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**METHOD OF PROACTIVE CHANGE MANAGEMENT  
IN DEVELOPMENT PROJECTS BASED ON A DIGITAL TWIN**

**Abstract.** *Traditional approaches to managing changes in construction development projects are predominantly reactive, relying on manual progress tracking and heuristic decision-making, which often leads to significant cost overruns, schedule delays, and scope creep. This research addresses the critical need for a more predictive and data-driven management paradigm in the development of educational infrastructure. To overcome these limitations, this study develops and proposes a Method of proactive change management in development projects based on a Digital Twin (PCMM-DT). The research aim is to establish a closed-loop system where real-time site data, integrated via a Digital Twin (DT) and Building Information Modeling (BIM), allows for the dynamic simulation and mitigation of construction deviations before they disrupt project baselines. The core of the study is the development of a PCMM-DT method, which functions as an intelligent decision support system. The PCMM-DT method integrates a four-layer architecture – physical, digital twin, analytics, and action layers – to manage the project lifecycle. A PCMM-DT method algorithm was formulated to perform multi-objective optimization, balancing conflicting criteria such as lifecycle cost, functional utility, and project resilience. The evaluation is conducted using a PCMM-DT model for constraint handling, which validates proposed changes against geometric, safety, and quality standards. Furthermore, a PCMM-DT model for multi-objective fitness evaluation was constructed to quantify the impact of changes across economic, functional, and adaptability vectors. The application of the PCMM-DT method allows for the generation of a Pareto-optimal frontier, providing project managers with a robust, evidence-based ranking matrix for selecting the most appropriate mitigation strategies. This approach transforms the management of change orders from an ad-hoc process into a systematic, optimized workflow. The proposed PCMM-DT method represents a paradigm shift from reactive project governance to proactive, predictive management. By leveraging the PCMM-DT model for real-time analytics and decision support, project teams can identify deviations early, assess their impacts precisely, and select optimal configuration changes. This integration enhances the digital resilience of educational development projects, ensuring that capital investments remain aligned with both pedagogical objectives and budgetary constraints. Future research will focus on the empirical validation of the PCMM-DT method in large-scale infrastructure environments to further refine the predictive accuracy of the integrated digital twins.*

**Keywords:** *digital twin; project management; change management; proactive management; multi-objective optimization; BIM; educational infrastructure*

**Introduction**

The contemporary construction industry operates within an environment of unprecedented complexity, characterized by high levels of project interdependency, stringent time constraints, and the constant emergence of unforeseen technical and environmental variables. Despite the adoption of advanced digital tools such as Building Information Modeling (BIM), project management practices in the development sector remain largely reactive, struggling to mitigate the disruptive

impact of late-stage design modifications and site-level changes. The inability to predict and proactively manage these deviations often results in critical project failures, manifested as severe budget overruns, schedule slippages, and the degradation of overall project quality. Given these systemic challenges, there is a pressing need for a fundamental shift toward proactive change management, where digital ecosystems are leveraged not only to visualize the construction process but to dynamically simulate and optimize response strategies. This study seeks to address this gap by developing and

proposing a Method of proactive change management in development projects based on a Digital Twin (PCMM-DT). The primary objective of this research is to establish a systematic, data-driven framework that integrates real-time physical site data with the predictive power of a Digital Twin (DT) to enable continuous project monitoring, anomaly detection, and automated impact assessment. By shifting the focus from manual, document-based oversight to an integrated, algorithmic governance model, this research aims to provide project managers with a reliable toolkit for maintaining project baselines in the face of dynamic and uncertain construction conditions.

The construction industry is undergoing a fundamental shift from static, document-based project management toward dynamic, data-driven approaches enabled by the convergence of Building Information Modeling (BIM), the Internet of Things (IoT), and Artificial Intelligence (AI). Central to this transformation is the concept of the Digital Twin (DT) – a virtual representation of a physical asset that is continuously synchronized with real-time sensor data. Deng et al. systematized the evolution of BIM technologies into five distinct maturity levels, demonstrating that the transition from basic 3D visualization to a fully functional digital twin requires the progressive integration of automatic feedback loops, real-time data processing, and intelligent control mechanisms [1]. This evolutionary trajectory implies that digital twins must transcend static geometric representations and become comprehensive cyber-physical systems capable of continuous interaction with the built environment.

A prerequisite for achieving such integration is the reliable identification and classification of construction site objects throughout the project lifecycle. Dolhopolov et al. demonstrated that the creation of high-fidelity digital twins depends on the ability to fuse heterogeneous data sources – including photogrammetry (Structure-from-Motion) and IoT sensor networks – within a unified information model [2]. Their work established that deep learning architectures, specifically Convolutional Neural Networks (CNNs) combined with Feed-Forward Neural Networks (FFNNs), provide a robust mechanism for multi-stage detection, classification, and evaluation of construction objects. This capability enables real-time monitoring and quantitative assessment of construction progress, which are essential for maintaining adherence to quality standards and project schedules [3]. The effectiveness of such AI-driven approaches is further contingent upon the availability of semantically enriched BIM datasets, which enable multi-label classification and systematic reconciliation of as-built site conditions with design-phase reference models [2; 3].

The practical significance of these technologies is particularly evident in the context of change management – one of the most persistent challenges in construction

project delivery. Traditional reliance on manual progress tracking methods has historically constrained construction productivity, largely due to the inability to respond to project complexity in real time [4]. The introduction of Digital Twin technology within the framework of the Fourth Industrial Revolution (Industry 4.0) addresses this limitation by enabling predictive maintenance, cost optimization, and data-driven decision-making throughout the project lifecycle [4]. However, the adoption of DT technology in the construction sector remains at an early stage, and its implementation is frequently hindered by organizational resistance, insufficient specialized expertise, and the persistence of legacy workflows [4].

Compounding these implementation challenges is the inherent instability of construction projects, manifested most acutely through frequent and often unavoidable project changes. Bitamba and An demonstrated that the absence of formalized change management processes in developing contexts leads to uncontrolled scope variations, cost overruns, and significant project uncertainty [5]. Their findings underscore the need for proactive rather than reactive management paradigms, where the Digital Twin serves not merely as a record of the current project state but as a simulation environment for assessing the potential impact of changes prior to their physical implementation. The integration of AI-based classification mechanisms – such as the CNN-FFNN architectures proposed by Chernyshev et al. – with BIM data enables real-time detection of deviations between the reference model and actual construction progress, thereby providing the analytical infrastructure for early-stage intervention [6].

The challenge of managing project changes extends to the specific problem of Variation Orders (VOs), which are particularly prevalent in complex public projects. Ismaeil and Sobaih identified ambiguous client requirements and incomplete tender documentation as primary causes of variation orders and demonstrated that traditional VO management is predominantly reactive, resulting in cost escalation, schedule delays, and contractual disputes [7]. Their work highlights the need for predictive capabilities that can mitigate the impact of changes before they affect the critical path. At the same time, the adoption of Digital Twin technology introduces its own set of risks. Wang et al. conducted a comprehensive risk assessment of DT implementation, identifying technical incompatibility, unclear maturity levels, and policy constraints as significant barriers [8]. These findings suggest that DT adoption must be treated as a purpose-driven strategy, carefully mapped to the specific requirements and risk profile of each project, rather than as a universally applicable solution.

The operational difficulties of change management are particularly acute in developing construction markets. Taher et al. established a correlation between the lack of

formalized change management tools and project failure in the Indian construction sector, identifying insufficient awareness and specialized technical knowledge as primary barriers to effective implementation [9]. This evidence reinforces the need for integrated frameworks that combine the predictive capabilities of Digital Twins with structured workflows for evaluating change impacts – enabling a transition from reactive crisis management to proactive, evidence-based project governance.

The applicability of proactive management principles extends beyond building construction to road infrastructure, where scheduling and resource allocation deficiencies represent critical obstacles. Castañeda et al. demonstrated that the integration of BIM into road construction enables 4D planning and real-time schedule adjustments, transforming infrastructure management from a rigid, error-prone process into an adaptive, data-driven workflow [10]. The reliability of such management systems, however, depends on the geometric accuracy of the underlying data models. Meyer et al. addressed the problem of sensor orientation uncertainty in image-based change detection, arguing that proactive management models must incorporate rigorous accuracy assessment methods to ensure that digital twins remain metrically consistent with the physical environment [11].

Beyond geometric fidelity, proactive management must encompass real-time monitoring of operational environmental factors that affect both occupational health and project continuity. Likhitrungsilp et al. developed a BIM-integrated digital twin platform for real-time monitoring of dust, noise, and vibration during building renovation, demonstrating that low-cost IoT sensors integrated into a Common Data Environment (CDE) provide the granular data necessary for environmental compliance and dynamic site management [12]. This work illustrates that effective proactive management requires the holistic integration of spatial data, environmental monitoring, and geometric quality assurance within a unified digital twin ecosystem.

The scope of Digital Twin applications has further expanded into high-consequence domains where the cost of failure is particularly severe. Song et al. demonstrated the effectiveness of DT-BIM integration for real-time risk monitoring in subway construction, employing multi-source data mapping and state-driven mechanisms to overcome the persistent problem of delayed risk information acquisition in underground environments [13]. In the healthcare sector, Kumar et al. proposed a DT-based health monitoring system integrated with Augmented Vision for real-time emergency response in intensive care units, illustrating the broader potential of digital twin technology for synthesizing high-velocity data streams into actionable insights [14]. The integration of AI and Machine Learning into these systems is further supported by the work of Arif et al., who demonstrated

that AI-driven risk assessment models have become a core component of operational resilience in critical infrastructure protection, capable of analyzing large-scale, heterogeneous datasets for proactive threat identification and mitigation [15].

Collectively, the reviewed literature establishes that the proactive management of development projects requires an integrated intelligence framework combining spatial modeling (BIM), real-time sensor monitoring (IoT), and predictive machine learning (AI). However, a significant gap remains in the development of unified methodologies that synthesize these capabilities into a coherent, implementable system for change management across the full project lifecycle. The present study addresses this gap by proposing an integrated method for proactive management of changes in development projects, leveraging the Digital Twin paradigm to enable continuous, data-driven project control.

## Main Research

The management of construction projects has traditionally been hampered by the fragmentation of information and the prevalence of reactive decision-making in response to unplanned changes. To mitigate the risks associated with such volatility, this study introduces the Proactive Change Management Method based on a Digital Twin (PCMM-DT). As illustrated in Figure 1, the general algorithmic model of this method establishes a closed-loop cyber-physical system. The framework is composed of four hierarchically integrated layers: the physical layer, the Digital Twin layer, the analytics layer, and the action layer. This multi-layered architecture ensures that information collected from the physical construction site is continuously synchronized with the BIM reference model, creating a dynamic feedback loop that enables real-time project control.

The process initiates at the physical layer, where actual construction site conditions are captured and processed by the Digital Twin engine. This digital representation is not a static snapshot; instead, it is an evolving model that synchronizes with the BIM reference model to verify site status against project baselines. The core of the method resides in the analytics layer, where Anomaly Detection algorithms systematically compare the actual site state with the planned BIM specifications. When discrepancies are identified, the system automatically triggers a Change Impact Assessment. This assessment phase is critical, as it calculates the downstream effects of potential changes on the project's performance indicators. The decision support block then utilizes a Pareto-based optimization logic to generate a series of viable corrective scenarios. Finally, the action layer engages the Project Management Office (PMO) to select the most suitable strategy, resulting in an Updated Baseline or revised construction plans. This closed-loop feedback mechanism ensures that the project remains

aligned with its objectives despite the inherent uncertainties of the construction environment.

A fundamental requirement for the proactive management of variation orders is the existence of a robust validation mechanism that filters unauthorized or non-viable design changes. The proposed constraint handling model, depicted in Figure 2, serves as the primary gateway for any change request submitted to the system. This model is designed to ensure that every proposed modification adheres to the physical, regulatory, and technical requirements established during the pre-investment and design phases. The input to this model is a formal change request, which triggers a multi-stage validation sequence.

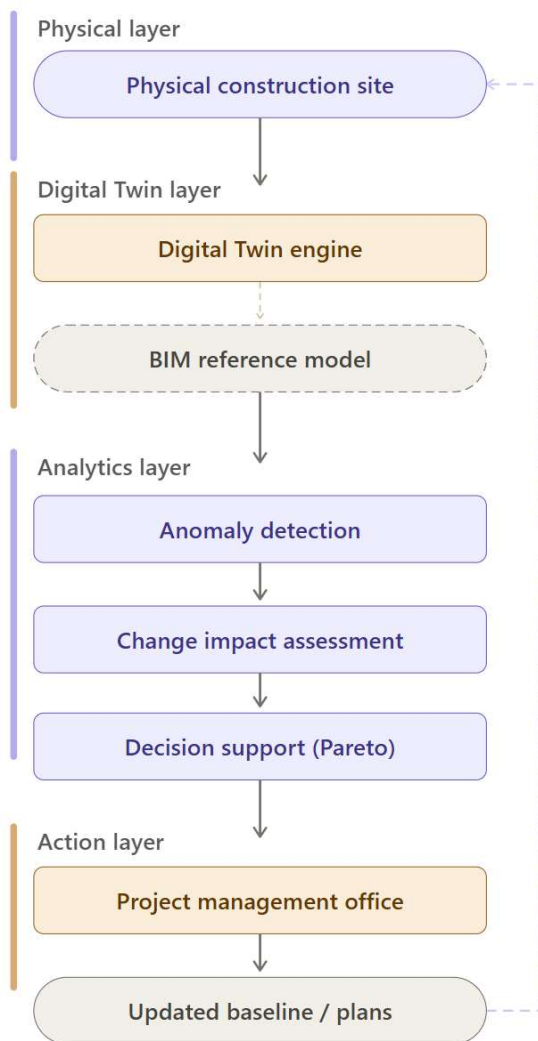


Figure 1 – Algorithmic Model of the PCMM-DT Method for Proactive Change Management

The constraint validation model executes three core checks: geo-constraints, which verify if the change respects the site boundaries and spatial limitations; safety norms, which analyze structural integrity and evacuation requirements; and quality standards, which ensure that the proposed changes do not compromise the architectural or engineering specifications defined within

the BIM environment. If a change request fails any of these criteria, the system applies a penalty function, effectively signaling that the change is inadmissible or requires redesign. This proactive screening process reduces the likelihood of disruptive rework at the site level, as design reviews are conducted while the change is still in a virtual or conceptual state. Only when a change scenario passes all validation tests is it marked as approved, at which point it proceeds to the implementation stage. This systematic approach minimizes the burden of manual document review and ensures that the project team is shielded from non-viable changes, thereby maintaining consistency across the project’s digital and physical components.

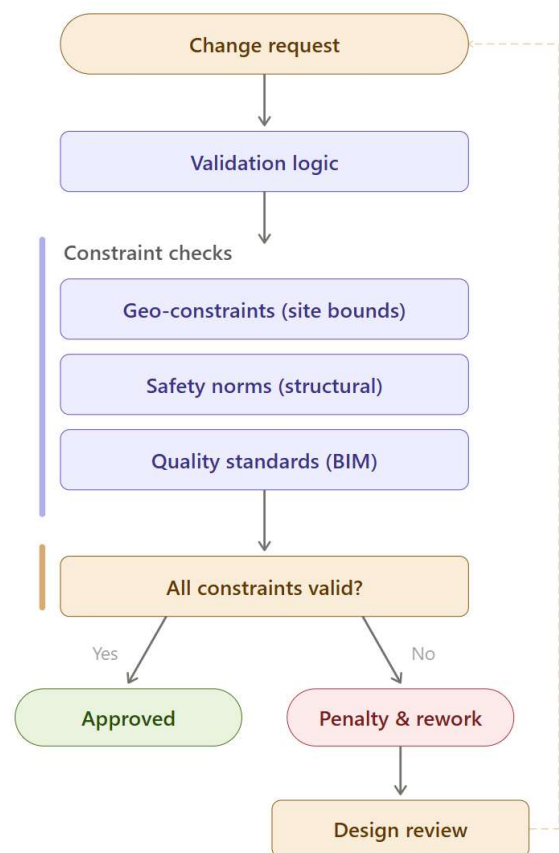


Figure 2 – Constraint Handling Model for Automated Layout Validation

The core of the PCMM-DT method, as presented in Figure 3, is the generative algorithm responsible for propagating and refining design changes. Unlike traditional project management, where changes are handled through sequential and often disjointed approval processes, this method adopts an evolutionary approach to manage the impact of changes on the project baseline. The process begins with the «Current project state (t),» which is a snapshot of the project’s geometric, scheduling, and cost parameters. When a change request is triggered, the system does not simply update the model; it initiates an evolutionary cycle designed to find the most resilient and efficient response to that change.

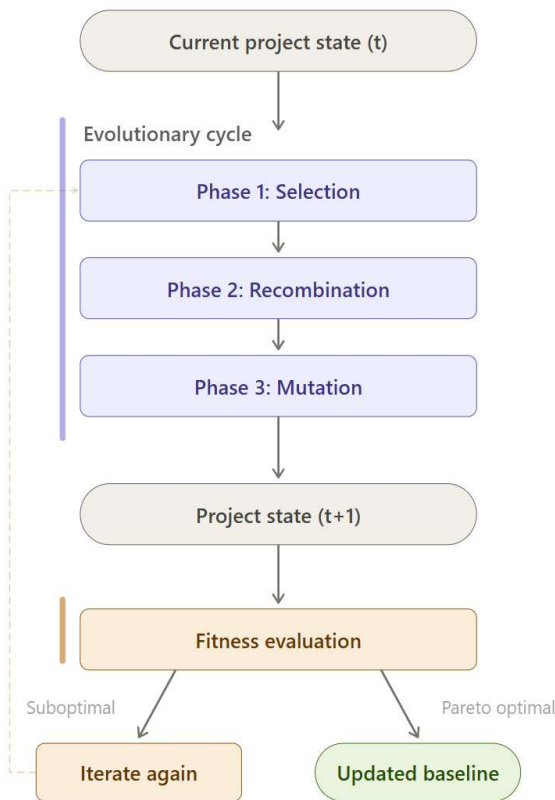


Figure 3 – Generative Algorithm Model for Change Propagation and Mitigation

The evolutionary cycle is structured into three fundamental phases: Selection, Recombination, and Mutation. During the Selection phase, the algorithm identifies the project parameters that are most sensitive to the proposed change, filtering out non-impacted elements to focus computational resources on the project areas that require adjustment. The Recombination phase then acts as a simulation engine, mixing various response strategies – such as alternative resource allocations, sequence reordering, or material substitutions – to create a set of potential «Offspring» or design alternatives. These alternatives are then subjected to the Mutation phase, where the algorithm introduces controlled, stochastic variations to test for unconventional yet potentially superior solutions that a human planner might overlook due to cognitive biases.

This iterative process of selection, recombination, and mutation is designed to converge on a new «Project state (t+1)» that reconciles the proposed change with the original project goals. After each iteration, the fitness evaluation block assesses whether the new project state meets the project’s performance requirements. If the resulting scenario is suboptimal, the algorithm performs another iteration, continuously refining the solution. Only when the model achieves a Pareto-optimal configuration – balancing cost, utility, and resilience – does the system produce an «Updated baseline.» This evolutionary approach ensures that project changes are

not handled in isolation but are optimized within the context of the entire project scope, significantly reducing the risk of cascading failures or secondary errors often caused by poorly coordinated manual change management.

The evaluation of a change scenario is a complex task that requires reconciling conflicting project objectives. As illustrated in Figure 4, the method employs a dedicated model for multi-objective evaluation to ensure that any proposed change is beneficial to the project’s overall performance. This model takes a «Candidate change scenario» as input and processes it through a series of objective vectors that measure the proposed solution across three critical dimensions. The first vector, F1: Economic impact (LCC), calculates the change’s effect on the project’s total lifecycle cost, encompassing initial capital expenditures, potential rework costs, and long-term operational savings. The second vector, F2: Functional utility (KPIs), evaluates the impact of the change on the project’s functional requirements, such as spatial usage efficiency, compliance with educational standards, and operational throughput. The third vector, F3: Resilience score, measures the change’s effect on the building’s future adaptability, specifically its potential to withstand unforeseen disruptions or accommodate future technological upgrades.

By deconstructing the evaluation into objective vectors, the model assigns a numerical identity to each change scenario, enabling the comparison of diverse, otherwise incomparable options. The model maps these vectors within a Pareto-optimal decision space to identify solutions with the most favorable trade-offs. This approach formalizes decision-making by providing a transparent, evidence-based justification for selecting specific scenarios, grounded in importance weights assigned by stakeholders. Consequently, the multi-objective fitness evaluation model transforms change management from reactive adjustments into a strategic optimization process that maximizes long-term project value.

The effectiveness of the PCMM-DT method relies on its seamless integration into the existing organizational structure, particularly the Project Management Office (PMO). Within this framework, the PMO orchestrates the PCMM-DT ecosystem, functioning as the primary interface between the automated analytics layer and human stakeholders. This operational integration upholds the “human-in-the-loop” principle, ensuring that while the method provides data-driven recommendations, ultimate authority and strategic oversight remain with qualified project professionals.

In traditional construction projects, the Project Management Office (PMO) often faces a temporal gap between identifying a change and completing its impact analysis. The PCMM-DT method eliminates this delay

by delivering automated, real-time updates directly to management dashboards. Upon detecting a change, the system generates optimized scenarios with computed performance metrics, allowing the PMO to transition from manual data consolidation to high-level strategic decision-making. By delegating scenario simulation to the Digital Twin engine, project teams can focus on the qualitative implications of changes, such as stakeholder alignment, risk management, and the long-term educational objectives of the project.

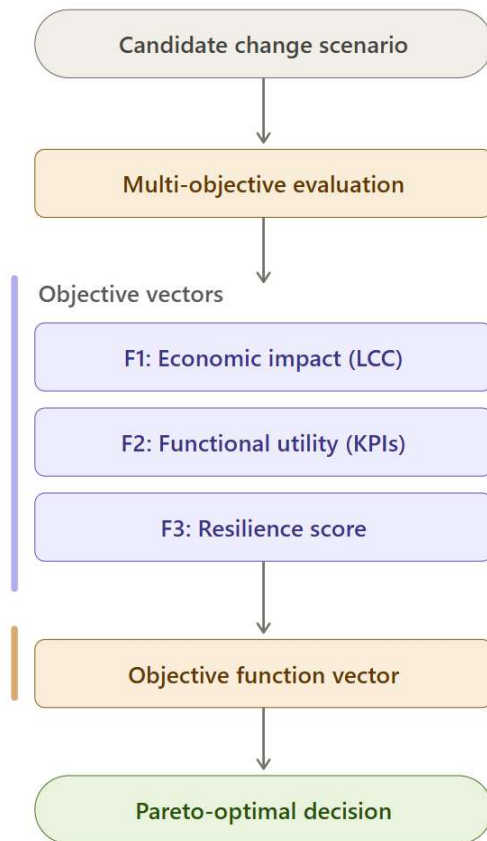


Figure 4 – Multi-Objective Fitness Evaluation Model for Scenario Selection

Furthermore, the PMO acts as the governance hub for the method's updated baselines. Upon selecting a Pareto-optimal configuration, the PCMM-DT method automatically archives the decision-making rationale, including input parameters and trade-offs. This audit trail is invaluable for dispute resolution and post-project evaluation. By institutionalizing this process within the PMO workflow, proactive change management becomes a standard procedure rather than an ad-hoc reaction. This integration enhances transparency and builds organizational memory, where lessons learned are encoded into the Digital Twin's historical dataset to continuously improve future prediction accuracy.

While the PCMM-DT method leverages advanced machine learning to automate the detection and analysis of changes, the strategic oversight remains firmly under human control. This «human-in-the-loop» architecture is

designed to address the potential for algorithmic bias and to ensure that technical solutions do not inadvertently undermine broader project goals. The human oversight mechanism is embedded into the «Decision support (Pareto)» stage, where the PMO reviews the AI-generated ranking of alternatives. This is where professional experience and project-specific knowledge are brought to bear, as managers may interpret indicators – such as the «Resilience score» – in the context of current market trends or shifts in pedagogical requirements that the AI model may not yet fully account for.

The control layer of the method provides the PMO with the ability to adjust weights within the multi-objective evaluation function. If a specific project phase requires a temporary prioritization of speed over cost, the project manager can dynamically re-calibrate the fitness functions, instructing the AI to favor scenarios that minimize schedule impact above all else. This flexibility allows the method to remain responsive to the evolving priorities of the educational development project throughout its lifecycle. The system acts as an «intelligent assistant» rather than an autonomous actor, augmenting the manager's capabilities by providing rapid, high-fidelity impact assessments that would be impossible to derive through manual effort. This collaborative synergy between human expertise and machine intelligence creates a robust management environment capable of sustaining the complexity of modern construction, ensuring that even in the face of unexpected changes, the project trajectory remains optimized and resilient.

## Conclusions

This study has addressed the critical challenges associated with managing changes in complex development projects, where traditional reactive approaches often lead to significant schedule delays, cost overruns, and scope creep. Conventional project management practices frequently struggle to bridge the gap between initial design intent and the volatile reality of construction site execution. To mitigate these risks, this paper developed and proposed a Method of proactive change management in development projects based on a Digital Twin (PCMM-DT). By leveraging the PCMM-DT method, this research introduces a proactive paradigm where changes are not merely documented after they occur but are simulated, evaluated, and optimized within a digital environment before being implemented on-site.

The research results demonstrate that the proposed PCMM-DT method serves as a robust decision support tool that significantly enhances the digital resilience of development projects. By integrating a multi-layered architecture – encompassing physical data, the digital twin, analytics, and project management actions – the method allows for the seamless synchronization of real-

time site data with the BIM reference model. The PCMM-DT model for constraint handling successfully filters non-viable changes, while the PCMM-DT model for multi-objective fitness evaluation provides project managers with a scientifically grounded basis for decision-making. The generation of a Pareto-optimal set of solutions transforms the management of variation orders from an ad-hoc, manual process into a structured, data-driven workflow that prioritizes project objectives such as lifecycle cost, functional utility, and future adaptability.

The scientific contribution of this study lies in the formalization of change management as a dynamic optimization task, rather than a static administrative procedure. The PCMM-DT method facilitates a shift toward predictive project governance, where potential impacts of changes are assessed across multiple performance vectors simultaneously. This integrated approach ensures that project baselines are not only maintained but continuously optimized in response to evolving site conditions, thereby maximizing the long-term value of the educational asset. Consequently, this study establishes a foundation for applying cyber-physical systems to improve project management efficiency and sustainability in high-stakes infrastructure development. Despite these advancements, the study has identified certain limitations. The accuracy of the PCMM-DT method is intrinsically tied to the fidelity of the Digital Twin and the granularity of the underlying BIM data. Furthermore, the reliance on automated classification and prediction models necessitates large,

high-quality historical datasets, which may not be readily available for all types of construction projects. The current model also assumes a level of digital maturity within the project team that may vary across different regional or organizational contexts.

Future research should focus on extending the PCMM-DT method to incorporate more diverse stakeholder perspectives and social impact metrics, ensuring that change management decisions remain human-centric. Additionally, the development of a real-time, interactive interface – based on the PCMM-DT model presented – would further enhance the practical usability of this method for project directors and on-site engineers. Investigating the integration of transfer learning techniques to adapt the method to projects with limited historical data also presents a promising avenue for broadening the applicability of this research, ultimately paving the way for more resilient, intelligent, and efficient project delivery in the construction sector.

**Conflict of Interest.** The author confirms that there are no financial, personal, or other interests that could be considered a potential conflict of interest regarding the publication of this article.

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**Use of Artificial Intelligence.** The author confirms that no artificial intelligence tools were used in the creation of this work.

## References

1. Deng, M., Menassa, C. C., & Kamat, V. R. (2021). From BIM to digital twins: A systematic review of the evolution of intelligent building representations in the AEC-FM industry. *J. Inf. Technol. Constr.*, 26, 58–83. <https://doi.org/10.36680/J.ITCON.2021.005>
2. Dolhopolov, S., Honcharenko, T., Terentyev, O., Savenko, V., Rosynskyi, A., Bodnar, N., & Alzidi, E. (2024). Multi-stage classification of construction site modeling objects using artificial intelligence based on BIM technology. *2024 35th Conference of Open Innovations Association (FRUCT)*, 179–185. <https://doi.org/10.23919/fruct61870.2024.10516383>
3. Dolhopolov, S., Honcharenko, T., Terentyev, O., Predun, K., & Rosynskyi, A. (2023). Information system of multi-stage analysis of the building of object models on a construction site. *IOP Conference Series: Earth and Environmental Science*, 1254. <https://doi.org/10.1088/1755-1315%2F1254%2F1%2F012075>
4. Che Haron, R., & Muhd Zafir, N. B. (2025). Digital twin application in construction cost management. *Planning Malaysia: Journal of the Malaysian Institute of Planners*, 23(1), 81–96. <https://doi.org/10.21837/pm.v23i35.1665>
5. Bitamba, B. F., & An, S.-H. (2020). Construction project change management in the Democratic Republic of the Congo: Status, causes, and impacts. *Sustainability*, 12(22), 9766. <https://doi.org/10.3390/su12229766>
6. Chernyshev, D., Dolhopolov, S., Honcharenko, T., Haman, H., Ivanova, T., & Zinchenko, M. (2022). Integration of building information modeling and artificial intelligence systems to create a digital twin of the construction site. *2022 IEEE 17th International Conference on Computer Sciences and Information Technologies (CSIT)*, 36–39. <https://doi.org/10.1109/CSIT56902.2022.10000717>
7. Ismaeil, E. M. H., & Sobaih, A. E. E. (2024). A proposed model for variation order management in construction projects. *Buildings*, 14(3), 726. <https://doi.org/10.3390/buildings14030726>
8. Wang, M., Ashour, M., Mahdiyar, A., & Sabri, S. (2024). Opportunities and threats of adopting digital twin in construction projects: A review. *Buildings*, 14(8), 2349. <https://doi.org/10.3390/buildings14082349>
9. Taher, A., Khan, R. A., & Khan, M. A. (2025). Construction project change management in Indian construction industry: Status, importance and impact. *Journal of Engineering and Applied Science*, 72(40). <https://doi.org/10.1186/s44147-025-00605-z>
10. Castañeda, K., Sánchez, O., Peña, C. A., Herrera, R. F., & Mejía, G. (2025). BIM uses for mitigating deficiencies in road scheduling planning. *Sustainability*, 17(6), 2729. <https://doi.org/10.3390/su17062729>

11. Meyer, T., Brunn, A., & Stilla, U. (2021). Accuracy investigation on image-based change detection for BIM compliant indoor models. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 4, 105–112. <https://doi.org/10.5194/isprs-annals-v-4-2021-105-2021>
12. Likhitruangsilp, V., Pham, T., & Ioannou, P. G. (2025). A smart digital twin platform for real-time monitoring of pollution in building renovation projects. *Proceedings of International Structural Engineering and Construction*, 12(1). <https://doi.org/10.14455/isec.2025.12%281%29.con-43>
13. Song, M., Lu, J., Huang, Y., Guo, S., & Zhao, B. (2025). Integrating digital twin technology with BIM for real-time monitoring and risk prediction in subway construction. *Conference on Intelligent Traffic Systems and Smart City*, 13792. <https://doi.org/10.1117/12.3090268>
14. Kumar D, A. (2025). Augmented vision-enabled digital twin system for real-time ICU patient monitoring and emergency response. *International Journal of Scientific Research in Engineering and Management (IJSREM)*, 9(5). <https://doi.org/10.55041/ijsrem46582>
15. Arif, M. H., Rabby, H. R., Nadia, N. Y., Tanvir, M. I. M., & Masum, A. A. (2025). AI-driven risk assessment in national security projects: Investigating machine learning models to predict and mitigate risks in defense and critical infrastructure projects. *Journal of Computer Science and Technology Studies*, 7(2), 71–85. <https://doi.org/10.32996/jcsts.2025.7.2.6>

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Аспірант кафедри управління проєктами

### МЕТОД ПРОАКТИВНОГО УПРАВЛІННЯ ЗМІНАМИ В ДЕВЕЛОПЕРСЬКИХ ПРОЄКТАХ НА ОСНОВІ ЦИФРОВОГО ДВІЙНИКА

**Анотація.** Традиційні підходи до управління змінами в девелоперських проєктах переважно є реактивними, оскільки спираються на ручний моніторинг та евристичне прийняття рішень, що призводить до значних перевищень бюджету, затримок графіків та «розповзання» змісту (*scope creep*). Це дослідження спрямоване на вирішення критичної потреби в предиктивній та заснованій на даних парадигмі управління в девелопменті освітньої інфраструктури. Для подолання цих обмежень у дослідженні розроблено та запропоновано метод проактивного управління змінами в девелоперських проєктах на основі цифрового двійника (англ. *Proactive Change Management Method based on a Digital Twin, PCMM-DT*). Метою роботи є створення замкненої системи, в якій дані з майданчика, інтегровані через цифровий двійник та інформаційне моделювання будівель (BIM), дозволяють здійснювати динамічне моделювання та мінімізацію відхилень до того, як вони вплинуть на базові показники проєкту. Ядром дослідження є розробка методу PCMM-DT, який функціонує як інтелектуальна система підтримки прийняття рішень. Метод PCMM-DT інтегрує чотиришарову архітектуру – фізичний шар, шар цифрового двійника, аналітичний шар та шар управлінських дій – для управління життєвим циклом проєкту. Було сформульовано алгоритм методу PCMM-DT для проведення багатокритеріальної оптимізації, що балансує суперечливі критерії, такі як вартість життєвого циклу, функціональна корисність та стійкість проєкту. Оцінка здійснюється з використанням моделі PCMM-DT для перевірки обмежень, яка верифікує запропоновані зміни відповідно до геометричних, безпекових та якісних стандартів. Крім того, побудовано модель PCMM-DT для багатокритеріальної оцінки пристосованості, що дозволяє кількісно визначити вплив змін за векторами економічної ефективності, функціональності та адаптивності. Застосування методу PCMM-DT дозволяє генерувати множини Парето, надаючи менеджерам проєкту надійну матрицю ранжування для вибору оптимальних стратегій реагування на зміни. Цей підхід трансформує управління змінами з випадкового процесу на системний, оптимізований робочий потік. Запропонований метод PCMM-DT забезпечує парадигмальний зсув від реактивного управління до проактивного, предиктивного менеджменту. Використовуючи модель PCMM-DT для аналітики в реальному часі, команди проєктів можуть завчасно виявляти відхилення, точно оцінювати їхній вплив та обирати оптимальні коригувальні конфігурації. Ця інтеграція підвищує цифрову стійкість девелоперських проєктів освітньої інфраструктури, гарантуючи, що капітальні інвестиції залишаються узгодженими з педагогічними цілями та бюджетними обмеженнями. Майбутні дослідження будуть зосереджені на емпіричній валідації методу PCMM-DT у реальних проєктних умовах для підвищення точності прогнозів інтегрованих цифрових двійників.

**Ключові слова:** цифровий двійник; управління проєктами; управління змінами; проактивне управління; багатокритеріальна оптимізація; BIM; освітня інфраструктура

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- ДСТУ Цай М. І. Метод проактивного управління змінами в девелоперських проєктах на основі цифрового двійника. *Управління розвитком складних систем*. Київ, 2026. № 65. С. 22 – 29, dx.doi.org\10.32347/2412-9933.2026.65.22-29.