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THE CHALLENGES OF THE INTERNET OF THINGS (IoT) IN THE CONTEXT OF CONSTRUCTION COST MANAGEMENT

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Nur Dini Farzana Jamlus[1], Roziha Che Haron[2*]

[1] Department of Quantity Surveying, International Islamic University Malaysia, dinifarzanaa@gmail.com
[2] Department of Quantity Surveying, International Islamic University Malaysia, roziharon@iium.edu.my*

**Corresponding author:*
Roziha Che Haron
Corresponding author's email: roziharon@iium.edu.my

ABSTRACT

The construction industry faces significant challenges related to cost overruns, project delays, and inefficiency. Traditional cost management methods rely on manual processes and limited data sources, but the advent of technology and the Internet of Things (IoT) offers innovative solutions. This research explores the application of IoT in construction cost management, starting with a literature review that highlights the limitations of current methods and areas where IoT can enhance value. The study aims to identify IoT applications and challenges in construction cost management. It employs a mixed-method approach, including a questionnaire survey of 47 respondents and interviews with four construction stakeholders. The research finds that IoT sensors provide real-time data, addressing historical inefficiencies and improving project outcomes. However, it also reveals challenges such as additional budget for acquiring IoT technologies and poor collaboration among construction parties. In summary, IoT promises to transform construction cost management but requires addressing budgetary and collaboration issues to maximize its potential.

Keywords: Application, Challenges, Construction cost management, Internet of Things (IoT)

1.0 INTRODUCTION

The Construction 4.0 Strategic Plan (2021-2025) was formulated collaboratively by the Ministry of Works, the Construction Industry Development Board of Malaysia (CIDB), and the Construction Research Institute of Malaysia (CREAM) to foster digitalization in the construction industry. This plan seeks to position the construction sector as a leader in Construction 4.0 within Southeast Asia, and it employs agile governance to engage stakeholders comprehensively (Ahmad Farhan et al., 2022). As the construction industry approaches the fourth industrial revolution (IR 4.0), there has been a surge in construction technology innovation. Among the nine pillars of this revolution, the Internet of Things (IoT) is recognized as a key element that can boost productivity (Farah Salwati Ibrahim et al., 2019). IoT is characterized by integrating sensors, devices, and systems into physical environments, enabling real-time data collection and exchange (Papageorgiou and Demetriou, 2019). The utilization of IoT devices is growing rapidly, with projections indicating that up to 75.44 billion devices will be integrated into IoT networks. However, the construction industry currently faces multiple challenges, including material shortages, environmental concerns, safety

issues, varying technology adoption rates, escalating material costs, a shortage of skilled labour, inadequate design processes, high transportation and energy expenses, and delays in technology adoption (Qi et al., 2021).

Moreover, the construction industry has largely relied on manual labour, extensive machinery, and an outdated business model, which has not seen significant updates for decades (Khurshid et al., 2023). Fakunle et al. (2020) emphasize that revenue losses and production delays stem primarily from inadequate building specifications and enforcement of regulations. Amidst this backdrop, the realm of Construction Cost Management stands at the forefront of these challenges, demanding innovative solutions that enhance efficiency and transparency (Shen et al.,2001). Historically, cost management in construction has been entrenched in traditional methods that heavily rely on manual processes, spreadsheets, and limited data sources (Hegazy et al., 2020). However, IoT technology offers a transformative solution to longstanding challenges in the construction industry, potentially tracking, measuring, and optimising project processes and reducing time and costs (Tang et al., 2019). Ghosh et al. (2020) highlight that IoT can save between 22 and 29 per cent of total construction costs, equivalent to $75 to $96 billion in annual benefits. Furthermore, IoT is expected to become indispensable for various aspects of the construction industry, including waste management, cost reduction, maintenance and repair, safety improvements, and tenant requirement management (Khurshid et al., 2023).

2.0 LITERATURE REVIEW

2.1 Internet of Things

The Internet of Things (IoT) is a groundbreaking concept first introduced by Kelvin Ashton in 1999 within the realm of supply chain management (Ashton, 2009, as cited in Yaser Gamil et al., 2020; Ghosh et al., 2020; Evdokimov et al., 2019). Alzubi et al. (2020) define IoT as the interconnection of trillions of electronic devices, each equipped with sensors that regulate various aspects of human existence (Alzubi et al., 2020). Kim et al. (2018) and Syamsul H. Mahmud et al. (2018) describe IoT as a technological framework where intelligent items, including sensors, communication devices, and computer equipment, are networked via wired and wireless communication networks, enabling information collection, sharing, and utilization without human intervention. Balaji et al. (2019) define IoT as a dynamic network structure merging the real and virtual worlds through the Internet for communication and data transmission. IoT envisions a future where every day physical objects connect to the Internet and communicate with other devices to self-identify (Laghari et al., 2021). Originally, IoT was closely associated with radio frequency identification (RFID), a technology introduced in 1945 and considered a precursor to IoT (David R., 2014, as cited in Laghari et al., 2021). In addition to RFID, various technologies contribute to IoT, as mentioned in Figure 1, including WSN, Electronic Product Code (EPC), Bar Code, ZigBee, and Bluetooth, with Bluetooth gaining popularity due to its low energy consumption and convenience (Laghari et al., 2021).

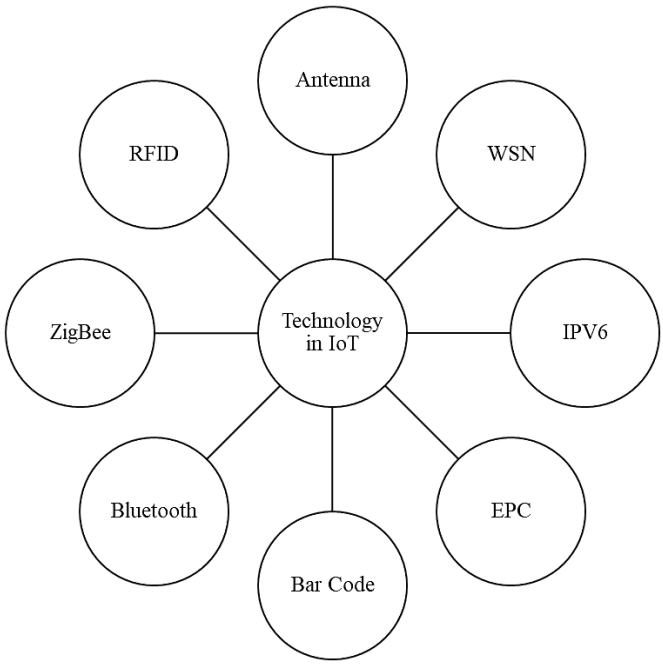

Fig. 1: Technology in the Internet of Things (IoT).
(Source: Balaji et al., 2019)

2.2 Construction Cost Management

Construction cost management is a critical aspect of the construction industry, ensuring that projects are completed within budgetary constraints and financial goals are met. It involves various processes such as budgeting, estimating, cost control, and financial reporting (Ashworth & Hogg, 2007). It is utilised to manage project costs (Miri & Khaksefidi, 2015), and its purpose is to ensure that projects are completed within the approved budget and on schedule (Igwe et al., 2020). Meanwhile, according to Herszon (2017, as cited in Vigneault et al., 2019), cost management encompasses estimating all activities and efforts required to complete the project. Accurate cost management is essential to avoid cost overruns, significantly impacting project profitability and sustainability. It requires a systematic approach to assess and allocate resources effectively, covering both direct and indirect costs associated with construction projects (Faten Albtoush et al., 2020). Figure 2 shows the RIBA Plan of Work, a comprehensive blueprint for project management in the construction industry, encompassing stages from inception to post-occupancy. Among its key stages are the Design and Construction phases, with prominent cost management activities.

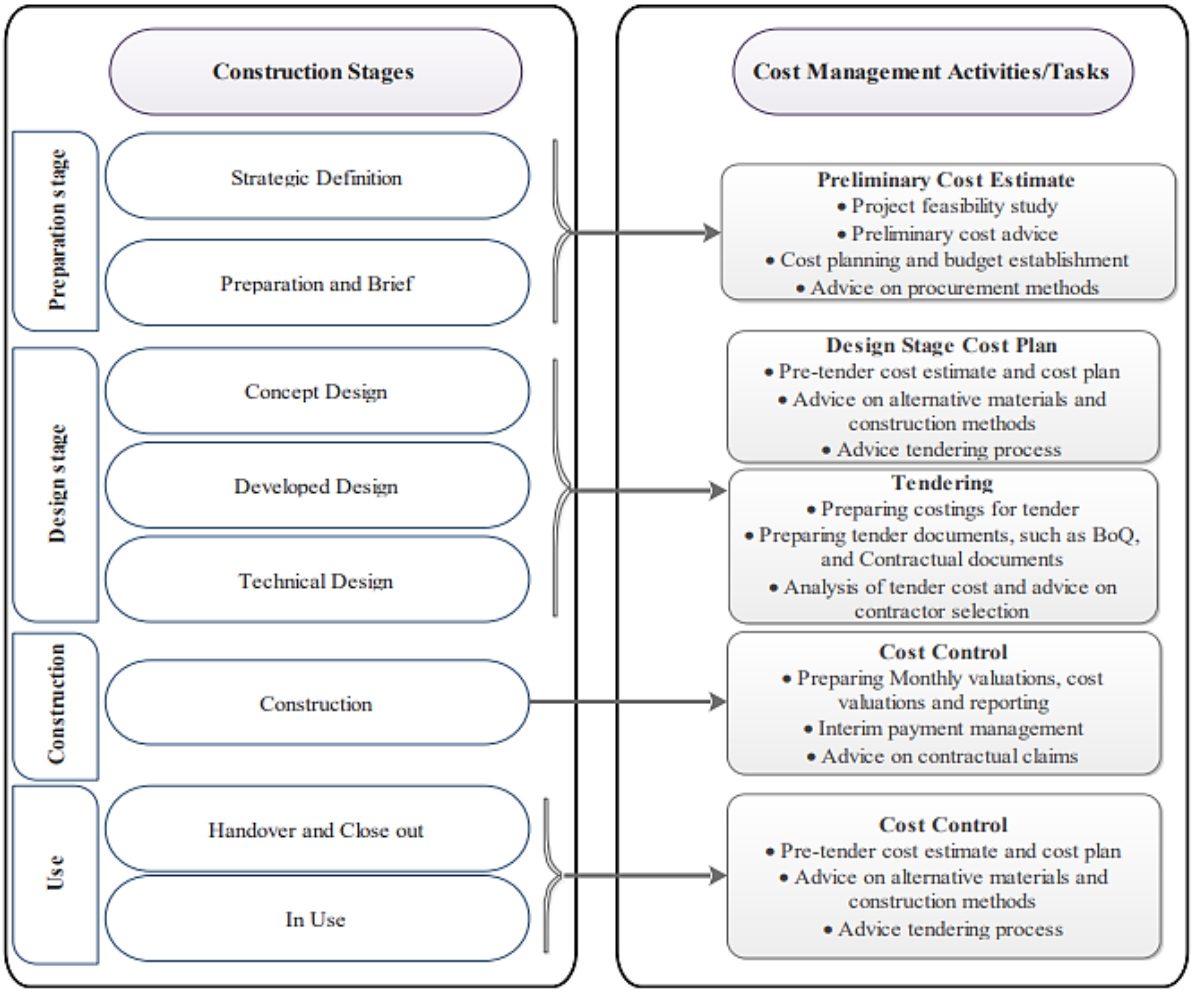

Fig. 2: Overview of the Cost Management activities within the RIBA Plan of Work framework.
(Source: Malkanthi et al., 2017)

2.3 Application of IoT in Construction Cost Management

Information and Communication Technology (ICT) in construction can significantly benefit various aspects, including construction planning, cost control, financial planning, and facilities management. However, the adoption of ICT for cost management in construction projects still needs to be improved. The complexity of modern constructions makes cost management increasingly challenging, and more than conventional approaches may be needed for effectively managing costs in competitive and complicated projects. One promising application of the Internet of Things (IoT) in construction cost management is addressing cost overruns, a prevalent issue in project management. Inaccuracies in quantity take-offs, project cash flow forecasting, and inadequate cost management often cause these overruns. Accurate cost estimation is crucial, and IoT, integrated with other IT innovations such as Big Data and Artificial Intelligence (AI), can automate certain traditional roles, including cost estimators. IoT can also be applied to supply chain monitoring in construction, where material costs constitute a significant portion of the total project cost. IoT technologies, including Radio Frequency Identification (RFID), enable tracking material data throughout construction,

optimizing material management and cost accounting. Often arbitrary and needing more standardization, traditional material management practices can hinder proper cost management.

Table 1: Application of IoT in construction cost management

No.	Application of IoT in Construction Cost Management	Citations									
		Igwe et al. (2022)	Vigneault et al. (2019)	Evdokimov et al. (2019)	Woodhead et al. (2018)	(Ding, Nemati, Ranaweera, & Choi, 2020)	Zhang et al. (2021)	Shen (2022)	Ha (2021)	Ghosh et al. (2020)	Khurshid et al. (2023)
1.	Cost estimation		✓	✓	✓				✓		
2.	Real-time monitoring and control of project expenses	✓				✓	✓	✓			✓
3.	Transparency and visibility into cost data										✓
4.	Early identification and mitigation of cost overruns		✓								
5.	Streamlined communication and collaboration among project stakeholders	✓									
6.	Connected project site enables easy and fast communication of project information, saving cost, time and energy	✓									✓
7.	Project monitoring and control resources	✓				✓		✓			✓
8.	Waste management								✓		✓

During the construction stage, various technologies such as Building Information Modeling (BIM), Augmented Reality and Virtual Reality (AR&VR), Mobile Technology, IoT, Artificial Intelligence and Machine Learning (AI & ML), Drones, Robotics, and Predictive Analytics play vital roles in cost management. These technologies enable real-time monitoring and control, accurate cost estimation, and efficient project management. Implementing IoT systems for construction site safety can yield significant cost savings compared to manual and sensor systems. Additionally, IoT technology can effectively reduce procurement lead time and project expenses by utilizing real-time data, project stock levels, and environmental conditions to facilitate efficient decision-making. RFID technology and sensors integrated into construction materials provide valuable information regarding material quality and characteristics, enhancing market research and reducing costs. IoT has the potential to

significantly impact the construction industry by improving cost management, reducing overruns, enhancing material procurement, and increasing transparency, as mentioned in Table 1. The financial benefits are substantial, with potential cost savings of 22% to 29% of total costs annually. IoT's ability to improve communication, process control, and data analysis at a micro level position it as a transformative technology in construction cost management (Ghosh et al., 2020; Kiran Khurshid et al., 2023).

2.4 Challenges of applying IoT in construction cost management

The application of IoT in construction cost management offers significant advantages but encounters several challenges across various dimensions. These challenges encompass technology, database management, operational, administrative, legislative, and knowledge-related barriers. Understanding and addressing these challenges are crucial for the successful integration of IoT in construction cost management practices. Table 1 summarises the challenges faced in IoT applications for construction cost management, as documented by various authors.

2.4.1 Technology barrier

Integrating the Internet of Things (IoT) into construction cost management offers significant benefits, including real-time data collection, enhanced project monitoring, and improved decision-making (Kiran Khurshid et al., 2023). However, several technology barriers must be addressed for successful implementation. One challenge arises from the limited advancement in research and development in IoT and Construction 4.0, often necessitating adjustments to architectures and technologies, impacting the market (Kiran Khurshid et al., 2023). Scalability is another crucial factor, as IoT deployments must accommodate diverse project sizes and complexities (Wu et al., 2022). The absence of unified standards in the construction industry limits flexibility, potentially hindering vendor switching and scaling operations (Zhong, 2022). Additionally, IoT technology complexity may disrupt existing workflows and processes, with resistance from construction teams due to perceived complexity and time constraints for learning and managing new technologies (Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman., 2021). Intricate IoT device installation processes can lead to delays and disruptions on construction sites (Laghari et al., 2021).

2.3.2 Database barrier

Database barriers in construction cost management pertain to data organization, storage, management, and utilization challenges. These barriers significantly impact cost tracking and control efficiency. IoT devices generate substantial and diverse data, including sensor readings, equipment data, and environmental conditions (Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman., 2021). Conventional database systems may need help to handle the volume and diversity of IoT data, resulting in performance degradation and slow query execution. Managing complex data relationships within IoT data, which includes sensor data linked to locations and timestamps, presents additional challenges (Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman., 2021).
Moreover, IoT service providers who need more comprehensive knowledge of construction industry requirements may develop solutions that align with cost management needs (Wu et

al., 2022). Integration of IoT data with construction cost management systems is vital for successful implementation but can be hindered by providers' limited data analytics capabilities (Zhong, 2022). Data privacy concerns arise due to weak user authentication and access control mechanisms in IoT systems, potentially leading to unauthorized access, data manipulation, and compromised decision-making (Balaji et al., 2019). The continuous collection and transmission of sensitive data by IoT devices heightens the risk of unauthorized access and breaches when data security measures are insufficiently robust (Kiran Khurshid et al., 2023).

2.3.3 Operational barrier

The implementation and operation of IoT technology within the construction industry encounter several operational barriers that stem from the challenges associated with deploying, managing, and maintaining IoT devices and systems in construction environments. One of the primary challenges is the low cost-benefit ratio of IoT implementation. The upfront investments required for IoT hardware, software, connectivity infrastructure, and skilled personnel can be significantly high, potentially discouraging construction companies from adopting IoT solutions. Moreover, the uncertainty in estimating the return on investment (ROI) for IoT implementations in construction cost management poses a hurdle (Balaji et al., 2019; Waqar et al., 2023). Additionally, an extra budget for IoT technology can strain project funds, especially when ROI is not guaranteed or immediate (Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman, 2021). Energy and device management poses another set of challenges. IoT devices require a consistent power supply, which can be challenging in remote or temporary construction sites with limited access to power sources. Managing the finite lifespans and frequent monitoring and replacement needs of battery-powered IoT devices can be time-consuming and costly (Balaji et al., 2019).
Furthermore, implementing IoT technology introduces inherent safety risks for collecting and transmitting sensitive project data. Inadequate security measures can lead to unauthorized access, data breaches, and potential legal and financial repercussions (Kiran Khurshid et al., 2023). Integrating IoT technology with existing construction processes may also result in operational disruptions, errors, or malfunctions, causing inefficiencies and delays (Yaser Gamil et al., 2020).

2.3.4 Administrative and Legislative Barrier

Administrative and legislative barriers further complicate IoT implementation in construction. The need for more training centres for IoT can hinder effective implementation, leading to inefficiencies or project failures (Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman, 2021). A lack of government support, in the form of financial resources or grants, can be a significant barrier, especially for financially constrained construction companies (Das & Abhijit Rastogi, 2023). Additionally, the absence of documented standards for implementing IoT can create uncertainties surrounding compliance with data privacy, security, and other regulations, posing risks of data breaches and unauthorized access (Kiran Khurshid et al., 2023). Legal issues related to IoT-generated data ownership and sharing agreements among multiple stakeholders can also lead to disputes (Khurshid et al., 2023). The lack of an IoT knowledge management system can further impede adoption and utilization of IoT solutions (Laghari et al., 2021; Gbadamosi et al., 2019).

2.3.5 Knowledge barrier

Knowledge barriers within the construction industry also play a significant role in hindering IoT adoption. Many professionals in the construction sector may resist IoT technology due to their familiarity with traditional cost management methods. A lack of knowledge about IoT's potential benefits may lead to reliance on conventional approaches. Additionally, the unfamiliarity with IoT technology and its operational systems can result in a reluctance to adopt new technologies and difficulties performing maintenance duties (Khurshid et al., 2023; Gamil et al., 2020). Concerns about the complexity of implementation, potential faults, and negative impacts on existing projects may further discourage IoT adoption (Khurshid et al., 2023; Gamil et al., 2020). Lack of collaboration can fragment knowledge and experience, hindering the development of a comprehensive understanding of IoT technology's advantages and applications (Khurshid et al., 2023; Yaser Gamil et al., 2020; Das & Rastogi, 2023).

Table 2: Summary of Challenges Applying IoT in Construction Cost Management

No.	Challenges		Citations
1.	Technology barriers	Limited IoT technology implementation in construction scope	Khurshid et al. (2023), Wu et al. (2022), Zhong (2022), Gamil et al. (2020)
2.		Lack of unified technical standards and specifications	Zhong (2022), Waqar et al. (2023), Das & Abhijit Rastogi (2023)
3.		Complexity of use/not user-friendly of IoT technology	Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman. (2021) Laghari et al. (2021), Zhong (2022), Gamil et al. (2020)
4.	Database barrier	The complexity of the data architecture in IoT	Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman (2021), Waqar et al. (2023), Oke et al. (2020)
5.		Lack of IoT service providers' capabilities	Zhong (2022), Gamil et al. (2020), Das & Abhijit Rastogi (2023), Wu et al. (2022), Das & Abhijit Rastogi (2023)
6.		IoT technology can lead to data privacy concerns for users.	Balaji et al. (2019), Khurshid et al. (2023), Waqar et al. (2023), Gamil et al. (2020), Das & Abhijit Rastogi (2023), Alzubi et al. (2020),
7.	Operational barrier	Requirement of extra budget to acquire IOT technologies	Khurshid et al. (2023), Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman (2021), Das & Abhijit (2023), Igwe et al. (2022), Gamil et al. (2020),
8.		IoT has a low-cost-benefit ratio.	Waqar et al. (2023)
9.		Implementing IoT requires energy and device management	Waqar et al. (2023)

No.	Challenges		Citations
10.		Implementation of IoT technology carries inherent safety risks.	Gamil et al. (2020), Khurshid et al., (2023)
11.	Administrative and legislative barrier	Lack of government support for IoT implementation	Das & Abhijit Rastogi (2023), Farah Salwati Ibrahim, Muneera Esa & Rahimi A. Rahman (2021)
12.		Shortage of training centres for IoT	Gamil et al. (2020)
13.		Lack of documented standards for implementing IoT	Gamil et al. (2020), Das & Abhijit Rastogi (2023)
14.		Legal issues about IoT	Gamil et al. (2020)
15.		Lack of an IoT Knowledge management system	Gamil et al. (2020), Khurshid et al., (2023)
16.	Knowledge barrier	Players in the construction industry are hesitant to adapt.	Khurshid et al. (2023), Lo et al. (2021)
17.		Lack of awareness among construction industry players regarding the benefits available to them	Khurshid et al. (2023), Gamil et al. (2020), Lo et al. (2021)
18.		Lack of IOT knowledge	Khurshid et al. (2023), Gamil et al. (2020), Lo et al. (2021)
19.		Lack of expertise in IoT technology	Khurshid et al. (2023), Gamil et al. (2020), Lo et al. (2021)
20.		Fear of failure when attempting to implement IoT technology	Khurshid et al. (2023), Gamil et al. (2020)
21.		Unfamiliarity and lack of IOT experience	Khurshid et al. (2023), Gamil et al. (2020)
22.		Poor collaboration among construction parties	Khurshid et al. (2023), Yaser Gamil et al. (2020), Das & Rastogi (2023)

3.0 METHODOLOGY

The research employed a mixed-methods approach to comprehensively investigate the application of IoT in construction cost management. This multifaceted methodology combined both quantitative and qualitative data collection methods. A questionnaire survey was conducted to gather quantitative data from various sectors within the construction industry. A sample of 47 respondents participated in the survey, providing insights into their experiences, perceptions, and attitudes regarding the use of IoT in construction cost management. The survey responses were subjected to statistical analysis to identify trends and patterns. In addition to the quantitative data, qualitative insights were obtained through interviews with four key stakeholders in the construction industry, representing diverse

perspectives and roles, including project managers, contractors, and technology experts. Semi-structured interviews were conducted to delve deeper into their experiences and perspectives on the challenges and benefits of implementing IoT in construction cost management.

The questionnaire is organized into five distinct sections: A, B, C, D, and E. Data analysis for sections A, B, C, D, and E was also conducted using Statistical Package for Social Science (SPSS), version 29.0. In this study, the mean values obtained for each impact have been organised in descending order, from the highest mean value to the lowest mean value. The Likert scale (Table 4.8) is the primary measurement tool, proving an effective and straightforward data collection and mean analysis method. In this study, the mean analysis for each effect has been organised in descending order, from the highest mean value to the lowest minimum value.

Table 3: Average index (AI) for the Likert scale

Scale	Item	Average index (AI)
1	Strongly disagree	0.00<AI<1.50
2	Disagree	1.50<AI<2.50
3	Neutral	2.50<AI<3.50
4	Agree	3.50<AI<4.50
5	Strongly agree	4.50<AI<5.00

The data from the Interview will be analysed by content analysis. Content analysis systematically identifies patterns, themes, and meanings within qualitative data, such as interview transcripts. It requires a methodical approach to classifying and interpreting data to draw meaningful conclusions (Bengtsson, 2016).

4.0 RESULTS

4.1 Application of IoT in Construction Cost Management

4.1.1 Questionnaire survey

Table 4: Areas or aspects of the construction industry would benefit the most from IoT application

Areas or aspects of the construction industry would benefit the most from IoT application.	Mean
Supply chain management and material tracking	4.2340
Construction project management and planning	4.1915
Equipment and asset tracking and maintenance	4.1489
Safety monitoring and risk mitigation	4.1064
Building design and energy management	4.0000

All the available choices of domains or facets of the construction sector would get significant advantages from implementing IoT, as indicated by their high scores, which surpass a value of 4.0 on the AI scale. The findings indicate that the mean values of the variables do not differ considerably. The variable with the lowest mean value is building design and energy management, with a score of 4.00. In contrast, the variable with the greatest mean value is supply chain management and material tracking, with a score of 4.23. Construction project management and planning had the second-highest AI value, with a recorded score of 4.19. Subsequently, implementing equipment and asset tracking, maintenance and safety monitoring, and risk reduction achieved AI values of 4.14 and 4.11, respectively.

Table 5: Benefits of using IoT in construction cost management

Benefits of using IoT in construction cost management	Mean
Improved accuracy and efficiency in cost estimation	4.2766
Real-time monitoring and control of project expenses	4.2766
Connected project site enables easy and fast communication of project information, saving cost, time and energy	4.1277
IoT is greatly used for project monitoring and control of resources	4.1064
Enhanced transparency and visibility into cost data	4.0851
Early identification and mitigation of cost overruns	4.0851
Streamlined communication and collaboration among project stakeholders	4.0638
It has great applications in waste management	3.9787

Table 5 shows the benefits of using IoT in construction cost management. From Table 5, all the options that answer to the potential benefits of using IoT in construction cost management are high, as the average index for all benefits is more than 3.9. The highest potential benefits are Improved accuracy and efficiency in cost estimation and real-time monitoring and control of project expenses, which recorded 4.28 AI value. The connected project site follows this, which enables easy and fast communication of project information, saving cost, time and energy (AI=4.13), and IoT is greatly used for project monitoring and control of resources (AI=4.11). Enhanced transparency and visibility into cost data and early identification and mitigation of cost overruns have similar A. I value 4.09. The next benefit is streamlined communication and collaboration among project stakeholders, scoring a 4.06 AI value. The lowest AI value of the potential benefit is 3.98, indicating IoT has significant waste management applications.

4.4.2 Interview

This section comprehensively discusses IoT's practical application and challenges in construction cost management through in-depth interviews with industry professionals. Table 6 will delineate the similarities and differences in data about the benefits of IoT in construction cost management, as derived from both the questionnaire survey and interview responses.

Respondent 1
"…especially drones because we would like to have the aerial view of our sites so that you could give a better view or better picture of the site progress as time goes."
"… BIM and Cost X. In JKR, we have an application called Cost X, which we have been using to generate all these costs as part of the project. And then we have JKR e-tender that also accommodates the system."

Respondent 2
"…Autodesk and then even from Glodon, a good software. From the design stage, you can monitor up to operation. So, at least people can use software instead of Excel because Autodesk and Glodon have software that helps the organisation monitor the budget.

"…maybe we can apply these IOT sensors on smart or intelligent buildings, which is not new. Some have done it. It's just that it may not exist in Malaysia. So, from the application of IoT on smart building, from there we can develop an IoT-based construction cost prediction."

"…you have to come up with an algorithm, and you get that input, and then you put it in the algorithm, and then from the algorithm, you will get an analysis where you can predict so that we can optimize each parameter in the building itself. So that we don't waste, one thing we can optimize is revenue cost. In return, you will get a cost control and cost prediction model for intelligent building. So, that's what we want to get. In terms of integrating IoT in the CCM process itself."

Respondent 3
"…in terms of CCM, estimate, what potential development cost and implementation can differ real-time cost which includes VO
"…process of CCM. From an earlier stage, there is value engineering, and in the execution, value engineering also cuts down costs.
"…benefits of IoT in CCM; if there is an IoT with the same environment, which all parties in one environment, cost estimate might be great, example like BIM that includes all M&E, architects, engineers in one drawing, QS can make work easy, all the information is there, just the accuracy of the info that BIM provide has to be tied back with updated cost data. In terms of project management, easy to track all work related to tendering and designing has progressed as an all-in-one environment."

Respondent 4
"Application of IoT in construction cost management is a game-changer. By integrating IoT devices and sensors into various elements of a construction project, we can gain real-time insights into resource usage, equipment performance, and project progress.
"…IoT can help us optimize resource allocation, prevent costly delays, and respond promptly to potential overruns."
"…IoT-enabled project tracking allows us to monitor progress in real-time real-time, ensuring that we stay on schedule and within budget."

Table 6: Similarities and differences data of benefits of using IoT in construction cost management from questionnaire survey and Interview

	Questionnaire Survey	Interview
Improved accuracy	Ranking no. 1	Respondent 1,2,3
Real-time data	Ranking no. 2	Respondent 1,3,4
Connected project site enables easy and fast communication of project information, saving cost, time and energy.	Ranking no. 3	Respondent 1,2,3,4

4.2 Challenges Implementing IoT in Construction Cost Management

4.2.1 Questionnaire survey

Table 7 below shows the challenges compiled according to the ranking. The average score for all IoT challenges rated by respondents is high, with only one barrier scoring a moderate average index. The requirement of extra budget to acquire IOT technologies is rated as the most challenging challenge to implement IoT in CCM. Moreover, the lowest-rated challenge is IoT's low-cost-benefit ratio.

Table 7: Summary of all challenges of implementing IoT in construction cost management

Ranking	Challenges	Mean
1	Requirement of extra budget to acquire IoT technologies	4.3404
2	Poor collaboration among construction parties	4.2979
3	Lack of expertise in IoT technology	4.2766
	Unfamiliarity and lack of IoT experience	4.2766
4	Lack of awareness among construction industry players regarding the benefits available to them	4.2553
	Lack of IOT knowledge	4.2553
	Lack of unified technical standards and specifications	4.2553
5	Implementing IoT requires energy and device management	4.2340
6	Limited IoT technology implementation in construction scope	4.1489
7	Lack of government support for IoT implementation	4.1277
8	Players in the construction industry are hesitant to adapt	4.1277
9	Shortage of training centres for IoT	4.0851
10	Lack of an IoT Knowledge management system	4.0851
11	Fear of failure when attempting to implement IoT technology	4.0426
12	Lack of documented standards for implementing IoT	4.0213
13	Lack of IoT service providers' capabilities	3.9787
14	IoT technology can lead to data privacy concerns for users	3.9362
15	Complexity of use/not user-friendly of IoT technology	3.8298
16	Legal issues about IoT	3.8511
17	Implementation of IoT technology carries inherent safety risks	3.7872
18	Complexity of the data architecture in IoT	3.7447
19	IoT has a low-cost-benefit ratio	3.4255

4.2.2 Interview

Based on the result below in Table 8, the biggest challenges mentioned by all respondents are a requirement for an extra budget to acquire IOT technologies, a lack of expertise in IoT technology, and players in the construction industry hesitant to adapt. The least challenging challenges mentioned by the respondents are the need for unified technical standards and specifications, limited IoT technology implementation in the construction scope, no enforcement from the government, and the complexity of the data architecture in IoT. These interviews were conducted to validate the findings from the questionnaire.

Table 8: Summary of challenges mentioned by respondents.

No.	Challenges	Respondent
1	Requirement of extra budget to acquire IOT technologies	1,2,3,4
2	Poor collaboration among construction parties	1,2,4
3	Lack of expertise in IoT technology	1,2,3,4
4	Unfamiliarity and lack of IOT experience	1,4
5	Lack of awareness among construction industry players regarding the benefits available to them	1,4
6	Lack of IOT knowledge	1,3,4
7	Lack of unified technical standards and specifications	4
8	Implementing IoT requires energy and device management	1,2,4
9	Limited IoT technology implementation in construction scope	4
10	Lack of government support for IoT implementation	3,4
11	Players in the construction industry are hesitant to adapt	1,2,3,4
12	No enforcement from the government	1
13	Lack of an IoT Knowledge management system	3,4
14	The complexity of the data architecture in IoT	4
15	IoT has a low-cost-benefit ratio	3,4

5.0 DISCUSSIONS

5.1 Application of IoT in Construction Cost Management

The study's findings indicate that most respondents know the term "IoT" and demonstrate awareness of its application in the construction industry. The limited utilization of IoT in the construction industry needs to be more effectively utilized. The findings presented in Table 6 and respondent from the Interview highlight that implementing IoT technology offers significant benefits to the supply chain sector, positioning it as the top-ranked area to benefit from such applications. The study by Ali et al. (2020) highlights the potential of IoT technology in supply chain management, specifically in reducing costs. The highest-ranked application of IoT technology in CCM is its ability to improve accuracy and efficiency in cost estimation and enable real-time monitoring and control of project expenses, as indicated in Table 6.

Moreover, Reja & Varghese (2019) have the same viewpoint that IoT-driven real-time monitoring in construction sites utilizes strategically embedded sensors to collect data on equipment operations, worker activities, and material movement, resulting in improved project efficiency and cost avoidance, which also connected to the point no.2 on the Table 5.

From the findings, the IoT has the potential to enhance accuracy and efficiency in cost estimation by providing real-time real-time and precise data. Based on the researcher's findings, it can be inferred that the implementation of the Internet of Things (IoT) in construction cost management is not fully maximized despite the awareness of its potential benefits in this field.

5.2 Challenges of Implementing IoT in Construction Cost Management

The primary issue in integrating IoT in CCM is the need for more financial resources to procure IoT technologies, which is the most significant demand. Singh et al. (2022) conducted a study which found that the primary obstacle to implementing IoT is the cost or budgetary constraints. Furthermore, as seen in Table 2, numerous authors have highlighted cost as a significant obstacle in IoT technology.
Furthermore, the lack of effective coordination among various stakeholders in the construction industry is seen as one of the major obstacles, which is consistently observed among the top five issues, albeit sometimes in different order. In this study, the issue of poor teamwork is ranked second, as indicated by Kissi et al. (2022), but it is ranked fifth in another source. According to researchers, inadequate collaboration can lead to suboptimal integration of IoT devices, inconsistent data formats, and challenges in developing a cohesive data gathering and analysis framework.

Furthermore, one of the primary issues associated with the Internet of Things (IoT) is its low-cost-benefit ratio. Based on the findings shown in Table 6, the researcher noted that a significant number of respondents demonstrated awareness of the advantages associated with utilising Internet of Things (IoT) technology, as indicated by their responses to the section B question. Nevertheless, the IoT can provide a favourable cost-benefit ratio in certain circumstances. Conversely, in other situations, the initial expenses associated with establishing IoT devices may surpass the immediate benefits.

6.0 CONCLUSION

In conclusion, the application of IoT in construction cost management holds great promise for revolutionizing the industry. Providing longstanding challenges such as cost overruns and project delays enables real-time data collection, analysis, and decision-making capabilities in the construction sector to optimize project outcomes and enhance efficiency. However, challenges such as additional budget allocation and improved collaboration among stakeholders must be addressed for IoT to reach its full potential in construction cost management. As technology advances, embracing IoT in construction cost management is not just an option but a necessity for staying competitive and efficient in the modern construction landscape. It is a transformative tool that can lead to more transparent and streamlined processes, ultimately benefiting industry professionals and project stakeholders.

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