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Digital Transformation Framework for Construction SMEs : Lesson Learned from Manufacturing Industry

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ABSTRACT

The construction industry in Kelantan, Malaysia, is undergoing a critical transformation amidst national calls for digital adoption aligned with Industry 4.0. However, Construction SMEs in the region face fragmented technological environments, policy misalignment, and limited digital readiness. This study proposes a contextualized digital transformation (DT) framework for IoT Construction SMEs, drawing insights from the more mature manufacturing sector. Using a qualitative case study approach supported by interviews,the findings of this study indicated that the level of DTs adoption in Kelantan is still low. The major challenges identified in IoT adopt included difficulties managing change towards new technology and human resource . Furthermore, the study highlights that benefits significantly impact future trends. Therefore, it is highly recommended that managers in the construction industry, Kelantan in Malaysia embrace the adoption of IoT to improve benefits and leverage the wide range of benefits they offer.

1. Introduction

The ultimate goal of digital transformation (DT) in construction SMEs is to create tangible value through enhanced customer satisfaction, stronger industry collaboration, and improved productivity. Drawing inspiration from manufacturing best practices and aligning with the Construction 4.0 paradigm, digital transformation in construction is expected to deliver several critical outcomes. Firstly, customer experience can be significantly enhanced through IoT-enabled monitoring. These technologies enable end-to-end visibility of project progress, materials, and quality standards, allowing clients to track milestones in real time. Digital platforms also enable personalization, tailoring project delivery to client-specific needs and preferences, thereby fostering stronger trust and satisfaction. Secondly, ecosystem symbiosis can be achieved through the integration of supply

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chains. Digital platforms enhance collaboration among suppliers, contractors, and clients, reducing fragmentation and improving coordination across the value chain. This shift toward digital ecosystems mirrors the integrated production networks of advanced manufacturing industries, supporting efficiency and resilience. Technology platforms such as cloud-based project management systems and data. Digital transformation drives productivity improvements. IoT-driven predictive maintenance, real-time monitoring, and automated scheduling help reduce downtime by minimizing equipment failures and resource mismanagement.

Despite these potential benefits, construction SMEs continue to lag in digital transformation adoption**.** Unlike manufacturing, where Industry 4.0 principles are well-structured and widely applied, construction lacks a coherent theoretical and practical integration of digital transformation. This gap has limited both academic understanding and practical implementation in the sector.The following critical gaps are identified:

I. **Limited theoretical integration** existing studies rarely combine insights from RBV, dynamic capabilities, and collaborative innovation to explain DT in construction SMEs.
II. **Fragmented adoption framework** emphasize technology adoption but neglect organizational readiness, cultural shifts, and ecosystem collaboration.
III. **Weak transferability from manufacturing** while construction seeks to replicate manufacturing's Industry 4.0 journey, direct application often fails due to sector-specific complexities, such as project-based work and fragmented supply chains.
IV. **Low SME capacity** of construction SMEs face financial, technological, and skills-related constraints that hinder their ability to exploit DT opportunities.
V. **Inconsistent value creation** although DT promises customer satisfaction, collaboration, and productivity gains, the mechanisms through which SMEs achieve these outcomes remain underexplored.This lack of theoretical integration limits both academic understanding and practical implementation of DT in construction in digital transformation (DT). The following critical gaps are identified:

a. **Lack of holistic frameworks** that existing DT frameworks for construction SMEs in Malaysia are fragmented, focusing on tools rather than organizational readiness, governance, and sustainability.
b. **Limited empirical evidence** because a few studies examine the barriers and enablers of DT adoption among Malaysian construction SMEs, particularly in localized contexts like Kelantan.
c. **Scarcity of cross-sector replication** lessons from the manufacturing sector, which has advanced in IoT and IR4.0 adoption, are underexplored in construction SMEs.
d. **Insufficient theoretical integration** of existing studies rarely combine multiple lenses (RBV, TOE, dynamic capabilities, and collaborative innovation) to produce a comprehensive DT framework for SMEs.
e. **Neglect of socio-organizational factors** prior research emphasizes technology while overlooking workforce skills, culture, and change management that shape DT adoption.

1.1 Research Objectives

This study is guided by the need to close the above gaps and therefore sets out to:

1. **Identify** the key barriers hindering IoT and digital transformation adoption in Malaysian construction SMEs.

2. **Examine** the enabling factors that support DT adoption, including government policies, collaboration, and affordable digital tools.
3. **Compare** the readiness and adoption pathways of DT in construction SMEs with manufacturing SMEs to extract transferable lessons.
4. **Develop** a contextualized digital transformation framework that integrates barriers, enablers, and lessons learned from manufacturing, tailored to Malaysian construction SMEs.

1.2 Significance of the Study of the Research Makes Both Theoretical and Practical

- **Theoretical Contribution**
    - Advances academic knowledge by integrating RBV, TOE, and dynamic capabilities into a comprehensive DT framework for construction SMEs.
    - Provides empirical evidence on IoT adoption in Malaysia, addressing the scarcity of localized studies.
    - Bridges cross-industry learning by adapting manufacturing's DT pathways into construction.
- **Practical Contribution**
    - Offers construction SMEs in Kelantan and Malaysia a roadmap for overcoming barriers such as high costs, poor digital skills, and fragmented systems.
    - Supports policymakers (e.g., CIDB, MITI, MDEC) in designing more effective incentives, training, and governance mechanisms for SME digitalization.
    - Helps industry practitioners enhance competitiveness, productivity, and sustainability by leveraging IoT-enabled digital transformation.

Several studies have examined the role of the Internet of Things (IoT) in the building and construction industry. For instance, Albishi *et al*., [1] investigated the challenges and potential solutions associated with IoT technologies in areas such as smart buildings focused on the security challenges emerging within IoT environments,also discussed the applications, opportunities, and obstacles of IoT adoption in China.Although these studies provide valuable insights, they have largely been conducted in contexts outside of Malaysia. The Malaysian construction industry, in particular, has yet to fully understand the practical challenges and implications of integrating IoT into its operations. This raises important questions like how is IoT currently being adopted in the Malaysian construction sector? What barriers and issues do local contractors face in implementing IoT solutions?and how is the adoption of IoT within the Malaysian construction industry, with a specific focus on identifying the issues and challenges that local contractors encounter during its implementation.According to Qing [3] exploring the adoption of internet of things in Malaysian construction industry with Malaysian context to highlight the research gap more clearly that several studies have examined the role of the Internet of Things (IoT) in the building and construction industry. For example, Albishi et al.[1]investigated the challenges and potential solutions associated with IoT technologies in areas such as smart cities, smart energy and smart buildings.

While these studies provide useful international perspectives, research specifically focusing on the Malaysian construction industry remains limited. According to the Construction Industry Development Board, digital adoption among local contractors especially small and medium enterprises (SMEs) is still at an early stage, with IoT integration facing significant barriers such as cost, lack of expertise, and resistance to change. Recent studies on digital transformation in Malaysia highlight that although technologies like Building Information Modelling (BIM) have gained some attention, the systematic adoption of IoT for real-time monitoring, automation, and smart project management is far less understood.

This gap raises key questions: How is IoT currently being adopted in the Malaysian construction sector? What specific barriers and challenges are faced by local contractors in implementing IoT applications?These questions form the foundation of this research.The aim of this research is to explore the adoption of IoT within the Malaysian construction industry, with particular emphasis on the issues and challenges faced by local contractors during its implementation.

Table 1
Transformation outcomes of digital adoption in construction SMEs

Outcome dimension	Key benefits	Examples in construction
Customer experience upgrade	Improvement traceability and personalization of project delivery	IoT-based progress dashboards, client-spesific BIM models
Ecosystem symbiosis	Integrated supply chain and shared technology platforms enhance collaboration	Cloud project management, supplier-contractor data sharing
Productivity Improvement	Reduced downtime and higher throughput via automation and data driven practices	Predictive maintainance, AI-driven scheduling optimization

2. Literature Review
2.1 Digital Transformation and Technology Adoption

Digital transformation, as delineated encompasses the enhancement of existing products through the integration of digitization and digital innovation resources . This phenomenon is inherently multidisciplinary, affecting multiple facets of an organization, including strategy , workforce technology culture and the broader social and organizational structures .

These elements collectively shape how businesses engage with their customersHowever, it is essential to recognize that the most critical aspect of digital transformation is the human element. The rapid evolution of technology only becomes impactful when it is embraced and adopted by people. Individuals tend to adopt disruptive technologies more swiftly than organizations, which may require more time and a greater degree of flexibility to adjust. This highlights the necessity of exploring digital transformation from the perspective of individual adoption within organizations. There is not an official, state-level statistic for IoT adoption in Kelantan; most Malaysian data is national or sector-wide. But multiple signals point to relatively lower digital usage among Kelantan businesses with emerging interest driven by universities and state/national programs.Kelantan has been reported among the lower states for ICT use in business(e.g., web presence and internet use), implying a lower readiness base for IoT.In light of the problem statement and the research gaps identified, this study seeks to provide a deeper understanding of digital transformation (DT) adoption in the Malaysian construction industry, with a comparative perspective from the manufacturing sector. By addressing these gaps, the study aims to contribute both theoretically and practically to the advancement of digital transformation frameworks tailored to construction SMEs.

Table 2
Summary characteristics of SMEs

Type of enterprise	Number of employees
Micro	Less than 5 employees
Small	Between 5 & 19 employees
Medium	Between 20 & 50 employees

Source : Malaysia SMEs

This study is guided by the following research questionson what are the differences and similarities in digital transformation readiness and adoption between construction SMEs and manufacturing SMEs in Malaysia? What are the key barriers and enablers influencing DT adoption in construction compared to manufacturing? How do IR 4.0 technologies (IoT) integrate strategically across construction and manufacturing SMEs? How can lessons learned from manufacturing DT frameworks be adopted to develop a comprehensive framework for construction SMEs in Kelantan?

This study argues that the digital transformation of construction SMEs in Kelantan, Malaysia, requires a contextualized framework that integrates leadership commitment, organizational readiness, technology fit, process re-engineering, stakeholder engagement, and continuous learning; by adopting a qualitative comparative case approach inspired by manufacturing sector practices, this research demonstrates that overcoming barriers such as limited resources, resistance to change, and lack of digital skills can enhance productivity, competitiveness, and long-term sustainability in the construction industry.Qualitative comparative case studies informed by best practices from the manufacturing sector, this research identifies critical barriers such as limited financial and human resources, resistance to organizational change, and inadequate digital skills and proposes strategies to overcome them. The findings aim to support the enhancement of productivity, competitiveness, and long-term sustainability within the region’s construction industry amidst the paradigm shifts driven by the Fourth Industrial Revolution. The construction sector is vital to Malaysia's expanding economy. However, the construction industry has been criticized for its reliance on technology and management problems. The digital transformation under Industry 4.0 is complex and resource-intensive, making a strategic digitalization guideline vital to small and medium-sized enterprises' success in the Industry 4.0 transition. The present study aims to provide manufacturing small and medium-sized enterprises (SMEs) with a guideline for digital transformation success under Industry 4.0 .

Most of construction professionals still do not embrace and are not exposed with the current technology especially the Internet of Things (IoTs) to improve their communication and business activities while serving their clients. With the view of technology awareness and adoption among construction professional in East Cost Malaysia . Kelantan’s IoT adoption among SMEs is best described as “early-stage/low but growing.The Internet of Things (IoT) is a network of technologies that use sensors, software, and other technologies to connect and exchange data with other devices and systems. The construction industry in Kelantan is facing significant challenges [9].The framework presented in Figure 1 encapsulates four key components of DT are drivers, enablers, processes, and outcomes which collectively shape the digital maturity of SMEs. While extensively applied in manufacturing, this study contextualizes the framework for construction SMEs in Malaysia, a sector characterized by project-based operations, fragmentation, and relatively low digital adoption.

Digital transformation (DT) has emerged as a critical strategy for organizations to sustain competitiveness, respond to evolving market pressures, and leverage new opportunities arising from Industry 4.0. For small and medium-sized enterprises (SMEs), particularly within the construction sector, DT is not merely a technological adoption exercise but a reconfiguration of organizational capabilities, processes, and business model**.** Construction SMEs Digital Transformation framework compare to manufacturing shows knowledge transfer from manufacturing to construction which research gaps as below :

Table 3
Comparison manufacturing and construction SMEs

Framework layer	Manufacturing	Constuction SMEs
Digital consciousness	Technical resource : IOT Organizational resource Talent resource	Technical resource IOT Organizational resource Talent resource
Enterprise external element	Market competition	Market competition
Digital process and mode innovation	Process innovation: IOT predictive maintenance	Process innovation: Digital site monitoring, drone for surveying
Transformation outcomes	Customer experience upgrade :traceability,personalization Ecosystem symbiosis:integrated supply chain,tech platforms Productivity improvement: reduce downtime, higher throughput	Client experiences upgrade: Transparency (real time project dashboard),quality assurance, faster project-delivery Ecosystem symbiosis: Collaboration among SMEs,GLCs,tech vendors Productivity improvement: less rework,faster approvals, better resource utilization
Strategic results	Enterprise value: Innovation,profitability, digital reputation,agility. Sustainable competitive: market, resilience in digital economy, innovation continuity	Enterprise value: higher project win rates,profitability, digital reputation,agility. Sustainable competitive: market, resilience in digital economy, differentiation in tendering

The construction industry in Malaysia, particularly small and medium-sized enterprises (SMEs), faces significant challenges in adopting digital transformation (DT) despite the growing imperative to leverage Industry 4.0 technologies. Unlike the manufacturing sector, which has made more considerable strides in digitalization, construction SMEs are hindered by various barriers such as financial constraints, skill shortages, technological limitations, and organizational weaknesses. These obstacles limit their competitiveness, productivity, and ability to innovate in a rapidly evolving digital economy. Consequently, the slow pace of DT adoption in construction SMEs represents a critical bottleneck to the sector's modernization and sustainable growth.While numerous studies have explored digital transformation in broad industry contexts, there remains a paucity of research that specifically compares the DT readiness and adoption dynamics between construction and manufacturing SMEs in Malaysia. Existing literature often treats construction SMEs in isolation without leveraging insights or frameworks that have proven effective in manufacturing. Additionally, most DT frameworks do not fully integrate the complex interplay of technological, organizational, environmental, cultural, and governance factors unique to construction SMEs. This gap underscores the need for a comprehensive, contextually relevant DT framework that assimilates cross-sector lessons to support construction SMEs in their digital journey. IoT as one of the pillars in digital transformation can be illustrated as the communication of a huge group of objects such as actuators, sensors, Radio-Frequency IDentification (RFID) tags and mobile phone (Atzori, Iera and Morabito, 2010) over the Internet or network. The object consists of sensors and electronics and controls by software to generate and collect data from surrounding. The data collected will be transferred to central database or other objects through network. In the era with ubiquitous networking, IoT undoubtedly becomes the leading path in forming a smart world . Services provided through the Internet developed from time to time by identifying the needs of current society. It has evolved from interactions between persons by the helps of machines, such as phone or email services to interactions between machines without human involvement. There is an argument that the Internet of Things (IoT) adoption is relatively low especially in the construction industry. Hence, an initiative to examine the IoT adoption amongst contractors becomes the main focus of this study. This initiative is achieved by studying the current standing on relationship of attitudes, awareness, readiness and barriers towards the IoT adoption among contractos in Kelantan.

Government programs (MDEC,2025) are pushing state-level digitalisation and sector pilots (agri, etc.), which Kelantan can leveragebut these are enablers, not evidence of high adoption yet Practical read on level for Kelantan SMEs (overall) is IoT adoption level, usually describing how far an organization, sector, or region has progressed in integrating Internet of Things (IoT) technologies into its operations. Researchers often measure adoption in stages or levels, which can show readiness, maturity, or depth of use IoT Adoption Level gap transparently and then produce Readiness (TOE) connectivity, data skills, budget, leadership support, vendor access.Despite the growing interest in the Internet of Things (IoT) within the construction industry, several critical gaps remain unaddressed, particularly in the Malaysian contextof limited Focus on Behavioral and Organizational Factors. Most existing studies emphasize the technical benefits of IoT but give insufficient attention to socio-organizational dimensions such as attitudes, awareness, readiness, and perceived barriers that influence adoption decisions. Scarce Empirical Evidence in Malaysia is a notable lack of primary data examining IoT adoption specifically among Malaysian contractors, especially those registered in top CIDB grades (G5–G6) who have the capacity to implement such technologies. Contextual Specificity is Overlooked like a few studies have explored IoT adoption within localized settings such as Kelantan, where regional industry characteristics, infrastructure, and government support structures may differ from national averages.Policy Implementation Insights Are Inadequate guidance for policymakers to effectively promote IoT adoption aligned with Malaysia's IR 4.0 agenda remains underdeveloped due to limited research exploring the real-world enablers and barriers from the contractors' perspective.Integration of key factors in adoption is a need for research that simultaneously examines multiple interrelated factors (awareness, readiness, and barriers) to provide a comprehensive understanding of IoT adoption dynamics in the construction sector.Digital transformation is becoming more and more necessary in construction industry areas. The road to accomplishing such a change is not simple, though. For many businesses, meeting future demands by proactively adjusting and expanding their technological infrastructures and business processes presents both a challenge and an opportunity. According to Díaz-Arancibia *et al.*, [7], companies that are slow to accept these changes run the danger of being hindered by interoperability and digital literacy. Lack of knowledge and expertise is one of the most important problems in the construction. Similarly, Vial (2019) underscores that digital transformation requires not only technological investment but also organizational and cultural shifts to harness its full potential. One of the most pressing obstacles is the lack of knowledge and expertise, which undermines firms' ability to adopt and implement advanced digital solutions effectively . In addition, high implementation costs ,fragmented digital standards and resistance to change among employee, further complicate the transition process. These barriers are particularly acute for small and medium-sized enterprises (SMEs), which often lack the necessary resources, talent, and strategic frameworks to manage transformation successfully . Consequently, while digital transformation presents opportunities to enhance value creation and organizational resilience, its realization requires overcoming systemic challenges related to people, processes, and technology.IoT adoption in the construction industry, especially focusing context in Kelantan, Malaysia are barriers same to manufacturing to IoT adoption in the Construction Industry. Common barriers faced by contractors in adopting IoT technologies include high initial costs in purchasing IoT devices, software, and infrastructure can be expensive, especially for smaller contractors.Another is lack of Skilled Personnel. Contractors may lack employees who understand IoT technologies or how to integrate them effectively.Resistance to Change like in Traditional construction practices are deeply rooted, and some stakeholders may be hesitant to shift from familiar methods.A comparative barrier framework that categorizes the barriers to digital transformation (DT) adoption in construction SMEs and then shows how manufacturing practices have addressed them. This will make a strong bridge for Digital Transformation in Construction SMEs vs. Manufacturing Practices.Technological Barriers Construction SMEs are limited access to advanced digital tools (IoT). Lack of interoperability between platforms (fragmented project software). Poor IT infrastructure (especially among SMEs in rural/regional areas). How Manufacturing Overcame is adoption of standardized digital platforms. Government or industry-driven Industry 4.0 roadmaps to support SMEs. Development of low-cost, scalable digital solutions tailored to SMEs.Organizational & Human Resource Barriers Construction SMEs: Resistance to change among managers or IT workers. Shortage of digitally skilled employees. Lack of leadership's enterprises. Comparative barrier framework that categorizes the barriers to digital transformation (DT) adoption in construction SMEs and how manufacturing practices have addressed similar barriers. Process and Cultural Barriers like Cultural resistance expected values, beliefs, and norms that shape stakeholder behaviour and their work process are called culture. Adopting new technology within organisations is hampered by existing cultural behaviour, which necessitates systemic transformation. Digitalization for a circular economy in the building industry: Multiple-case study of Dutch social housing organizations. Stakeholders must adopt new attitudes and behaviours that modify the construction industry's culture to enable the transition from linear to circular construction. However, such a significant change is challenging to implement in the sector where adopting supply chain fragmentation and hesitant technology are typical. cultural variations.The n the construction industry also impact the adoption of new technologies like blockchain. Cultural variances and technological advancements influence one another's growth. Reluctance to adopt DTs: Employees are unlikely to embrace new technology unless their work environment encourages creativity, cooperation, and a readiness to change. The study by showed that a full implementation of DTs in daily operations is needed for both digitalisation and Construction, which are currently limited to pilot projects and the company's corporate that organisations typically oppose using DTs in favour of maintaining the status quo. Organisational resistance makes a company rigid and unable to adjust to internal or external demands for change.Kelantan SMEs, barriers, enablers, lessons from manufacturing) and aligned with the conceptual DT framework (RBV, TOE, Dynamic Capabilities, Collaboration.

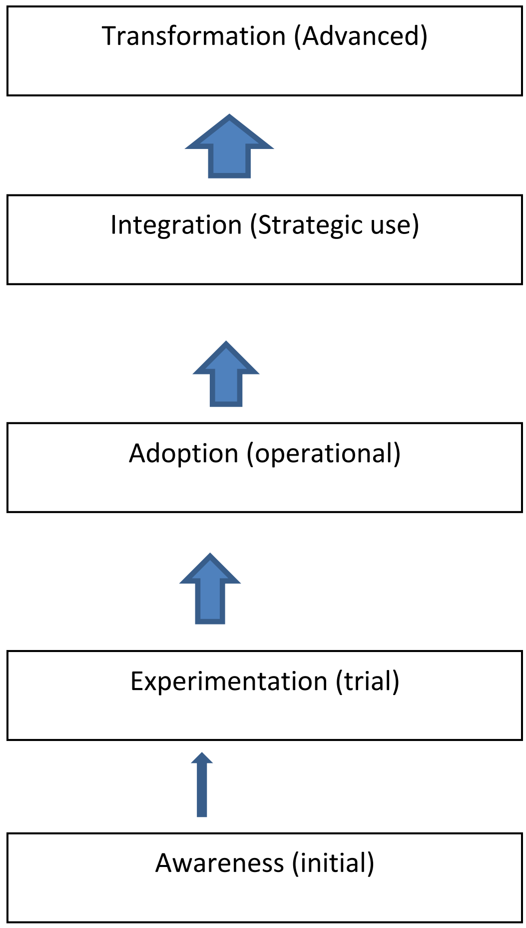

Fig. 2. Five stages of DT levels of SMEs

Above Figure 2 illustrates the IoT Adoption Level Framework, which outlines the progressive stages organizations typically undergo when adopting Internet of Things (IoT) technologies. The framework is structured in a hierarchical sequence from the lowest level of awareness to the highest level of transformation, showing how maturity in IoT adoption evolves over time. Each stage reflects the extent of usage, purpose, and integration of IoT solutions within an organization.Kelantan contractors still in awareness stage. IoT Adoption for Digital Transformation in Malaysian Construction in construction industry is undergoing profound changes under Industry 4.0, with the Internet of Things (IoT) being a key driver of digital transformation. However, adoption among small and medium-sized enterprises (SMEs) in Malaysia remains low due to structural, financial, and skill-related barriers. This thesis develops a conceptual framework that identifies the barriers (high costs, lack of skilled staff, poor internet infrastructure) and enablers (government incentives, affordable digital tools, capacity building, and peer pressure) that shape IoT adoption. Using insights from global and local literature, this study examines how Malaysian SMEs can leverage enabling factors to overcome challenges and achieve.There is growing evidence that the adoption of the Internet of Things (IoT) remains relatively low, particularly within the construction industry. Despite its potential to enhance efficiency, productivity, and project delivery, the construction sector lags behind other industries in leveraging IoT technologies. Recognizing this gap, the present study focuses on examining IoT adoption among contractors in Kelantan. Specifically, it investigates the interrelated factors of attitudes, awareness, organizational readiness, and barriers that influence the adoption process. By exploring these dimensions, the study seeks to provide a clearer understanding of the current state of IoT adoption and identify critical challenges that need to be addressed to accelerate digital transformation in the local construction industry.

2.2 Digital Transformation and IoT in Construction

Digital transformation (DT) in construction refers to the integration of digital technologies such as IoT, Building Information Modeling (BIM), cloud computing, and AI to improve productivity, decision-making, and project delivery (Oesterreich & Teuteberg, 2016). IoT, in particular, enables real-time data collection through connected sensors and devices, supporting predictive maintenance, safety monitoring, and supply chain optimization (Li et al., 2019). While manufacturing has achieved significant IoT penetration, construction especially SMEs lags due to fragmented project structures and low digital maturity [ ].

2.3 Barriers to IoT Adoption in Construction SMEs

a.High Costs

The financial burden of IoT adoption covering hardware, software, integration, and maintenance is a critical barrier for SMEs. Studies show SMEs face disproportionate costs compared to large firms due to limited economies of scale. In Malaysia, limited access to affordable financing and dependency on government grants exacerbate this challenge.

b. Lack of Skilled Staff

IoT adoption requires specialized technical knowledge in sensors, networking, and data analytics. However, SMEs often struggle to attract or retain talent due to lower salaries and limited training opportunities compared to large corporations. Workforce readiness is further hampered by a mismatch between university curricula and industry digital needs.

c. Poor Internet Infrastructure

IoT is highly dependent on reliable connectivity. Rural and semi-urban areas in Malaysia where many SMEs operatestill experience limited broadband coverage and low internet speed, creating digital divides. This issue mirrors findings in other developing economies where weak digital infrastructure hampers digital adoption.

d. Government Incentives and Policy Support

Policy-driven support is one of the strongest enablers. Malaysia’s Industry4WRD policy and Construction 4.0 Strategic Plan (2021–2025)provide roadmaps for digital adoption (MITI, 2018; CIDB, 2020). Government subsidies, tax incentives, and public-private partnerships can reduce adoption barriers [4].

e.Affordable Digital Tools and Shared Platforms

Cloud-based IoT solutions and shared digital platforms reduce capital expenditure by offering subscription-based services. SMEs can pool resources and collaborate through industry-driven consortia to access advanced digital tools at lower costs.

f.Capacity Building and Training Programs

Training and continuous professional development are critical for addressing the digital skill gap. Initiatives by CIDB Malaysia,HRDF, and universities aim to upskill construction professionals in IoT, BIM, and data analytics. Research shows training significantly improves SME readiness for digital adoption.

g. Peer and Market Pressure

SMEs are often influenced by competitive dynamics and the digital adoption levels of larger contractors. Market-driven digital requirements (e.g., BIM mandates, IoT-enabled project tracking) compel SMEs to adopt new technologies to remain competitive.

3. Methodology

A qualitative method was used for this study to clarify the data, thus giving a better explanation. The interview will take place over the phone, the conversation will be audio-recorded, and the notes will be taken to analyze and interpret further without missing any crucial aspects. The data gathered and processed from the conducted interview can be used to develop the research findings that are intended as a goal to achieve the research aim. Purposive sampling was used to choose the participants for the semi-structured interviews. Participants involved in this research studywere contractors in Kelantan like a developer, a project manager, and IT people. A structured interview method was used with the parties directly involved in the operation at the construction. These involved parties include construction managers, surveyors, engineers and supervisors in the contractor's organization. Apart from that, supplier managers were also involved in this study to give their views on the digital transformation in the construction . This qualitative research approach is used because these IoT have issues lagging in contractors' firms. Specifically, their selection as respondents is based on their experiences in construction. Below are the comparison contribution of focus study:

Table 4
Four key components of DT are drivers, enablers, processes, and outcomes of SMEs

Author(s) & Year	Focus of Study	Key Contribution	Relevance/Comparison
Albishi et al. (2017)	Challenges and solutions of IoT across domains (smart cities, energy, healthcare, buildings)	Identified broad technical, infrastructural, and adoption barriers; proposed solution-oriented approaches (lightweight protocols, interoperability frameworks, policy support)	Provides a comprehensive, cross-sector baseline of IoT adoption issues. Forms the foundation for comparing sector-specific studies.
Conti et al. (2018)	IoT security challenges	Focused specifically on cybersecurity threats (privacy, denial-of-service,	Complements Albishi's breadth by providing depth in security, one of the barriers Albishi highlighted

Author(s) & Year	Focus of Study	Key Contribution	Relevance/Comparison
		data integrity); offered frameworks for secure IoT deployment	only generally.
Chen et al. (2014)	IoT applications and adoption in China	Examined opportunities, obstacles, and national policy influences on IoT; highlighted cost and infrastructure as main issues	Provides context-specific insights (China) compared to Albishi's global view. Shows how national context shapes IoT adoption challenges.
Qing (2019)	IoT adoption in Malaysian construction	Investigated practical barriers (cost, expertise, resistance to change) faced by local contractors	Narrows Albishi's general framework to Malaysia-specific realities, highlighting socio-organizational barriers not emphasized by Albishi.
Halim et al. (2021)	Awareness and readiness of construction professionals in East Coast Malaysia	Found low awareness and skill gaps as primary challenges; most SMEs at early stage of IoT adoption	Shows that Albishi's proposed solutions assume a higher maturity level, whereas in Kelantan, basic readiness and awareness remain the main barriers.
CIDB (2021)	Construction 4.0 Strategic Plan (Malaysia)	Provided policy roadmap with incentives, training, and BIM/IoT adoption guidelines	Aligns with Albishi's recommendation for policy interventions but contextualized to Malaysia's construction sector.

Albishi *et al*., [1] provided one of the early systematic discussions of challenges and solutions for IoT adoption across diverse application domains such as smart cities, smart energy, healthcare, and buildings. Their contributions are significant in three ways:

1. **Comprehensive Identification of Challenges**
   They highlighted technical challenges (e.g., interoperability, scalability, and security), infrastructural limitations (e.g., poor connectivity, fragmented systems), and adoption barriers (e.g., cost, lack of standardization).
2. **Solution-Oriented Perspective**
   Instead of only diagnosing problems, Albishi *et al*., [1] proposed potential solutions such as lightweight protocols, middleware for interoperability, and policy interventions, making their work actionable.
3. **Cross-Sectoral Insights**
   By comparing multiple industries, they created a generalizable knowledge base useful for sectors still at an early stage of IoT adoption (like Malaysian construction SMEs).

The framework (Figure 3) integrates echnical Barriers
These include interoperability issues between IoT devices, lack of robust infrastructure, poor cybersecurity measures, and limited standardization. In construction SMEs, integrating IoT with existing tools (e.g., BIM, project management software) is challenging. While technology is often blamed, the real challenge is system integration*. IoT providers tend to develop siloed solutions, creating dependence on vendors. Thus, technical barriers are less about the availability of technology and more about its* usability and compatibility*.*

4.1 Organizational Barriers

Relate to resistance to change, lack of skilled personnel, and insufficient digital leadership. SMEs often lack a digital strategy or alignment between IoT initiatives and business goals. Organizations may wrongly perceive IoT as “just another technology project.” The deeper issue is strategic misalignment: unless leadership embeds IoT into value creation and project workflows, adoption remains superficial.

4.2 Financial Barriers

IoT requires upfront investment in hardware, software, training, and cybersecurity. SMEs often face cash flow constraints and limited access to financing. The financial challenge is often overstated. Instead, the problem is SMEs’ difficulty in demonstrating ROI due to fragmented implementation. With proper planning (e.g., adopting IoT incrementally), financial barriers can be minimized.

4.3 Cultural Barriers

- **Elaboration:** Employees may resist IoT adoption due to fear of job loss, increased monitoring, or disruption of established routines. Trust issues (e.g., data privacy) also emerge.
- **Critical argument:** Culture is the most underestimated barrier. Even if financial and technical resources exist, a workforce unwilling to adapt can stall progress. Leaders must foster digital trust and learning culture.

4.4 Regulatory and Policy Barriers

- **Elaboration:** Unclear IoT data governance, cybersecurity laws, and lack of standardized policies create uncertainty. In Malaysia, for example, fragmented digitalization incentives make SMEs hesitant to adopt IoT.
- **Critical argument:** While policymakers often focus on subsidies, SMEs need clarity, simplicity, and enforceable standards. Without consistent regulatory frameworks, IoT adoption risks being piecemeal and insecure.

3. Results

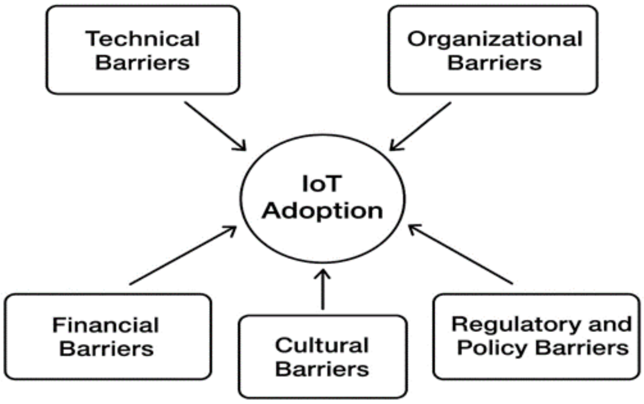

Fig. 4. Four key components of DT are drivers, enablers, processes and outcomes of SMEs

Framework (Fig.3) are based on reult interview with contractors as below :

Table 4
Barriers of DT in SMEs

Barrier Category	Interview Question
Technical Barriers	1. What challenges have you faced in integrating IoT with your current systems (e.g., project management, BIM)?
	2. How confident are you in the security and reliability of IoT technologies?
	3. Do interoperability issues affect your willingness to invest in IoT?
Organizational Barriers	4. How do decision-makers in your company view IoT adoption?
	5. Do you have staff with the right skills to manage IoT systems?
	6. What role does leadership play in driving or resisting IoT adoption?
Financial Barriers	7. What are the main financial concerns regarding IoT adoption in your company?
	8. How do you evaluate the return on investment (ROI) for digital technologies like IoT?
	9. Are there financing schemes or incentives you wish were available?
Cultural Barriers	10. How do employees perceive IoT adoption—supportive, skeptical, or resistant?
	11. Do you see IoT as a tool for empowerment or surveillance in the workplace?
	12. What training or cultural shifts would make IoT adoption easier?
Regulatory & Policy Barriers	13. Are you familiar with government policies or incentives for IoT adoption?
	14. Do you feel regulations provide enough guidance on data privacy and cybersecurity?
	15. What policy changes would most encourage your organization to adopt IoT?

Key Insights from the diagram framework by overcoming Digital Transformation in Construction SMEs learning from Manufacturing

1. Awareness (Initial)

At this stage, organizations have only a basic understanding of IoT and its potential. IoT is recognized as a technological trend, but firms are not yet actively implementing solutions. The focus here is on learning, knowledge acquisition, and exploring possibilities. Barriers include limited digital literacy, lack of strategy, and uncertainty about costs and benefits.

2. Experimentation (Trial)

Companies begin to experiment with IoT technologies on a small scale, often through pilot projects or proof-of-concepts. The aim is to test feasibility, assess benefits, and evaluate challenges. At this point, IoT adoption is not yet systematic it is exploratory, with outcomes providing lessons for broader implementation.

3. Adoption (Operational)

IoT moves from trial to operational deployment. Organizations start to integrate IoT into their core operations for efficiency, monitoring, and automation. This stage focuses on practical applications, such as real-time data collection, predictive maintenance, or supply chain tracking. Adoption here demonstrates tangible value, though the use remains largely operational rather than strategic.

4. Integration (Strategic Use)

At this level, IoT becomes embedded in business strategy. Instead of being used only for operational improvements, IoT data and systems inform decision-making, innovation, and long-term planning. Integration ensures alignment between IoT investments and organizational goals, creating cross-functional synergies across processes, products, and services.

5. Transformation

The highest maturity level, where IoT drives digital transformation and business model innovation. Organizations achieve advanced capabilities such as smart ecosystems, AI-driven IoT analytics, autonomous operations, and customer-centric services. IoT is no longer a tool but a core enabler of competitiveness, agility, and value creation.This excerpt offers a social perspective on the implications of IoT adoption and highlights the tensions between technology-driven change and broader systemic, cultural, and workforce issues. A structured breakdown could use framework analysis.

6.Workforce skills gaps

IoT adoption in construction SMEs is constrained primarily by shortages in both technical and socio-cognitive skills. Technical gaps include limited familiarity with sensor networks, data cleaning, systems integration, and cloud/edge processing required to manage continuous IoT data streams. Equally important are gaps in data literacy, digital project coordination (e.g., linking IoT outputs with BIM workflows), and higher-order skills such as problem framing and cross-disciplinary collaboration that enable workers to convert IoT data into actionable.

4. Discussions

Social Challenges in IoT Adoption for Construction SMEs, emphasizing four interconnected aspects that hinder or shape successful integration of Internet of Things technologies. Let's critically discuss each element:

4.1 Workforce Skills Gaps

Many workers in construction SMEs lack digital literacy and advanced technical skills required to use and manage IoT solutions.Without training, IoT adoption risks underutilization, errors, and resistance among employees. Skilled labor shortages also increase dependency on external consultants, raising costs. SMEs often struggle to balance upskilling investments with tight budgets. The gap is not just technical but also cultural workers may resist moving away from traditional practices [12].

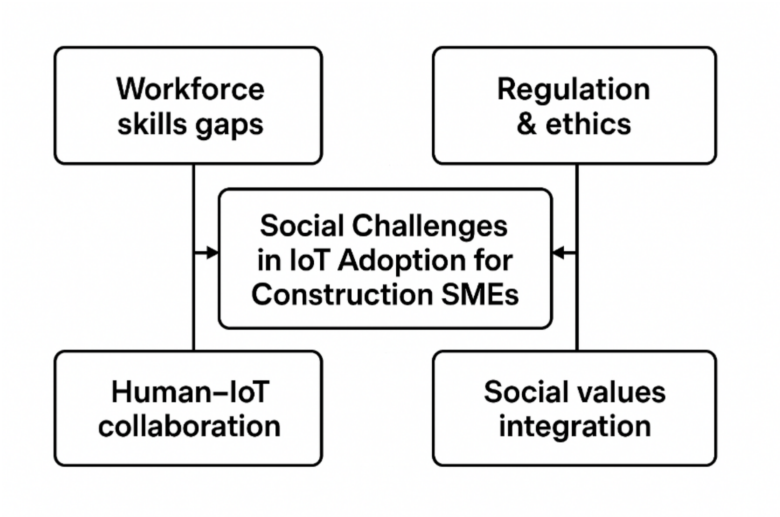

Fig. 5. Key Insights from the diagram Framework: Overcoming Digital Transformation in Construction SMEs (Learning from Manufacturing)

IoT adoption Mourtzis, Dimitris [7] in construction SMEs is constrained primarily by shortages in both technical and socio-cognitive skills. Technical gaps include limited familiarity with sensor networks, data cleaning, systems integration, and cloud/edge processing required to manage continuous IoT data streams. Equally important are gaps in data literacy, digital project coordination (e.g., linking IoT outputs with BIM workflows), and higher-order skills such as problem framing and cross-disciplinary collaboration that enable workers to convert IoT data into actionable decisions on site. These skill deficits are compounded by structural labour-market trends: technology-driven polarization has expanded demand for high-skill cognitive roles while hollowing out routine middle-skill occupations, increasing the risk that SMEs especially those with low training budgets will fall behind. Empirical work on automation risk further suggests many current occupations are susceptible to computerization unless retraining and education policies are implemented [6]. For Malaysian construction specifically, recent industry surveys report low awareness and limited competency in IR4.0 technologies (including IoT) among many SMEs, underlining the urgent need for targeted upskilling and government–industry training programmes.

4.2 Regulation and Ethics

IoT in construction collects large volumes of locationed, behavioural, and sometimes personal data (worker biometrics, access logs, CCTV feeds). This raises privacy, consent, data minimization, and data-security obligations that SMEs must acknowledge and operationalize. The GDPR (EU) established robust principles (lawfulness, purpose limitation, data minimization, rights to access/erase, breach notification) that have become a global benchmark for privacy-aware system design and contractual practice (e.g., vendor requirements, data processing agreements). In Malaysia, the Personal Data Protection Act (PDPA) 2010 sets national expectations around consent, retention, and security of personal data; non-compliance can create legal and reputational risk for contractors handling client or worker data. For SMEs, compliance burdens are nontrivial: implementing privacy-by-design, documenting data flows, and securing IoT endpoints and pipelines require both technical controls and governance processes (policies, staff training, supplier contracts). Thus regulatory/ethical readiness must be included as a core dimension of digital-transformation readiness covering legal literacy, affordable compliance checklists, and partnerships with trusted platform providers.

4.3 Human Resource–IoT Collaboration

IoT systems do not replace human actors in construction so much as change the nature of interaction between humans and automated agents. Construction site environments are dynamic, with ad-hoc workarounds, unpredictable physical conditions, and multi-actor coordination across contractors and subcontractors. IoT design must therefore support resilient collaboration sensors and dashboards should be interpretable by frontline operatives, alarm/failure modes must avoid alert fatigue, and control policies must be robust to human absence, adversarial behaviour, or deliberate non-use. From a technical standpoint, gaps in IoT middleware particularly around interoperable data-stream discovery, query primitives, and stream fusion slow ability to produce cross-platform, human-centric applications; researchers have called out the need for primitives that make it easier to query, fuse and aggregate heterogeneous IoT data, thereby enabling faster application development and better human interpretation of results.

4.4 Social Values Integration

IoT systems operate within complex social and institutional contexts of values such as fairness, dignity, worker autonomy, safety, and local cultural norms may conflict or be sidelined by purely efficiency-driven deployments. Integrating social values means (a) explicitly articulating which values the system should uphold (safety, privacy, equity), (b) operationalizing them into design constraints (e.g., anonymization thresholds, retention limits, human override mechanisms), and (c) embedding governance processes that include worker voice, community stakeholders, and contractual mechanisms for third-party platforms. The pace of automation and AI can intensify socio-cultural disruption (displacement, re-skilling needs, and relocation), so social integration must be proactive anticipating transitions and providing social protection and retraining pathways rather than reacting after displacement occurs. Sectoral studies on digitalisation in Malaysia’s construction industry emphasize these social dimensions: digital programmes that ignore local practices and stakeholder expectations tend to have low uptake, whereas interventions that combine technical support with social engagement and governance show better results.

4.5 Practical Recommendations (Operationalising the Four Elements for Construction SMEs)

1. Workforce skills gaps in short, modular training packages co-funded by government and industry; competency matrices (e.g., IoT sensor install, basic data analytics, BIM linking) for each job grade; apprenticeships linking vocational schools with pilot projects.
2. Regulation & ethics as simple PDPA/GDPR compliance checklist for small contractors; standardized contract addenda for data processors/providers; low-cost security baselines (device authentication, encrypted links, minimal retention)
3. Human–IoT collaboration participatory pilot projects with frontline workers; dashboard design workshops; fallback/human-override procedures and logging.
4. Social values integration tafor stakeholder impact assessments before large rollouts; KPI set that includes social outcomes (worker satisfaction, retraining completion) as well as technical KPIs (uptime, defect rates); dedicated change-management budget line.

4.6 Value Beyond Technology

The value of IoT is not purely technical it depends on how people perceive, adapt, and integrate it into work and social relations.Digital transformation is as much about social appropriation as it is about technological integration.

2. Labour Market Polarization

Digital transformation risks exacerbating inequalities if systemic labour market issues are not addressed alongside digital skills development.

4.7 IoT-Specific Challenges

Lack of developer support for cross-platform IoT applications [2]. Need for tools to query, fuse, and aggregate data streams. IoT must be integrated in ways that protect social contracts and citizen rights.Digital Skills Development include education strategies are required to avoid deepening digital divides [5].Human-IoT Collaboration,IoT must learn to interact with unpredictable human behaviors safely.Integration of Social Values incorporating ethics, governance, and cultural considerations into complex IoT socio-technical systems is highly challenging. Workforce Skills Gap must as the UK faces polarization, Malaysian construction SMEs risk a similar divide between tech-enabled firms and those left behind. Upskilling in IoTmust go hand in hand with systemic workforce policies.Socio-Technical Balance Construction is highly fragmented and people-driven. IoT adoption must account for collaboration with human actors (site workers, subcontractors, engineers) and ensure cultural acceptance.Policy & Regulation GDPR parallels can be drawn with Malaysia’s Personal Data Protection Act (PDPA) in shaping digital trustnclusive Transformation Digital adoption must reduce not reinforce .Inequalities among SMEs by ensuring access to affordable digital tools, training, and government support.A conceptual framework mapping as diagram below explanation of social challenges in IoT adoption for construction.

Table 6
Four key components of DT are drivers, enablers, processes, and outcomes of SMEs

Theme / Dimension	Key Issues	Supporting Literature	Implications for Construction SMEs
Developer Support	Lack of cross-platform IoT application support; limited tools for data querying, fusion, and aggregation	Mineraud *et al.*, [2]	SMEs struggle with interoperability, slowing integration of IoT across diverse platforms and systems.
Digital Skills Development	Risk of digital divide; need for systemic education and training strategies	Frey & Osborne [6]	Without structured upskilling, SMEs risk being left behind, worsening inequality between digitally mature and lagging firms.
Human–IoT Collaboration	IoT must adapt to unpredictable human behaviors and complex site conditions	—	Systems must be designed to support human actors (site workers, subcontractors), not replace them, ensuring resilience and safety.
Integration of Social Values	Need to incorporate ethics, governance, fairness, cultural norms, and trust	—	Without embedding social values, IoT risks rejection by workers and communities, undermining adoption.
Workforce Skills Gap	Polarization of workforce; divide between tech-enabled and traditional firms	Goos & Manning (2007); Frey & Osborne [6]	Malaysian SMEs face shortages in IoT, BIM, and data literacy; risk of widening skill inequality if unaddressed.
Socio-Technical Balance	Construction is fragmented and people-driven; IoT must align with human collaboration	—	Adoption requires cultural acceptance and integration into collaborative project workflows.
Policy & Regulation	IoT raises privacy and data governance challenges; GDPR parallels PDPA (Malaysia)	—	SMEs need clear, affordable compliance mechanisms to build digital trust and ensure data protection.
Inclusive Transformation	Risk that DT reinforces inequalities if SMEs lack access to tools, training, or support	Díaz-Arancibia *et al.*, [7]	Policies must ensure inclusivity so SMEs of all sizes can participate in the digital economy.

Barriers in Construction SMEs	Framework Response (Layer + Theory)	Interview Evidence (Illustrative Quotes)
Financial Constraints	Inputs (Capital, RBV) + Collaboration	“We cannot afford full BIM licenses, but if the government or main contractors provide shared access, SMEs like us can participate.” *(Interviewee 4)*
Lack of Digital Skills & Culture	Inputs (Skills, Culture) + Processes (Change, Governance, DASAT)	“Our staff are good with AutoCAD but BIM and cloud platforms are difficult — we need training and simple tools to start.” *(Interviewee 7)*
Fragmentation & Poor Collaboration	Processes (Collaboration) + Outputs (Ecosystem)	“Every contractor uses a different system; we don’t share information effectively. A common platform would solve many problems.” *(Interviewee 2)*
High Implementation Risk	Processes (GROOM – Governance, Risk, Organization, Management)	“If the system fails during a live project, we lose credibility. We need pilot projects first, not full rollout.” *(Interviewee 6)*
Unclear Value Proposition of Digital Tools	Outputs (Productivity, CX, Ecosystem) + Outcomes (RBV: Value, Advantage, Maturity)	“We only invest if technology reduces rework or improves productivity. Otherwise, management won’t approve it.” *(Interviewee 9)*
Regulatory Pressure & Compliance Burden	External Drivers (TOE – Policy, Market, Tech Push)	“CIDB requirements are pushing us, but we see it as both a cost and an opportunity to modernize.” *(Interviewee 3)*

4.8 Implications of the Framework

It helps organizations assess their current IoT maturity and identify gaps for improvement.It guides strategic planning by showing the pathway from basic awareness to full transformationIt emphasizes that IoT adoption is a gradual process, requiring not only technology but also cultural change, skills development, and strategic alignment.This framework is especially relevant for industries like construction and manufacturing where IoT adoption can significantly enhance productivity, sustainability, and innovation Accoding to Halim *et al*., [9] studies show intention/attitudes toward IoT (not adoption rates) and related SME digital topics in Kelantan i.e., interest and groundwork, but not widespread deployment. At the national level, multiple studies conclude SME IoT adoption remains low or early in Malaysia even in manufacturing supporting the "early-stage" characterization for less-digitized states like Kelantan. The Internet of Things (IoT) has emerged as a critical enabler of digital transformation, offering new possibilities for real-time monitoring, predictive analytics, and process optimization across industries. In the construction sector, IoT technologies facilitate the integration of sensors, equipment, and platforms to enhance safety, efficiency, and project visibility. However, the adoption of IoT is far from straightforward. According to Díaz-Arancibia *et al*., [7], organizations that delay adoption risk falling behind due to issues of interoperability and limited digital literacy. Lack of knowledge and expertise in IoT application remains one of the most significant barriers, particularly among SMEs that often lack the technical capacity to implement complex systems . High costs of sensor deployment, maintenance, and data management further hinder adoption while fragmented standards and security concerns raise additional challenges. In the context of construction SMEs, IoT integration is complicated by project-based operations, reliance on subcontractors, and the absence of unified digital platforms . Despite these barriers, IoT holds considerable potential to transform construction by enabling smarter asset management, enhancing decision-making through data-driven insights, and improving collaboration across supply chains. Thus, IoT adoption reflects both a strategic opportunity and a readiness challenge, requiring organizations to invest in digital skills, infrastructure, and change management to fully realize its benefits.

The literature on digital transformation (DT) demonstrates substantial progress in understanding its drivers, processes, and outcomes across sectors. However, the majority of this research has been concentrated in the manufacturing industry, which has long been regarded as the frontrunner in implementing Industry 4.0 (IR 4.0) technologies such as robotics, automation, IoT, artificial intelligence (AI), and advanced data analytics [7]. Manufacturing frameworks typically emphasize integrated supply chains, standardization, and continuous process improvement, resulting in more mature digital transformation pathways. In contrast, the construction industry particularly in Malaysia has received comparatively limited scholarly and policy attention in terms of digital transformation readiness, adoption, and framework development while these technologies offer localized benefits, their isolated implementation does not deliver the systemic improvements required to achieve competitiveness, sustainability, and resilience. Moreover, the fragmented and project-based nature of construction work creates additional barriers to digital adoption compared to the relatively stable and standardized operations in manufacturing . In the Malaysian context, construction SMEs face distinct challenges such as financial limitations, insufficient digital skills, limited awareness of digital opportunities, and weak integration across the project lifecycle. Although national policies such as the Industry4WRD framework and the Construction 4.0 Strategic Plan emphasize the importance of digital adoption, there remains a lack of empirical studies assessing the readiness, barriers, and enablers of DT among construction SMEs. Furthermore, while the manufacturing sector has benefited from structured frameworks and maturity models to guide digital adoption, construction lacks a comparable, comprehensive framework that is contextually tailored to its unique challenges and opportunities.Another critical gap is the absence of comparative studies between construction and manufacturing in Malaysia. Cross-sectoral comparisons are particularly important because manufacturing's success with DT offers transferable lessons in governance, risk management, technology integration, and workforce development. Yet, limited research has systematically examined how these lessons can be adapted to the construction sector, which differs in organizational structure, workflows, and project lifecycles. Without such comparative insights, construction SMEs risk falling further behind in the digital economy, reducing their competitiveness both domestically and regionally.

The target participants were contractors registered with the Construction Industry Development Board (CIDB) in Kelantan, specifically within Grades G4, G5, and G6. These categories represent small and medium-sized contractors who are considered most likely to benefit from and face challenges in adopting IoT technologies. A purposive sampling strategy was used to ensure that participants had relevant experience with digital practices in construction.This design enables the researcher to capture rich, contextual insights that may not emerge from purely quantitative surveys. The findings are expected to provide a deeper understanding of the barriers, enablers, and readiness factors influencing IoT adoption in the Malaysian construction industry, while also offering a basis for developing future quantitative measures.

Table 7
Demographic of the participant

Stakeholder	Role	Position	Years of Experience
Participant 1 (C1)	Contractor	Landscaper	12
Participant 2 (C2)	Contractor	Engineer	9
Participant 3 (C3)	Developer	Supervisor	20
Participant 4 (C4)	Contractor	Project Manager	9
Participant 5 (C5)	Information Tech.	Surveyor	10
Participant 6 (C6)	Contractor	Owner	21
Participant 7 (C7)	Contractor	Owner	15
Participant 8 (C8)	Contractor	Owner	17
Participant 9 (C9)	Contractor	Owner	11

According to Table 2, the individuals who were participated in the interview session were from various organizations. Only one representative from each organization was selected to participate in the interview. Different stakeholder and respondent position was chosen to participate in the interview session. As a result, the reliability of the data obtained was ensured by the fact that it was collected from the most relevant individuals. The degree of perception heavily depended on the experience one had working in the construction sector. Because of this, one may conclude that despite the number of years spent working in the construction industry that might fall anywhere on a spectrum, every single one of them is qualified because they have adequate engagement in this field. The framework (Fig. 4) as result question and answer (Table 3) as below integrates barriers and enablers of IoT adoption.Overall, the findings reveal that IoT adoption among contractors in Kelantan is still in its early and fragmented stage. Organizational and technological readiness are constrained by limited resources and low digital maturity, while environmental and regulatory pressures serve as selective adoption triggers rather than consistent drivers. Firms with stronger dynamic capabilities and collaborative networks demonstrate higher readiness and adaptability.

These results suggest that without targeted support in capacity building, financial incentives, and digital infrastructure**, t**he widespread adoption of IoT in the Malaysian construction industry .

Table 8
Themes and key findings

Contractor	Construct / Theme	Question	Answer / Key Findings
C1	Organizational Readiness (RBV – Resources & Capabilities)	Does your company have a clear digital transformation strategy or roadmap?	Budget is limited; no in-house IT specialists. Reliance on external consultants for training, with gradual internal skills development.
C2	Organizational Readiness (RBV – Resources & Capabilities)	What resources (financial, human, technical) do you have to support digital initiatives?	Budget is limited; no in-house IT specialists. Reliance on external consultants for training, with gradual internal skills development.
C3	Technological Capability (TOE – Technology)	What digital tools or platforms (BIM, IoT, cloud, drones) are currently used in your projects?	Mostly AutoCAD and WhatsApp for communication; IoT considered too costly. Started using cloud storage and simple project management apps, which improved coordination.
C3	Technological Capability (TOE – Technology)	Do you face challenges with interoperability or system integration?	Yes. Each consultant and subcontractor uses different software, making integration difficult. Effort to standardize by requesting all parties to use the same cloud platform.
C4	Environmental Factors (TOE – External Pressures)	How do client requirements and regulations influence your digital adoption?	Clients rarely request digital tools, so adoption is slow. However, government projects requiring BIM submissions force compliance and accelerate adoption.
C5	Environmental Factors (TOE – External Pressures)	Do you receive any government or CIDB support for digitalization?	Limited awareness of programs; application process seen as complicated. Partial funding from CIDB training programs helped adopt new software.
C6	Dynamic Capabilities (Sensing)	How does your company identify new digital opportunities?	Often wait until suppliers introduce tools. Some firms actively monitor industry trends and learn from others.
C6	Dynamic Capabilities (Reconfiguring)	Once you adopt a new digital tool, how do you reconfigure your workflows?	Some firms run new tools in parallel with old methods, causing duplication and resistance. Others redesigned workflows and trained staff, making digital part of daily operations.
C7	Collaboration & Innovation (Network-based, Manufacturing Lessons)	Do you collaborate with larger firms, consultants, or suppliers to learn about digital tools?	Limited collaboration; some work in isolation and adopt slowly. Others benefit from partnerships with consultants, which exposed them to BIM workflows.
C7	Collaboration & Innovation (Cross-industry Lessons)	What lessons from other industries (like manufacturing) could be useful for construction SMEs?	Manufacturing benefits from automation, but construction projects are unique. Standardized digital platforms and modular approaches could be adapted.

Contractor	Construct / Theme	Question	Answer / Key Findings
C8	Barriers to Digital Transformation	What are the biggest barriers preventing your company from digital transformation?	High costs, lack of skilled staff, poor internet connectivity.
C9	Enablers for Digital Transformation	What could enable or motivate your company to adopt digital solutions faster?	Greater financial support from government and stronger client demand. Lack of knowledge and skills, especially in IoT, remains a major hindrance,this can be overcome with collaboration from IT Company

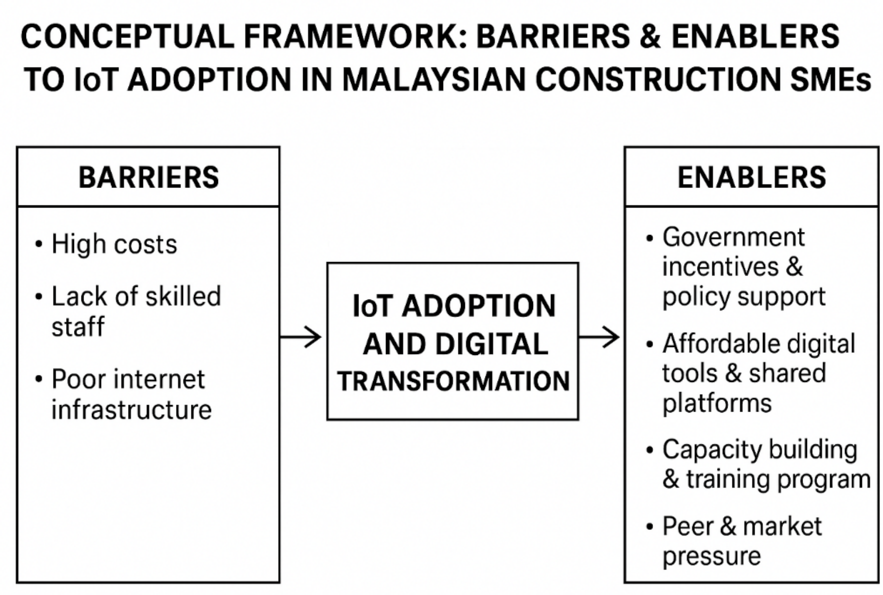

Fig. 7. Framework integrates barriers and enablers of IoT adoption

Fig. 7 as result question and answer as below integrates barriers and enablers of IoT adoption.grouped under the constructs/themes in interpretations and link them to the broader context of IoT adoption in Malaysian construction SMEs.

4.9 Theories underpinnings

4.9.1 Organizational Readiness (RBV – Resources & Capabilities)

Organizational readiness, in the context of the Resource-Based View (RBV), refers to a firm's ability to leverage its valuable, rare, inimitable, and non-substitutable (VRIN) resources and capabilities to achieve a sustainable competitive advantage. A firm's "readiness" is determined by its collection of internal strengths including tangible assets, intangible assets like brand reputation, and organizational processes and its ability to effectively deploy these in the market to outperform competitors. The findings indicate that most contractors lack a clear digital transformation roadmap. Budget constraints and the absence of in-house IT specialists are consistent barriers, forcing firms to depend heavily on external consultants for training and implementation. While this outsourcing helps build some digital awareness, it results in fragmented adoption strategies rather than a holistic organizational plan. Gradual internal skill development was noted, but progress remains slow and uneven across firms. This suggests that SMEs possess limited resource-based capabilities to support IoT adoption, aligning with past studies that highlight resource limitations as a common challenge in digital transformation [8].

4.9.2 Technological capability (TOE – technology)

Awa [10] recommended technology adoption like digital tools.The contractors' use of digital tools remains at a basic operational level**.** AutoCAD and WhatsApp dominate daily activities, while advanced tools such as BIM, IoT, drones, or AI are rarely implemented due to perceived high costs. Some incremental adoption is visible, particularly in cloud storage and project management apps, which improved team coordination. However, interoperability issues emerged as a major challenge, as consultants and subcontractors often use different software platforms. Although some firms attempt to standardize practices by encouraging the use of a common cloud platform, the lack of systemic integration reduces efficiency. These findings confirmed technological maturity among SMEs is still low, with adoption largely opportunistic rather than strategic.

4.9.3 Environmental factors (TOE – external pressures)

External drivers significantly influence adoption patterns. Contractors revealed that client demand for digital tools is minimal the urgency for change. However, in government projects requiring BIM submissions, firms are compelled to adopt digital solutions more quickly. This highlights the importance of regulatory enforcement in shaping industry behavior. On the other hand, although CIDB and government provide training and partial funding support, awareness among SMEs is low and the application process is perceived as complicated. Thus, while top-down policies have potential as enablers, their impact is weakened by poor dissemination and accessibility.

4.9.4 Dynamic capabilities (sensing, seizing, reconfiguring)

A mixed picture emerges regarding SMEs' dynamic capabilities**.** Aghimien, Douglas, Clinton Aigbavboa, and Kefilwe Matabane [10] referred some firms are passive, waiting for suppliers to introduce tools, while others actively monitor industry trends and learn from peers. Similarly, workflow reconfiguration varies: certain firms maintain old and new methods in parallel, creating duplication and resistance; others successfully redesign workflows and invest in staff training, embedding digital tools into daily operations. This shows that while sensing and seizing opportunities is inconsistent, firms that demonstrate flexibility in reconfiguring operations are more likely to gain tangible benefits from digital adoption.

4.9.5 Collaboration and innovation (network-based and manufacturing lessons)

Wang, Haijun, and Chaohui Shu [13] as an enduring challenge of soaring market complexity has significant impact on global manufacturing firms. The purpose of this paper is to explore a product modularity-based routine that enables global manufacturing firms to leverage product innovation, particularly in an open challenging environment through the collaborative innovation network.Collaboration emerged as a critical enabler. Many SMEs admitted to limited cooperation with larger firms or consultants, resulting in slower adoption. However, those that partnered with consultants benefited significantly, gaining exposure to BIM workflows and learning best practices.

Lessons from manufacturing were also acknowledged, particularly the value of standardization and modular approaches**,** although respondents emphasized the uniqueness of construction projects as a challenge for direct replication. This suggests that cross-industry learning can accelerate adoption, provided lessons are adapted to the construction context.

Barriers and Enablers of IoT Adoption from c8 overarching barriers identified include:

i. **High costs** of digital tools and IoT solutions
ii. **Lack of skilled staff** and insufficient digital knowledge.
iii. **Poor internet connectivity** especially in less urban areas.
iv. **Resistance to change**, particularly when old and new systems run in parallel.

Enablers from C9 highlighted include:

i. **Financial support and training** provided by CIDB and government initiatives.
ii. **Regulatory requirements,** particularly BIM compliance in government projects.
iii. **Client demand** which has strong potential to accelerate adoption when present.
iv. **Collaboration with IT Company** exposing SMEs to advanced digital workflows.

This is a well-structured framework showing the pathway from barriers to outcomes in what appears to be a digital transformation or technology adoption context. The flow clearly illustrates how enablers can help overcome barriers to achieve desired outcomes.

5. Conclusions

Barriers represent the core challenges organizations face - from human capital limitations (knowledge gaps, digital literacy) to resource constraints, technical integration issues, and security concerns.Enablers provide the mechanisms to address these barriers through policy support, collaborative partnerships, and technological infrastructure that makes adoption more accessible and scalable.Outcomes demonstrate the value proposition operational improvements, risk mitigation, better decision-making capabilities, and environmental benefits.The framework (Fig. 6) suggests that successful transformation requires addressing all barrier categories simultaneously rather than tackling them in isolation. For instance, cloud platforms can help with cost constraints while collaborative ecosystems can address knowledge gaps.

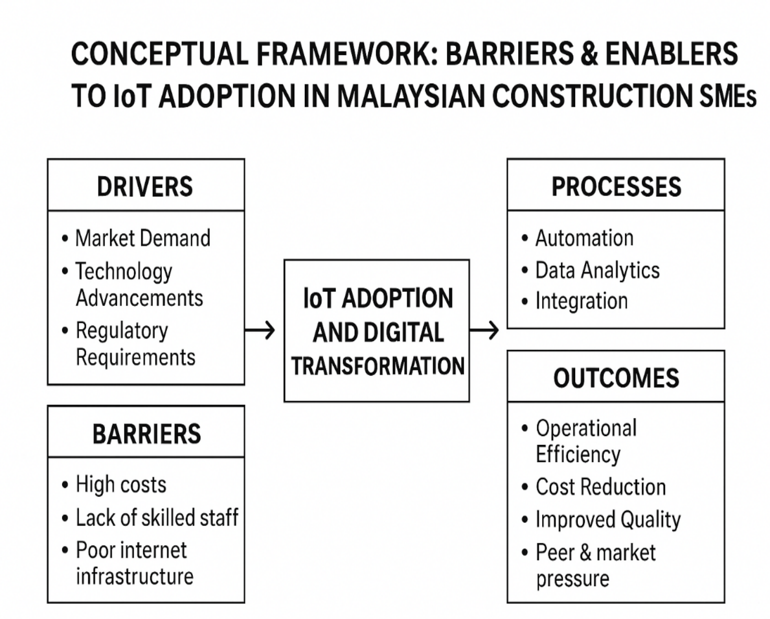

Fig. 8. IoT Adoption in Construction SMEs (Barriers & Enablers) combine with Digital Transformation Framework (Drivers → Enablers → Processes → Outcomes)

5.1 A Few Observations about Potential Enhancements

The framework could benefit from feedback loops - outcomes often create new enablers (success stories become policy evidence, improved efficiency frees up resources for further investment). Also, some barriers might persist even after initial success (cybersecurity concerns often intensify with greater digital adoption).What context is this framework being applied to understand the specific domain would help assess whether there are missing barrier or enabler categories that might be relevant.It can be concluded that there are challenges that construction industry players in the East Coast Region have to face to implement the digital transformation in their region. For some people, even if this digital transformation to brings many benefits to individuals and the environment, they still need to overcome the challenges they encounter regarding awareness and infrasturcture making it difficult for them . According to the findings, the participants' primary challenge is one of a financial nature. However, this challenge can be overcome or minimized if the government offers increased financial incentives to contractors especially SMEs.Particularly those need to digital transformation in their business as game-changer and this research can also help as guidelines. Nevertheless, there is still need for further improvement which can be achieved in future research; for instance, in future research, it is recommended that the researcher use mix-method to gather the data needed to be more accurate compared to this research which only uses one method to gather the data.

The findings highlight that achieving inclusive and sustainable IoT-enabled digital transformation in construction SMEs requires addressing interconnected socio-technical, workforce, policy, and inclusivity challenges. The data indicate that workforce polarization and digital skills gaps (particularly in IoT, BIM, and data literacy) risk leaving some SMEs behind, thereby creating uneven progress. Moreover, the fragmented and people-driven nature of the construction industry necessitates a strong socio-technical balance, where collaboration with workers, subcontractors, and engineers becomes critical for effective technology adoption.

At the regulatory level, policy and compliance frameworks such as Malaysia’s PDPA, guided by lessons from GDPR, are essential to build digital trust, ensure privacy, and foster compliance.

Importantly, transformation must be inclusive, with deliberate measures to reduce inequalities rather than exacerbate them. This includes providing access to digital tools, training, and government support, ensuring SMEs of varying capacities can participate in the digital economy [11].

In conclusion, sustainable IoT-enabled digital transformation in construction SMEs [14] hinges on integrating policy, skills development, socio-technical collaboration, and inclusivity strategies. Without this holistic approach, digitalization risks deepening inequalities rather than driving industry-wide progress.

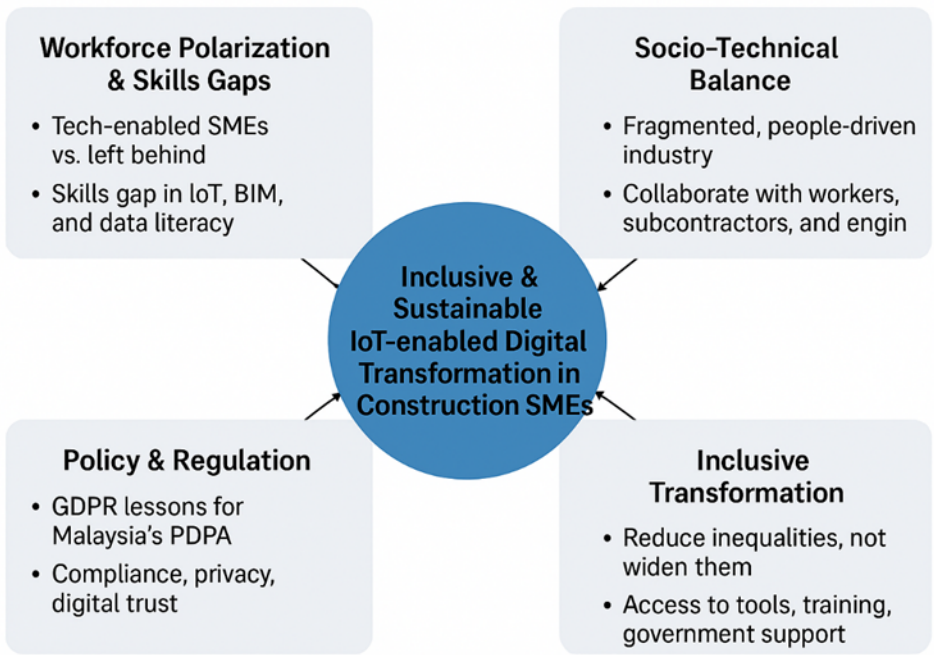

Fig. 9. Framework of feedback loops - outcomes create new enablers

In conclusion, this study contributes significant novelty by combining a broad range of theoretical perspectives to produce a comprehensive framework for Inclusive and sustainable IoT-eabled Digital Transformation in construction SMEs implementation. It emphasizes the importance of a multidimensional approach, addressing risks from technical, organizational, socio-technical, and legal angles. This framework (Fig.9) has the potential to serve as a critical resource for both industry practitioners and researchers, guiding future IoT adoption strategies globally. Further research is recommended to refine and expand this framework, ensuring its relevance and adaptability tothe evolving challenges faced by the construction industry. his study supports . Samaranayake [16] by reaffirming that IoT adoption in construction and SMEs remains at an early stage of evolution and continues to face both technological ("hard") and organizational or cultural ("soft") challenges. The findings align with the call for future research to focus on systematically identifying and analyzing these barriers, particularly in resource-constrained environments like SMEs. Moreover, the lack of comprehensive models for implementing IoT and evaluating its success, as highlighted by Samaranayake, is also evident in this study's context, where SMEs struggle with integration frameworks, readiness assessments, and performance measurement. Therefore, this study reinforces the importance of developing structured models and practical frameworks that not only guide IoT implementation but also establish metrics for evaluating its effectiveness in the construction sector.

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