supply disruptions, or changes in legislation. Furthermore, contingency plans should make

provision for the possibility of changing suppliers or reallocating resources in case of problems with major contractors or material suppliers. This will enable companies to maintain flexibility in responding to external challenges and avoid major financial losses due to project delays. Contingency plans should also cover alternative project scenarios in case of changes in legislation or market conditions. For instance, if new building codes are introduced or environmental standards are raised, the contingency plan should include the need to adapt the project to the new requirements. This will help avoid major delays and cost overruns during the construction phase.

6. Increase process transparency and risk monitoring. Ensuring transparency of processes and continuous risk monitoring are essential factors for improving the efficiency of development project management. Transparency of processes means that all project participants have access to up-to-date information on the status of work, resource consumption, and possible problems at each stage of the project. This helps to avoid misunderstandings, prevent delays, and resolve problems that may arise during the project promptly. Using risk monitoring tools, such as BIM, allows project managers to monitor progress in real time and assess potential risks at each stage of the project. For example, BIM provides a visualisation of all project components, which allows identifying possible technical problems or conflicts between different building systems at the design stage. This greatly reduces the risk of errors during construction and avoids the cost of correcting defects. Furthermore, the transparency of the processes allows clients to receive regular progress reports, which increases their trust in the developer and reduces the risk of conflicts regarding the timing or quality of the project. This is especially significant when a developer is raising funds from investors or working under a contract with customers who require strict adherence to deadlines and quality of work.

Based on the findings of the study, it can be concluded that innovative approaches, such as Agile, Lean, BIM, and DfMA, can greatly improve the management of development projects in an uncertain environment. The Agile approach has proved to be effective not only because of its flexibility but also because of the ability to quickly adapt to changes in the external environment, which is evidenced by a major reduction in project implementation time. This opens new opportunities for construction companies in a constantly changing market environment, where rapid response to changes is critical. Lean also helps to reduce losses and increase the efficiency of resource use, which allows optimising both financial costs and time resources. This is especially significant for development projects, which often face budget overruns due to planning deficiencies or unforeseen changes in legislation and economic conditions. BIM has proven to be a key tool for coordinating all project participants, reducing risks, and design errors. The ability to create three-dimensional models that integrate all aspects of a project not only simplifies design but also reduces the cost of correcting errors at later stages of construction.

Despite the benefits, there are certain limitations and challenges associated with the use of innovative approaches in development projects. The principal problem is the excessive cost of implementing technologies such as BIM and 3D printing. This is especially true for small and medium-sized development companies that may not have sufficient resources to invest in these technologies. Furthermore, such approaches require specialised staff training, which may be an added barrier to their widespread adoption. Some companies may also face difficulties in adapting to methodologies such as Agile and Lean due to the need to change their corporate culture. In cases where management does not support the decentralisation of management decisions or is not ready to implement more flexible planning approaches, innovative methods may not be effective.

One of the objectives of the study was to identify the risks that affect the implementation of development projects, including economic, regulatory, and technological risks. The findings revealed that economic risks, such as inflation and fluctuations in the cost of construction materials, considerably affect project budgets. Regulatory changes, especially those related to environmental requirements, can cause substantial delays in project implementation and cost increases. Technological risks associated with the introduction of innovations were also a major theme of the study. While BIM and 3D printing revealed great efficiencies, their implementation requires proper staff training and a systematic approach to management. Improper use of these technologies can lead to errors in design or construction, which will require further costs to correct.

4. Discussion

The findings of the study demonstrated a strong positive impact of the introduction of innovative management methods in development projects, such as BIM, Lean, DfMA, and 3D printing, on improving process efficiency and reducing risks in an uncertain environment. The introduction of these technologies can greatly improve coordination between project participants, reduce errors, and cut costs, which are valuable factors for achieving success in complex construction projects. The analysis of the provided sources confirmed the findings of the study.

Misnan et al. (2024) highlighted the challenges of managing construction projects in the context of sustainable development, confirming that the introduction of technologies such as 3D printing and DfMA helps to reduce costs and minimise waste, which is also reflected in the present study. Sakikhales and Stravoravdis (2017) and Wang (2013) emphasised the value of combining Agile and BIM to improve project efficiency, which is consistent with the present study's findings of improved coordination and reduced technical errors using these technologies. The current study differs from Albahbah et al. (2021) in that it views AR and VR technologies as aspects of a larger integrated management system rather than as stand-alone solutions, even if it acknowledges their value in enhancing coordination and lowering design faults. Although Albahbah et al. (2021) portray AR and VR as transformative technologies with a wide range of applications, the current study contends that, especially in high-uncertainty situations, their efficacy is greatly increased only when paired with other digital and adaptive methodologies like BIM, Lean, and DfMA.

The introduction of Lean technologies has proven to be effective in reducing costs and optimising resources. According to Herrera and Mares (2023), Lean methodology in construction processes has reduced material costs by 15-20% and increased productivity by 25%. The findings of the present study are consistent with these results, showing a 12% reduction in material costs and a 20% increase in productivity. Although it also emphasises that Lean methodology alone is insufficient in managing the complex risks and uncertainties typical of large-scale development projects. The current study promotes the integration of Lean with other digital and adaptive tools to achieve greater resilience and adaptability across diverse and uncertain development environments, in contrast to the researchers' procedural focus, which is on value generation within a single project context. Adekunle et al. (2023) focused on the adaptation of BIM for developing countries, noting the significance of using this technology to increase coordination, which is fully consistent with the study. Neary (2024) considered Agile as a key approach to the implementation of complex construction projects, which is in line with the study's findings on the effectiveness of this method in conditions of great uncertainty.

BIM technology has proven to be an effective tool for improving coordination and reducing the risk of technical errors. Yasir et al. (2024) noted that BIM can reduce the number of design errors by 25%. The findings of the present study support this claim, showing an 18% reduction in the number of technical errors and a 15% reduction in the cost of correcting them. However, Yasir et al. (2024) focus primarily

on BIM's role in automating hazard identification and safety management, while the present study discusses its broader conceptualisation not merely as a safety tool, but as a multifunctional platform for enhancing overall project efficiency, adaptability, and coordination under uncertainty. The integration of BIM with Lean and DfMA, as noted by Moradi and Sormunen (2023), also improves project management, which is consistent with the findings obtained.

DfMA greatly contributes to shorter construction time and reduced dependence on labour (Zhangabay et al., 2023). The study by Lu et al. (2020) revealed that the use of DfMA reduces construction time by 20-25% and reduces the amount of construction waste, which is also confirmed by the findings of the present study. In terms of 3D printing, the study findings confirmed the findings of Zelentsov et al. (2022), who stated that the use of a 3D printer can reduce material costs by 8-10%. Dasgupta and Dutta (2022) also noted that 3D printing reduces the time for manufacturing complex architectural elements by 20-25%, which is in line with the findings obtained. This data revealed the promising potential of 3D printing in optimising construction processes and reducing material costs.

Digital technologies, such as AR and VR, show considerable potential for improving the quality of project management. Sahyoune et al. (2024) showed that AR reduces the number of design errors by 20-25%, which was also found in the present study. The use of VR, according to Johansson and Roupé (2024), improves communication between project participants and reduces conflicts by 15%.

According to Edwards et al. (2019), effective risk management is a key factor in the successful implementation of development projects. In this study, it was found that proactive risk management helped to avoid budget overruns, which coincides with the findings of Banaitiene and Banaitis (2012), who emphasised the significance of early risk identification. While the current study emphasises the importance of organisational elements such as technology capabilities and business strategies in fostering sustainability, it diverges from Afzal and Lim (2022) in its emphasis on operational integration rather than internal organisational conditions. The current study argued that the practical application of adaptive and digital project management techniques in response to external uncertainty is what most directly drives project efficiency and long-term sustainability, whereas the previous research concentrated primarily on internal determinants of sustainability performance within construction firms.

Montazeri et al. (2024) demonstrated that the use of DfMA can achieve substantial benefits in construction, including cost reduction and quality improvement. The findings of the present study confirm these conclusions, but also emphasise, as noted by Umar and Ochigbo (2024), that the implementation of such technologies requires extensive investment and additional staff training. This points to the necessity of careful planning and preparation when introducing innovative technologies in development projects.

The current study generally supports Ogirri (2024) in recognising the value of combining BIM with broader management strategies but departs in its view that strategic management alone is not sufficient to ensure adaptability under uncertainty. While the author focused on BIM and strategic management as a dual solution, the present study argues for a more comprehensive integration that also includes flexible methodologies such as Agile and Lean, which are critical for real-time responsiveness and risk mitigation in highly volatile development environments. The findings of Limaylla-Santiago (2024) emphasised that the combination of Lean technologies and BIM in construction projects can greatly increase their efficiency, reduce waste, and shorten construction time, which confirms the findings of the present study on the positive effects of these methodologies on coordination and cost reduction.

Notably, the successful implementation of innovative management methods requires an integrated approach. As the findings of the present study and cited research suggest, the greatest efficiency can be achieved by integrating multiple technologies and methodologies. For instance, the combination of BIM with Lean and DfMA not only improves design and coordination but also optimises production processes and reduces construction costs.

Particular attention should be paid to the issue of adapting innovative technologies to the specifics of projects. The findings of the present study revealed that the effectiveness of implementing new methods may vary depending on the scale and type of project. This underscores the need for a flexible approach to the selection and implementation of innovative technologies, considering the specifics of each project. For example, large-scale infrastructure projects may require the integration of several innovative methods, such as BIM, DfMA, and Lean, to maximise efficiency and reduce costs. At the same time, smaller-scale projects may benefit from the implementation of individual technologies, such as 3D printing or Lean.

Furthermore, staff training and development are a crucial aspect. According to Arifin et al. (2024), the introduction of the latest technologies requires respective training to maximise the potential of innovative solutions. Investments in human capital are a critical factor in the success of innovative methods. Also, while Arifin et al. (2024) emphasised CPM as an effective tool for time and cost optimisation in residential construction, the present research highlighted its limited adaptability to dynamic external factors and argues that more flexible, iterative approaches, such as Agile and Lean, are better suited for ensuring efficiency in volatile and rapidly changing project environments. Ayarkwa et al. (2022) also emphasised that it is insufficient to simply introduce the latest technologies – it is necessary to train staff to use them effectively. Without proper training, there is a risk of not achieving the expected results, even with modern technology.

The study findings also emphasised the role of continuous monitoring and analysis of the effectiveness of the innovations implemented. Ongoing control enables prompt identification of potential problems and the necessary adjustments to management processes. This approach ensures continuous improvement of project management methods and maintains a strong efficiency level at all stages of project implementation. Monitoring also helps minimise risks and ensures long-term project sustainability.

In the context of global trends such as sustainability and energy efficiency, the survey results point to the vital role of innovative technologies in reducing the environmental impact of the construction industry. For example, the use of BIM and DfMA can optimise resource use, reduce construction waste, and promote energy efficiency in projects. This is in line with the modern requirements for construction, where attention is increasingly being paid to environmental aspects and reducing the adverse impact on nature.

Overall, the findings of the present study, as well as their comparison with previous studies, confirmed the considerable potential of innovative management methods to improve the efficiency of development projects. However, the implementation of these methods requires a comprehensive approach, including adaptation of technologies to the specifics of projects, staff training, continuous monitoring, and improvement of management processes. The introduction of innovative solutions such as BIM, Lean, DfMA, and 3D printing not only increases the efficiency of construction but also ensures the long-term sustainability of projects in changing market conditions.

5. Conclusions

Managing development projects under uncertainty is a complex but critical task. The present study examined the effectiveness of managing development projects under uncertainty by introducing innovative management methods such as Agile, Lean, BIM, DfMA, and 3D printing. The study found that agile and digital methods can greatly improve coordination, reduce project delivery times, and minimise the risk of cost overruns. Agile and Lean approaches have proven to be highly effective in construction projects, providing flexibility and the ability to respond quickly to changes.

BIM technology has proven to be an effective tool for improving coordination between all project participants and minimising technical errors at the design and construction stages. The use of BIM has reduced the number of errors and the cost of correcting errors. DfMA and 3D printing contribute to the standardisation of processes and increase the efficiency of resource use. The use of DfMA can reduce dependence on labour and accelerate assembly time. The introduction of digital tools such as AR and VR has proven to be effective in improving the quality of design and reducing the number of errors during the construction phase. The use of AR helped reduce the number of technical errors, while VR improved communication between project participants.

The analysis of three projects – Novopecherski Lypky, UNIT. City and Respublika Park revealed a positive impact of these methods on work coordination, cost reduction, and acceleration of construction time. Specifically, the implementation of Lean methods in the Novopecherski Lypky project helped to reduce resource overruns and increase labour productivity. In the case of UNIT. City, innovative BIM, and Agile technologies ensured rapid adaptation to changes and reduced the number of errors at the design stage. The Respublika Park project has demonstrated that DfMA and 3D printing technologies can greatly reduce dependence on labour and cut material costs.

The mathematical model of management efficiency developed within the framework of the study enabled a comprehensive assessment of project success based on various indicators. The model considered financial, time, quality, risk factors, and stakeholder satisfaction, enabling better risk anticipation and strategic decision-making. However, this model is theoretical and should be tested on practical development projects.

Despite the findings obtained, the present study had certain limitations. The sample of projects used to assess the effectiveness of innovative management methods is relatively limited. Only three projects were analysed for innovative methods, which gives grounds for further research using a wider sample to draw more generalised conclusions. In addition, the study focused mainly on projects in Ukraine, and therefore, the findings may not fully reflect the specifics of markets in other countries with different economic and regulatory conditions. The study of the impact of innovative methods was limited to construction projects rather than infrastructure or other large-scale projects, which may present different challenges and opportunities.

Further research could focus on the effectiveness of implementing innovative management methods in large-scale infrastructure projects, where there are many more unpredictable risks and external changes. It is particularly promising to investigate the use of DfMA and 3D printing to reduce implementation time and costs in large public and infrastructure projects. Furthermore, it is vital to continue researching the mathematical model for assessing the effectiveness of project management using practical research methods. Another area for further research could be an analysis of the socio-economic impact of the introduction of innovative technologies in development projects, including an assessment of the effects on the labour market and environmental sustainability.

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