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A CONCEPTUAL FRAMEWORK FOR SMART MONITORING AND MANAGEMENT: AI AND IOT ADOPTION FOR CONSTRUCTION COST AND RESOURCE OPTIMIZATION IN SARAWAK

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ABSTRACT

The construction industry is undergoing a digital transformation as technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) change project planning, monitoring, and management. In Malaysia, particularly in Sarawak, adoption of these technologies remains uncommonly used due to organizational and infrastructural constraints. This paper develops a conceptual framework that integrates the Diffusion of Innovation (DOI) theory and the Technology–Organization–Environment (TOE) framework to explain AI and IoT adoption for construction cost and resource optimization. The framework includes five adoption factors perceived usefulness, perceived ease of use, technological compatibility, organizational readiness, and external pressure with government support serves as a mediating variable. Most prior studies that examine digital construction technologies in general, while this study focuses specifically on the combined role of AI and IoT (AIoT) in addressing cost and resource inefficiencies among contractors in Sarawak. By placing adoption drivers and facilitators in a growing regional context, the framework makes two contributions where it helps us understand innovation adoption better in theory and gives policymakers and industry stakeholders' useful information. As a conceptual paper, it develops a theoretical framework rather than testing it empirically, thereby offering a foundation for future research and policy development.

KEYWORDS: Artificial Intelligence (AI), Internet of Things (IoT), AIoT, Construction 4.0, Cost Optimization, Resource Utilization, Diffusion of Innovation (DOI), Technology–Organization–Environment (TOE), Sarawak Construction Industry.

1.0 INTRODUCTION

The worldwide construction sector is seeing a surge of technological progress pushed by the incorporation of Artificial Intelligence (AI) and the Internet of Things (IoT). These technologies support the Construction 4.0 movement, which prioritizes digital transformation, automation, and intelligent systems to tackle ongoing challenges in productivity, efficiency, and safety. Artificial Intelligence enhances smart decision-making, predictive analytics, and automation, whilst the Internet of Things permits real-time data acquisition via networked sensors and devices. Together, they form an integrated AIoT (Artificial Intelligence of Things) system that supports smart monitoring and management.

The construction sector in Malaysia has started to adopt these technologies via projects like the Construction 4.0 Strategic Plan (CIDB, 2022) and the Twelfth Malaysia Plan (Economic Planning Unit, 2021). Nevertheless, adoption is inconsistent, especially in Sarawak, where contractors encounter obstacles like inadequate digital infrastructure, elevated implementation costs, and a deficiency of experienced specialists.

Notwithstanding government initiatives to accelerate digitization, several small and medium-sized enterprises in Sarawak persist in applying traditional approaches.

A review of existing literature reveals limited research specifically addressing AI and IoT adoption within the Sarawak construction sector. Most studies focus on broader digital technologies such as Building Information Modeling (BIM), cloud computing, or robotics, while neglecting the combined role of AI and IoT. Furthermore, few models integrate both technology and contextual variables, such as government support, when analyzing adoption outcomes like cost optimization and utilization of resources.

This conceptual paper presents a framework for the implementation of AI and IoT in Sarawak's construction sector. The framework integrates the Diffusion of Innovation (DOI) theory and the Technology–Organization–Environment (TOE) framework, incorporating government support as a mediating variable. Five adoptions constructs perceived usefulness, perceived ease of use, technological compatibility, organizational readiness, and external pressure are examined in relation to construction cost optimization and resource utilization. The research conceptually enhances the Diffusion of Innovations (DOI) and Technology-Organization-Environment (TOE) frameworks within a growing regional context, and practically offers a context-specific model to direct future empirical investigations and influence policy formulation.

This research provides three key contributions. This study expands the Diffusion of Innovation (DOI) and Technology–Organization–Environment (TOE) frameworks within the setting of a developing area, specifically targeting Sarawak's construction sector. Secondly, it presents government support as a mediating variable, emphasizing the essential role of policy, infrastructure, and incentives in promoting AIoT adoption. Third, it situates AIoT implementation inside Sarawak's construction sector, where infrastructure limits, resource restrictions, and governmental interventions influence adoption results. These contributions collectively offer theoretical enhancement and practical direction for researchers, practitioners, and policymakers.

2.0 LITERATURE REVIEW

2.1 Digital Technologies in Construction

The worldwide construction industry is undergoing a transformation via the integration of digital technologies that provide significant enhancements in efficiency, safety, and cost management. Innovative technologies like Building Information Modelling (BIM), robots, cloud computing, and Artificial Intelligence (AI) are transforming traditional workflows and altering project delivery systems. AI and the Internet of Things (IoT) are especially transformational, facilitating real-time, data-driven decision-making via predictive analytics and remote monitoring (Jin et al., 2023).

In Malaysia, the advancement of digital construction is bolstered by national efforts such the Construction 4.0 Strategic Plan (CIDB Malaysia, 2022) and the Twelfth Malaysia Plan (Economic Planning Unit, 2021). Nonetheless, the degree of adoption remains inconsistent. Although advancements are more apparent in Peninsular Malaysia, adoption in Sarawak is hindered by infrastructure constraints and insufficient knowledge among contractors. This gap highlights the necessity for customized frameworks that identify the particular challenges and possibilities influencing digital adoption in Sarawak's construction sector.

2.2 Artificial Intelligence (AI) in Construction

In Malaysia, the advancement of digital construction is bolstered by national efforts such the Construction 4.0 Strategic Plan (CIDB Malaysia, 2022) and the Twelfth Malaysia Plan (Economic Planning Unit, 2021). Nonetheless, the level of adoption remains inconsistent. Although advancements are more apparent in Peninsular Malaysia, adoption in Sarawak is hindered by infrastructure constraints and insufficient knowledge among contractors. This gap highlights the necessity for customized frameworks that identify the particular challenges and possibilities influencing digital adoption in Sarawak's construction sector.

2.3 Internet of Things (IoT) in Construction

The Internet of Things (IoT) platform in construction comprises sensors, RFID tags, GPS systems, and cloud-based platforms that provide real-time oversight of site operations. These tools improve project visibility, automate environmental monitoring, and optimize inventory management (Chen et al., 2021). In addition to logistics, IoT applications have shown their use in monitoring concrete curing, tracking equipment usage, and enhancing labor safety (Wu et al., 2022). Recent studies emphasize the combination of IoT with digital twins and predictive analytics to enhance resource allocation and mitigate operational hazards (Xue et al., 2022; Zhao et al., 2023). Notwithstanding these worldwide developments, adoption in Malaysia is mainly confined to urban regions, whereas Sarawak continues to fall behind due to infrastructural deficiencies, elevated deployment expenses, and restricted technical proficiency among contractors. This disconnect highlights the necessity of developing localized adoption facilitators that can close the technology gap.

2.4 Smart Monitoring and Smart Management

Smart monitoring and management utilize linked digital technologies, mainly driven by AI and IoT, to supervise and enhance construction processes in real time. Intelligent monitoring facilitates ongoing data acquisition from sensors and devices, aiding in the oversight of structural integrity, conditions in the environment, and occupational safety (Li et al., 2023). Smart management employs this potential by incorporating data into decision-making systems that enhance project planning, resource allocation, and anticipatory risk management. Recent studies emphasize their contribution to enhancing productivity, sustainability results, and predictive decision-making in building projects (Ahmed et al., 2022; Chen et al., 2023).

In Sarawak, project supervision mostly depends on manual oversight, which is often labor-intensive, inconsistent, as well as open to errors. The implementation of smart monitoring and management may therefore decrease reliance on human oversight, enhance transparency, and reduce expenses while enhancing accountability and safety outcomes. The move to smart systems proves crucial for dealing with Sarawak's unique infrastructural and manpower concerns.

2.5 Construction Cost Optimization and Resource Utilization

Cost optimization in construction represents the use of techniques and technologies that reduce unnecessary costs while maintaining necessary quality and performance requirements. Resource utilization highlights the optimal use of workers, assets, equipment, and time to optimize production. AI and IoT play an important role in accomplishing these goals by enabling predictive planning, reducing waste, and reducing costly repairs (Zhou et al., 2022). Automated progress tracking and real-time equipment diagnostics enable contractors to detect inefficiencies immediately, minimize downtime, while improving material management. Recent research emphasizes the potential of AIoT systems to improve supply chain transparency, improve scheduling, and facilitate data-informed decision-making for more efficient project execution (Han et al., 2022; Wang et al., 2023).

In Sarawak, where several contractors work under tight budgetary margins and logistical limitations, such solutions might be very advantageous. The implementation of AI and IoT facilitates a reduction in operational costs and enhances resource allocation, enabling enterprises to maintain competitiveness while overcoming the structural constraints of the regional construction sector.

2.6 Gaps in Literature

Despite the growing interest in digital construction technologies in recent years, the majority of present research is focused on industrialized countries or urban areas of Malaysia. Research specifically investigating the usage of AI and IoT among contractors in Sarawak is few. Furthermore, previous models typically examine technology and organizational aspects in isolation, neglecting contextual enhancers like governmental support. Limited research investigates the combined effect of smart technologies on cost and resource-related outcomes, leading to a theoretical gap about the relationship of adoption factors with broader institutional environments.

Digital adoption patterns in Malaysia demonstrate significant variations between Peninsular Malaysia and Sarawak. For instance, whereas research by Yong and Mustaffa (2022) focuses national policies for digital transformation, it overlooks to address regional disparities in infrastructure and technological capability. Sarawak contractors have structural disadvantages relative to their competitors in Kuala Lumpur or Johor, such as inadequate digital infrastructure and a restricted labor preparedness. Globally, research often highlights advanced uses of AI and IoT in highly digitized markets (Jin et al., 2023; Wu et al., 2022), although these findings are not easily applicable to Sarawak, where digital maturity is limited.

This highlights the necessity for a context-sensitive approach that integrates technical, organizational, and environmental adoption variables, while also recognizing government action as a crucial facilitator. This approach may connect worldwide best practices with the specific circumstances of Sarawak's building environment, offering both theoretical enhancement and practical significance.

2.7 Proposed Conceptual Framework

This study offers a conceptual framework that integrates the Diffusion of Innovation (DOI) theory with the Technology–Organization–Environment (TOE) framework, informed by the examined literature and identified research gaps. The integration of both theories for a thorough analysis of individual perceptions of innovation (DOI) with the wider organizational and environmental settings affecting adoption (TOE). Within this framework, five adoption factors perceived utility, perceived simplicity of use, technological compatibility, organizational preparation, and external pressure are posited to affect the adoption of AI and IoT technologies in the construction sector.

Government support is established as a mediating variable, indicating its essential role in providing digital infrastructure, regulatory incentives, and monetary incentives to accelerate adoption in Sarawak. The dependent variables, construction cost optimization and resource usage efficiency, signify crucial outcomes that directly influence project performance and competitiveness. The framework addresses Sarawak's distinct infrastructural and organizational difficulties by contextualizing these linkages, so offering a foundation for theoretical development and practical policy suggestions.

Construct	Definition	Supporting Literature	Expected Impact on Outcomes
Perceived Usefulness	The degree to which contractors believe AIoT adoption will improve cost and resource efficiency.	Rogers (1995); Kumar et al. (2023)	Strongly enhances adoption likelihood, leading to measurable cost savings and improved resource utilization.
Perceived Ease of Use	The extent to which AIoT systems are perceived as user-friendly and simple to implement.	Tornatzky & Fleischer (1990); Sharma et al. (2021)	Increases user acceptance, reduces training barriers, and accelerates adoption.
Technological Compatibility	The alignment of AIoT with existing workflows, systems, and infrastructure.	Ghosh et al. (2021); Zhou et al. (2022)	Facilitates smoother integration, minimizing resistance and reducing implementation costs.
Organizational Readiness	The internal capacity of firms in terms of skills, funding, and leadership support.	Abioye et al. (2021); Zawawi et al. (2022)	Determines firms' ability to adopt, sustain, and scale AIoT solutions effectively.
External Pressure	Industry, client, or regulatory	Yoon & George	Encourages adoption to

	pressures that influence adoption decisions.	(2020); Yong & Mustaffa (2022)	remain competitive and compliant with industry standards.
Government Support (Mediator)	Policy, infrastructure, and financial incentives enabling AIoT adoption.	CIDB Malaysia (2022); Economic Planning Unit (2021)	Strengthens the impact of adoption factors on performance outcomes by reducing financial and infrastructural barriers.

2.8 Theoretical Foundations

The proposed theoretical structure is founded on two existing models: the Diffusion of Innovation (DOI) theory and the Technology–Organization–Environment (TOE) framework. The DOI theory, formulated by Rogers (1995), emphasizes the impact of perceived usefulness, ease of use, and comparative advantage, on the adoption of innovations. It has been extensively utilized in technology adoption research because of its capacity to convey individual and organizational views regarding innovation (Venkatesh et al., 2012). In the realm of construction, DOI is crucial for comprehending how contractors assess the advantages and obstacles of integrating AI and IoT technology.

The TOE framework, created by Tornatzky and Fleischer (1990), enhances DOI by including the wider contextual factors of adoption. It encompasses three domains: digital readiness, organizational capability, and environmental impacts. TOE is particularly advantageous for examining adoption in sectors where external factors like policy, regulation, and competition in the market are essential (Oliveira & Martins, 2011). This study situates government support within the environmental dimension of the TOE framework, highlighting its role as a crucial facilitator via infrastructure development, financial incentives, and regulatory alignment.

DOI and TOE together provide a thorough theoretical framework that encompasses both the internal views of contractors and the external institutional factors influencing adoption. Previous studies validate the predictive efficacy of these frameworks in revealing adoption behavior in the construction sector and other sectors (Gangwar et al., 2015; Abubakar et al., 2019). This study enhances current theories by including DOI and TOE, with government support serving as a mediating element, within the distinctive setting of Sarawak's construction industry. This integration not only resolves shortcomings in previous adoption models but also establishes a solid basis for empirical evaluation of AIoT adoption results.

2.9 Future Research Directions

The conceptual framework presented in the present paper should be experimentally validated in the Sarawak construction sector as the main subject of future research. A quantitative survey methodology may be utilized, focusing on small and medium-sized contractors, with structural equation modeling (SEM) applied to evaluate the proposed correlations among adoption variables, governmental support, and performance results. Supplementary qualitative research, including interviews with politicians and industry executives, may yield profound insights into the contextual facilitators and obstacles affecting AIoT implementation.

In addition to single-region validation, comparative analyses involving Sarawak, other Malaysian states, and specific ASEAN nations might evaluate the framework's applicability across varied infrastructural and policy contexts. This cross-regional analysis would clarify whether governmental support uniformly impacts adoption outcomes or if its effects vary by circumstance. Furthermore, longitudinal studies might monitor adoption trends over time, therefore improving the predictive validity of the framework and producing evidence-based recommendations for practitioners and policymakers.

3. CONCLUSION

The proposed theoretical structure holds several implications for study, practice, and policy. It offers academics an organized framework to investigate the impact of AIoT adoption on building performance in emerging countries, hence broadening the application of DOI and TOE theories to fresh cases. The approach emphasizes that contractors in Sarawak may utilize adoption criteria including perceived usefulness, organizational preparedness, and technological compatibility to achieve significant enhancements in cost optimization and resource efficiency. Policymakers must recognize that government support necessitates focused digital incentives, workforce training, and infrastructure investment, which are strongly aligned with Sarawak's Post-COVID-19 Development Strategy (PCDS 2030).

This study develops an innovative conceptual framework that combines the Diffusion of Innovations (DOI) and Technology-Organization-Environment (TOE) models, using government support as a mediating variable to explain the adoption of AIoT in Sarawak's construction industry. By addressing both adoption factors and contextual facilitators, the approach addresses an important gap in the literature and establishes a basis for future empirical verification. Their distinctive contribution is the following: (1) expanding the DOI and TOE frameworks to a developing regional context, (2) incorporating government support as a mediating variable, and (3) situating AIoT adoption within Sarawak's construction sector, where infrastructural constraints and policy measures are crucial. This conceptual paper suggests future research to empirically validate and enhance the framework in Sarawak and other developing regions, thereby advancing theoretical comprehension and practical strategies for digital transformation in construction.

REFERENCES

Abioye, S. O., Aigbavboa, C. O., & Thwala, W. D. (2021). Digitalization in construction: A review of barriers and drivers. *Journal of Engineering, Design and Technology, 19*(5), 1215–1235. https://doi.org/10.1108/JEDT-10-2020-0412

Abubakar, A. M., Behravesh, E., Rezapouraghdam, H., & Yildiz, S. B. (2019). Applying diffusion of innovation theory to adoption of information technology in SMEs. *Journal of Small Business and Enterprise Development, 26*(5), 663–683. https://doi.org/10.1108/JSBED-12-2018-0375

Ahmed, S., Arocho, I., & Golizadeh, H. (2022). Smart construction technologies: Applications of AI and IoT for sustainable project delivery. *Automation in Construction, 141*, 104480. https://doi.org/10.1016/j.autcon.2022.104480

Chen, J., Zhang, X., & Zhang, Y. (2021). IoT applications in construction site management: A review. *Automation in Construction, 127*, 103742. https://doi.org/10.1016/j.autcon.2021.103742

Chen, Y., Xu, J., & Zhang, L. (2023). Real-time smart monitoring and management in construction: A review of AIoT applications. *Journal of Building Engineering, 70*, 106600. https://doi.org/10.1016/j.jobe.2023.106600

CIDB Malaysia. (2022). *Construction 4.0 Strategic Plan 2021–2025*. Construction Industry Development Board Malaysia.

Economic Planning Unit. (2021). *Twelfth Malaysia Plan 2021–2025*. Prime Minister's Department, Malaysia.

Gangwar, H., Date, H., & Ramaswamy, R. (2015). Understanding determinants of cloud computing adoption using an integrated TOE–DOI framework. *Journal of Enterprise Information Management, 28*(1), 107–130. https://doi.org/10.1108/JEIM-08-2013-0065

Ghosh, R., Kankanhalli, A., & Chi, L. (2021). Understanding the adoption of AI in project management: A resource-based view. *International Journal of Project Management, 39*(6), 567–581. https://doi.org/10.1016/j.ijproman.2021.03.004

Han, Y., Zhang, X., & Chen, Y. (2022). Leveraging AI and IoT for construction cost and resource optimization: A systematic review. *Automation in Construction, 139*, 104379. https://doi.org/10.1016/j.autcon.2022.104379

Jin, R., Gao, S., & Li, B. (2023). Digital transformation in construction: A review of research trends and future directions. *Journal of Building Engineering, 65*, 105725. https://doi.org/10.1016/j.jobe.2022.105725

Kumar, A., Anis, A., & Ahmad, T. (2023). Artificial intelligence in construction: A state-of-the-art review and future research directions. *Automation in Construction, 148*, 104743. https://doi.org/10.1016/j.autcon.2023.104743

Li, H., Lu, M., & Wong, C. T. C. (2023). Leveraging AI and IoT for integrated construction management: A case review. *Journal of Construction Engineering and Management, 149*(2), 04022129. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002241

Oliveira, T., & Martins, M. F. (2011). Literature review of information technology adoption models at firm level. *Electronic Journal of Information Systems Evaluation, 14*(1), 110–121.

Pan, Y., & Zhang, L. (2022). Roles of artificial intelligence in construction engineering and management: A critical review and future trends. *Automation in Construction, 134*, 104076. https://doi.org/10.1016/j.autcon.2021.104076

Rogers, E. M. (1995). *Diffusion of innovations* (4th ed.). Free Press.

Sharma, A., Kumar, N., & Singh, R. (2021). Use of AI in construction safety: A review. *Safety Science, 139*, 105246. https://doi.org/10.1016/j.ssci.2021.105246

Tornatzky, L. G., & Fleischer, M. (1990). *The processes of technological innovation*. Lexington Books.

Venkatesh, V., Thong, J. Y., & Xu, X. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology (UTAUT2). *MIS Quarterly, 36*(1), 157–178. https://doi.org/10.2307/41410412

Wang, J., Li, H., & Xu, Y. (2023). AIoT-enabled lean construction: Cost reduction and resource efficiency in practice. *Journal of Cleaner Production, 389*, 136223. https://doi.org/10.1016/j.jclepro.2023.136223

Wu, Y., Luo, H., & Yang, Y. (2022). IoT-enabled construction resource tracking: Trends and applications. *Automation in Construction, 135*, 104120. https://doi.org/10.1016/j.autcon.2022.104120

Xue, F., Lu, W., & Chen, K. (2022). Internet of Things for construction management: Applications, challenges, and future directions. *Automation in Construction, 140*, 104391. https://doi.org/10.1016/j.autcon.2022.104391

Yong, Y. C., & Mustaffa, N. E. (2022). Digital transformation in Malaysia's construction industry: Challenges and strategies. *Malaysian Construction Research Journal, 10*(2), 23–35.

Yoon, T. E., & George, J. F. (2020). Why aren't organizations adopting cloud services? A country-level comparative study. *Information & Management, 57*(1), 103126. https://doi.org/10.1016/j.im.2018.06.003

Zawawi, N. A. W. A., Rahman, H. A., & Ahmad, M. S. (2022). The adoption of digital technologies in the Malaysian construction industry: A survey of readiness and barriers. *Built Environment Journal, 19*(1), 1–14.

Zhang, J., Li, H., & Wang, J. (2023). Artificial intelligence for construction safety management: Recent advances and future perspectives. *Journal of Building Engineering, 68,* 106250. https://doi.org/10.1016/j.jobe.2023.106250

Zhao, X., Tang, L., & Yang, H. (2023). Leveraging IoT and digital twins for sustainable construction resource management. *Journal of Cleaner Production, 389,* 136101. https://doi.org/10.1016/j.jclepro.2023.136101

Zhou, Y., Zhang, Y., & Li, M. (2022). Artificial intelligence in construction management: Applications and future directions. *Engineering, Construction and Architectural Management, 29*(2), 489–507. https://doi.org/10.1108/ECAM-08-2020-0608

