

Digital Transformation in Malaysia's Construction Industry: Challenges in Implementing IR 4.0 Technologies

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ABSTRACT

The Fourth Industrial Revolution (IR 4.0) introduces twelve (12) core digital technologies aimed at improving productivity, safety, and sustainability in the construction sector. However, the pace of adoption in Malaysia remains slower compared to other industries, raising questions about industry readiness and implementation barriers. Therefore, this study investigates the familiarity, implementation levels, and key challenges associated with all twelve technologies identified in CIDB's Construction 4.0 Strategic Plan (2021–2025). A mixed-methods approach was adopted, combining a quantitative survey of 73 Grade G7 contractors with structured interviews involving three (3) senior construction experts. The survey captured contractors' awareness and implementation levels, while the interviews provided contextual insights and validation of the quantitative findings. Results reveal that Building Information Modelling (BIM), Big Data, and the Internet of Things (IoT) are relatively mature, demonstrating high familiarity and moderate implementation. In contrast, technologies such as Blockchain, Augmented Reality (AR) and Virtualisation Reality (VR), and Autonomous Construction remain in early implementation stages with limited practical use. The study identifies high initial costs, workforce skill gaps, interoperability issues, resistance to change, and policy limitations as the main barriers. The paper suggests customized training, financial and policy incentives, standardisation efforts, and stronger collaboration among stakeholders to broaden acceptance. The findings provide a structured framework of high, moderate, and low adoption categories, offering valuable implications for policymakers, contractors, and training institutions to accelerate digital transformation and enhance Malaysia's competitiveness in the global construction industry.

Keywords: Industrial Revolution 4.0 (IR 4.0); digitalization technologies; technology adoption challenges

INTRODUCTION

The Fourth Industrial Revolution (IR 4.0) is transforming industries worldwide, including construction. It involves the integration of advanced digital technologies, particularly the twelve key technologies outlined in CIDB's Construction 4.0 Strategic Plan (2021–2025), such as Building Information Modelling (BIM), Artificial Intelligence (AI), the Internet of Things (IoT), Blockchain, Big Data and

Predictive Analytics, Cloud and Real-Time Collaboration, 3D Printing and Additive Manufacturing, Augmented Reality (AR) and Virtual Reality (VR), Autonomous Construction, Prefabrication and Modular Construction, 3D Scanning and Photogrammetry, and Advanced Building Materials (Schwab 2017; CIDB 2022a). These technologies offer opportunities to enhance efficiency, safety, sustainability, and competitiveness (CIDB 2022a; Anak Sajat 2024).

Despite these benefits, adoption in Malaysia's construction industry remains moderate, with contractors facing high entry costs, limited digital skills, interoperability issues, and organisational inertia (Abdul Samad et al. 2024; Ahmad Sekak et al. 2022; Jaafar et al. 2024; Tayib et al. 2023; Wei 2024; Almatari et al. 2024). Traditional practices continue, leading to inefficiencies, errors, and delays, limiting the industry's modernisation and global competitiveness (Tayyib et al. 2022; Md Arif et al. 2022; Masram et al. 2024). As a result, the construction industry struggles to match its digitalisation progress with other sectors, limiting its modernisation and ability to compete globally. These challenges highlight the need to investigate the barriers hindering adoption and guide strategies for digital transformation.

Most prior studies have focused on developed countries (Won et al. 2022; Li et al. 2023; Oke et al. 2023) or on individual technologies like BIM or IoT (Alawag et al. 2021; Tayib et al. 2023). In Malaysia, Jaafar et al. (2024) assessed awareness and adoption of all twelve IR 4.0 technologies but mainly relied on quantitative data, offering limited insight into underlying challenges. Research examining all twelve technologies holistically, particularly from the perspective of G7 contractors involved in large-scale projects, remains scarce. Moreover, few studies combine quantitative breadth with qualitative depth through a mixed-methods approach. This study addresses these gaps by investigating familiarity, implementation levels, and challenges associated with IR 4.0 adoption among G7 contractors in Malaysia.

The findings are expected to support national initiatives such as CIDB's Construction 4.0 Strategic Plan (2021–2025) and the Twelfth Malaysia Plan, while offering practical implications for contractors aiming to improve competitiveness and resilience. The paper proceeds with a review of related studies, outlines the research methodology, presents findings and analysis, and concludes with implications, recommendations, and directions for future practice and policy.

LITERATURE REVIEW

OVERVIEW OF INDUSTRIAL REVOLUTION 4.0 (IR 4.0)

The Fourth Industrial Revolution (IR 4.0) represents a transformation from mechanisation and electrification to cyber-physical integration, interconnectivity, and automation across industries (Schwab, 2017; Liao et al. 2017; Aoun et al. 2021). In construction, IR 4.0 shifts traditional labour-intensive practices towards technology- and data-driven approaches, promising enhanced

productivity, safety, and sustainability (Alaloul et al. 2020; Abdul Samad et al. 2024).

Globally, digital adoption varies. Developed countries benefit from top-down enforcement, incentives, and structured frameworks, enabling measurable improvements in project coordination, monitoring, and predictive maintenance (Wang et al. 2020; Musarat et al. 2024). Conversely, developing countries, including Malaysia, face fragmented adoption due to project-based structures, uneven digital readiness, and limited cross-sector collaboration (Jaiswal et al. 2024; Almatari et al. 2024).

In Malaysia, the Construction Industry Development Board (CIDB) introduced the Construction 4.0 Strategic Plan (2021–2025), highlighting twelve key technologies and aligning with international initiatives such as those in the UK and Singapore (CIDB 2022a; European Commission 2021; Singapore Government 2022). Despite a strong policy foundation, implementation is inconsistent, reflecting gaps between strategic vision and practical adoption (CIDB 2024b; Romeli et al. 2024; Musarat et al. 2024). Contractors, particularly large-scale G7 companies, show interest in digital technologies, yet actual adoption remains limited by costs, training, interoperability, and change management challenges (Ahmad Sekak et al. 2022; Tayib et al. 2023; Jaafar et al. 2024; Jaafar et al. 2025).

Effective adoption requires not only technological readiness but also policy-based incentives, partner ecosystems, and continuous professional education (Mansour et al. 2023; Khudzari et al. 2025; Anak Sajat et al. 2024). Current literature largely focuses on developed countries or isolated technologies, leaving a research gap in Malaysia for holistic, mixed-methods studies covering all twelve IR 4.0 technologies.

This study aims to address this gap by examining familiarity, implementation levels, and challenges associated with IR 4.0 adoption among G7 contractors in Malaysia. The findings are expected to provide actionable insights for practitioners, policymakers, and academic institutions, supporting a more innovative, competitive, and sustainable construction industry.

DIGITALIZATION TECHNOLOGIES IN IR 4.0

The integration of Industry 4.0 digital technologies is a key driver in transforming Malaysia's construction industry towards greater productivity, efficiency, and sustainability. Recognising this potential, the Malaysian CIDB formulated the Construction 4.0 Strategic Plan (2021–2025), which identifies twelve core technologies as essential enablers of digital transformation (CIDB, 2022a; CIDB, 2024a).

Building on these foundations, this study synthesises existing literature and classifies the twelve technologies into four analytical categories: (i) design and modelling tools, (ii) automation and robotics, (iii) data-driven analytics, and (iv) advanced construction materials.

While previous research has discussed these technologies individually, empirical findings indicate uneven levels of adoption and diverse implementation challenges across technology types and firm scales. The following subsections critically examine each category, integrating and comparing findings from multiple studies to reveal current trends, barriers, and research gaps in Malaysia's Construction 4.0 landscape.

1. Design and Modelling Tools

- a. Building Information Modelling (BIM) has consistently emerged as the most mature IR 4.0 technology within Malaysia's construction sector. Studies show broad familiarity and policy support, yet practical adoption remains uneven (Tanko et al. 2024; Zulkifli et al. 2023). While large firms integrate BIM into coordination and clash detection, SMEs struggle with high software costs and limited data integration (Raman and Husain, 2025; Ern et al. 2022). This aligns with Waqar et al. (2023b), who reported interoperability and collaboration issues that hinder wider diffusion. The contrast between policy targets in the CIDB's BIM Roadmap (2021–2025) and on-the-ground capability indicates that BIM adoption is not constrained by awareness, but by organisational readiness and cost structures.
- b. Augmented Reality (AR) and Virtual Reality (VR) have been widely recognised for improving project visualization, training, and safety management (Wen, 2023; Mekudishvili, 2025). Yet, despite positive perceptions, adoption remains minimal due to high equipment costs and lack of integration with BIM workflows (Tayib et al. 2023; Jaafar et al. 2024). Comparative studies reveal that, unlike BIM, AR and VR technologies in Malaysia are still experimental. This divergence reflects a maturity gap, suggesting that without targeted training and financial support, AR/VR will remain peripheral tools rather than core project platforms.
- c. 3D Scanning and Photogrammetry technologies provide high-precision digital models supporting BIM workflows and site monitoring (Dixit et al. 2019; Jaafar et al. 2024). However, their use is

hindered by the need for specialised personnel and data-heavy processing (Tayib et al. 2023). While these technologies are successfully applied in large-scale projects globally, their Malaysian uptake is inconsistent, indicating structural gaps in training and integration frameworks. Comparatively, BIM adoption has benefited from national policy support, something still lacking for 3D scanning tools.

Taken together, these three tools demonstrate a hierarchy of maturity: BIM at a semi-mainstream stage, AR and VR at an emerging stage, and 3D scanning at a niche stage. The critical barrier across all is not awareness but capability alignment - financial, technical, and human resource capacities remain uneven across firm categories.

2 Automation and Robotics

- a. Autonomous construction, encompassing robotics and unmanned machinery, offers transformative potential in improving safety and efficiency. However, its adoption remains limited in Malaysia, primarily due to high capital costs, technical complexity, and regulatory uncertainty (Delgado et al. 2019; Yusof et al. 2023; Oke et al. 2024). Unlike manufacturing, where robotic applications are standardised, construction lacks unified safety and governance frameworks (Pradhananga et al. 2021). These findings reveal that technological feasibility does not guarantee adoption; institutional readiness and trust play a decisive role.
- b. 3D printing and additive manufacturing provide a pathway for automation in housing and prefabrication. Yet, local implementation remains largely experimental due to high costs, lack of material standards, and insufficient technical expertise (Samsudin et al. 2023; Jalil et al. 2025). Comparative analyses highlight that while Singapore's R&D incentives have supported trial-scale projects (Won et al. 2022), Malaysia's progress remains incremental and policy-driven (Jaafar et al. 2024). This suggests a clear implementation gap between regional counterparts despite similar awareness levels.
- c. Prefabrication and modular construction improve speed, quality, and sustainability but face persistent logistical and cultural challenges. While adoption in affordable housing projects shows promise, widespread use is hampered by integration difficulties, supply chain limitations,

and skill shortages (Aziz et al. 2019; Yi, 2023; Almatari et al. 2023). In comparison with Japan and Singapore, where industrialised construction has become mainstream (European Commission, 2021; Singapore Government, 2022), Malaysia remains in a transition phase. Collectively, these studies indicate that while automation technologies are technically viable, their adoption is restricted by institutional inertia, fragmented supply chains, and inconsistent policy incentives.

3. Data-driven Analytics

- a. Artificial Intelligence (AI) supports predictive maintenance, quality control, and scheduling (Mohamed et al. 2021; Omar et al. 2022). Although Malaysian firms recognise AI's potential, adoption remains limited due to high costs, skill gaps, and data privacy concerns (Hilmy et al. 2024). Comparatively, developed economies have already embedded AI in safety monitoring and project management systems. The contrast suggests that Malaysia's adoption is exploratory rather than operational—reflecting institutional caution rather than technological unreadiness.
- b. Big Data and Predictive Analytics provide real-time insights for risk management and resource optimisation (Li et al. 2023; Jamarani et al. 2024). Yet, fragmented databases and lack of analytical capacity prevent effective utilisation (Razali et al. 2021; Ariffin et al. 2023). When compared with international studies where data-driven decisions enhance productivity, Malaysia's challenges reveal a gap between data collection and analytical translation, indicating that digital maturity is still at a formative stage.
- c. Internet of Things (IoT) enables real-time monitoring of equipment and workforce safety (Ibrahim et al. 2021). However, studies consistently highlight infrastructural deficiencies, compatibility issues with legacy systems, and cybersecurity concerns (Khouluddin et al. 2023; Manege et al. 2024). The contrast between Malaysia's pilot-scale applications and global smart-site systems reinforces the view that IoT adoption remains more aspirational than operational.
- d. Blockchain offers secure, transparent systems for payment, contract management, and supply chain traceability (Waqar et al. 2024; Tohfa

et al. 2025). Yet, despite theoretical interest, practical implementation is scarce. The lack of regulatory clarity, along with high costs and limited technical expertise create hesitation, particularly among SMEs (Waqar et al. 2024). This demonstrates a conceptual–practical gap similar to early BIM adoption phases a decade ago, signalling that policy incentives and pilot testing are crucial for blockchain diffusion.

- e. Cloud and Real-Time Collaboration Tools enhance accessibility and decision-making by enabling shared project data. However, Malaysian firms report challenges such as high subscription costs, security risk, and dependency on internet reliability (Sukiman, 2020; Fateh et al. 2024). A comparison with Singapore, where digital collaboration platforms have become the norm (Won et al. 2022), highlights that Malaysia's progress remains incremental, reflecting both infrastructural and behavioural limitations.

4. Advanced Materials

- a. Advanced building materials, such as nanomaterials, self-healing concrete, and recycled composites promise greater durability and sustainability (Sharma & Sharma, 2022; Shukla & Kaul, 2025). However, adoption is limited by high costs, limited availability, and the absence of regulatory guidelines. While global research has reported pilot-scale success in Europe and East Asia, Malaysian uptake remains slow. This reveals a broader issue: technological innovation in materials science is progressing faster than the regulatory and market frameworks required for implementation. The slow adoption of these materials underscores the need for stronger collaboration between policymakers, researchers, and industry players to bridge the innovation–practice divide.

Table 1 provides an integrated overview of the twelve (12) IR 4.0 digital technologies in Malaysia's construction sector, summarising their functions, challenges, and key references. Although each technology faces unique barriers, recurring issues such as high capital costs, skills shortages, and integration challenges with legacy systems reveal systemic constraints across the industry. These interrelated challenges are examined further in the subsequent section, which analyses the overarching factors influencing the implementation of IR 4.0 technologies in Malaysia's construction sector.

TABLE 1. Twelve IR 4.0 Technologies: Functions and Challenges in Malaysian Construction

Category	Technology	Main Function	Key Challenges in Malaysia	Reference
Design & Modelling	BIM	Integrates design, construction, and operations; enables collaboration and clash detection	High initial cost, skills gap, interoperability issues	Jaafar et al. 2024; CIDB, 2024a; Mohamed et al. 2021; Omar et al. 2022; Hilmy et al. 2024; Zulkiffi et al. (2023)
	AR & VR	Real-time visualization, immersive simulations, safety training	High equipment cost, technical expertise, poor system integration	Tayib et al. 2023; Jaafar et al. 2024
	3D Scanning & Photogrammetry	Generate accurate digital models for as-built verification and site monitoring	High equipment cost, skilled personnel shortage, large data storage needs	Dixit et al. 2019; Tayib et al. 2023; Jaafar et al. 2024
Automation & Robotics	Autonomous Construction	Robotics and unmanned machinery to perform repetitive or hazardous tasks	High capital cost, technical complexity, regulatory uncertainty, low trust, industry fragmentation, lack of standardization	Delgado et al. 2019; Amir et al. 2023; Yusof et al. 2023; Pradhananga et al. 2021; Oke et al. 2024).
	3D Printing & Additive Manufacturing	Automated fabrication of building components, reduced waste and labour	High setup cost, absence of material standards, lack of design codes, lack of technical skills, and industry/society acceptance	Kuppusamy et al. 2023; Samsudin et al. 2023; Waqar et al. 2023a; Jalil et al. 2025; Jaafar et al. 2024
	Prefabrication & Modular Construction	Off-site manufacturing for faster, safer, and sustainable construction	High investment cost, logistics, integration with traditional methods, supply chain constraints, lack of skills & acceptance.	Almatari et al. 2023; Tayib et al. 2023; Jaafar et al. 2024; Yi 2023; Eng & Zainal, 2021; Aziz et al. 2019
	Artificial Intelligence (AI)	Predictive maintenance, risk management, quality control & optimisation	High implementation costs, lack of awareness and digital skills, data privacy and cybersecurity	Mohamed et al. 2021; Omar et al. 2022; Hilmy et al. 2024
Data & Analytics	Big Data & Predictive Analytics	Analyze structured/unstructured data for decision-making, optimize resources, predict risks	Data fragmentation, privacy issues, shortage of qualified analysts	Razali et al. 2021; Ariffin et al. 2023; Li et al. 2023; Jamarani et al. 2024; Jaafar et al. 2024
	IoT	Real-time monitoring of workers, equipment, and environment	Network infrastructure gaps, legacy systems, cybersecurity risks & lack of skills & acceptance	Ibrahim et al. 2021; Khouluddin et al. 2023; Manege et al. 2024; Jaafar et al. 2024
	Blockchain	Secure, decentralized transaction recording, smart contracts	High cost, knowledge gap, lack of regulation, legacy integration	Waqar et al. 2024; Tohfa et al. 2025; Tayib et al. 2023; Jaafar et al. 2024
Advanced Materials	Cloud & Real-Time Collaboration	Enables simultaneous data access and updates, improves coordination	Internet dependency, data security, subscription cost, low acceptance level	Sukiman, 2020; Won et al. 2022; Fateh et al. 2024; Jaafar et al. 2024
	Advanced Building Materials	Enhances durability, energy efficiency and sustainability	High cost, limited local availability, lack of standardization & usage guidelines, technical integration with existing building	Sharma & Sharma, 2022; Shukla & Kaul, 2025; Tayib et al. 2023; Jaafar et al. 2024

CHALLENGES IN THE IMPLEMENTATION OF IR 4.0 IN THE CONSTRUCTION INDUSTRY

Despite its transformative potential, the adoption of IR 4.0 technologies in Malaysia's construction industry remains slow due to several interrelated challenges. The key challenges identified include fragmented technological integration, high initial investment costs, workforce skill gaps, resistance to organisational change, and policy or regulatory limitations (Musarat et al. 2024; Jaafar et al. 2024; CIDB, 2022a–b; Alaloul et al. 2020; Almatari et al. 2024; Mohd Nasir et al. 2024; Siddiqui et al. 2023). These challenges are widely recognised, yet studies vary in their assessment of which factors exert the greatest influence, indicating uneven readiness across firm sizes and project types.

1. Technological Integration

Integrating BIM, IoT, and AI into existing legacy systems remains difficult. Most studies (Musarat et al. 2024; Jaafar et al. 2024) report fragmented workflows and poor interoperability, consistent with earlier observations by Alaloul et al. (2020). However, Ern et al. (2024) note emerging pilot projects that demonstrate partial integration success through cloud-based data sharing, suggesting progress but limited scalability. These mixed findings highlight that Malaysia's integration issue is structural rather than technical, being rooted in non-standardised data formats and isolated system development.

2. High Initial Investment Costs

Most researchers agree that the financial burden is the strongest deterrent to digital adoption (CIDB, 2022a–b; Jaafar et al. 2024; Almatari et al. 2024), particularly for SMEs. While Tayib et al. (2022) identify capital cost and software licensing as primary barriers, Almatari et al. (2024) add that weak fiscal incentives worsen the problem. Few studies, however, assess cost–benefit ratios or long-term ROI, revealing a gap in understanding the economic feasibility of IR 4.0 investments.

3. Skills Gap

Skills deficiencies remain a general barrier. Musarat et al. (2024) and Siddiqui et al. (2023) link low adoption to inadequate digital competencies, while Adepoju and Aigbavboa (2021) show that this challenge is global but exacerbated locally by minimal digital content in higher-education curricula. Compared

to countries with compulsory BIM or IoT training, Malaysia's upskilling efforts remain voluntary, highlighting a gap between policy intent and workforce preparedness.

4. Resistance to Change

Behavioural resistance continues to limit digital transformation. Most studies (Jaafar et al. 2024; Musarat et al. 2024) associate reluctance with risk aversion and entrenched work culture, whereas Mohd Nasir et al. (2024) emphasise leadership inertia and fear of workflow disruption. This contrast indicates that resistance stems both from managerial attitudes and institutional norms, reinforcing calls for structured change-management strategies and digital leadership development.

5. Policy and Regulatory Limitations

Although the CIDB Construction 4.0 Strategic Plan (2021–2025) sets a clear direction, its implementation is uneven (CIDB, 2022a–b; Musarat, 2024). Ahmad Sekak (2022) and Almatari (2024) highlight inconsistent enforcement and fragmented responsibilities between agencies, while CIDB (2022b) notes improvements through pilot initiatives and digital standardisation projects. These contrasting findings suggest that policy formulation has advanced faster than operational coordination.

In summary, existing literature shows broad agreement on the main barriers to IR 4.0 implementation but divergence in their relative severity and proposed solutions. This reveals a research gap in comparative analysis across contractor categories and technology types, an area that this study addresses through its mixed-methods examination of G7 contractors in Malaysia.

METHODOLOGY

RESEARCH DESIGN

This study employed a mixed-methods research design, integrating both quantitative and qualitative approaches to yield a comprehensive understanding of the adoption and challenges associated with Industry 4.0 digitalisation technologies in Malaysia's construction industry. The research design comprised a survey of G7 contractors and a series of structured interviews with industry experts, thus enhancing the robustness and increasing the validity of the findings (Creswell & Creswell, 2022).

The quantitative phase involved the distribution of structured questionnaires to contractors registered under Grade G7 with CIDB. The G7 contractors were chosen due to their ability to undertake large-scale projects, thus increasing the likelihood of engaging with Industry 4.0 technologies (Ahmad Sekak et al. 2022; Abdul-Samad et al. 2024).

The qualitative phase involved formal interviews with three senior construction project managers with extensive experience in digital implementation in both public and private sector projects. These interviews were developed based on the same set of constructs as the questionnaire to provide methodological consistency while allowing for a deeper understanding of context-specific issues, expert perspectives, and survey result validation (Ahmad Sekak et al. 2022).

The mixed-methods approach complements the generalisability of quantitative data with in-depth, practical insights from qualitative interviews, providing a well-rounded understanding of industry readiness and barriers (Creswell & Creswell, 2022).

DATA COLLECTION

QUANTITATIVE DATA COLLECTION

1. Sampling Strategy

The population of the study comprised 2,276 Grade G7 contractors operating in the Klang Valley, as recorded by the CIDB. Based on the Krejcie and Morgan (1970) criteria, a representative sample size for this population would be 327 contractors. A total of 73 valid responses were obtained through an online survey distributed over a four-week period, resulting in a 22% response rate. Such a percentage is regarded as sufficient in research within the built environment field, as low response rates of up to 14% have been considered adequate in the literature (Takim et al. 2004; Akintoye, 2000).

2. Instrument Design

The structured questionnaire comprised four main sections. Section A focused on demographic information, while Section B assessed the level of familiarity with IR 4.0 technologies. Section C examined implementation levels, with both Sections B and C employing a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Section D explored the challenges in adoption through open-ended items, allowing respondents to provide in-depth perspectives. To ensure clarity and reliability, the questionnaire was validated through expert evaluation and pilot testing.

3. Distribution Method

The questionnaire was distributed using Google Forms to facilitate easy access and real-time data capture. Respondents were invited via email invitations and professional networks. All responses were anonymised to protect confidentiality and uphold ethical research standards.

QUALITATIVE DATA COLLECTION

Three industry experts were interviewed using purposive sampling, based on the same thematic framework as the questionnaire. Although the interview questions were aligned with the survey instrument, the design allowed probing and clarification of responses. The experts were selected for their extensive experience with IR 4.0 technologies in the construction industry.

The interviews were conducted face-to-face, audio-recorded with consent, and manually transcribed. A thematic analysis approach, following Dawadi (2020), was employed to code responses and identify common patterns, enabling triangulation of the qualitative findings with the survey data (Khudzari et al. 2025; Lim, 2024).

DATA ANALYSIS

Data from the survey were analysed using the Statistical Package for the Social Sciences (SPSS) Version 26.0. The analysis was conducted in the following stages:

1. Descriptive Statistics

Descriptive statistics, including frequency, mean, and standard deviation, were used to summarise the demographic data, levels of technology adoption, and key challenges (Schwab 2017).

2. Reliability Test

The internal consistency of the survey instrument was assessed using Cronbach's alpha. A reliability coefficient of $\alpha = 0.968$ was obtained, indicating excellent internal reliability (Nunnally & Bernstein 1994).

3. Inferential Analysis

Comparative analyses based on mean and standard deviation were conducted to explore relationships between demographic factors (e.g., years of experience) and the adoption or perception of IR 4.0 technologies (Ahmad Sekak et al. 2022). While inferential statistical techniques such as regression or correlation analyses could provide deeper insights into variable relationships, this study emphasised identifying and describing adoption trends and barriers rather than predicting causal relationships. Nevertheless, the findings from this stage provide a foundational dataset for future studies employing more advanced inferential models.

4. Qualitative Analysis

A structured content analysis was carried out on the interview responses, which were aligned with the survey instrument. This approach enabled direct comparison and triangulation of findings from both data sources. Responses were reviewed for consistency, convergence, and divergence with the survey trends, focusing on key aspects such as technological readiness, cost challenges, and workforce skills.

5. Ethical Considerations

All participants were informed of the purpose of the study, and informed consent was obtained prior to data collection. Anonymity and confidentiality were maintained throughout the research process. Ethical clearance was obtained from the relevant university ethics committee.

This chapter outlined the mixed-methods approach adopted for the study. The combination of survey data and expert interviews provided a comprehensive understanding of the current state, challenges, and future directions of IR 4.0 technology adoption in Malaysia's construction industry. Overall, this methodological design is well-suited to exploratory research in emerging fields such as IR 4.0 in construction, where baseline data and contextual insights are equally critical. Future research could expand upon this foundation by applying regression analysis or structural equation modelling (SEM) to test hypothesised relationships among adoption factors, organisational readiness, and performance outcomes.

RESULTS AND DISCUSSION

The chapter presents the key findings from a quantitative survey of seventy-three (73) Grade G7 contractors and structured interviews with three (3) senior project managers. The analysis is structured around the study's research objectives, focusing on: (i) contractors' familiarity with Industry 4.0 (IR 4.0) technologies, (ii) their levels of implementation, and (iii) the challenges limiting effective adoption within Malaysia's construction industry.

An integrated analysis was conducted to compare contractors' familiarity with each technology against its actual application in practice. This dual-lens approach provides a clearer understanding of the industry's digital maturity and highlights critical gaps between awareness and implementation. To enhance interpretive depth and reliability, the quantitative findings generated using SPSS were triangulated with qualitative insights derived from expert interviews. This integration strengthens the validity of the results and provides a richer contextual understanding of IR 4.0 adoption trends in Malaysia's construction sector.

FAMILIARITY AND IMPLEMENTATION OF IR 4.0 TECHNOLOGIES IN THE MALAYSIAN CONSTRUCTION INDUSTRY

This section integrates findings from the survey and expert interviews to assess the familiarity with and implementation levels of twelve (12) key IR 4.0 technologies among G7 contractors in Malaysia. By analysing both awareness and actual usage, the study reveals not only which technologies are known and applied, but also why certain technologies remain underutilised. Table 2 and Figure 1 summarise the results by grouping the technologies into three categories of digital maturity:

1. High Familiarity – High Implementation
2. Moderate Familiarity – Moderate Implementation
3. Low Familiarity – Low Implementation

As illustrated in Figure 1, this three-tier framework provides a visual overview of digital maturity progression among Malaysian contractors. It also clarifies how each technology group aligns with Research Objective 1 (to determine familiarity with IR 4.0 technologies) and Research Objective 2 (to examine their level of implementation). Together, these results explain the depth of Malaysia's digital transformation and expose areas where awareness has yet to translate into adoption.

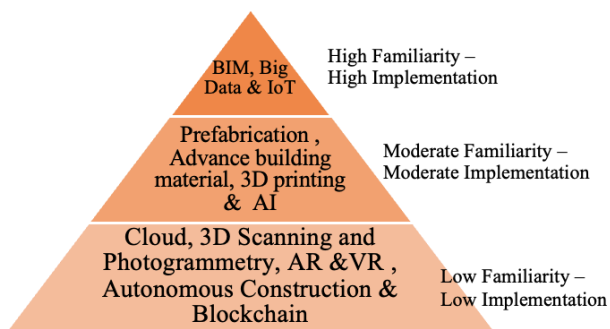


FIGURE 1. Three-Category Model of IR 4.0 Technology Adoption

1. High Familiarity – High Implementation

Technologies in this category are widely recognised and actively implemented by Malaysian G7 contractors, demonstrating strong digital maturity. BIM recorded the highest familiarity (mean = 4.20, SD = 0.95) and implementation (mean = 3.90, SD = 1.00), confirming its established role in project coordination, clash detection, and cost control (Ern et al. 2022; Fateh et al. 2024; Musarat et al. 2024; Jaafar et al. 2024). Likewise, Big Data and Predictive Analytics (mean familiarity = 4.18; mean implementation = 3.70) and IoT (mean familiarity = 4.10; mean implementation = 3.60) are becoming standard tools for data-driven decision-making and real-time monitoring (Musarat et al. 2024; Ibrahim et al. 2021).

Expert perspectives reinforce this pattern. Expert 1 explained that “BIM is successful because its main function directly supports project coordination, clash detection, and cost control, where contractors can see immediate benefits.” Expert 2 highlighted that IoT’s role in real-time monitoring of site safety, logistics, and equipment tracking makes it highly relevant to Malaysia’s fast-paced construction projects. Expert 3 described Big Data and predictive analytics as “tools that provide visibility and reduce uncertainty, which contractors increasingly value for tendering and risk management.”

These findings demonstrate that technologies offering clear functional benefits and measurable returns on investment (ROI) are more rapidly adopted. This directly supports Research Objectives 1 and 2 by illustrating how familiarity and implementation converge when tangible project efficiencies are realised. It also implies that government and industry initiatives, such as the CIDB Construction 4.0 Strategic Plan, are effectively driving adoption where policy alignment, skill readiness, and technological maturity coexist. This category thus sets a benchmark

for expanding successful adoption models to less mature technologies.

2. Moderate Familiarity–Moderate Implementation

Technologies in this category show moderate familiarity and practical usage among contractors, reflecting ongoing engagement but noticeable gaps in integration. AI, Prefabrication and Modular Construction, 3D Printing and Additive Manufacturing, and Advanced Building Materials fall into this group. Familiarity scores ranged from 3.70 to 4.00, while implementation scores were lower (3.10 to 3.50), highlighting the gap between awareness and deployment (Musarat et al. 2024; Jaafar et al. 2024; Alaloul et al. 2020). Contractors reported that the technical complexity of AI and 3D printing, combined with the need for specialised skills and high initial investment, hindered large-scale adoption (Almatari et al. 2024; Oke et al. 2024; Kuppusamy et al. 2023; Jalil et al. 2025). In contrast, prefabrication demonstrated more consistent implementation due to tangible efficiency and time-saving advantages.

Expert 2 noted that “AI is powerful in theory, but the industry struggles because its main function — predictive modelling and automation — requires large datasets and skilled data scientists, which are scarce locally.” Regarding 3D printing, Expert 1 explained that its main function of rapid prototyping and customised component production is attractive but that “the cost of equipment and lack of regulatory standards limit practical use.” Meanwhile, prefabrication was described by Expert 3 as “a proven technology where the benefits are clear — speed and cost reduction — but adoption is slowed by supply chain readiness and resistance to change.”

The moderate adoption of these technologies underscores the transitional stage of Malaysia’s digital maturity. This directly addresses Research Objective 2, showing that while familiarity is increasing, practical uptake is constrained by capability and cost barriers. These technologies represent the next frontier of adoption, requiring government-backed training, fiscal incentives, and demonstration projects to bridge the awareness–implementation gap. Addressing these mid-tier technologies effectively could accelerate the sector’s overall digital transformation trajectory.

3. Low Familiarity–Low Implementation

This category includes technologies that remain in the conceptual stage with limited practical application in Malaysia. Blockchain, Augmented Reality and Virtual Reality (AR & VR), Autonomous Construction, Cloud

and Real-Time Collaboration, and 3D Scanning and Photogrammetry recorded low implementation scores, ranging from 2.20 to 3.00, despite moderate familiarity in some cases (Musarat et al. 2024; Jaafar et al. 2024).

Expert 1 mentioned that “Blockchain’s main function is to ensure transparency and traceability in transactions, but contractors don’t see its immediate benefit compared with existing systems.” Expert 2 added that AR/VR tools offer design visualisation and immersive training potential, yet “hardware costs and content development remain barriers.” Expert 3 noted that “autonomous construction through robotics and drones faces cost–benefit issues given Malaysia’s reliance on low-cost labour.” Experts also agreed that

cloud collaboration, though beneficial, is hampered by data security and connectivity issues.

The low adoption of these technologies highlights early-stage digital diffusion, where both economic feasibility and regulatory clarity are weak. This outcome is significant for Research Objective 2, revealing that high familiarity does not guarantee implementation when perceived value and local readiness are low. The findings suggest that Malaysia’s construction industry requires foundational initiatives — pilot testing, awareness programmes, and cybersecurity frameworks — to normalise these technologies. Strengthening this bottom tier is vital to ensure balanced progress across all IR 4.0 categories and prevent digital inequality within the sector.

TABLE 2. Familiarity and Implementation Level of IR 4.0 Technologies (n = 100)

No	Technologies	Familiarities				Implementation Level			
		Mode	Mean	SD	Rank	Mode	Mean	SD	Rank
High Familiarity and High Adoption									
1	Building Information Modelling (BIM)	5	4.20	0.95	1	5	3.90	1.00	1
2	Big Data and Predictive Analytic	5	4.18	0.85	2	5	3.70	0.95	2
3	Internet of Things (IoT)	5	4.10	0.90	3	4	3.60	1.00	3
Moderate Familiarity and Implementation									
4	Prefabrication & Modular Construction	4	4.00	0.80	4	4	3.50	0.95	4
5	Advanced Building Materials	4	3.90	0.90	5	4	3.30	1.00	6
6	3D Printing & Additive Manufacturing	4	3.85	0.85	6	4	3.37	1.05	5
7	Artificial Intelligent (AI)	4	3.70	1.00	7	3	3.10	1.10	7
Low Familiarity and Implementation									
8	Cloud and Realtime Collaboration	4	3.65	1.00	8	3	3.00	0.90	8
9	3D Scanning and Photogrammetry	3	3.50	1.00	9	3	2.90	1.05	9
10	Augmented Reality & Virtualisation	3	3.40	1.10	10	3	2.70	1.20	10
11	Autonomous Construction	3	3.10	1.20	11	2	2.40	1.25	11
12	Blockchain	2	2.70	1.30	12	2	2.20	1.35	12

The results presented in Table 2 reveal a distinct digital maturity gradient across Malaysia’s construction sector. Technologies with high familiarity and implementation, such as BIM, IoT, and Big Data, reflect areas where policy alignment, skill readiness, and demonstrable return on ROI have supported successful digital transformation.

Meanwhile, those with moderate familiarity, including AI, 3D printing, and prefabrication, demonstrate growing engagement but remain hindered by technical complexity, cost, and skill limitations. Finally, low-familiarity technologies such as blockchain, AR/VR, and autonomous construction remain largely conceptual, constrained by

high capital requirements, fragmented regulation, and cultural inertia.

These findings directly address Research Objectives 1 and 2, showing that awareness alone does not guarantee adoption. Instead, the gap between familiarity and implementation underscores that digital transformation in Malaysia's construction sector is uneven progressing rapidly where institutional support, financial viability, and human capability align, but stagnating where these enabling conditions are weak.

From a strategic perspective, the three-category framework (Figure 1) serves as a diagnostic tool for policymakers, CIDB, and industry stakeholders to identify which technologies require targeted interventions such as fiscal incentives, training programs, or pilot projects. Moreover, this analytical synthesis bridges to Research Objective 3, which explores the underlying challenges constraining adoption. The subsequent chapter ("Challenges in Implementation") extends this discussion by examining the structural, organisational, and financial barriers that sustain the uneven digital maturity pattern observed here. Together, these analyses complete the logical progression from identifying adoption patterns to understanding their causal mechanisms and policy implications.

CHALLENGES IN IMPLEMENTATION OF IR 4.0 TECHNOLOGIES

While awareness of IR 4.0 technologies is growing in Malaysia's construction sector, actual implementation remains inconsistent. Survey shows strong familiarity and usage for technologies like BIM and Big Data, but significant underutilisation of others, including Blockchain, AR/VR, and Autonomous Construction. These gaps suggest the presence of barriers beyond awareness, affecting the industry's digital transformation (Alaloul et al. 2020; Jaafar et al. 2024; Musarat et al. 2024; Jaafar et al. 2025; Almatari et al. 2024).

This section identifies five key challenges that limit the effective adoption of IR 4.0 technologies, integrating both survey data and expert insights to establish a holistic interpretation aligned with Research Objectives 2 and 3.

1. Technological Integration Issues

One of the most persistent barriers to IR 4.0 implementation in Malaysia's construction industry is the difficulty of integrating new technologies into existing legacy systems. While contractors report high familiarity with tools such as BIM (mean = 4.20), IoT (4.10), and AI (3.70), their practical integration remains limited due to fragmented workflows, non-

standardised data formats, and poor interoperability between platforms (Alaloul et al. 2020; Ern et al. 2024; Tanko et al. 2024).

Expert interviews further confirmed that BIM, although widely used in design and tendering phases, often fails to interface with on-site management systems. Expert 1 stated, "We can design efficiently in BIM, but it stops there, linking it with site tools or procurement systems is still difficult." Expert 2 added that IoT integration is also constrained because "most contractors still depend on standalone systems without a shared data environment."

These findings reveal that integration challenges are not merely technical but structural, reflecting the fragmented nature of Malaysia's project delivery ecosystem. This directly supports Research Objective 3, demonstrating that without interoperability standards and cross-platform compatibility, even highly familiar technologies cannot deliver their intended productivity gains. Establishing a national-level digital integration protocol would therefore be essential to realise the full potential of IR 4.0 adoption in Malaysia's construction sector.

2. High Implementation Costs

High implementation costs remain one of the most continual barriers to IR 4.0 adoption in Malaysia's construction industry. The financial burden of purchasing software and hardware, upgrading digital infrastructure, and training personnel continues to weigh heavily, particularly on small and medium-sized enterprises. Survey results indicate that technologies such as AI and Cloud & Real-Time Collaboration exhibit moderate familiarity but considerably lower implementation, reflecting firms' reluctance to invest in tools with uncertain or delayed returns (Almatari et al. 2024; Mansour et al. 2023).

Expert interviews revealed that contractors perceive these investments as high-risk due to unclear ROI and limited policy incentives. These findings reinforce Research Objective 2, highlighting that the implementation gap is driven less by awareness and more by economic feasibility.

From a strategic standpoint, financial support mechanisms, such as tax incentives, digitalisation grants, and shared technology hubs, could substantially reduce entry barriers and accelerate industry-wide transformation. Aligning these supports with the CIDB Construction 4.0 Strategic Plan (2021–2025) would ensure that cost constraints no longer impede Malaysia's progress toward full digital adoption.

3. Skills Gap and Workforce Readiness

Limited technical skills remain a core challenge to IR 4.0 implementation. Contractors demonstrate moderate familiarity with AI (3.70) and IoT (4.10), yet actual implementation lags (3.10 for AI, 3.60 for IoT), reflecting insufficient workforce readiness. Traditional workflows persist in many firms, and personnel often lack proficiency in digital tools such as BIM, AI, and data analytics. Technologies with lower familiarity, including Blockchain and AR&VR, show even wider adoption gaps.

Expert interviews further confirmed that even when awareness exists, the absence of structured training and practical exposure prevents real adoption. This underscores the need for systematic training programs, upskilling initiatives, and closer collaboration between educational institutions and industry players to build a digitally competent workforce (Khudzari et al. 2025).

This finding directly supports Research Objective 3, demonstrating that human capital, not just technology, determines the success of digital transformation. Addressing this requires systematic capacity-building through technical upskilling, certification programmes, and academia–industry collaboration. Such initiatives would strengthen the talent pipeline envisioned in Malaysia’s Construction 4.0 Strategic Plan (2021–2025) and ensure sustainable digital readiness across all contractor categories.

4. Data Security and Cybersecurity Concerns

As construction processes become increasingly digitised, data security and privacy have become critical barriers to IR 4.0 adoption. Technologies like IoT, Cloud Collaboration, and BIM involve real-time data exchange, making them vulnerable to cyberattacks and unauthorised access.

Expert interviews revealed that most contractors lack robust cybersecurity frameworks, and the additional cost of securing digital systems discourages especially small enterprises. Lower implementation of Blockchain and AR & VR further reflects industry concerns about data integrity and system reliability (Aoun et al. 2021; Tohfa et al. 2025).

These findings are significant to Research Objective 3, as they show that digital trust is a prerequisite for successful technology implementation. Without reliable data protection mechanisms, even familiar tools remain underutilised. Strengthening cybersecurity governance, promoting awareness of cyber hygiene, and developing national-level standards for the construction sector are essential steps to

enhance confidence in digital collaboration platforms and sustain IR 4.0 transformation.

5. Organisational and Cultural Resistance

Cultural inertia remains a persistent barrier to IR 4.0 adoption. Although awareness of digital innovation is increasing, many contractors, particularly long-established firms, remain hesitant to abandon traditional workflows. This hesitation is reflected in the limited use of AI, AR/VR, and Autonomous Construction, which require new management approaches and workflow restructuring.

Expert interviews revealed that senior management often perceives digital transformation as risky, expensive, and disruptive, while smaller firms assume that advanced technologies are relevant only to large-scale projects (Alawag et al. 2021; Jaafar et al. 2025; Raman & Husain, 2025).

These findings are critical to Research Objective 3, as they highlight that the success of digital adoption depends not only on technology readiness but also on organisational mindset. Overcoming this barrier requires strong leadership commitment, targeted change management, and incentive-based policies to reshape industry culture, ensuring that innovation becomes a shared value rather than an imposed directive.

CONCLUSION AND RECOMMENDATION

CONCLUSION

This study highlights a distinct disparity in the adoption and diffusion of Industry 4.0 (IR 4.0) technologies within Malaysia’s construction industry. Technologies such as Building Information Modelling (BIM), Big Data and Predictive Analytics, and the Internet of Things (IoT) demonstrate both high familiarity and strong implementation among G7 contractors. Their success reflects tangible project benefits, proven efficiency, supportive policy frameworks, and measurable returns on investment (ROI). Conversely, technologies such as Blockchain, Augmented and Virtual Reality (AR/VR), and Autonomous Construction remain underutilised. Their slow adoption is primarily attributed to high capital costs, limited technical expertise, low industry readiness, and the absence of clear integration standards. This uneven digital diffusion suggests that Malaysia’s construction sector is advancing selectively, favouring technologies with immediate operational value and institutional support.

The findings also reveal five critical challenges constraining widespread digital transformation: (1) technological integration issues, (2) high implementation costs, (3) workforce skills and competency gaps, (4) cybersecurity and data protection concerns, and (5) organisational and cultural resistance to change. These barriers demonstrate that digitalisation challenges extend beyond technological awareness—they are rooted in systemic and structural issues relating to financial capacity, institutional readiness, and human capital development.

Importantly, this study introduces a three-category (High–Moderate–Low) framework to map Malaysia's digital maturity level across IR 4.0 technologies. The framework serves as a practical tool for policymakers, contractors, and industry stakeholders to prioritise interventions, target resource allocation, and track progress toward digital transformation. The results directly support national objectives outlined in the CIDB Construction 4.0 Strategic Plan (2021–2025) and the Twelfth Malaysia Plan (2021–2025), reinforcing the alignment between empirical evidence and Malaysia's broader policy direction for a digitally enabled construction sector.

RECOMMENDATIONS

To accelerate the implementation of Industry 4.0 (IR 4.0) technologies and enhance the competitiveness of Malaysia's construction sector, several strategic measures are recommended based on the study's findings:

1. Upskilling and Education Initiatives

Stronger collaboration between universities, the Construction Industry Development Board (CIDB), and industry stakeholders is essential to design targeted digital training and certification programmes. Special emphasis should be given to emerging technologies such as Artificial Intelligence (AI), Blockchain, Augmented and Virtual Reality (AR/VR), and Data Analytics. These initiatives will help develop a digitally competent workforce, addressing long-term skill shortages and improving industry readiness for technological adoption.

2. Financial Incentives and Policy Support

Government agencies should introduce or expand digital adoption grants, tax incentives, and public–private partnership schemes to reduce high initial investment costs—particularly for small and medium-sized enterprises (SMEs). Such financial mechanisms can mitigate economic barriers and encourage broader participation in digital transformation efforts.

3. Standardisation and Regulatory Frameworks

The establishment of national-level standards for interoperability, cybersecurity, and data governance is critical. Clear regulatory frameworks will promote seamless integration across digital platforms, ensure data integrity, and strengthen stakeholder confidence in adopting connected construction systems.

4. Digital Ecosystem and Knowledge-Sharing Platforms

Shared technology hubs, construction data repositories, and collaborative innovation networks should be developed to foster cross-industry learning and best-practice exchange. These platforms can accelerate knowledge diffusion, support pilot testing of new technologies, and nurture a culture of continuous improvement in digitalisation.

5. Tailored Implementation Roadmaps

Phased and context-specific digitalisation roadmaps should be developed for different contractor categories (e.g., G7, medium-sized, and small firms). Aligning these roadmaps with organisational capacity and readiness levels will promote scalable and inclusive transformation across the sector, ensuring that all contractor groups progress toward digital maturity.

In summary, Malaysia's construction industry is at a critical inflection point in its digital transformation journey. Strengthening digital skills, financial mechanisms, and policy frameworks will enable a more balanced, sustainable, and inclusive adoption of IR 4.0 technologies. Through coordinated national efforts—anchored by CIDB's Construction 4.0 Strategic Plan (2021–2025)—the industry can advance towards the long-term vision of a productive, innovative, and globally competitive Construction 4.0 ecosystem.

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None.

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