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Machine Learning for Promoting Green Building Practices: Implications for Construction Project Delivery in Malaysia

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ABSTRACT

The construction industry in Malaysia is undergoing a transformative shift as digital technologies, aligned with Industrial Revolution 4.0 (IR 4.0), are increasingly adopted to enhance sustainability, efficiency, and project delivery. Among these technologies, machine learning (ML), a branch of artificial intelligence, has garnered growing interest due to its potential to support green building practices. However, despite its benefits, the practical implementation of ML within the Malaysian construction sector remains limited. This study examines the impact of machine learning on promoting green building practices and assesses its implications for the delivery of construction projects. A quantitative approach was adopted, with data collected from 125 construction professionals, including contractors, quantity surveyors, engineers, and architects. The analysis employed descriptive statistics, the Relative Importance Index (RII), and the perceived effectiveness of ML applications. The findings highlight the positive impact of ML on key sustainability outcomes, including energy efficiency optimization, sustainable material use, and project planning. Nonetheless, several barriers impede its widespread adoption, including high initial investment costs, inadequate infrastructure, limited stakeholder awareness, and resistance to technological change. The study also identifies future opportunities for ML integration in areas such as predictive analytics for cost and cash flow management, real-time risk mitigation, and enhanced decision support systems. This research contributes to the growing body of knowledge on digital transformation in construction by offering empirical evidence on the benefits and challenges of ML adoption in green building initiatives. The study highlights the strategic value of ML in enhancing sustainable project delivery and offers actionable insights for policymakers, industry stakeholders, and researchers seeking to advance green construction through intelligent technologies.

Keywords: *machine learning, green building, project management, construction industry, sustainability*

1.0 INTRODUCTION

The construction industry is one of the most significant contributors to environmental degradation, accounting for substantial energy consumption, greenhouse gas emissions, and the use of raw materials worldwide. In response to increasing climate concerns and the need for sustainable development, the global construction sector is undergoing a paradigm shift toward green building practices, which emphasize environmental responsibility and resource efficiency throughout a building's life cycle (Lim & Talukdar, 2024; Rahim et al., 2023).

In Malaysia, regulatory initiatives such as the Green Building Index (GBI) and national policies aligned with the Industrial Revolution 4.0 (IR 4.0) support the push toward green construction. However, achieving sustainability in construction projects goes beyond compliance and requires intelligent integration of digital technologies. Among these technologies, ML, which is a subset of artificial intelligence (AI), is gaining attention for its ability to process vast amounts of data, generate predictive insights, and optimize decision-making in real-time (Ensafi et al., 2022; Baduge et al., 2022). ML offers promising applications in forecasting energy demand, optimizing building performance, improving cost estimation, and minimizing construction waste, all of which are aligned with the principles of green building (Alshboul et al., 2022; Masrom et al., 2022).

Despite its growing global relevance, the adoption of ML in the Malaysian construction industry remains nascent, with limited practical implementation observed across local firms and project sites. Several barriers have been reported, including high capital investment requirements, limited infrastructure readiness, low stakeholder awareness, and cultural resistance to change (Tran et al., 2020; Aghili et al., 2016). These challenges hinder the integration of ML into project-level green construction strategies, slowing down the sector's digital and sustainable transformation. While previous studies have explored digital tools in construction, few have examined the specific implications of ML adoption on project delivery performance within green construction frameworks, particularly in the Malaysian context. This gap necessitates a systematic investigation into how ML contributes to sustainability-driven project outcomes and what factors influence its adoption among construction stakeholders.

Therefore, this study aims to assess the role of machine learning in promoting green building practices and its impact on the delivery of construction projects in Malaysia. It also seeks to identify key challenges and future opportunities for ML integration, offering practical insights to guide industry adoption and policy direction.

2.0 MACHINE LEARNING IN CONSTRUCTION MANAGEMENT

The construction management industry is undergoing a significant digital transformation driven by rising demands for productivity, environmental accountability, and operational efficiency. Technologies such as Building Information Modelling (BIM), the Internet of Things (IoT), robotics, and artificial intelligence (AI) are increasingly embedded into construction workflows, offering strategic value across project lifecycles (Ensafi et al., 2022; Rahimian et al., 2020). Among these, ML has emerged as a particularly disruptive force due to its data-driven capabilities in prediction, classification, and optimization (Kazeem et al., 2023; Masrom et al., 2022).

Unlike rule-based systems, ML algorithms have improved performance as they process more data, making them well-suited to complex and dynamic construction environments. In the context of green building initiatives, ML enhances decision-making by enabling project teams to forecast outcomes, detect anomalies, and optimize resource use (Alshboul et al., 2022; Masrom et al., 2022). The integration of ML into digital construction ecosystems has reflected a broader industry shift toward intelligent automation and sustainability-centric innovation (Baduge et al., 2022; Rahim et al., 2023). In the context of construction project management, ML has already found application in a wide range of construction management tasks, including risk prediction, schedule optimization, quality assurance, and cost estimation. Algorithms such as supervised learning are deployed to anticipate project delays or cost overruns based on historical data. Unsupervised learning techniques, including clustering and dimensionality reduction, allow for pattern recognition in complex datasets, which is particularly useful in site performance analysis or contractor evaluation. Reinforcement learning, though less mature in construction, offers the potential for real-time resource management by continuously learning from environmental feedback (Ensafi et al., 2022; Kazeem et al., 2023).

2.1 Integration of ML with BIM, IoT, and Smart Systems in Construction

Among the key strengths of ML in construction lies in its predictive capacity. Forecasting equipment breakdowns, predicting material demand, or simulating the impact of project changes under varying constraints empowers managers to make proactive decisions. ML-driven insights reduce reliance on intuition, enabling construction professionals to allocate resources more strategically, minimize waste, and avoid costly disruptions. These capabilities are critical in high-stakes green projects where efficiency and sustainability must be balanced under tight constraints (Alshboul et al., 2022; Lim & Talukdar, 2024). Beyond operational efficiency, ML is also known to support green construction at the planning and material selection stages. Algorithms can assess the lifecycle impacts of different materials, suggest alternatives with lower carbon footprints, and optimize site layouts to reduce energy consumption (Lim & Talukdar, 2024; Rahim et al., 2023). Waste minimization is another area where ML adds value, particularly through image recognition models that classify construction waste or identify inefficiencies. (Masrom et al., 2022). Furthermore, ML has enabled early detection of design flaws or coordination conflicts that might compromise energy performance or material sustainability. The predictive and adaptive nature of ML makes it especially relevant in green construction, where dynamic site conditions and evolving stakeholder goals require agile, informed responses (Mohd Rahim et al., 2024).

Green building practices prioritize reduced environmental impact, efficient energy use, and enhanced occupant well-being. ML contributes to these objectives by enabling smart systems that optimize building performance in real-time. For example, ML models can regulate HVAC systems based on occupancy patterns and external weather conditions, leading to substantial energy savings (Ohueri et al., 2018). Similarly, lighting, water usage, and ventilation systems can be automated and refined using real-time data inputs.

ML's full potential in construction is realized when integrated with complementary digital technologies. Its synergy with BIM, for instance, enables enhanced visual analytics and parametric modeling, allowing stakeholders to simulate project outcomes under different sustainability scenarios (Rahim et al., 2023; Mustafa et al., 2023). ML algorithms embedded in Building Information Modeling (BIM) platforms can evaluate energy consumption across various design iterations or predict the long-term performance of materials.

The integration of ML and IoT adds another dimension of real-time responsiveness. IoT sensors, when deployed on-site or embedded in building systems, generate granular data on temperature, humidity, equipment performance, and human activity. When processed through ML models, this data informs decisions about workflow optimization, energy usage, safety compliance, and environmental monitoring (Cai et al., 2018; Baduge et al., 2022). Together, the convergence of ML, BIM, and IoT forms an intelligent infrastructure for project management that is not only reactive but also increasingly anticipatory. This interconnected ecosystem represents a shift from fragmented decision-making toward integrated, data-driven project delivery models aligned with sustainability objectives (Rahimian et al., 2020; Kazeem et al., 2023).

2.2 Barriers to ML Adoption in Malaysian Construction

ML adoption in construction remains relatively low, especially in developing economies such as Malaysia (Hilmy et al., 2024). One of the primary challenges is the high capital requirement for implementation. Investment in computational infrastructure, cloud storage, secure networks, and customized software remains a substantial barrier, particularly for small and medium-sized enterprises (Tran et al., 2020). Another challenge lies in the fragmented nature of construction data. In many firms, project information is stored across disparate systems with varying levels of completeness, standardization, and accessibility. Poor data quality undermines the accuracy and reliability of ML models, thereby reducing trust among potential users (Aghili et al., 2016). Cultural resistance also plays a significant role. The construction industry has historically been conservative, with a deep-rooted reliance on traditional practices and skepticism toward automation. Even when technological tools are available, a lack of strategic vision, leadership support, or user confidence often results in underutilization (Tran et al., 2020). Furthermore, decision-makers may struggle to justify ML investment without clear, immediate returns.

A critical limiting factor is the skills gap. Most construction professionals lack the data literacy and technical expertise necessary to develop or interpret ML models. Conversely, data scientists often lack domain-specific knowledge of construction workflows, standards, and regulatory environments. Bridging this divide necessitates interdisciplinary training, collaborative innovation labs, and institutional support for digital capacity-building (Aghili et al., 2016; Ensafi et al., 2022).

2.3 Emerging Trends and Opportunities

Despite these challenges, the trajectory for ML adoption in construction remains positive. Advances in deep learning, generative design, and hybrid human-AI workflows are creating new possibilities. Generative design tools powered by ML can produce optimized layouts and structural systems based on user-defined constraints, enhancing not only design quality but also construction feasibility and sustainability (Kazeem et al., 2023). Predictive financial modeling is gaining traction as ML tools improve accuracy in estimating cash flows, assessing economic risks, and tracking budget variance, such as through the use of blockchain technology. In green projects, where financial planning is closely tied to sustainability objectives, such tools serve as a critical bridge between cost efficiency and environmental performance (Mamun et al., 2023).

Human-AI collaboration is another emerging area. Voice-enabled interfaces, intelligent scheduling assistants, and ML-augmented robotics allow construction professionals to interact with digital tools intuitively. These systems reduce cognitive load and increase productivity, particularly in complex, time-sensitive project environments (Baduge et al., 2022; Rahimian et al., 2020).

Governments and regulatory bodies are also beginning to recognize the role of ML in achieving sustainability and productivity goals. Green certification schemes, such as Malaysia's Green Building Index (GBI), could be revised to include digital performance indicators, encouraging firms to integrate ML tools into their sustainability strategies (Mohd Rahim et al., 2024).

Malaysia presents a compelling case for ML-driven transformation. As the country aspires to strengthen its green infrastructure portfolio and align with Industry 4.0 objectives, integrating ML into construction project management becomes both strategic and necessary. However, progress has been uneven. While BIM adoption is gaining ground, ML remains underutilized due to gaps in awareness, skills, and infrastructure (Rahim et al., 2023; Mustafa et al., 2023; Tran et al., 2020). Capacity-building through industry partnerships, government incentives, and the integration of ML into educational curricula are critical enablers (Aghili et al., 2016).

Additionally, pilot projects and demonstrator programs can serve as proof-of-concept platforms to de-risk investment and build stakeholder confidence (Masrom et al., 2022). As Malaysia continues to pursue green and smart construction pathways, the application of machine learning offers a transformative opportunity. It can accelerate the shift from compliance-based sustainability to performance-based delivery by improving both environmental outcomes and project execution. Understanding the unique challenges and opportunities of ML in the local context is therefore crucial for shaping effective adoption strategies (Lim & Talukdar, 2024; Mamun et al., 2023).

3.0 METHODOLOGY

This study employs a quantitative research design to critically examine the impact of machine learning on the delivery of green building projects and its influence on construction practices in Malaysia. A quantitative approach was selected for its ability to produce generalizable insights through measurable data, enabling systematic analysis of trends, perceptions, and relationships among key variables. Given the complexity and evolving nature of digital adoption in construction, a structured methodology is essential to capture the multifaceted impacts of machine learning across project management and sustainability dimensions.

The study targeted construction professionals directly involved in project planning and execution, including architects, engineers, contractors, and quantity surveyors, to ensure the relevance and validity of the data. These participants were selected due to their technical knowledge, operational experience, and exposure to digital tools in construction environments.

A total of 400 structured questionnaires were distributed via email and professional networks, such as WhatsApp construction groups, between March and April 2025. The sample consisted of professionals actively engaged in green or digital construction initiatives, representing diverse roles such as architects, engineers, contractors, and quantity surveyors. The targeted sample size was determined using Krejcie and Morgan’s (1970) formula, which recommends a minimum of 385 responses for large populations. Despite the widespread distribution, 125 valid responses were obtained. While the response rate was lower than anticipated, the diversity of professional backgrounds represented within the dataset supports meaningful exploratory analysis.

The survey instrument was divided into multiple sections to ensure comprehensive coverage of the research dimensions. The first section captured demographic variables such as professional role and years of experience, which are likely to influence familiarity with emerging technologies. The subsequent sections assessed participants' understanding of machine learning, their perceptions of its applicability to green construction, and their views on the challenges and future outlook of integrating machine learning. The instrument employed a 5-point Likert scale to capture varying degrees of agreement, providing a scalable metric for analyzing behavioral and attitudinal data.

Data analysis was conducted using both descriptive and inferential statistical techniques. Descriptive statistics summarized overall trends in the dataset, offering insights into baseline awareness, adoption readiness, and perceived benefits of ML in construction. The Relative Importance Index (RII) was used to quantify and rank the significance of factors related to ML adoption based on participants' evaluations. This method enables the prioritization of variables that affect implementation, including cost, infrastructure, and stakeholder support.

4.0 RESULT AND DISCUSSION

This section presents the findings from the survey on the perceived impacts of ML in the Malaysian construction industry.

Table 1. Impacts of machine learning on project delivery in construction industry

Impacts of machine learning on construction industry	Level of Agreement					Mean	Median	Standard Deviation	RII	Rank
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree					
Facilitates more efficient project management and scheduling in the construction industry	0	1	10	53	61	4.39	4.00	0.671	0.8784	1
Increasing the precision and speed of cost overrun prediction	0	3	19	88	17	3.94	4.00	0.619	0.8000	10
Enhances safety measures and reduces accidents	0	0	18	77	30	4.10	4.00	0.615	0.8192	2
Improve quality of works and identify frequent flaws	0	2	19	76	28	4.04	4.00	0.665	0.8080	8
Reduce construction waste and promote sustainability	0	1	21	70	33	4.08	4.00	0.679	0.8160	5
Mitigate construction risks by predicting potential issue	0	2	20	79	24	4.00	4.00	0.648	0.8000	10
Improves decision-making through data analysis	0	1	20	81	23	4.01	4.00	0.616	0.8176	4
Effective predictive maintenance of construction equipment to reduce downtime	0	3	18	76	28	4.10	4.00	0.683	0.8064	9
Facilitate communication among the construction team	0	2	19	75	29	4.03	4.00	0.670	0.8096	7
Increase the productivity of the construction process	0	0	12	89	24	4.10	4.00	0.530	0.8192	2
Reduce energy consumption and also impact to the environment	0	2	17	75	31	4.08	4.00	0.667	0.8160	5

The data in Table 1 demonstrate broad agreement among respondents on the positive impact of ML across multiple aspects of construction project delivery. The highest-ranked impact was the facilitation of efficient project management and scheduling (RII = 0.8784), underscoring ML's perceived effectiveness in improving planning accuracy, streamlining workflows, and enhancing real-time coordination. This finding supports Research Objective 1, which investigates the role of ML in improving construction performance.

Closely following were impacts on safety enhancement (RII = 0.8192), construction productivity (RII = 0.8192), and predictive maintenance (RII = 0.8064). These suggest that ML is seen not only as a planning tool but also as a driver of operational efficiency. By identifying safety risks early and optimizing equipment usage, ML supports both human and capital resource management. Interestingly, while cost overrun prediction is one of the most discussed theoretical applications of ML, it ranked lowest (RII = 0.8000). This disparity may reflect practical limitations in the availability of cost-related data or a lack of real-world applications known to respondents. It also suggests a gap between the potential of ML and its implementation in financial forecasting within local firms.

Table 2. Perceived contribution to green building practices.

Contribution of machine learning to green building practices.	Level of Agreement					Mean	Median	Standard Deviation	RII	Rank
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree					
Energy Efficiency Optimization	0	0	9	71	45	4.29	4.00	0.593	0.8576	1
Predictive Maintenance for Sustainable Operations	0	3	24	67	31	4.01	4.00	0.735	0.8016	6
Waste Reduction	0	1	19	77	28	4.06	4.00	0.639	0.8112	4
Sustainable Material Usage	0	0	13	71	41	4.22	4.00	0.620	0.8448	2
Water Conservation	0	4	27	72	22	3.90	4.00	0.716	0.7792	10
Enhanced Design for Sustainability	0	1	21	80	23	4.00	4.00	0.622	0.8000	7
Carbon Footprint Reduction	0	1	18	79	27	4.06	4.00	0.626	0.8112	4
Resource Efficiency	0	2	14	78	31	4.10	4.00	0.645	0.8208	3
Improving Indoor Environmental Quality	0	5	23	67	30	3.98	4.00	0.767	0.7952	8
Application in forecasting	0	4	30	63	28	3.92	4.00	0.768	0.7840	9

As shown in Table 2, respondents strongly recognize the role of ML in advancing green construction objectives. The most highly rated contribution is energy efficiency optimization (RII = 0.8576), followed by sustainable material usage (RII = 0.8448) and resource efficiency (RII = 0.8208). These findings are consistent with prior research, which has emphasized the effectiveness of ML in supporting environmental performance through automated control systems and predictive modeling.

Energy optimization is particularly critical in green building performance. Respondents noted the usefulness of ML in regulating energy consumption through intelligent systems, such as HVAC automation and occupancy-based sensors. Similarly, the use of ML in material selection and waste minimization is seen as supporting Malaysia's broader green infrastructure initiatives.

In contrast, water conservation (RII = 0.7792) and indoor environmental quality (RII = 0.7952) were ranked lower. These results suggest that ML applications in these areas remain underexplored or less familiar to industry practitioners, indicating future opportunities for research and tool development in green building design and operations.

Table 3. Future outlook of machine learning on project deliveries in construction industry.

Outlook of machine learning in construction industry	Level of Agreement					Mean	Median	Standard Deviation	RII	Rank
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree					
Cash flow prediction	0	7	18	48	52	4.16	4.00	0.874	0.8320	2
Integration with advanced technology such as BIM	0	2	9	88	26	4.10	4.00	0.580	0.8208	3
Better building design using generative design (GD) based on the design objectives	0	2	30	57	36	4.02	4.00	0.772	0.8032	5
Human-AI Collaboration	0	4	16	74	31	4.06	4.00	0.711	0.8112	4
Advancements in Deep Learning	0	5	29	68	23	3.87	4.00	0.751	0.7744	6
Efficient Project Management	0	4	40	53	28	3.84	4.00	0.807	0.7680	7
Sustainability and Green Building	0	6	11	63	45	4.18	4.00	0.784	0.8352	1
Safety and Risk Management	1	10	43	53	18	3.62	4.00	0.859	0.7232	8

Table 3 presents respondents' expectations regarding the future roles of ML in the construction sector. These results align with Research Objective 3, which aims to assess the future potential and integration of ML with digital construction technologies. Sustainability and green building remain the top-ranked future applications (RII = 0.8352), reinforcing the industry's prioritization of environmentally focused digital innovation. Cash flow prediction (RII = 0.8320), the second highest rated outlook, indicates increasing recognition of ML's value in financial risk management.

The integration of ML with advanced technologies, such as BIM (RII = 0.8208) and generative design systems (RII = 0.8032), also ranked highly. These findings suggest that respondents foresee a shift toward collaborative, data-rich project environment where ML complements digital modelling tools to enhance design quality, decision-making, and sustainability outcomes.

At the lower end of the ranking, safety and risk management (RII = 0.7232) and efficient project management (RII = 0.7680) appeared less emphasized compared to other categories. This is unexpected, given the strong current impact rating for these dimensions in Table 1. This discrepancy, relative to their high rankings in Table 1, suggests that these functions are already perceived as well-supported by current digital systems or are not considered immediate priorities for further ML development.

4.1 Synthesis and Implications

The combined results reflect a maturing awareness of ML's role in improving both construction efficiency and sustainability. High ratings across current impact and green contributions suggest that professionals see ML as a practical tool with immediate benefits, particularly in optimizing scheduling, enhancing site safety, and supporting environmentally responsible operations. Nonetheless, the somewhat lower recognition of ML's role in financial forecasting and indoor environmental optimization implies implementation gaps and a lack of demonstrable case studies in the Malaysian context. The future outlook findings also indicate a positive disposition toward integrating ML with digital ecosystems, such as Building Information Modeling (BIM), generative design, and other sustainability-driven tools. These findings have several implications. First, they suggest the need for industry-wide awareness programs and training to bridge the knowledge gap in underrecognized ML applications. Second, they highlight the importance of aligning national digitalization policies with sustainability mandates to promote ML uptake. Finally, they provide a strong foundation for future research into the development of ML-based tools tailored to the specific challenges of the Malaysian construction landscape.

The analysis of Relative Importance Index (RII) values highlights the perceived contributions and future potential of ML in Malaysia's green construction context. Figure 1 presents a visual summary of the Relative Importance Index (RII) rankings across current applications, green building contributions, and future-oriented ML strategies. Project management (RII = 0.8784), energy efficiency (RII = 0.8576), and sustainable material use (RII = 0.8448) were ranked among the top current applications, demonstrating a strong alignment between ML and the operational goals of green building initiatives. These outcomes reinforce ML's established value in optimizing scheduling, resource allocation, and performance-based delivery within green construction projects.

Several other green building indicators, including resource efficiency, waste reduction, and carbon reduction, are also strongly represented, with each exceeding an RII of 0.81. This suggests a robust alignment between ML applications and environmental performance goals, supporting earlier studies on the operational benefits of intelligent systems in minimizing environmental impacts (Rahim et al., 2023; Lim & Talukdar, 2024). The data support the view that ML tools, such as predictive energy models and lifecycle impact simulations, are gaining traction as part of sustainable construction strategies (Masrom et al., 2022; Alshboul et al., 2022). Notably, future-oriented applications of ML, such as cash flow prediction (0.8320), BIM integration (0.8208), generative design (0.8032), and human-AI collaboration (0.8112), also ranked highly. These areas reflect a forward-looking strategic vision, wherein stakeholders anticipate greater integration of ML into high-level decision-making and real-time project simulation frameworks. The emphasis on BIM-driven analytics and hybrid AI models resonates with global shifts toward Construction 4.0 and performance-based sustainability (Baduge et al., 2022; Mustafa et al., 2023).

However, several future applications, such as deep learning (RII = 0.7744), efficient project management (RII = 0.7680), and safety and risk management (RII = 0.7232), were ranked lower despite their relevance. This disparity may indicate a lack of awareness or technical readiness to implement such tools in real-world projects, particularly in Malaysia's fragmented construction landscape (Tran et al., 2020). It also signals the need for pilot projects and institutional frameworks that de-risk adoption and improve stakeholder confidence. Regarding aspects of communication, safety, and soft systems integration, the moderate RII scores for safety enhancement (0.8192), team communication (0.8096), and predictive maintenance (0.8064) reflect awareness but also suggest implementation gaps. These functions often depend on advanced sensor networks, digital twins, or IoT integration technologies not yet mainstream in many Malaysian project settings (Cai et al., 2018; Kazeem et al., 2023). As such, more empirical evidence and proof-of-concept initiatives are needed to validate ML's performance and ROI in these domains.

Furthermore, while ML's role in cost overrun prediction and indoor environmental quality is acknowledged (both with RII values near or above 0.79), its lower rankings in forecasting (0.7840) and water conservation (0.7792) suggest an underutilization of ML's predictive capabilities in resource-intensive areas. Overall, the RII analysis confirms that the Malaysian construction sector is beginning to embrace the multidimensional potential of ML across both environmental and operational fronts. High-priority areas, such as energy and resource efficiency, as well as emerging interests in BIM integration and AI collaboration, reveal a progressive trajectory. However, targeted interventions, especially in regulatory alignment, data infrastructure, and skills development, remain crucial to accelerating adoption and realizing the full potential of ML in green construction.

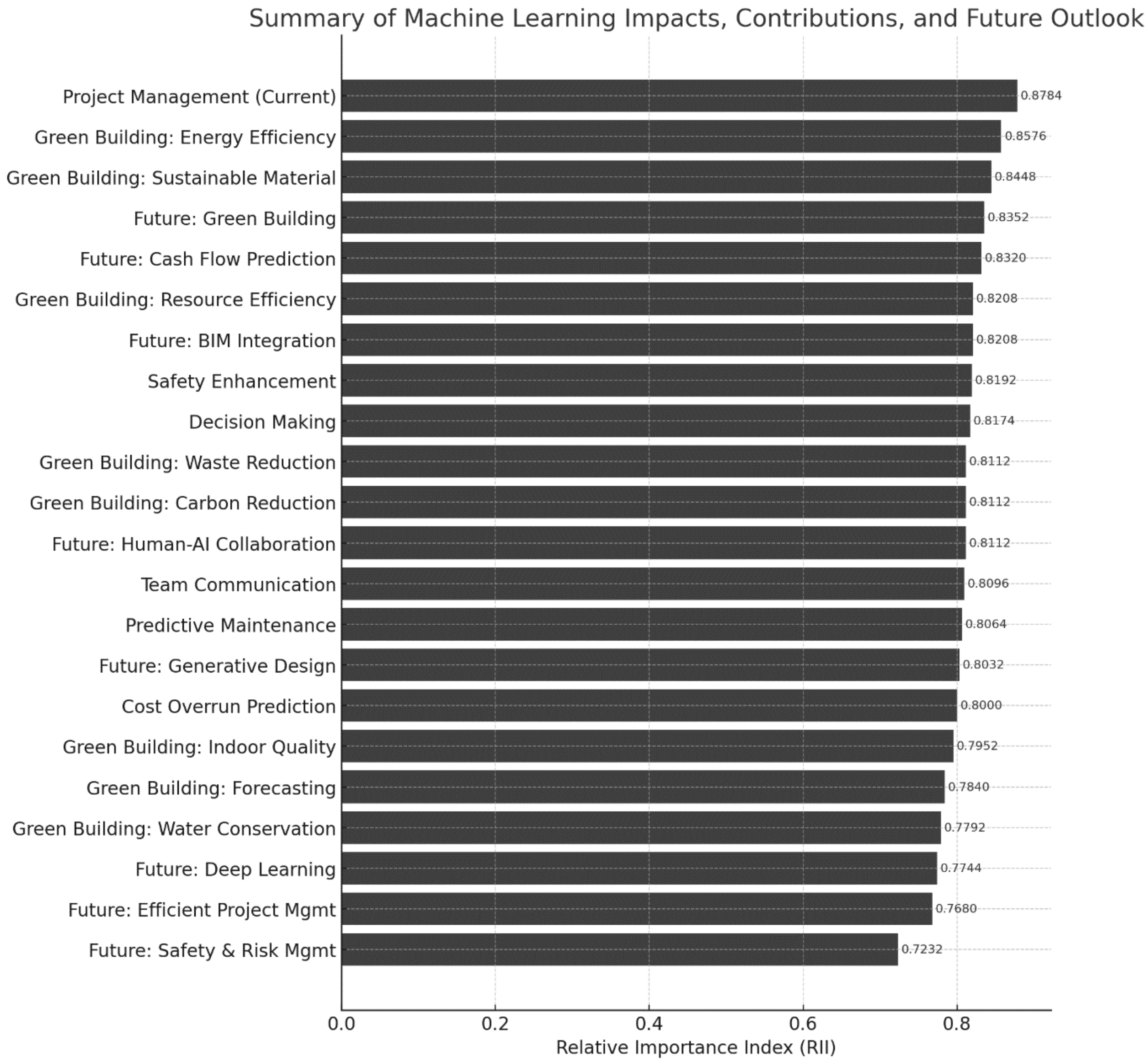

Figure 1. Summary of RII Analysis Results.

5.0 CONCLUSION AND FUTURE RECOMMENDATIONS

This study examined the influence of ML on green building practices and its implications for the delivery of construction projects in Malaysia. The findings reveal that while the integration of ML remains at a nascent stage, its perceived value across a wide range of construction functions, particularly in project management, sustainability optimization, and predictive analytics, is significant and continues to grow.

Respondents identified ML as a key enabler of enhanced project efficiency, with the highest-rated impact being its role in improving construction scheduling and coordination. Equally important is its capacity to elevate safety performance and operational predictability through real-time monitoring and predictive maintenance. These capabilities address some of the construction sector's most persistent inefficiencies, reinforcing the argument for ML as a strategic tool in modernizing project delivery systems.

Within the sustainability domain, ML's contributions to energy efficiency, resource optimization, and waste minimization underscore its alignment with the principles of green building. The high ranking of these functions by industry professionals suggests a growing awareness of ML's relevance to environmental objectives and its potential to strengthen Malaysia's national green building agenda. However, the study also reveals structural and cultural impediments to adoption. High implementation costs, limited digital infrastructure, fragmented data systems, and a shortage of interdisciplinary talent all constrain the scale and effectiveness of ML integration. Notably, while future-oriented applications such as cash flow prediction and generative design were positively received, a clear knowledge gap remains regarding ML's role in financial planning, indoor environmental quality, and water conservation. These are areas with substantial unrealized potential.

In summary, this research highlights both the promise and the practical limitations of ML in the Malaysian construction context. The industry recognizes the strategic value of ML, but realizing its full benefits requires coordinated action across policy, practice, and education. To accelerate the adoption of ML in Malaysia's green construction sector, a system-level strategy is necessary. Capacity-building should begin by embedding ML competencies into construction education and professional training, with an emphasis on practical applications such as energy modeling and predictive maintenance. Regulatory tools such as the Green Building Index (GBI) must evolve to reward ML-enabled innovations, including real-time energy and waste optimization. Aligning performance-based incentives with digital capabilities will drive broader industry transformation. Finally, national policies under the IR4.0 and sustainable development agendas should explicitly position ML as a core enabler of intelligent, low-carbon construction systems. While the study provides a valuable snapshot of industry perspectives, it also acknowledges methodological limitations. The reliance on self-reported perceptions may introduce bias, and the limited sample size, although diverse, restricts generalizability. Nonetheless, the rigor in instrument design, coupled with the multi-method statistical approach, enhances the reliability and validity of the findings. Future research could incorporate qualitative interviews or case-based analysis to triangulate and expand upon these quantitative insights.

6.0 AUTHOR CONTRIBUTIONS

Mustafa, M. H. led the conceptualization of the study, contributed to the development of the literature review. Ho, W. A. developed the methodology and conducted the data collection. Choy, P. K. was responsible for data analysis, and provided critical revisions to the manuscript. Mahdzir, M. and Abdul Samad, Z. provided technical input on green building practices and contributed to the analysis and discussions for this research.

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