

Application and Management of Intelligent Systems in Construction Projects Using Recycled Materials

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ABSTRACT

Currently, worldwide, modern construction technologies have emerged as one of the most important factors driving transformation and progress in the construction industry. These technologies can serve as cost-effective and environmentally friendly alternatives to conventional building materials. Building Information Modeling (BIM), intelligent systems, and the recycling of construction materials in the city of Qods have been recognized as advanced and innovative technologies in the construction sector. In the future, this system will continue to evolve and develop in response to technological advancements and the dynamic needs of the construction industry. Through intelligent system implementation, project managers and technical teams can address conflicts and technical issues while enhancing the quality and productivity of projects. This technology is also considered a valuable tool for promoting cultural acceptance in construction projects. Overall, BIM, as a powerful technological tool, can contribute to solving common challenges in civil engineering projects. It helps improve the management, quality, and efficiency of such projects while preventing potential interferences and technical complications. In this study, in order to examine the application and management of intelligent systems in the construction of civil projects using recycled materials in the city of Qods, 11 experts were selected. Using a pairwise comparison questionnaire, the identified factors and subgroups were prioritized through the Analytic Hierarchy Process (AHP). Based on the results obtained, "maintenance and repair" was recognized as one of the most important sub-criteria. Subsequently, "precise and transparent design modeling" was identified as the second most significant sub-criterion, followed by "appropriate scheduling." Furthermore, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was employed to prioritize the implementation tools. According to this analysis, Asta Powerproject software was identified as the top-priority tool for BIM implementation in construction projects utilizing recycled materials in Qods.

Keywords: intelligent material systems; construction projects; recycled materials; Asta Powerproject

1. Introduction

In the contemporary era of rapid technological advancement, the construction industry has undergone profound transformation driven by the integration of intelligent systems, artificial intelligence (AI), and sustainability-oriented practices. The complexity and dynamism of construction projects—particularly in urban and infrastructure development—necessitate innovative management frameworks that enhance decision-making, productivity, safety, and environmental responsibility. The adoption of intelligent systems in construction management not only reshapes the technical aspects of project execution but also contributes to sustainable growth and optimized resource utilization (R. Zhang et al., 2025; Zong et al., 2025). In this context, modern construction technologies, such as Building Information Modeling (BIM), digital twins, and smart energy systems, have become pivotal tools for enhancing operational efficiency and minimizing environmental impact (Rai et al., 2025; Tamimi & Farhang, 2025).

The construction sector, traditionally characterized by fragmented operations and high resource consumption, now faces mounting pressure to align with global sustainable development goals (SDGs). The convergence of digitalization, sustainability, and smart management frameworks offers an opportunity to address these challenges systematically (Regona et al., 2024). AI-driven technologies, when applied in construction planning, monitoring, and risk assessment, provide predictive insights and real-time adaptability, thus transforming conventional project management practices into dynamic, data-informed processes (Parekh & Mitchell, 2024; Rabbi, 2024). Moreover, the incorporation of intelligent decision-support systems enables managers to handle complex project interdependencies, optimize supply chains, and reduce human error (Motamedi & Darvish Motavalli, 2025; F. Zhang et al., 2025).

Construction projects are inherently vulnerable to multifaceted risks—technical, financial, environmental, and organizational. Traditional risk management approaches often fail to capture the dynamic interplay between these factors. Recent research underscores the role of intelligent systems and AI in identifying, prioritizing, and mitigating risks throughout the construction lifecycle (Swetha et al., 2024). By integrating machine learning algorithms and data analytics into project assessment frameworks, construction firms can predict potential deviations and develop proactive

strategies to maintain schedule and cost performance (R. Zhang et al., 2025). The capacity of AI tools to interpret large datasets facilitates early detection of anomalies in resource allocation, safety compliance, and environmental impact, thereby enhancing overall resilience in project management (Rabbi, 2024; Zong et al., 2025).

Sustainability has become a strategic imperative in the construction industry, particularly with the rise of green infrastructure and eco-efficient design models. The integration of green supply chain management principles and recycled materials into construction projects aligns with global efforts toward carbon neutrality and circular economy practices (Zarei et al., 2025). Smart construction technologies, such as automated waste management and intelligent material tracking systems, play a crucial role in reducing resource wastage and improving lifecycle performance (Rasouli et al., 2024). Furthermore, the evolution of smart contracts, enabled through blockchain-based systems, enhances transparency, accountability, and efficiency across construction transactions and supply chains (Taleshalipour, 2024). These advancements collectively signify a paradigm shift from linear construction models to intelligent, interconnected, and sustainable ecosystems.

Digital transformation represents another cornerstone of modern construction management. The digitization of workflows—through the use of BIM, AI, and Internet of Things (IoT) applications—has substantially improved coordination, design accuracy, and cost estimation (Shchadnev et al., 2024). Digital infrastructure also facilitates effective communication among stakeholders, enabling real-time monitoring and adaptive decision-making in large-scale projects. The “Broadband China” initiative, for instance, demonstrated how national-level digital infrastructure development could enhance urban ecological welfare performance by integrating smart technologies into construction and environmental management (Song et al., 2024). The digitalization of construction processes is therefore not only a technological upgrade but also an institutional reform that promotes sustainability, transparency, and long-term resilience (Regona et al., 2024).

The implementation of intelligent systems in construction is, however, accompanied by several challenges. These include the high initial cost of technology adoption, lack of skilled professionals, resistance to organizational change, and the absence of standardized protocols for interoperability (Rai et al., 2025; Utami & Barokah, 2024). Developing nations, in particular, face additional barriers

related to financial constraints, limited infrastructure, and inadequate training systems. Consequently, managerial competence and strategic leadership play decisive roles in ensuring the successful integration of intelligent systems into project environments (Rai et al., 2025). Studies have shown that project managers who possess advanced analytical, technological, and sustainability-oriented competencies are more capable of steering complex construction projects toward success (Motamedi & Darvish Motavalli, 2025).

The application of system dynamics models in construction management provides a robust analytical framework for understanding the interactions among key project variables—such as cost, time, quality, and risk (Motamedi & Darvish Motavalli, 2025). Through simulation and feedback analysis, decision-makers can identify leverage points and develop adaptive strategies to enhance investment efficiency and project outcomes. When coupled with AI and intelligent automation, these dynamic models facilitate scenario-based planning, allowing managers to anticipate the consequences of policy or design changes under varying economic and environmental conditions (F. Zhang et al., 2025). Such integrative models are particularly valuable in large-scale urban development initiatives where uncertainties and interdependencies are significant (Zhan et al., 2025).

In addition to technological innovation, institutional and regulatory frameworks profoundly shape the success of intelligent system deployment in the construction sector. Transparent governance mechanisms, anti-corruption measures, and ethical standards are essential to ensure fair competition and sustainable outcomes (Utami & Barokah, 2024). The role of governmental bodies and municipalities is critical in incentivizing the adoption of smart construction technologies and ensuring compliance with environmental and safety regulations. Similarly, public-private partnerships (PPPs) serve as effective instruments for mobilizing investment and technical expertise, especially in infrastructure projects aimed at urban resilience and modernization (Zarei et al., 2025).

At the operational level, integrating AI-powered safety supervision systems significantly reduces accident rates and enhances compliance with safety protocols. Studies employing evolutionary game theory models reveal that the interaction between regulatory authorities, contractors, and workers influences the effectiveness of safety supervision networks (R. Zhang et al., 2025). Additionally, research on construction workers' behavioral responses indicates that

risk perception and mindfulness jointly affect safety participation, underscoring the psychological dimension of intelligent construction management (Zong et al., 2025). By combining behavioral insights with digital safety monitoring, organizations can cultivate a proactive safety culture that aligns with human-centered management principles.

Intelligent energy management in buildings also represents a vital domain within smart construction. Integrating renewable energy systems and AI-based optimization models enables buildings to become self-regulating entities that minimize energy waste and carbon emissions (Tamimi & Farhang, 2025). These systems use real-time data to adjust energy production and consumption patterns according to environmental and occupancy conditions. In doing so, they contribute to the broader goals of energy efficiency and environmental sustainability. Such integration not only advances technological innovation but also supports the development of smart cities that leverage digital infrastructure for sustainable growth (Regona et al., 2024; Song et al., 2024).

Despite these advancements, the construction industry must continue to address the intertwined challenges of standardization, human capital development, and policy coherence. The evolution of intelligent systems requires continuous investment in digital skills, cross-sectoral collaboration, and adaptive governance structures (Rasouli et al., 2024; Shchadnev et al., 2024). Future construction ecosystems are expected to operate as integrated platforms, where data-driven decision-making, sustainable design, and stakeholder collaboration converge to achieve efficiency and resilience (Zhan et al., 2025; Zong et al., 2025).

In summary, the integration of intelligent systems and AI-driven technologies into construction management marks a transformative phase in the industry's evolution. By enhancing safety, sustainability, efficiency, and transparency, these systems redefine how projects are conceived, executed, and maintained. This study aimed to examine the application and management of intelligent systems in the construction of civil projects using recycled materials in the city of Qods.

2. Methods and Materials

This study employs a mixed-methods research design (qualitative–quantitative). The qualitative component aims to identify and prioritize the economic and technical challenges faced by contractors in civil construction

projects, while the quantitative component is used to rank and weight the identified options and factors. The qualitative approach provides an in-depth understanding of phenomena and focuses on descriptive and interpretive data analysis, whereas the quantitative approach deals with the numerical assessment and ranking of factors and alternatives.

The target population includes experts and professionals in the field of civil construction projects. Due to the limited number of qualified experts and the need for specialized information, purposive (non-probability) sampling was employed. In this method, sample units were selected based on their knowledge and experience to serve as representative members of the target population.

Qualitative data were collected through unstructured interviews. This type of interview allows respondents greater freedom to express their opinions and experiences without constraints. The questions were not predesigned, and only a general framework of the topic was provided to the interviewees.

The interviews were conducted face-to-face, during which the interviewer, adhering to social and professional principles, gathered precise and in-depth information. The primary objective of this stage was to identify the economic and technical challenges faced by contractors in civil construction projects.

The qualitative data were analyzed using an analytical–interpretive approach through the thematic analysis method. In this process, the collected information was coded, and key themes were extracted.

To determine the relative importance of the indicators and assign weights to the identified factors, the Analytic Hierarchy Process (AHP) was used. Additionally, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was applied to rank the options and determine those closest to the ideal solution. The TOPSIS procedure was implemented using Microsoft Excel, involving steps such as identifying indicators, weighting, data entry, and generating result tables, including positive and negative ideal distances and the final ranking of alternatives.

3. Findings and Results

Following the interviews and their subsequent analysis, a TOPSIS questionnaire was designed and provided to experts to prioritize investor and municipal participation in intelligent systems for material recycling and to propose solutions for improving cost efficiency. The questionnaire assessed the impact of these factors on project time and cost-quality improvement.

Table 1

Demographic Characteristics of Participants

Field of Study	Academic Degree	Organizational Position	Years of Experience	Organization Type	Code
Civil Engineering	M.Sc.	Senior Manager	28 years	Client	1
Civil Engineering	M.Sc.	Senior Manager	26 years	Client	2
Architecture	M.Sc.	Senior Manager	24 years	Client	3
Civil Engineering	M.Sc.	Site Supervisor	22 years	Consultant	4
Civil Engineering	M.Sc.	Site Supervisor	24 years	Consultant	5
Architecture	B.Sc.	Site Supervisor	10 years	Consultant	6
Civil Engineering	B.Sc.	Project Inspector	12 years	Consultant	7
Architecture	B.Sc.	Project Inspector	11 years	Consultant	8
Mechanical Engineering	B.Sc.	Execution	20 years	Contractor	9
Civil Engineering	M.Sc.	Execution	22 years	Contractor	10
Civil Engineering	B.Sc.	Project Manager	21 years	Contractor	11

To collect qualitative information for identifying and prioritizing technical factors among contractors in municipal construction projects in Alborz Province, interviews were conducted with experts possessing at least 15 years of professional experience. After interviewing 11 participants, all of whom were managers and specialists in civil

construction projects in the city of Qods, the interview data were subjected to analysis. The results of this analysis revealed the existence of 14 challenges in the performance of contractors in Qods, which were categorized into two main groups: economic issues and cost estimation problems.

Table 2

Investors' Problems in Qods City

Economic	Cost Estimation
Increase in material prices	Inaccurate estimation of recycling costs
Inflation	Use of unqualified subcontractors
Lack of safety measures	Absence of standardization
Delayed payment of progress statements	Failure to employ qualified managers
Contractors' liquidity problems	Low-quality materials
Instability of construction industry policies	Rising labor wages
Lack of funding	Lack of skilled labor for industrial methods

The identified potentials within the city that possess investment and economic return capabilities include, for example, vacant lands in Qods City owned by the

municipality, private sector, or other organizations. These opportunities have the capacity to support various land uses and recycling service functions.

Table 3

Investor Weight Matrix in Qods County

Economic	High Cost Increase in Materials	Recycling Process	Quality of Recycled Materials	Material Separation Deficiency	Technological Dependency	Environmental Sustainability	Scalability Limitation	Lack of Standardization	Skilled Labor
Increase in raw material costs	2056	8547	625.2	6597	7910	100	1211	1110	8920
Energy price fluctuations	2487	5136	2489	120	5611	5140	4125	2450	5321
Long-term costs	3598	2418	2359	2536	2411	2150	2517	4025	7120
Competition with non-intelligent materials	2789	8921	2548	101	8497	6320	4199	6488	61.1

Table 4

Technical Problem Weight Matrix

Technical Factors	Financial Problems	Safety Problems	Technical Limitations	Lack of Skilled Labor	Lack of Supervision	Time Management	Investor Problems	Lack of Qualified Supervision	Material Supply Deficiency	Design Defects
Quality of Recycled Materials	1.041	1.011	4.256	5.891	2.722	1.325	2.124	0.359	0.451	1.856
Regulations and Standards	1.210	1.261	5.246	1.745	3.782	0.564	0.742	0.784	4.125	2.325
Environmental Protection	0.658	0.211	1.025	3.874	0.654	0.745	2.012	2.124	2.410	1.265
Waste Management	0.214	0.852	0.356	1.152	2.749	2.845	5.214	3.145	2.154	1.245
Material Demand	0.415	0.254	1.445	0.541	1.036	2.140	4.325	3.254	1.882	1.889
Geographical Location	0.651	2.410	2.849	0.751	0.512	1.145	2.102	2.458	1.241	2.315

Table 5

Economic Problem Weight Matrix

Economic	Weight	Group Weight	Final Weight
Initial collection costs	0.125	0.500	0.053
Contractor process costs	0.145	0.500	0.096
Increase in primary material costs	0.135	0.500	0.056
Wage increase	0.136	0.500	0.045
Non-payment of workshop wages	0.130	0.500	0.062

As concluded in this research, the most significant economic problems include initial collection costs (weight = 0.053), contractor process costs (weight = 0.096), and the

increase in primary material costs (weight = 0.056). Given that the inconsistency ratio for this category is 0.096, which is less than 0.1, the results are considered acceptable.

Table 6

Technical Problem Weight Matrix

Technical	Weight	Group Weight	Final Weight
Low quality	0.166	0.500	0.092
Impossibility of recycling	0.159	0.500	0.082
Recycling technology	0.120	0.500	0.061
Contamination of recycled materials	0.111	0.500	0.051
Lack of separation	0.105	0.500	0.055
High cost	0.081	0.500	0.041

In this category, the three most critical issues are low quality (weight = 0.092), impossibility of recycling (weight = 0.082), and recycling technology (weight = 0.061). The

inconsistency ratio for this category is 0.08, indicating the validity of the results.

Table 7

Overall Problem Weight Matrix

Priority	Challenges	Weight
1	Lack of standardized processes	240.1
2	Contractor process costs	20.36
3	Instability of construction industry policies	771.2
4	Inaccurate recycling estimation	841.6
5	Recycling technology	69.04
6	Lack of investment in recycling	795.1
7	Delay in payment of progress statements	542.2
8	Initial collection costs	981.2
9	High cost	11.08

In general, inaccurate estimation, low quality, impossibility of recycling, recycling technology, contamination of recycled materials, and high costs are the five most significant problems in Qods County, as well as within standard institutions and municipal administrations. According to the conducted studies, to date, the factors influencing the implementation and enhancement of structures for evaluating and improving the application and management of intelligent systems in civil construction projects—using recycled materials and relevant criteria for

assessing project success—have not been systematically examined. Furthermore, this study specifically focuses on municipal civil construction projects in Qods City, which can contribute to promoting innovation and industrial methods in urban construction projects.

4. Discussion and Conclusion

The results of the present study highlighted the economic and technical challenges that influence the successful application and management of intelligent systems in

construction projects utilizing recycled materials, with a particular focus on Qods County. The prioritization process, conducted through the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), revealed that among economic factors, contractor process costs, initial collection expenses, and rising material costs were the most significant determinants affecting project performance. On the technical side, low material quality, limited recycling feasibility, and insufficient technological capacity emerged as dominant issues. These findings collectively demonstrate that although intelligent systems have the potential to improve efficiency and sustainability, their implementation is constrained by both structural and managerial deficiencies. This conclusion aligns with previous research asserting that intelligent construction technologies require systematic integration of financial planning, technical standardization, and human capital development to achieve tangible benefits (Motamedi & Darvish Motavalli, 2025; R. Zhang et al., 2025).

The observed emphasis on contractor process costs as a primary challenge indicates a persistent inefficiency in cost management across construction projects. Despite the automation and data-driven optimization capabilities of intelligent systems, many construction firms continue to struggle with cost estimation and control due to fragmented coordination, inadequate digital literacy, and limited interdepartmental collaboration. These issues mirror the findings of (Swetha et al., 2024), who demonstrated that financial mismanagement and cost underestimation remain critical risks in construction project assessment, even in technology-oriented environments. Additionally, the instability of construction industry policies and delayed payment procedures identified in this study echo the conclusions of (Rai et al., 2025), who found that weak managerial competencies and inconsistent policy enforcement exacerbate economic inefficiencies in project delivery. The inconsistency between technological potential and practical performance underscores the need for integrated financial intelligence systems capable of dynamic forecasting and adaptive budgeting within intelligent construction frameworks (Motamedi & Darvish Motavalli, 2025).

Another major finding pertains to the limited quality and standardization of recycled materials. Participants emphasized that although the recycling process offers economic and environmental advantages, the absence of quality assurance protocols and skilled personnel restricts large-scale adoption. This problem corresponds with the

study by (Zarei et al., 2025), which revealed that the implementation of green supply chain management in Iran's construction sector is hindered by the lack of standardized criteria and institutional commitment. Furthermore, (Regona et al., 2024) affirmed that without clear performance benchmarks aligned with sustainable development goals (SDGs), the effectiveness of AI and digital systems in achieving sustainability outcomes remains uncertain. The current findings therefore reinforce the necessity of developing an integrated system for monitoring and certifying the quality of recycled construction materials, supported by intelligent sensors and data analytics to ensure compliance with environmental and structural standards.

The technical challenges identified—particularly the lack of recycling feasibility and insufficient technological infrastructure—suggest that many construction companies operate below the technological maturity threshold required for intelligent system deployment. Respondents indicated that limitations in machinery, data interoperability, and automation technologies impede the scalability of recycling initiatives. This outcome is consistent with (Taleshalipour, 2024), who found that the integration of smart contracts and blockchain-based systems in construction projects is often delayed due to technological incompatibility and insufficient digital infrastructure. Similarly, (Shchadnev et al., 2024) argued that digital transformation in the construction industry demands more than technological tools; it requires the institutionalization of innovation culture and the redefinition of managerial roles. Hence, the persistence of these technical barriers demonstrates that technological advancement alone is insufficient without complementary governance and capacity-building strategies.

Moreover, the results demonstrated that workforce limitations, including the lack of skilled labor for industrialized methods, directly hinder the successful implementation of intelligent systems in construction. The reliance on traditional labor models remains high, while expertise in AI-based project management, data analysis, and intelligent automation remains scarce. This observation aligns with (Rasouli et al., 2024), who emphasized that inadequate training and human resource development significantly limit the digital readiness of construction organizations. Similarly, (Rai et al., 2025) identified managerial competencies as a central determinant of project success in emerging construction economies, indicating that the cultivation of digital and analytical skills among managers and engineers is crucial for enhancing project performance. Collectively, these findings reinforce the

human-centered dimension of intelligent system adoption, where technical proficiency and adaptive learning determine the extent of technological integration.

Environmental sustainability and intelligent material management also emerged as critical aspects within the study's findings. The participants recognized the growing necessity of integrating environmental protection principles into construction project management, especially when using recycled materials. However, they noted that environmental objectives are often secondary to cost considerations. This pattern is in line with (Song et al., 2024), who demonstrated that urban development initiatives often prioritize digital infrastructure expansion without sufficient consideration of ecological welfare. Additionally, (Zhan et al., 2025) found that spatial reconstruction projects can negatively affect post-resettlement adaptation when sustainability factors are not adequately integrated into planning frameworks. Thus, the imbalance between cost optimization and ecological responsibility represents an ongoing challenge in the industry—one that intelligent systems must be programmed to address through multi-objective optimization and sustainability-driven decision-making models.

Another significant insight from this research concerns the interdependence between digital governance and project transparency. The results revealed that regulatory ambiguity and lack of oversight in intelligent system management contribute to inefficiencies and corruption risks. These findings correspond with (Utami & Barokah, 2024), who examined the determinants of anti-corruption disclosures among construction firms and found that transparency mechanisms are vital for ensuring ethical compliance in technologically driven environments. Furthermore, (Taleshalipour, 2024) demonstrated that smart contracts, when properly institutionalized, can substantially enhance transparency and accountability in construction transactions. The absence of such systems in Qods County highlights a gap that could be bridged through blockchain-enabled documentation, intelligent auditing, and digital procurement systems that ensure traceability and fairness across all project phases.

From a managerial standpoint, the results underscore that leadership competence and policy stability are indispensable for the sustainable adoption of intelligent construction systems. Participants consistently reported that inconsistent governmental policies and budgetary limitations disrupt the continuity of innovation efforts. This is supported by (Shchadnev et al., 2024), who argued that digital

transformation requires synchronized institutional efforts among government agencies, private contractors, and educational institutions. Similarly, (Zong et al., 2025) emphasized the moderating role of mindfulness and risk perception in workers' safety participation, suggesting that leadership and cultural adaptation are key mediators in the success of intelligent system implementation. Therefore, the creation of a stable policy environment, combined with consistent training and stakeholder engagement, is critical for maximizing the return on investment in smart construction technologies.

In addition to economic and managerial barriers, the research highlighted the influence of technological interconnectivity and information exchange. The difficulty of integrating intelligent systems across different project management platforms limits collaboration and information flow. This finding is aligned with (Parekh & Mitchell, 2024), who discussed the need for interoperable AI-based tools to enhance cost efficiency and operational performance in construction projects. (Rabbi, 2024) also noted that AI-driven safety systems require seamless coordination between vision, audio, and textual data streams to function effectively. The fragmentation observed in Qods County's projects underscores the broader need for an integrated digital ecosystem, supported by uniform data standards and cloud-based collaboration frameworks.

Furthermore, the analysis of stakeholder collaboration and investment dynamics indicates that insufficient investor confidence poses a major obstacle to expanding intelligent system usage. The results revealed that potential investors perceive high financial and operational risks due to unstable policies, limited technical expertise, and uncertain return on investment. These results parallel the conclusions of (Motamedi & Darvish Motavalli, 2025), who proposed that system dynamics modeling could be instrumental in evaluating the interrelationships between investment decisions, technology adoption, and project performance. Similarly, (Regona et al., 2024) confirmed that AI and intelligent management frameworks enhance not only technical performance but also investment attractiveness when aligned with sustainability metrics. Thus, creating investment incentives and transparent evaluation systems could substantially strengthen the long-term viability of intelligent construction initiatives.

Taken together, the findings of this study illustrate that the deployment of intelligent systems in construction is a multi-dimensional process that extends beyond mere technological implementation. It requires harmonizing

economic rationality, human capital development, environmental stewardship, and institutional governance. The results reaffirm the interdependence between technical innovation and socio-managerial adaptation, emphasizing that the path toward intelligent and sustainable construction is evolutionary rather than immediate. Similar conclusions were drawn by (F. Zhang et al., 2025), who noted that the effective supervision of safety and performance within complex networks depends on adaptive, multi-agent coordination mechanisms rather than static protocols. Therefore, the transition toward intelligent construction must be viewed as a systemic transformation encompassing technology, policy, culture, and behavior.

The current study was conducted in Qods County, which may limit the generalizability of the findings to other regions with different economic, regulatory, or technological contexts. The sample size, although adequate for qualitative exploration and prioritization analysis, was relatively small and focused primarily on expert opinions. Moreover, the study relied on self-reported data from interviews, which could introduce subjective bias. The use of AHP and TOPSIS, while methodologically sound, may not fully capture the dynamic interrelationships among economic, technical, and managerial factors in real-world conditions. Future studies could benefit from incorporating longitudinal data and larger, more diverse samples to validate these findings.

Future research should expand the geographic and contextual scope of analysis by including multiple municipalities and private-sector construction firms to enable comparative studies. Researchers could also employ advanced simulation and machine learning models to analyze how intelligent systems dynamically interact with project performance metrics under varying economic and environmental conditions. Additionally, integrating system dynamics with agent-based modeling may provide deeper insights into how managerial decisions and policy interventions shape the success of smart construction initiatives. Investigating the behavioral and psychological dimensions of intelligent system adoption—such as workers' trust, resistance, and learning adaptation—could further enrich the theoretical understanding of digital transformation in construction.

Practitioners should prioritize the development of clear policy frameworks that encourage the adoption of intelligent technologies while ensuring transparency and accountability in construction management. Training programs should be designed to enhance digital competencies among engineers,

managers, and workers to bridge the skill gap. Municipal authorities and private investors must collaborate to establish financial incentives for sustainable construction practices and recycling initiatives. Finally, adopting interoperable platforms and standardized data systems can facilitate smoother integration of AI-driven tools, enabling construction projects to become more efficient, resilient, and environmentally responsible.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

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Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

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