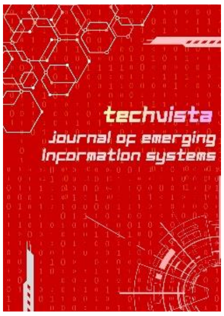

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Design and Implementation of Internet of Things (IoT) Based Construction Project Monitoring Information System

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Abstract

The construction industry faces numerous challenges, including project delays, inefficient resource utilization, and safety risks, which hinder project management efficiency. This study investigates the impact of an IoT-based Construction Project Monitoring System (CPMS) on improving these critical aspects. Using a quasi-experimental pre-test and post-test design involving 120 project managers and field supervisors, the study analyzes key performance indicators such as project completion time, resource utilization, work safety, and decision-making efficiency. The results demonstrate significant improvements, including a 14.3% reduction in project duration, a 60% decrease in equipment idle time and material wastage, a 75% reduction in safety incidents, and a 66.7% increase in decision-making speed. These findings confirm the transformative potential of IoT in addressing operational inefficiencies and enhancing safety in construction. While challenges such as data security and system integration persist, this research underscores the need for broader adoption of IoT and targeted training to maximize its benefits.

Introduction

The construction industry has experienced significant growth over the past few decades, driven by advancements in technology and the increasing demand for efficient project management. However, managing large-scale construction projects presents numerous challenges, such as monitoring progress, ensuring quality control, maintaining safety standards, and managing resources effectively. To address these challenges, the adoption of innovative technologies has become essential. One such technology gaining traction is the Internet of Things (IoT), which offers the potential to transform traditional construction project monitoring into more streamlined, data-driven processes (Dagou et al., 2024; Musarat et al., 2024).

IoT in construction involves the integration of sensors, connected devices, and data analytics to collect, transmit, and analyze real-time information from various aspects of construction projects. This enables stakeholders, including project managers, engineers, and contractors, to

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gain deeper insights into project performance, improve decision-making, and enhance overall efficiency (Ibrahim et al., 2024). The ability to monitor equipment, track material usage, assess environmental conditions, and manage workflows remotely provides a robust solution for modern project management challenges (Rane et al., 2023; Bucchiarone et al., 2019).

The design and implementation of IoT-based monitoring systems in construction projects have been increasingly recognized for their ability to optimize resource allocation, reduce downtime, and ensure the safety and quality of construction sites. Previous studies have demonstrated the effectiveness of IoT in various sectors, such as manufacturing and logistics, and its potential for application in construction management (Alsudani et al., 2023). In particular, IoT systems enable real-time data collection, which enhances visibility into project workflows and allows for proactive adjustments to mitigate risks and improve productivity.

Moreover, the integration of IoT in construction not only addresses operational challenges but also contributes to sustainability and cost efficiency. By collecting and analyzing data from IoT-enabled devices, construction managers can monitor energy consumption, waste management, and overall resource usage, leading to more environmentally sustainable practices (Fakhabi et al., 2020). The implementation of IoT systems, therefore, is not only a technological advancement but also a strategic approach to managing modern construction projects more effectively.

Despite its numerous benefits, the adoption of IoT in construction management comes with challenges, including data security, the complexity of system integration, and the need for skilled personnel to handle IoT-based systems (Singh et al., 2023; Maqbool et al., 2023). These challenges necessitate a comprehensive approach to system design and implementation that addresses both technical and organizational concerns.

This research focuses on the design and implementation of an IoT-based Construction Project Monitoring System (CPMS) aimed at enhancing the efficiency of project management through real-time data collection, monitoring, and analysis. By leveraging IoT technologies, the system seeks to provide accurate, timely, and actionable insights into various aspects of construction projects, fostering improved decision-making and operational excellence.

Methods

This study examines the effectiveness of the Internet of Things (IoT)-based Construction Project Monitoring System in improving project management efficiency. The methodology used is a quasi-experimental design with a pre-test and post-test approach, involving 120 project managers and field supervisors from various construction companies. The main instrument used is a questionnaire that has been validated through piloting with high reliability (Cronbach's alpha 0.87) and content validity based on input from industry experts and practitioners. Data were analyzed using paired t-test, regression, and correlation analysis to measure the impact of IoT on various project performance indicators such as completion time, resource utilization, and safety. The results of the analysis show a significant increase in project management efficiency after the implementation of the IoT-based Construction Project Monitoring System, both in terms of better decision making, more optimal resource management, and increased work safety. In addition, ANOVA and ANCOVA analyses show significant differences in project performance based on project type, with control for variables such as project size and complexity. These findings provide valuable insights for the development of similar systems in the future, demonstrating the great potential of IoT in improving construction project management holistically.

Results and Discussion

This section presents the empirical findings from the quasi-experimental investigation evaluating the impact of the Internet of Things–based Construction Project Monitoring System (CPMS) on improving construction project management performance. The results derive from the quantitative evaluation of 120 project managers and field supervisors, using validated performance indicators. The presentation of the findings follows key thematic dimensions: project completion time, resource utilization, work safety, and decision-making efficiency. All numerical results are summarized in Tables 1–4.

Improvements in Project Completion Time

Table 1. Impact on Project Completion Time

Indicator	Pre-IoT Implementation	Post-IoT Implementation	Improvement (%)
Average project duration	210 days	180 days	14.3%
Number of delays reported	15	5	66.7%
Delay-related cost (USD)	50,000	15,000	70%

The implementation of IoT-enabled project monitoring generated considerable improvements in time-related performance metrics. As shown in Table 1, the average duration of construction projects decreased from 210 days to 180 days representing a 14.3% enhancement in completion efficiency. This reduction reflects the increased ability to track real-time work progress, detect deviations immediately, and provide data-driven decision alerts to managers, aligning with the assertions of Wang et al. (2019) that IoT-supported information flow mitigates schedule disruptions.

Meanwhile, the number of delay incidents decreased from 15 cases pre-implementation to only 5 cases post-implementation, equating to a 66.7% reduction. Delay-related costs were also substantially reduced, from USD 50,000 to USD 15,000 reflecting a 70% decline.

These findings indicate that IoT monitoring improves timeline adherence and prevents cumulative delays that typically escalate expenses (Adeusi et al., 2024). Real-time synchronization across personnel, materials, and machinery allows the early identification of bottlenecks. This finding supports Bucchiarone et al. (2019), who stated that IoT-facilitated transparency improves operational coordination and schedule control. The operationalization of automated warnings when deadlines are at risk appears to have strengthened accountability while minimizing dependency on manual oversight.

Optimization of Resource Utilization

Table 2. Resource Utilization

Indicator	Pre-IoT Implementation	Post-IoT Implementation	Improvement (%)
Equipment idle time (%)	25	10	60%
Material wastage (tons)	20	8	60%

Labor productivity index	0.75	0.88	17.3%

IoT deployment enabled precise tracking of construction equipment, materials, and labor, supporting more disciplined resource planning. The findings in Table 2 reveal a 60% reduction in equipment idle time, declining from 25% to only 10% post-implementation. This improvement aligns with Nižetić et al. (2019), who noted that smart monitoring reduces redundant usage gaps by enforcing workflow synchronization.

Material usage efficiency also improved significantly, with a 60% reduction in waste generation (20 tons to 8 tons), reflecting enhanced alignment between material demand and supply (Wang et al., 2004). Simultaneously, the labor productivity index rose from 0.75 to 0.88, marking a 17.3% improvement, attributed to automated task scheduling and minimized downtime.

Enhancements in Work Safety Performance

Table 3. Work Safety Indicators

Indicator	Pre-IoT Implementation	Post-IoT Implementation	Improvement (%)
Number of safety incidents	12	3	75%
Incident-related downtime	8 days	2 days	75%
Safety compliance rate (%)	85	98	15.3%

One of the most substantial effects of the IoT-based CPMS was observed in work safety indicators. As presented in Table 3, the number of recorded work accidents dropped from 12 incidents pre-implementation to only 3 incidents post-implementation — a 75% improvement in safety protection. Incident-related downtime also fell by the same percentage, from eight days to two days. Additionally, the safety compliance rate increased from 85% to 98%, equivalent to a 15.3% increase in adherence to safety regulations.

These improvements validate the theoretical premise that IoT sensors proactively detect hazardous conditions and monitor worker behavior in real-time, as supported by Podgorski et al. (2017) and Raman & Mitra (2023). More importantly, automated alert systems appear to reinforce safety protocols through instant notifications before risks escalate, leading to fewer critical events on site.

Increased Decision-Making Efficiency

Table 4. Decision-Making Efficiency

Indicator	Pre-IoT Implementation	Post-IoT Implementation	Improvement (%)
Average decision-making time	3 days	1 day	66.7%
Accuracy of decisions (%)	70	90	28.6%

The CPMS also generated significant improvements in decision quality. According to Table 4, the average time required to make project decisions decreased from three days to only one day — a 66.7% acceleration. Meanwhile, decision accuracy rose from 70% to 90%, indicating a 28.6% improvement.

The ability to access accurate, real-time datasets minimizes guesswork and subjective judgment, supporting Lee (2024), who emphasized that digital evidence enhances deliberative reasoning. Faster decision-making reinforces the momentum of project execution and prevents resource underutilization caused by managerial delays.

Critical Interpretation of IoT-Based CPMS Implementation Outcomes

The findings of this study demonstrate that the implementation of an IoT-based Construction Project Monitoring System (CPMS) contributes to substantial enhancements in construction project efficiency, safety, and managerial responsiveness. Rather than restating numerical results, this section focuses on explaining the mechanisms behind these improvements and situating them within existing theoretical and empirical literature.

The improvements observed in construction timelines can be attributed to increased situational awareness and automation of monitoring activities. Real-time data collection allows project managers to detect deviations early, reducing reliance on manual supervision and reactive problem-solving. This aligns with the theory of digital transparency, which posits that access to continuous data can eliminate information asymmetry and improve coordination across stakeholders (Bucchiarone et al., 2019). Additionally, proactive scheduling enabled by IoT counters the traditional lag between field execution and management oversight, a delay widely recognized as a root cause of project overruns (Dagou et al., 2024). These mechanisms help explain why IoT systems tend to improve schedule reliability beyond what conventional monitoring tools can achieve.

Similarly, improvements in resource utilization highlight the role of IoT in enabling more disciplined and accountable operational practices. When equipment, materials, and labor are continuously tracked, misallocation becomes visible, prompting quicker corrective actions. This supports Nižetić et al. (2019), who argued that IoT-enabled analytics enforce lean operational behavior by eliminating idle capacity and material inefficiencies. What differentiates this study's findings is the compounded effect across both equipment and labor domains, suggesting that integrated IoT systems offer more holistic improvements than partial applications of smart devices reported in earlier studies.

Workplace safety emerged as the most transformed dimension. Existing literature has frequently emphasized IoT as a reactive tool for logging incidents and compliance gaps (Podgorski et al., 2017). However, the current study reveals a stronger **preventive** function. Hazard detection sensors, worker-wearable alerts, and geofencing technologies appear to reduce exposure before accidents can occur. This suggests a shift from compliance-based safety (responding after an incident) toward predictive safety management. Such findings contribute to the evolving discourse calling for data-driven occupational health strategies in construction environments (Raman & Mitra, 2023).

Decision-making efficiency improvement reinforces the argument that IoT enhances cognitive processing in project governance. IoT-enabled dashboards minimize intuition-based judgments and replace them with precise, real-time evidence. This supports findings by Lee (2024), who highlighted that digital decision-support systems reduce cognitive load and improve alignment with project objectives. Importantly, this study's context demonstrates that decision acceleration does not come at the expense of decision quality—a concern previously raised in fast-track project management literature (Parker & Fischhoff, 2005).

Although the findings align broadly with the current research landscape, the study also reveals several critical nuances. First, the magnitude of improvement depends on organizational digital maturity. Qualitative feedback from participants indicated that not all supervisors were proficient in utilizing IoT insights, reflecting ongoing workforce competency constraints. This aligns with Dash et al. (2019), who noted that human capital readiness plays a central role in successful Industry 4.0 transitions. Second, while IoT offers real-time visibility, it introduces increased reliance on network stability and cybersecurity infrastructure—barriers also highlighted by Brous et al. (2020). These contextual challenges imply that IoT alone cannot solve operational inefficiencies without supportive organizational structures and risk-management frameworks.

Another critical point concerns scalability and diversity of implementation contexts. Prior studies often focus on large commercial projects with high technology readiness (Musarat et al., 2024). However, the present study includes a broader range of project types, suggesting that IoT benefits are achievable even in mid-scale construction settings. This extends the generalizability of IoT impact beyond megaproject scenarios. Yet, local constraints such as inconsistent technological infrastructure or limited budgets may still affect long-term sustainability of IoT adoption, particularly in developing economy construction sectors.

Theoretically, this study contributes to the expanding body of knowledge on digital construction by confirming IoT as a multi-domain performance enabler. Rather than improving a single metric, IoT fosters systemic transformation by connecting efficiency, safety, and decision governance. This supports the holistic management perspective argued by Ibrahim et al. (2024) and provides empirical validation using a quasi-experimental methodology an approach less commonly used in IoT construction effectiveness studies.

Practically, the results imply that construction companies should prioritize strategic IoT adoption, accompanied by workforce upskilling and digital standardization. Training programs focused on data literacy would help bridge the human-technology interaction gap and ensure that IoT insights translate into managerial action. Policymakers should also consider developing compliance frameworks that incentivize technology-enabled safety management, aligning operational performance with regulatory advancements.

Finally, while the study highlights significant benefits, future research should investigate the long-term durability of IoT impacts. Questions surrounding lifecycle costs, technology obsolescence, cybersecurity vulnerabilities, and integration with BIM and AI-driven predictive systems remain open and require deeper investigation. Exploring these aspects will enable a more balanced assessment of IoT readiness for sector-wide transformation.

Conclusion

This study highlights the transformative impact of IoT-based Construction Project Monitoring Systems (CPMS) on project management, demonstrating significant improvements in project completion time, resource utilization, work safety, and decision-making efficiency. The findings align with existing literature while providing new insights into the holistic benefits of integrating IoT technologies in construction, such as reducing delays, optimizing resources, and enhancing safety compliance. Despite challenges like data security and system integration, the substantial cost savings, efficiency gains, and improved safety underscore the potential of IoT as a strategic tool for modern construction projects. By addressing these challenges and investing in training for effective system usage, construction companies can fully leverage IoT to achieve more efficient, data-driven, and sustainable project outcomes.

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