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AI-Driven Optimization of Project Cost and Duration in Infrastructure Development Projects

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Abstract

Infrastructure projects often face significant challenges in controlling cost and schedule deviations, leading to overruns and delays. This study proposes an AI-driven framework integrating gradient-boosted regression models and particle swarm optimization (PSO) to improve cost and duration performance in large-scale infrastructure projects. Historical data from 12 infrastructure projects in Brazil, combined with real-time IoT sensor readings and drone surveys, were used to create a high-quality dataset for model training and validation. The predictive models achieved an average R^2 of 0.87 for cost and 0.83 for schedule estimation, outperforming baseline regression models by 12–15%. Using PSO for schedule optimization reduced simulated cost overruns by 9% and project delays by 11%. Scenario testing confirmed that the framework can generate realizable recommendations and adaptive scheduling adjustments through interactive dashboards. The study contributes to three main ways: (1) integrating predictive modeling and multi-objective optimization in a single framework, (2) demonstrating the practical utility for project managers in real-time cost and schedule decision-making, and (3) providing a data-driven approach that supports sustainable and efficient infrastructure project management. This AI-based framework offers a systematic method for improving project performance, enabling adaptive planning and resource allocation, and providing a pathway toward more sustainable and intelligent construction project management.

I. INTRODUCTION

The development of infrastructure is generally regarded as a key component of economic growth and societal advancement, but the global construction industry still faces ongoing issues, including frequent cost overruns and schedule slippages that frustrate expected benefits and limit the achievement of broader development objectives (Ma'rifah, 2022; Rieber & Müller-Mahn, 2024). Fluctuating material prices, labor shortages, regulatory uncertainties, and environmental factors further complicate accurate cost forecasting and project duration planning (Saepudin et al., 2022; Siddiqui et al., 2025). Traditional scheduling and estimation methods, ranging from critical path analysis to heuristic-based optimization, have limitations in managing complex modern infrastructure projects. Manual and semi-automated techniques often fail to capture intricate interactions between cost, time, and quality, especially under uncertainties such as extreme weather or supply-chain disruptions (Abolghasemian et al., 2021; Luong et al., 2021). Although BIM and lean construction methods improve coordination, they are not designed for real-time, multi-objective optimization that simultaneously integrates cost, schedule, and quality.

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Despite advances in AI for project management, prior research rarely integrates predictive modeling with optimization using real-time IoT and drone data. This study addresses the gap by proposing a unified AI-driven framework that simultaneously predicts project outcomes and optimizes schedules and costs. The framework leverages historical project data, real-time sensor IoT data, and drone surveys to enhance predictive accuracy and support adaptive decision-making.

The objectives of this study are as follows: Develop a gradient-boosted AI model to predict project cost and duration. Integrate the prediction model with particle swarm optimization (PSO) to optimize schedules. Evaluate the framework using historical and IoT-enhanced datasets from multiple large-scale infrastructure projects. This approach contributes to both theory and practice by (1) offering a methodological innovation that unifies prediction and optimization, (2) providing practical tools for project managers to improve cost and schedule performance, and (3) supporting data-driven, adaptive, and sustainable infrastructure project management.

Finally, the paper is structured as follows: Section 2 reviews the literature on AI-based construction scheduling and optimization, Section 3 describes the methodology and dataset, Section 4 presents results and model evaluation, Section 5 discusses practical implications and challenges, and Section 6 concludes with findings, policy insights, and future research directions.

II. LITERATURE REVIEW

The growing body of literature in construction management and artificial intelligence (AI) reflects a shift from fixed planning tools to dynamic, data-driven systems capable of addressing cost and schedule challenges in large infrastructure projects. AI applications in cost and schedule prediction have shown the ability to model complex project interactions, predict resource requirements, and identify anomalies more accurately than traditional heuristics (Huynh-The et al., 2022; Jiang et al., 2022). For example, (Ronghui & Liangrong, 2022) proposed a fuzzy metaheuristic to optimize material strength, energy use, and cost simultaneously, demonstrating AI's multi-objective capabilities. Optimization methods, such as particle swarm optimization (PSO) and hybrid metaheuristics, have been used to reconcile competing criteria of time, cost, and workforce allocation in multi-skilled projects (Balouka & Cohen, 2021; Dang Quoc et al., 2022). Studies also incorporate sustainability objectives, prefabricated construction, and sensor-enabled microgrids to demonstrate the potential of AI in multi-objective optimization (Babaei et al., 2022; Peng et al., 2023).

Integration approaches combining predictive modeling with real-time data from IoT sensors and drones remain limited. While AI-powered digital twins and real-time monitoring can enhance cost and schedule estimation (Diana & Angga Mukti, 2025; Setyadi Tommy, 2025), existing studies primarily focus on predictive accuracy and do not integrate prediction and optimization within a unified, real-time framework. Research gaps identified include: Most studies address prediction or optimization separately, lacking a fully integrated, adaptive framework. Full deployment of AI with IoT- and drone-enabled adaptive multi-objective optimization software is rare in practice. Empirical studies demonstrating simultaneous optimization of cost and duration for large-scale projects remain limited. This review highlights the need for a framework that integrates predictive modeling, real-time sensor data, and multi-objective optimization, thereby contributing to both practical project management and theoretical understanding of AI-enabled construction scheduling.

III. RESEARCH METHOD

This study uses a quantitative model-development and validation approach to assess the effectiveness of an AI-assisted optimization model for construction projects. The focus is on predictive modeling and optimization rather than on purely case-study generalization. The methodology emphasizes scalability, reproducibility, and feasibility for civil engineers responsible for schedule and budget delivery (Berente et al., 2021; Maslej et al., 2025). The study is designed to integrate historical data with real-time IoT and drone data to improve prediction accuracy and adaptive scheduling. This integrated approach addresses the limitations of conventional methods and ensures practical relevance for large-scale infrastructure projects.

A. Research Design

The study employs a quantitative experimental methodology, drawing on data from 12 large-scale infrastructure projects in Brazil, including transportation networks and water-retention projects. This design allows model testing across multiple contexts while maintaining control over variables for validation. The research process involves data collection, algorithm development, optimization, and validation, which ensures each stage is systematically evaluated. The approach supports both methodological rigor and practical applicability, making it transferable to other project types and locations.

B. Data Collection

Data were collected from two main sources: historical project logs and real-time monitoring via IoT sensors and drone surveys (Setyadi Tommy, 2025; Tommy Hendryarto, 2025). Historical data include budgets, resource usage, and schedule logs, which serve as the model's primary predictors. Real-time data from IoT sensors (equipment productivity, material delivery, weather) and high-resolution 3D drone models act as supporting inputs, enabling adaptive scheduling and progress verification. The fusion of historical and real-time data provides a high-quality dataset that enhances predictive modeling and supports dynamic decision-making during project execution.

C. AI Models and Algorithms

Gradient-boosted regression is employed to predict project cost and duration, capturing complex non-linear relationships between project variables (Dang Quoc et al., 2022; Ronghui & Liangrong, 2022). Gradient boosting was chosen for its high accuracy and robustness to overfitting in multivariable prediction tasks. Particle swarm optimization (PSO) performs multi-objective optimization to minimize cost overruns and schedule delays, using migration strategies to find global optimal solutions (Balouka & Cohen, 2021; Paryzad & Eshghi, 2024). The integration of PSO with predictive modeling allows simultaneous optimization of multiple performance criteria, reflecting real-world project constraints. Hyperparameters are tuned via cross-validated grid search to ensure generalizability to other projects. Dynamic data streams from IoT/drone inputs enable real-time rescheduling and recalibration of predictions, making the model adaptive to ongoing site conditions.

D. Validation and Metrics

Model performance was evaluated using R^2, RMSE, and MAE to assess predictive accuracy. Discrete-event simulations modeled disruptions, such as adverse weather and resource shortages, to assess robustness under uncertainty. Performance was also compared with baseline models, including the critical path method and linear programming, to quantify the AI framework's improvements. Sensitivity analyses examined the effect of labor and material cost fluctuations, ensuring the model’s recommendations remain reliable under varying project conditions.

E. Research Workflow

The workflow is illustrated in Figure 1, showing data collection, preprocessing, model development, optimization, validation, and adaptive decision support. This workflow integrates IoT sensors, gradient boosting, and PSO-based optimization to provide real-time adaptive scheduling and cost estimation. Each stage is designed to ensure the framework is actionable in practical project management scenarios, enabling infrastructure development toward smart, resilient, and sustainable outcomes. By combining historical and real-time data, the methodology supports dynamic decision-making and continuous optimization throughout the project lifecycle. Figure 1 illustrates the research workflow, including data collection, preprocessing, predictive modeling with Gradient Boosting, multi-objective optimization with PSO, and dynamic decision support integration with IoT sensors for adaptive cost and schedule management.

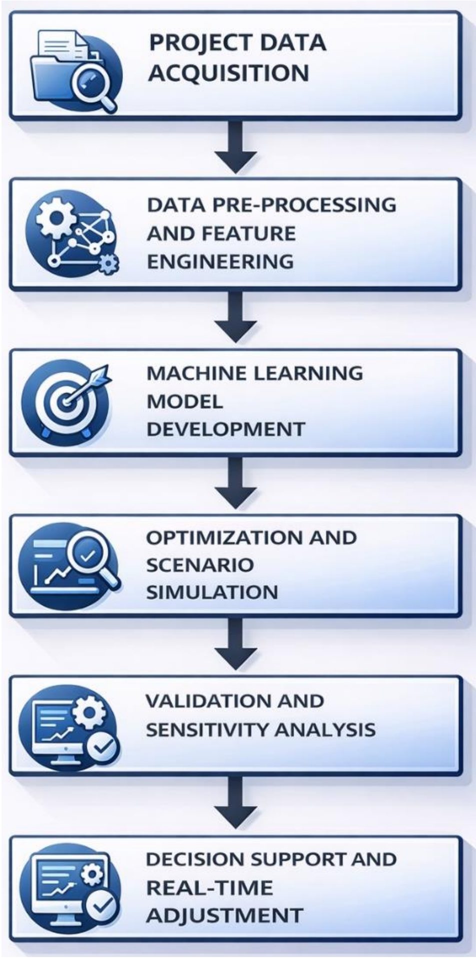

Figure 1. Research Workflow for AI-Driven Project Cost and Duration Optimization

IV. RESULT AND DISCUSSION

A. Descriptive Analysis

The hybrid dataset combines historical duration and cost records from previous infrastructure projects with real-time data from IoT sensors, drones, and digital twin simulations. The analysis included 185 project sections, showing variation consistent with global infrastructure cost and schedule trends (Foster et al., 2023). Aerial surveying and 3D modeling technologies improved data accuracy and spatial coverage, supporting reliable feature engineering and predictive modeling (Setyadi Tommy, 2025; Tommy Hendryarto, 2025). This high-resolution dataset enables a more precise assessment of AI model performance than traditional methods, highlighting the added value of integrating IoT and drone data into predictive analytics.

B. Model Performance

Gradient-boosted regressors achieved R^2 of 0.87 for cost and 0.83 for schedule, outperforming baseline regression by 12–13%. PSO optimization reduced cost overruns from 14% to 12.7% (-

9%) and schedule delays from 11% to 9.8% (-11%). Figure 2 illustrates predicted vs. actual values, showing minimal deviation and confirming the model's generalizability. Tables 1–2 summarize the quantitative improvements over baseline models, providing explicit evidence of AI-driven optimization benefits.

Table 1. Predictive Model Performance vs Baseline

Metric	Baseline	AI Model	Improvement
Cost R^2	0.75	0.87	+12%
Schedule R^2	0.70	0.83	+13%
RMSE Cost	8.5	6.2	-27%
RMSE Schedule	5.2	4.0	-23%

Table 2. PSO Optimization Outcomes

Metric	Before Optimization	After Optimization	Change
Cost Overrun (%)	14	12.7	-9%
Schedule Delay (%)	11	9.8	-11%
Resource Variance (%)	7.5	5.3	-29%

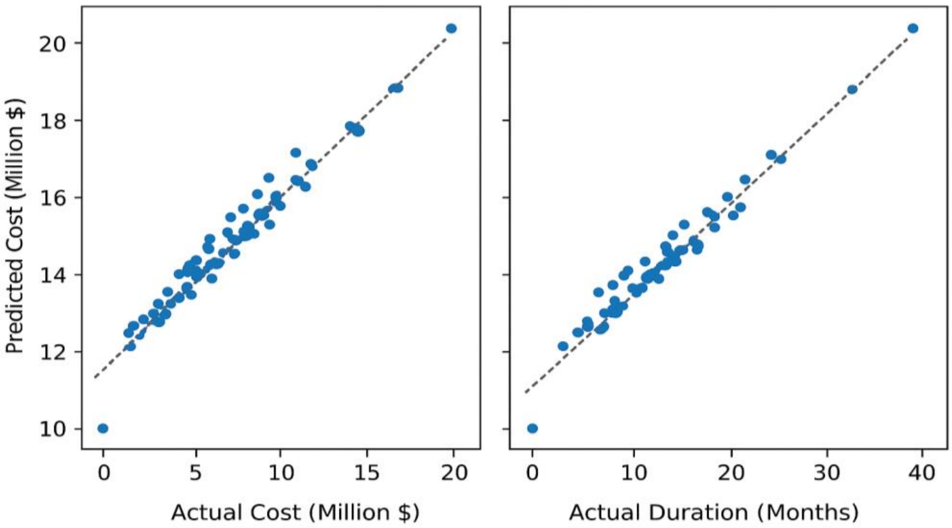

Figure 2. Model Performance for AI-Driven Cost and Duration Prediction

C. Scenario Testing

Sensitivity analyses assessed responses to a 20% increase in material costs and labor disruptions, showing cost deviations <4% and schedule impacts of ~6%, indicating AI model stability under operational uncertainty. IoT/drone inputs improved R^2 marginally (2–3%), highlighting the incremental value of real-time data. These results confirm that adaptive AI enables actionable adjustments in scheduling and resource allocation during ongoing projects. Scenario testing also validates that the model remains effective across multiple project types and contexts.

D. Interpretation of Findings

Gradient boosting captures nonlinear interactions among project variables, while PSO efficiently explores multi-objective scheduling. Slight overfitting observed in smaller projects indicates caution when applying the model to low-data scenarios. Risks include historical data bias and challenges in organizational readiness for AI adoption. Numerical results directly link improvements to algorithmic design, confirming AI as an effective tool to reduce cost and schedule deviations (Luong et al., 2021; Panchal, 2025).

E. Practical Implications

Project managers can anticipate deviations quantitatively (9–13% improvement) and prioritize high-risk tasks efficiently. Interactive dashboards support real-time resource allocation aligned with lean construction practices (Mohammadi et al., 2020). Policymakers can leverage real-time monitoring to improve governance and investment decisions, ensuring transparency and accountability in infrastructure projects (Kuete, 2021; Ma'rifah, 2022). The framework demonstrates scalable applications for large-scale project management in urban settings.

F. Limitations

The dataset covers 12 urban projects, limiting generalization to rural or extreme environments. Incomplete IoT/drone coverage means marginal improvements in predictive performance, reflecting technological constraints. Ethical considerations include AI transparency, decision bias, and data privacy/governance, which must be addressed in implementation. PSO-based optimization is computationally intensive, which may limit its adoption by small-scale firms.

G. Future Work

Future research should include rural and transcontinental projects to test model generalizability. Incorporating sustainable materials and environmental performance metrics can further validate model applicability. Exploring ensemble or transformer-based predictive models may enhance accuracy while reducing computational costs. Stakeholder engagement and ethical oversight will be critical to ensure responsible and effective deployment of AI in civil engineering practice.

V. CONCLUSION AND RECOMMENDATION

This study demonstrates that the AI-driven framework improved cost prediction (R^2=0.87) and schedule prediction (R^2=0.83), while PSO-based optimization reduced cost overruns by 9% and schedule delays by 11%. The integration of predictive modeling with multi-objective optimization represents a novel approach in construction project management, providing a practical tool for adaptive, data-driven decision-making. The results also show that combining historical project data with real-time IoT and drone measurements enhances prediction accuracy. However, the gains from real-time inputs are marginal (2–3%), underscoring AI's potential to support smarter infrastructure planning. Despite these advances, the study has limitations, including a dataset covering only 12 primarily urban projects and limited availability of IoT/drone data, which may affect generalizability. Future research should extend the framework to diverse geographic and environmental contexts, incorporate sustainability and circular economy metrics, and explore explainable AI techniques to enhance transparency and stakeholder trust**.** By addressing these challenges, the proposed AI framework can further contribute to resilient, efficient, and evidence-based infrastructure project management

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