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Research article

Influence of IoT implementation on Resource management in construction

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ABSTRACT

The desire to increase resource management efficacy in the construction sector is expanding because of measures to reduce costs, boost productivity, and minimize environmental impact. The Internet of Things (IoT) has the potential to alter resource management in the construction sector by delivering real-time data and insights that may assist decision-makers in optimizing resource allocation and usage. Incorporating Internet of Things (IoT) technology into the construction sector will be investigated in this study to discover how resource management is affected. The aim of the study is to identify the essential aspects that promote optimal IoT integration and to investigate how IoT may influence resource management. The relations between variables and their fundamental elements are investigated using structural equation modelling (SEM). In the context of building projects, the study analyses how IoT integration influences resource allocation and utilization, real-time monitoring, and proactive maintenance. The building sector in Malaysia provides concepts on IoT in resource management. Based on this research's outcomes, there is a distinct association between the utilization of IoT technology and effective resource management in the construction sector. IoT adoption is affected by a multiplicity of issues, including data analytics, data security and privacy, integration and interoperability, scalability, and flexibility. This study contributes to addressing considerable gaps in the corpus of information on IoT technology integration in the construction sector. It analyses how IoT may effect resource management, emphasizing how IoT technology may enhance the efficacy of human, mechanical, and material resources.

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1. Introduction

Statistics indicate a bright future for IoT implementation in the construction industry, which has experienced significant growth. According to research, the global IoT in the construction market is projected to reach $19.42 billion by 2025, representing a compound annual growth rate of 16.8 % during the forecast period. This expansion can be attributed to the pervasive adoption of Internet of Things (IoT) devices and sensors, driven by their ability to improve safety, productivity, and resource management [1,2].

One of the most important benefits of IoT adoption in the construction sector is real-time resource monitoring. Construction organizations can efficiently monitor and manage resources like workers, equipment, and supplies by using IoT-enabled sensors and devices [3,4]. Resource utilization and availability may be tracked in real time by project managers and other stakeholders [5,6]. Construction businesses can make better educated choices about resource allocation and utilization when they have access to precise and up-to-date data, resulting in more efficient and effective project outputs [7].

Predictive analytics and preventative maintenance are made possible by the integration of IoT technologies with resource management systems. For instance, Internet of Things sensors may collect information on how well equipment is working and flag potential issues or breakdowns before they become expensive issues [8,9]. This enables construction businesses to plan preventative maintenance, which reduces downtime and increases operational efficiency [10,11].

IoT resource management may enhance supply chain and inventory control. Construction companies may get real-time inventory data from IoT devices, alerting them to low stock levels and enabling prompt restocking [12]. Another benefit is that IoT-enabled monitoring devices can keep an eye on how supplies and tools are moved about a building site, reducing theft and improving logistical processes [13,14].

The construction industry faces multifaceted challenges in resource management, particularly concerning Materials, Manpower, and Machinery (the triple M). The intricate interplay between these three elements significantly impacts resource efficiency and, consequently, the profitability of construction firms. Materials management involves the procurement, transport, and utilization of construction materials, with challenges ranging from supply chain disruptions to wastage. Manpower management grapples with optimizing the allocation and utilization of skilled labor, addressing issues such as workforce shortages and skill gaps. Machinery management deals with the maintenance, deployment, and efficiency of construction equipment, with challenges including breakdowns and technology obsolescence. Recognizing the complexities of the triple M is essential for understanding the industry-specific obstacles that hinder resource efficiency. This research delves into the transformative potential of IoT in addressing these challenges, offering a strategic approach to enhance resource management in construction projects.

Several significant gaps are found in the examination of IoT adoption in the construction industry for resource management. IoT technology adoption is constrained, mostly as a result of economic considerations, a lack of knowledge, and opposition to change. Second, the vast amounts of data produced by IoT devices are being underutilized and under analyzed, underscoring the need for improved data analytics skills [15,16]. Inadequate emphasis is also placed on the security and privacy of IoT devices and data, necessitating the implementation of stringent safeguards against cyberattacks and compliance with privacy regulations [17,18]. To close these gaps, collaborative efforts are required to increase adoption, enhance data analytics, enhance integration and interoperability, establish standards, and prioritize security and privacy in IoT implementation for construction resource management [19].

The purpose of this study is to look at the key aspects for IoT adoption in the construction industry and how it influences resource management. This study intends to: (1) identify and investigate the critical factors that influence the effective implementation of IoT technology for resource management in the construction sector. (2) Evaluate the impact of IoT deployment on construction project resource management in terms of utilization and optimization of the triple M (man, machine, and material). One of the earliest studies conducted in Malaysia looked at the influence of IoT adoption on resource management in the construction sector. By researching this issue in a specific geographical context, the research provides insights and repercussions germane to the Malaysian construction business.

Likewise, this study uses extensive structural equation modelling (SEM) to evaluate how the adoption of IoT might affect resource management. SEM is a dependable statistical approach that allows for in-depth examination of the relationships between variables and the underlying constructs. This study used SEM to analyze the direct and indirect effects of IoT deployment on resource allocation, utilization, real-time monitoring, and preventative maintenance in the construction sector. The detailed modelling approach increases the study's validity and reliability, advancing knowledge in IoT application for building resource management.

This article is structured in which the Introduction establishes the significance of IoT in construction and outlines the research structure. The Literature Review explores existing knowledge and gaps in IoT adoption for construction resource management. Methodology details the research design, model development, and analysis. Results and Analysis present demographic details and PLS-SEM measurement outcomes. Discussion analyzes findings in context, and the Conclusion summarizes contributions and suggests future research. The References and Appendix sections conclude the article.

2. Literature review

Construction is one of the most important and major sectors of the global economy. But it is regarded as one of the least productive and inefficient sectors of the economy. The construction sector has tremendous resource management challenges as a result of the enormous amount of people, equipment, and materials that are required for construction projects [20]. Efficient management of these resources is crucial for timely and cost-effective project execution. The Internet of Things (IoT), a fast-growing technology, has the potential to revolutionize resource administration in the construction industry. IoT devices are tangible objects equipped with sensors and actuators that acquire and share data online [21]. These devices can monitor and measure the location, status, and utilization of resources on construction sites. The collected information can then be used to optimize resource utilization and reduce waste [1].

The involvement of all stakeholders in a construction project plays a vital role in defining the quality of the ultimate product. As a result, surveillance and control are crucial for ensuring high-quality outcomes in the construction sector [13]. Every step of the life cycle of a product, starting with the concept stage, must be covered by quality management. Prior to the introduction of Construction 4.0, analogue depictions of reality were the mainstay for design systems for decision-making and building monitoring and control [14]. However, this method was criticized for being strict in function adaptation and for being time- and money-consuming. In order to improve model output, construction 4.0 has incorporated sensor-based 3D systems for modelling building products [17]. The use of computer-aided design (CAD) makes it easier for designers to ensure the quality of their work by letting them picture how a drawing will appear [11]. This makes quick modifications and manipulation possible. The building industry now has calibrated apps. Quantitative quality management techniques that combine form and function are used by decision support systems and in the creation of quality parameters [2]. Applications that use augmented and virtual reality make it easier to see how quality effects may be assessed throughout the construction process [22,23]. These developments provide a wide range of chances to use Industry 4.0 in construction quality control.

In academia and industry, IoT use is still in its early stages and can be viewed as a post-advancement of the fourth industrial revolution, or Industry 4.0. The Internet of Things (IoT) is necessary in organizations in general and in human resource management (HRM) in particular to manage effectiveness, security, objectivity without prejudice, and transparency [24]. As a result, examinations have been conducted to determine the relevance of the technology and its potential use [25,26]. However, little study has focused on the HRM area and the use of IoT. Due to the young nature of the invention, previous research has mostly linked human resources to information technology rather than IoT [9,23]. The direct link between the use of information technology to human resources and the resource for innovation aims to improve business performance. It is necessary to provide a full display of information technology for assessing important organizational elements [27]. It is necessary to have a comprehensive understanding of information technology and management distinctions, especially human resource management [22,28]. Studies looking into the relationship between HRM and IoT are concerned about the future prospects of workplace change as a result of automated work environments, especially if work updating was required themselves with smart things that HR data systems would require, such as reporting time and schedule, skill gap, break utilization, staffing, etc. The duality of innovation depicts invention as both having intrinsic features and being the result of human action [29,30]. As a result, players in a social situation produce and socially construct innovation by giving multiple meanings to it as shown in Table 1. IoT implementation has a positive impact on resource management in construction. It enables real-time data collection and analysis, optimized resource allocation, predictive maintenance, reduced waste, improved safety, improved communication, and collaboration, as well as increased transparency and accountability [31,32]. It is important to consider several factors when implementing IoT in construction. Data security is crucial to protect the collected data from unauthorized access. Integration with existing construction management systems is necessary for effective implementation. Training workers on how to use and interpret IoT data is also important [16,33]. As a result, innovation emerges from the ongoing interplay of human decisions and institutional environments.

The data gathered may then be utilized to optimize resource use and eliminate waste. The construction industry oversees delivering building products to suit worldwide consumer demands, such as large housing and hotel facilities. The engagement of all stakeholders in a building project is critical in determining the final product's quality [7,12]. As a result, monitoring and controlling are critical for assuring high-quality outputs in the construction industry. Quality management must be rigorous, incorporating every stage of a product's life cycle beginning with conception [7,19]. Prior to the introduction of Construction 4.0, design decision support systems and construction monitoring and control were mostly based on analogue representations of reality [28,34]. This technique was criticized for its rigidity in function adaptability as well as its time- and cost-intensive nature [5,9]. Sensor-based 3D technologies for construction product modelling have been added in Construction 4.0, improving model output. Computer-aided design (CAD) improves design quality by allowing designers to visualize how a drawing will look or appear [6,15]. This allows for quick modifications and manipulation. In the construction industry, calibrated apps are now accessible. Quantitative quality management methods that combine function and form are used in decision support systems and quality [18,35].

A literature study was undertaken using Scopus, a vast database of scientific journals. The goal of the study was to find and analyze the keywords applied in earlier studies. The research focused on studies published between 2012 and 2023 that studied how the

Table 1
Comparison of IoT implementation impact factors.

S.No	Impact	IoT implementation	Data security	Integration	Training	Cost	Complexity
1	Reduced environmental impact	✔	�	�	�	✔	✔
2	Improved communication and collaboration	✔	�	�	�	✔	✔
3	Enhanced customer satisfaction	✔	�	�	�	✔	✔
4	Real-time data collection and analysis	✔	⚠	⚠	✔	✔	⚠
5	Predictive maintenance	✔	�	�	�	✔	✔
6	Optimized resource allocation	✔	�	�	�	✔	✔
7	Increased transparency and accountability	�	✔	⚠	✔	✔	⚠
8	Improved safety	✔	�	�	�	✔	✔
9	Reduced waste	✔	�	�	�	✔	✔
10	Improved profitability	✔	�	�	�	✔	✔

⚠ symbol to highlight the potential data security risks.

adoption of IoT influences resource management in construction projects. The inquiry employed co-occurrence analysis, which counts the number of times two words appear together in a single text. The unit of analysis was all keywords, including title words, index keywords, and author keywords. The research only considered words that appeared at least five times in the chosen papers. A visualization was built using 1500 of the 11,714 keywords that were analyzed and satisfied the requirements. The top 1000 keywords were chosen for the visualization based on their worth and relevancy.

According to the visualization analysis, most past studies on the deployment of IoT in resource management were confined to particular project kinds, geographical areas, or statistical techniques [9]. There is a paucity of study on a global and all-encompassing framework of IoT implementation in resource management that can be employed for a broad variety of construction projects such as building construction, infrastructure development, highways, and industrial projects. Future study may leverage this gap in the literature to build practical techniques for resource analysis and management leveraging IoT technologies [6]. Fig. 1 provides a depiction of the study environment based on word co-occurrence. The visualization emphasizes keyword networks and clusters, as well as their frequency and degree of association1. It gives insights into the links between multiple fields of research and may serve as a resource for academics interested in diving more into a given area of IoT use in resource management.

The Scopus-based literature analysis offers a thorough evaluation of prior research on IoT implementation in resource management in construction projects. It underscores the necessity of future study to establish a standard framework for IoT implementation that can be applied across various construction projects [18]. The most often used search terms include IoT, AND construction, OR resource OR management, OR smart AND cities. The keywords also emphasize the unique fields of research on IoT deployment and building resource management. Certain terms, for example, are associated with the use of IoT sensors to track and monitor resources, whilst others are associated with the use of big data and analytics to optimize resource utilization.

The countries with the greatest publications on IoT adoption and resource management in the construction sector are shown in Fig. 2. The top three nations in terms of published papers are India (2988 documents), the United States (1239 documents), and China (1194). Many previous studies on the deployment of IoT in resource management, according to the visualization analysis, were limited to certain project categories, geographical locations, or statistical approaches. India, the United States, and China are the top three nations in terms of published papers. Most previous research on the use of IoT in resource management was restricted to certain project categories, geographical locations, or statistical approaches [5,7,35]. There is a shortage of study on a global and all-encompassing framework of IoT deployment in resource management that may be employed in a variety of construction projects. Future study may leverage this gap in the literature to build practical techniques for resource analysis and management leveraging IoT technologies.

3. Methodology

The chosen research methodology aligns explicitly with the stated objectives of this study. To enhance methodological rigor, a

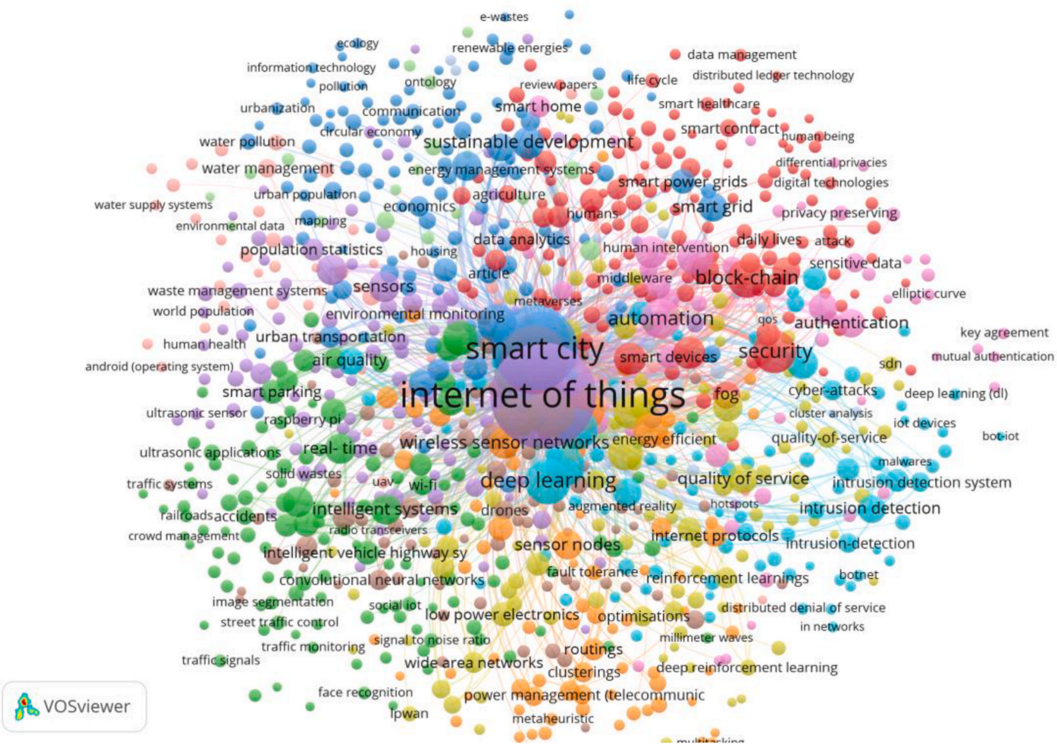

Fig. 1. Examining IoT implementation in Resource management in construction projects using keywords.

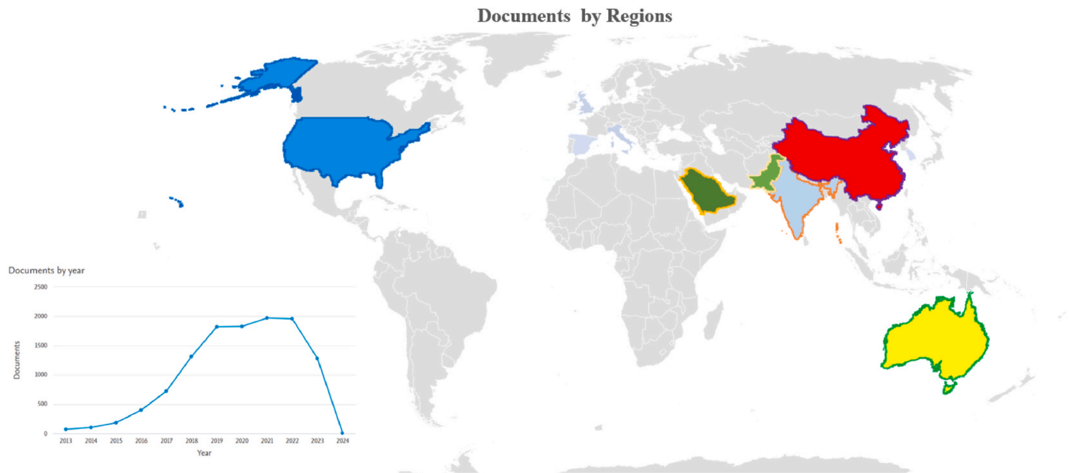

Fig. 2. The countries with the most documents.

theoretical framework has been integrated to provide a solid foundation for the selected qualitative components. Drawing inspiration from similar studies that have successfully employed comparable methodologies, the theoretical foundations and relevance of these approaches to the current research are explored. This nuanced approach strengthens the overall methodological framework, ensuring a robust foundation for the qualitative aspects of the study.

The research involved three main phases. In the first phase, a thorough literature evaluation was conducted to identify the most critical factors for IoT implementation and resource management in the construction industry. This phase involved reviewing

Table 2
Identification of factors from literature review along with expert opinion.

Group	Code	Critical Factors for IoT Implementation	References
Integration & Interoperability	IoT-II1	In IoT implementation, integration and interoperability enable seamless data transfer between IoT devices, sensors, and construction management systems.	[9,35]
	IoT-II2	They enable centralized monitoring and control of Internet of Things devices, which promotes effective project management.	[13,17]
	IoT-II3	In construction initiatives, IoT real-time data integration enables timely decision-making and proactive problem-solving.	[21,30]
Data Analytics & Actionable Insights	IoT-DA1	In the implementation of IoT, data analytics provides construction professionals with valuable insights for making informed decisions.	[21,31]
	IoT-DA1	Applying data analytics to IoT data improves safety by identifying potential hazards and enhancing compliance.	[2,33]
	IoT-DA1	It facilitates process optimization by analyzing data to identify improvement opportunities and enhance productivity.	[24,32]
Scalability & Flexibility	IoT-SF3	Scalability guarantees that the IoT solution can accommodate large-scale and complex projects.	[1,35]
	IoT-SF3	As project requirements evolve, adaptability makes integrating new devices and technologies possible.	[36,37]
	IoT-SF3	Scalability and adaptability allow for the expansion and modification of the IoT infrastructure without interruption.	[29,38]
Data Security and Privacy	IoT-DP1	Data security and privacy are crucial for protecting sensitive construction project data from unauthorized access and cyber threats.	[19,35]
	IoT-DP1	Robust security measures mitigate the financial and legal repercussions of data breaches.	[35,37]
	IoT-DP1	Data security measures foster confidence among clients, partners, and stakeholders, augmenting the company's standing.	[30,35]
Material Management	MT1	IoT enables real-time material monitoring, providing accurate inventory data and decreasing material loss and theft.	[7,9]
	MT2	The Internet of Things facilitates demand forecasting, enabling construction companies to optimize material planning and procurement, thereby minimizing superfluous inventory and stockouts.	[6,20]
Man Management	WT1	IoT provides real-time surveillance and monitoring of construction employees, allowing for the more efficient man- and resource management.	[15,27]
	WT2	IoT enables enhanced communication and coordination among construction teams, facilitating efficient human resource management and project collaboration.	[21,32]
Machine Management	ET1	IoT enables remote machine monitoring and control, facilitating efficient scheduling, troubleshooting, and optimization of construction machine operations.	[10,19]
	ET2	The Internet of Things enables real-time monitoring of machine performance, utilization, and maintenance requirements, thereby enabling efficient machine management.	[35,39]

academic articles, industry reports, and case studies to gain insight and identify key factors [9,20]. Examining the relationships between the identified factors and resource management outcomes using statistical methods such as regression analysis and correlation analysis [24]. In the final phase, an in-depth structural equation modelling (SEM) measurement model was used to evaluate the designed hypotheses further. Validating the proposed hypotheses, SEM enabled a comprehensive analysis of the relationships between multiple variables and their underlying constructs [32]. Overall the study followed mixed method 3 phase research approach and data collection was done under three phases. Phase I - literature review to identify factors, Phase II – verify those factors through interviews with 17 experts and Phase III – Establish the relationship between the factors using the data collected from Survey.

4. Research model development

Qualitative interviews and a comprehensive literature review were utilized to identify and categorize the critical factors for implementing IoT in the construction industry and to identify the variables involved in resource management through IoT implementation [19,33]. The literature review included a comprehensive analysis of pertinent scholarly articles, industry reports, and case studies. This assessment enabled a thorough comprehension of the existing knowledge and identified the key factors influencing successful IoT implementation and the variables associated with resource management in the context of construction projects [20,30]. In addition, qualitative interviews with 17 participants with 15 or more years of experience in the Malaysian construction industry were conducted. These interviews provided valuable perspectives and insights from industry professionals with direct experience implementing IoT technologies and administering construction project resources [27]. This study identifies the variables, as indicated in Table 2, associated with resource management through IoT implementation by integrating findings from qualitative interviews and a literature review. This method guarantees a comprehensive comprehension of the topic by combining theoretical insights from the literature with practical perspectives from industry experts.

Based on interviews and a review of the literature, and following the design and finalization of all factors, the following hypothesized Fig. 3 have been developed.

H1. IoT Implementation has a significant impact on resource management in construction.

- H1a-1: Data analytics and actionable insights positive relation with IoT implementation.
- H1a-2: Data security and privacy have a positive relation with IoT implementation.
- H1a-3: Integration and interoperability have a positive relation with IoT implementation.
- H1a-4: Scalability and flexibility have a positive relation with IoT implementation.
- H1a-1: Resource management has a positive relation with machine management
- H1a-2: Resource management has a positive relation with man management
- H1a-3: Resource management has a positive relation with material management

These hypotheses reflect the anticipated relationships between the critical factors identified through interviews and literature review and the impact of IoT implementation on resource management in the construction industry [31].

4.1. Data collection

This survey investigation for phase 3 was conducted in Perak, Malaysia. As respondents to the survey, 240 construction industry professionals were targeted. The survey was disseminated via email and was occasionally administered manually by local experts. With a response rate of 67 %, 158 valid responses were obtained from 240 distributed surveys. The sample size of 158 respondents was deemed adequate for this study, consistent with previous research studies that investigated IoT implementation and resource management in the construction industry using similar sample sizes [11,24]. Based on a 5-point Likert scale extending from strongly disagree to concur strongly, the questionnaire was designed. The questionnaire included questions about the critical factors identified

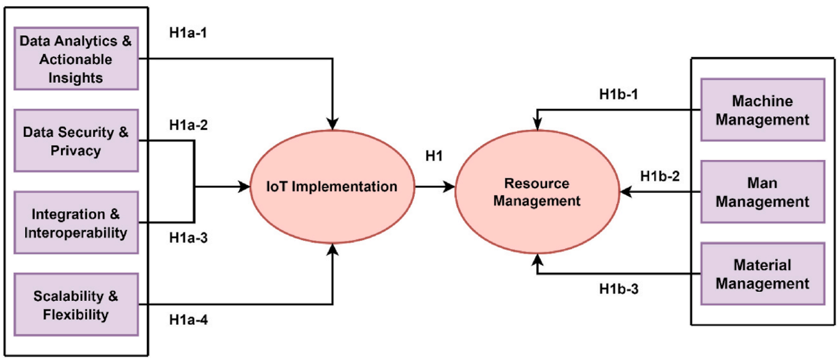

Fig. 3. hypothesized theoretical framework of the study.

through the literature review, intending to gauge respondents' perceptions and opinions regarding IoT implementation and its impact on resource management in construction projects [37]. Using a quantitative analysis with a sample of 158 respondents, this study intended to provide meaningful insights into the critical factors for IoT implementation and resource management in the construction industry in Perak, Malaysia. The survey methodology and questionnaire design were consistent with previous research studies and ensured an organized and trustworthy data collection and analysis approach.

Further this research adhered to the highest ethical standards and principles. Ethical approval for this research was obtained from the Ethical Committee for Research Involving Human Subjects at University, under the auspices of the Ethical Review Committee for Academic Research (ERCAR-UP). The research was carried out in full compliance with the guidelines, protocols, and regulations set forth by the ERCAR-UP. The ethical considerations encompassed all aspects of the research, including the recruitment of participants, data collection methods, data storage and protection, and the dissemination of findings. Informed consent was obtained from all participants involved in this study, and they were assured of their rights to privacy and confidentiality. Measures were taken to ensure the anonymity and confidentiality of sensitive data. Furthermore, any potential risks to the participants were minimized, and the research procedures were designed to maximize the benefits while minimizing harm. Any potential conflicts of interest were disclosed and managed in accordance with the guidelines established by the ERCAR-UP.

4.2. PLS-SEM algorithm measurement

The SmartPLS 4 software used the Partial Least Squares Structural Equation Modelling (PLS-SEM) algorithm to test the proposed hypotheses and analyze the relationships between variables. PLS-SEM is a statistical method for analyzing complex relationships between latent constructs and observed variables [18,30]. As part of the analysis, convergent validity and discriminant validity were evaluated. Convergent validity investigates whether the indicators of a latent construct measure the same underlying construct. The evaluation was based on the indicator factor loadings, average variance extracted (AVE), and composite reliability (CR). Factor loadings represent the intensity of the relationship between each indicator and its corresponding construct, whereas AVE quantifies the variance the construct represents relative to measurement error [31,32]. CR evaluates the construct's internal consistency reliability.

In contrast, discriminant validity determines whether the measures of different constructs are distinct. It ensures that the constructs capture distinctive aspects of the studied phenomenon. Examining the inter-construct correlations and comparing them to the square roots of the AVE values for each construct was used to assess discriminant validity [18,20]. If the inter-construct correlations were below the square roots of the AVE values, discriminant validity was deemed to exist.

4.3. Structural model development

The structural model analysis aimed to analyze the relationships between the identified critical factors and resource management outcomes in the construction industry due to IoT implementation [9,27]. The analysis included bootstrap analysis, a resampling technique used to estimate standard errors and confidence intervals of model parameters. For each hypothesis, the bootstrap analysis entailed resampling the original sample (O) multiple times. The resamples utilized to determine the sample mean (M) and standard deviation (STDEV) for every parameter estimate. The significance of the relationships between the critical factors and resource management outcomes was then determined by calculating the t-statistics and p-values [24,36]. In addition to evaluating the hypothesis, the R2 value was calculated to evaluate the structural model's fit. The R2 value indicates the proportion of the variance in the dependent variable explained by the model's independent variables. A more excellent R2 value indicates that the model fits the data more closely [24,30].

4.4. Predictive Relevance

The model's capacity to forecast resource management outcomes based on the identified essential components was evaluated using the Predictive Relevance (Q2) metric, which was developed to do so. It did this by calculating the squared correlation between the actual and anticipated values and dividing that result by the variance of the observed values [5,7]. If the value of Q2 is high, this shows that the model has superior predictive ability, which implies that it helps project resource management results in the construction business.

5. Results and Analysis

5.1. Demographic details

The demographic details of the participants in the study are as follows. In terms of profession, the respondents consisted of 12 Quantity Surveyors (6.9 %), 21 Architects (12.0 %), 70 Civil Engineers (40.0 %), 6 M&E Engineers (3.4 %), 30 Project Managers (17.1 %), and 19 individuals from other professions (10.9 %). Regarding the organization they belonged to, 67 respondents (38.3 %) were from contractor companies, 61 (34.9 %) were from consultant firms, and 30 (17.1 %) were from client organizations. In terms of their construction experience in Malaysia, 40 respondents (22.9 %) had 0–5 years of experience, 38 (21.7 %) had 6–10 years of experience, 40 (22.9 %) had 11–15 years of experience, 22 (12.6 %) had 16–20 years of experience, and 18 (10.3 %) had over 20 years of experience. The majority of the participants (149, 95 %) indicated that they knew digital technologies, specifically IoT, while nine respondents (5 %) responded with "No/Maybe" to knowing IoT.

5.2. PLS-SEM measurement model

The findings of the concurrent validity analysis, which evaluates the reliability and validity of the measurement model, are shown in Table 3 and may be found below. Cronbach's alpha (CA), composite reliability (CR), and average variance extracted (AVE) are the markers that may be found in the table.

Three different indicators (IoT-II1, IoT-II2, and IoT-II3) were used for the Integration and Interoperability build. The loadings represent the degree to which there is a connection between each indication and the construct it corresponds to. The variance inflation factor, or VIF, is a measurement tool for determining multicollinearity; values lower than 5 indicate no substantial multicollinearity [10,14]. The construct had a Cronbach's alpha of 0.76, indicating an adequate level of internal consistency. It also had a composite reliability of 0.801, which indicates that it has a strong level of reliability. Additionally, it had an average variance extracted of 0.673, which suggests that the indicators explain 67.3 % of the variation in the construct [5,7].

Similarly, the relevant indicators and their loadings are presented for the structures "Data Analytics and Actionable Insights," "Scalability and Flexibility," "Data Security and Privacy," "Material Management," and "Man Management," respectively. Each concept exhibited sufficient levels of internal consistency (as measured by Cronbach's alpha), strong reliability (as measured by composite reliability), and an appreciable amount of explained variance (as measured by the average variance extracted) [13,15].

It is essential to notice that some indicators (IoT-II3, IoT-DA4, and IoT-DP3) were removed from their respective constructions. This may have resulted from low factor loadings, problems with item relevance or dependability, or a combination of these factors [18,19]. These results provide credence to the robustness of the measurement methodology used throughout the research.

The findings of the discriminant validity study, as determined by using the Heterotrait-Monotrait (HTMT) criteria, are detailed in Table 4. The HTMT values are a representation of the degree to which distinct constructs are correlated with one another. The square roots of the AVE values for each build are located in the components of the table that are located along the diagonal. Because the HTMT values are lower than the cutoff of 0.85, the findings suggest that the constructs have a high degree of discriminant validity [30,35]. Compared to the square roots of the AVE values on the diagonal, the HTMT values are lower than the off-diagonal values, which shows that the constructions are separate. For instance, the HTMT value of 0.325 between Data Analytics and Actionable Insights (DA) and Data Security and Privacy (DP) is less than the square root of the AVE that exists for both constructs, which guarantees that their discriminant validity exists [21,24]. Similarly, the HTMT values for other construct pairings (such as DA and Integration & Interoperability (II), Machine (ET) and Material (MT), etc.) are all below the threshold, which provides further evidence that the constructs are unique from one another [36,38]. Overall, the discriminant validity analysis performed using the HTMT criteria verifies that the constructs investigated in this research are distinguishable [20,33]. This instils confidence in both the validity of the measurement model and the independence of the variables that are being evaluated.

The findings of the Fornell-Larcker criteria for determining the discriminant validity of a test are shown in Table 5. The square roots of the values extracted from the AVE (Average Variance Extracted) for each build are shown in the table. According to the Fornell-Larcker criteria, to ensure that the model is discriminant, the square root of the AVE for each construct has to be greater than the correlations between the respective construct and the other constructs in the model. The diagonal elements in Table 5 represent the square roots of the AVE values for each construct [5,6]. These figures provide an assessment of the amount of variation that each construct's indicators are able to capture [2,6]. The results show that the correlations with other constructs are less significant than the square roots of the AVE values for each construct, validating the discriminant validity [7,11]. When compared to its correlations with other constructs (DP, II, ET, WT, MT, SF), the square root of the AVE for Data Analytics & Actionable Insights (DA) is more significant, demonstrating that DA is different from the other constructs. This may be shown by contrasting the correlations between the DP, II, ET, WT, MT, and SF with the square root of the AVE [15,16]. The Fornell-Larcker criterion analysis shows that the constructs have sufficient discriminant validity overall [7,11]. This implies that the constructs assess different parts of the research phenomena and do not

Table 3
Convergent validity output indicating Cronbach alpha, composite reliability and average variance extracted.

Group	Code	Loadings	VIF	CA	CR	AVE
Integration & Interoperability	IoT-II1	0.681	1.145	0.76	0.801	0.673
	IoT-II2	0.939	1.138			
	IoT-II3	Deleted	2.141			
Data Analytics & Actionable Insights	IoT-DA1	0.822	1.142	0.725	0.808	0.678
	IoT-DA2	0.825	1.178			
	IoT-DA4	Deleted	1.122			
Scalability & Flexibility	IoT-SF1	0.781	1.369	0.707	0.837	0.63
	IoT-SF2	0.798	1.407			
	IoT-SF3	0.803	1.366			
Data Security and Privacy	IoT-DP1	0.939	1.178	0.844	0.927	0.865
	IoT-DP2	0.921	1.125			
	IoT-DP3	Deleted	1.211			
Material Management	MT1	0.638	1.125	0.761	0.79	0.662
	MT2	0.958	1.131			
Man Management	WT1	0.844	1.126	0.713	0.833	0.714
	WT2	0.846	2.145			
Machine Management	ET1	0.818	2.147	0.741	0.751	0.602
	ET2	0.731	1.110			

Table 4
Discriminant validity results in output through HTMT criterion.

Constructs	DA	DP	II	ET	WT	MT	SF
Data Analytics & Actionable Insights = DA							
Data Security and Privacy = DP	0.325						
Integration & Interoperability = II	0.365	0.173					
Machine = ET	0.686	0.34	0.57				
Man = WT	0.538	0.187	0.383	0.643			
Material = MT	0.365	0.173	0.786	0.57	0.383		
Scalability & Flexibility = SF	0.58	0.219	0.302	0.683	0.435	0.302	

Table 5
Fornell lacker criterion for discriminant validity.

Constructs	DA	DP	II	ET	WT	MT	SF
Data Analytics & Actionable Insights = DA	0.823						
Data Security and Privacy = DP	0.218	0.93					
Integration & Interoperability = II	0.214	0.129	0.82				
Machine = ET	0.72	0.189	0.243	0.776			
Man = WT	0.302	0.121	0.139	0.304	0.845		
Material = MT	0.216	0.131	0.998	0.236	0.157	0.814	
Scalability & Flexibility = SF	0.353	0.164	0.12	0.35	0.937	0.135	0.794

have a strong correlation with one another.

The findings of using the cross-loading criteria to determine the discriminant validity of the test are shown in Table 6. The loadings of each indicator are shown in the table, both on the construct for which it was designed and on any additional relevant structures [2,6]. Cross-loadings help determine whether or not an indicator predominantly measures its intended construct or whether or not it also has substantial loadings on other constructs, which may signal that there are possible problems with the discriminant validity of the indicator [20,27]. The findings demonstrate that the indicators, on average, have more significant loadings on their intended constructions than loadings on other constructs; this indicates that the discriminant validity of the indicators is good [21,32]. For instance, the indicators IoT-DA1 and IoT-DA2 have more significant loadings on the Data Analytics & Actionable Insights (DA) construct than the loadings they have on other constructs (DP, II, ET, WT, MT, and SF). Similarly, the Integration and Interoperability (II) construct has a more significant loading for the indicators IoT-II1 and IoT-II2 than for any other structures. This pattern holds for the other indicators and constructions included in the table [31,35].

5.3. Structural model development

The findings in Table 7, indicate that all of the hypotheses have been validated, including H1, H1a-1, H1a-2, H1a-3, and H1a-4, as well as H1b-1, H1b-2, and H1b-3. This indicates substantial evidence supporting the proposition that there is a positive link between the variables in each hypothesis.

In the “Relation” column, the predicted direction of the connection between the variables is shown by the direction of the arrow [20,35]. The values from the original sample are shown in the "(O)" column, while the values from the sample mean are shown in the "(M)" column. The “SD” column provides a representation of the average amount of variation across all of the variables [7,11]. The column labelled “T statistics” in the following table displays the computed t-statistics, which determine how strong a correlation exists

Table 6
Cross-loading criterion for discriminant validity.

Variables	DA	DP	II	ET	WT	MT	SF
IoT-DA1	**0.822**	0.252	0.183	0.617	0.348	0.184	0.366
IoT-DA2	**0.825**	0.107	0.169	0.568	0.149	0.171	0.216
IoT-DA1	0.232	**0.939**	0.11	0.208	0.14	0.112	0.189
IoT-DA2	0.17	**0.921**	0.133	0.139	0.08	0.133	0.111
IoT-II1	0.115	0.063	**0.681**	0.242	−0.133	0.238	−0.114
IoT-II2	0.215	0.133	**0.939**	0.192	0.237	0.258	0.205
Equipment Tracking 1	0.626	0.185	0.271	**0.818**	0.345	0.26	0.386
Equipment Tracking 2	0.482	0.101	0.092	**0.731**	0.108	0.093	0.137
Workforce Tracking 1	0.231	0.034	0.117	0.211	**0.844**	0.13	0.281
Workforce Tracking 2	0.279	0.17	0.118	0.301	**0.846**	0.134	0.203
Material Tracking 1	0.115	0.063	0.282	0.242	−0.133	**0.638**	−0.114
Material Tracking 2	0.215	0.133	0.238	0.192	0.237	**0.958**	0.205
IoT-SF1	0.231	0.034	0.117	0.211	0.244	0.13	**0.781**
IoT-SF2	0.331	0.182	0.05	0.317	0.238	0.056	**0.798**
IoT-SF3	0.279	0.17	0.118	0.301	0.246	0.134	**0.803**

Table 7
Hypothesis testing of the study.

Hypothesis	Relation	(O)	(M)	SD	T statistics	P values	Results
H1	IoT - > Resource	0.932	0.933	0.012	80.402	0	Accept
H1a_1	DA - > IoT	0.395	0.389	0.041	9.628	0	Accept
H1a_2	DP - > IoT	0.153	0.151	0.04	3.811	0	Accept
H1a_3	II - > IoT	0.628	0.625	0.057	11.061	0	Accept
H1a_4	SF - > IoT	0.31	0.307	0.038	8.064	0	Accept
H1b_1	Resource - > Machine	0.416	0.419	0.078	5.317	0	Accept
H1b_2	Resource - > Man	0.38	0.385	0.076	4.976	0	Accept
H1b_3	Resource - > Material	0.858	0.859	0.031	27.938	0	Accept

(O)= Original sample; (M) = Sample mean; SD= Standard deviation; DA = Data Analytics & Actionable Insights; DP = Data Security and Privacy; II= Integration & Interoperability; SF= Scalability & Flexibility.

between the variables. The significance level (p-value) linked with the t-statistics is shown in the "P values" column.

In every instance, the values of the t-statistics are high, which suggests that there is a meaningful connection between the variables. The fact that the p-values were both reported to be 0 suggests that the associations being studied are statistically significant [14,15]. The strength and direction of interactions between constructs may be determined by looking at the path loadings. In contrast, the statistical significance of these correlations can be determined by looking at the p-values [17,18]. A PLS model's path loadings and T-values are shown graphically in Fig. 2. While T-values reveal the statistical significance of these correlations, path loadings describe the intensity and direction of the existing relationships between constructs [5,6]. The T-values help determine the significance of the predicted route coefficients by identifying whether or not they deviate considerably from zero [10,11]. The findings of this research, summarized in Table 7, provide a concise overview of the significant influence of IoT implementation on resource management in the construction sector. Each hypothesis is discussed briefly below.

- H1: IoT implementation impact on Resources: The substantial positive correlation coefficient of 0.932 supports the beneficial connection between IoT adoption and effective resource management.
- H1a-1 to H1a-4: These hypotheses investigate the impact of Data Analytics & Actionable Insights (DA), Data Security and Privacy (DP), Integration & Interoperability (II), and Scalability & Flexibility (SF) on IoT deployment. The positive links underscore the importance of these factors in influencing the successful adoption of IoT technologies in construction resource management.
- H1b-1 to H1b-3: Investigating the influence of IoT-based resource management on machine, man, and material management, these hypotheses reveal statistically significant positive links. Efficient resource management positively contributes to the utilization and management of equipment, labor force, and materials in construction projects.

Taken together, these findings emphasize the relevance of variables such as data analytics, data security, integration, scalability, and resource management for the practical application of IoT technologies in the construction sector. This nuanced understanding

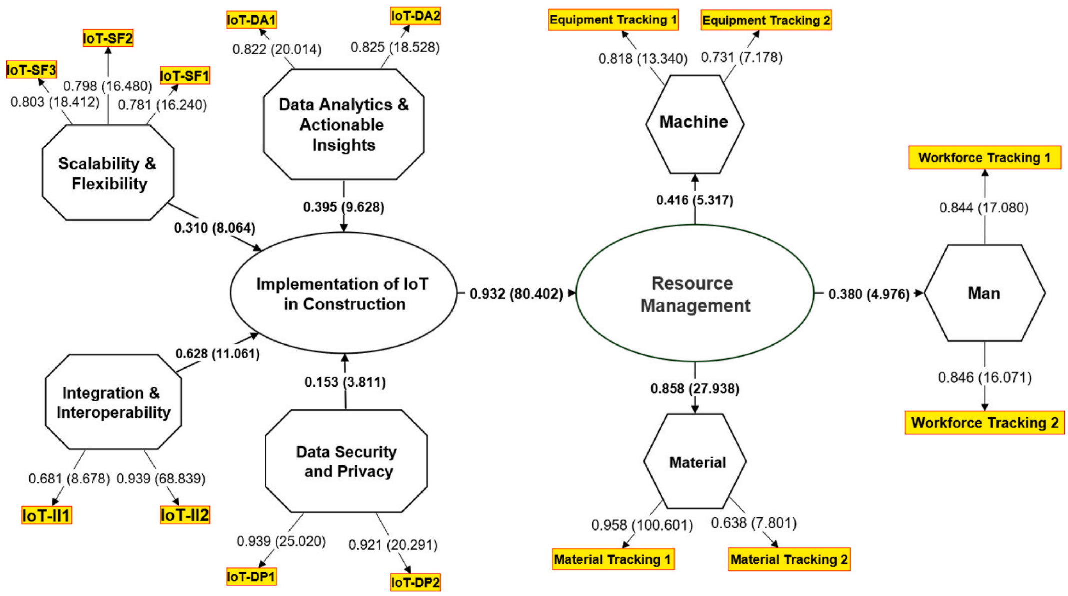

Fig. 4. Path loadings with T-stat value.

provides significant insights for practitioners and policymakers in the industry. Fig. 4 is indicating the relationship between implementation of IoT and resource management considering man machine and materials management.

5.4. Predictive Relevance

The predictive relevance findings are shown in Table 8, and they illustrate that the model displays a modest degree of predictive ability for IoT Implementation and Resource Management. It explains roughly 35.5 % of the variability in Resource Management and approximately 17.9 % in IoT Implementation. These results demonstrate that the model has crucial predictive relevance, indicating that it can give valuable insights into the link between IoT installation and resource management related to the research setting.

6. Discussion

The findings of this research provide convincing evidence to demonstrate the significant influence that the introduction of IoT has had on the resource management practices of the construction sector. According to the results, there is a significant and favourable association between resource management and IoT adoption. The evidence supports the idea that there is a beneficial connection between deploying IoT technologies and effective resource management. The statistical study demonstrates a substantial positive correlation coefficient of 0.932 (p 0.001) between the adoption of IoT and resource management. This indicates that there is a strong link between the two. This data lends credence to the hypothesis that integrating IoT technology into the building and construction sector benefits resource management.

Resource management in construction is a multifaceted process integral to project success, encompassing the efficient allocation and utilization of human, mechanical, and material resources. In the context of IoT implementation, resource management takes on a transformative dimension, driven by real-time data and insights [16,33]. Human resources, including skilled labor, benefit from IoT-enabled systems that provide real-time monitoring, facilitating optimized task allocation and productivity tracking. Mechanical resources, such as equipment and machinery, experience enhanced efficiency through predictive analytics and preventative maintenance enabled by IoT sensors [7,12]. Material resources benefit from improved inventory control and logistics, minimizing waste and ensuring timely restocking. The integration of IoT technologies contributes to proactive decision-making in resource allocation, enabling project managers to adapt dynamically to changing conditions. Real-time monitoring of resources ensures that projects stay on schedule and within budget, fostering overall project success [9,19]. Predictive analytics, driven by IoT data, aids in forecasting potential resource issues, allowing for preventative measures and minimizing downtime [6,15]. Moreover, the use of IoT in resource management enhances supply chain efficiency in the construction industry. Real-time data from IoT devices provides insights into inventory levels, enabling timely replenishment and reducing the risk of delays. Monitoring tools also contribute to reducing theft and improving logistical processes in the movement of supplies and tools around construction sites.

When thinking about how the Internet of Things (IoT) will affect the building industry, it is critical to remember that different elements will have different degrees of influence. Research shows that different criteria, including DA (Data Analytics & Actionable Insights), DP (Data Security and Privacy), II (Integration & Interoperability), and SF (Scalability & Flexibility), have different impacts on the rollout of IoT solutions. While all of these things help with resource management and Internet of Things adoption, their effects are different. For example, the importance of flawless integration across various IoT devices and systems is shown by the significant association between Integration & Interoperability and IoT implementation. On the other hand, Scalability & Flexibility's somewhat lower correlation highlights its significance while implying a subtle impact. Stakeholders in the industry must have this detailed knowledge since it suggests that optimizing the effect of Internet of Things (IoT) applications in construction resource management may need a customised strategy to handle certain elements. Practitioners and legislators may improve plans for the construction industry's use of IoT technology by acknowledging the variable relevance of these elements [6,9].

The outcomes of this research, taken as a whole, provide credence to the hypothesized connections between the adoption of IoT, resource management, and the elements that underlie both of these processes. To facilitate the practical application of IoT technologies in the construction sector, the findings emphasize the relevance of variables such as data analytics, data security, integration, scalability, and resource management [7,15]. These results lead to a better knowledge of the essential aspects and their influence on resource management via the adoption of IoT, giving significant insights for practitioners and policymakers in the construction sector who work in the industry<.

It is critical to recognise certain limitations, despite the fact that this research offers helpful insights into the impact of the internet of things on building resource management. Quantitatively evaluating the effect of Internet of Things technology on operational optimization is complicated by the technique, especially when surveys are used. The depth of quantitative insights might be limited due to the difficulty in accessing precise operational data for a full study. Furthermore, there are inherent constraints to generalising results to wider settings, as is the case with every case study. Despite these limitations, the research intends to fill knowledge gaps by providing a qualitative analysis of the topic and useful takeaways that add to the continuing conversation about Internet of Things

Table 8
Predictive relevance of the study.

Constructs	SSO	SSE	Q^2 (=1-SSE/SSO)
IoT Implementation	4922.000	4043.374	0.179
Resource Management	642.000	414.339	0.355

integration in the building industry.

7. Conclusion

This research unveils the substantial impact of IoT implementation on resource management within the construction sector. The results unequivocally establish a positive correlation between IoT utilization and resource management practices, marking a transformative shift in the way resources are handled in construction projects. Through the statistical validation of all hypotheses, this study contributes vital new insights into the essential elements of IoT deployment and their profound implications for resource management. The findings underscore the imperative for the construction industry to adopt IoT technology, emphasizing its potential to optimize resource utilization, enhance project efficiency, and yield superior project outcomes. The practical implications of these results extend to industry professionals, policymakers, and stakeholders, urging them to embrace IoT technologies for bolstering resource management practices in construction projects. As a pathway for future research, further exploration into specific facets of IoT deployment and resource management will deepen our understanding of the potential benefits and challenges associated with integrating this disruptive technology in the construction sector.

Ethics statement

Informed consent was obtained from all the participants before collection of data.

Data availability statement

The data associated with the study is not deposited into a publicly available repository and will be made available on request.

CRediT authorship contribution statement

Fadi Althoey: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision. **Ahsan Waqar:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Saleh Hamed Alsulamy:** Formal analysis, Data curation, Conceptualization. **Abdul Mateen Khan:** Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Abdullah Alshehri:** Project administration, Investigation, Funding acquisition. **Ibrahim Idris Falqi:** Writing – review & editing, Supervision, Resources, Software. **Maher Abuhussain:** Validation, Project administration, Funding acquisition. **Mohammed Awad Abuhussain:** Writing – original draft, Supervision, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

- **Profession**
  - o Quantity Surveyor
  - oArchitect
  - oCivil Engineer
  - oM&E Engineer
  - oProject Manager
  - oOther
- **Organization**
  - oContractor
  - oConsultant
  - oClient
- **Construction Experience in Malaysia**
  - o0–5 Years
  - o6–10 Years
  - o11–15 Years
  - o16–20 Years
  - oOver 20 Years
- **Knowledge of Digital Technologies (IoT)**
  - oYes
  - oNo/Maybe

Sr. #	Critical Factors for IoT Implementation	Strongly Agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly Disagree (1)
1	In IoT implementation, integration and interoperability enable seamless data transfer between IoT devices, sensors, and construction management systems.					
2	They enable centralized monitoring and control of Internet of Things devices, which promotes effective project management.					
3	In construction initiatives, IoT real-time data integration enables timely decision-making and proactive problem-solving.					
4	In the implementation of IoT, data analytics provides construction professionals with valuable insights for making informed decisions.					
5	Applying data analytics to IoT data improves safety by identifying potential hazards and enhancing compliance.					
6	It facilitates process optimization by analyzing data to identify improvement opportunities and enhance productivity.					
7	Scalability guarantees that the IoT solution can accommodate large-scale and complex projects.					
8	As project requirements evolve, adaptability makes integrating new devices and technologies possible.					
9	Scalability and adaptability allow for the expansion and modification of the IoT infrastructure without interruption.					
10	Data security and privacy are crucial for protecting sensitive construction project data from unauthorized access and cyber threats.					
11	Robust security measures mitigate the financial and legal repercussions of data breaches.					
12	Data security measures foster confidence among clients, partners, and stakeholders, augmenting the company's standing.					
13	IoT enables real-time material monitoring, providing accurate inventory data and decreasing material loss and theft.					
14	The Internet of Things facilitates demand forecasting, enabling construction companies to optimize material planning and procurement, thereby minimizing superfluous inventory and stockouts.					
15	IoT provides real-time surveillance and monitoring of construction employees, allowing for the more efficient man- and resource management.					
16	IoT enables enhanced communication and coordination among construction teams, facilitating efficient human resource management and project collaboration.					
17	IoT enables remote machine monitoring and control, facilitating efficient scheduling, troubleshooting, and optimization of construction machine operations.					
8	The Internet of Things enables real-time monitoring of machine performance, utilization, and maintenance requirements, thereby enabling efficient machine management.					

References

[1] B. Amade, C.I. Nwakanma, Identifying challenges of internet of things on construction projects using Fuzzy approach, J. Eng. Proj. Prod. Manag. (2021), https://doi.org/10.2478/jeppm-2021-0021.

[2] M.R. Babu, IoT implementation in construction industry (internet of things), Res. J. Eng. Technol. 12 (1) (2021) 19–25.

[3] K. El-Dash, Assessing human resource management in construction projects in Kuwait, J. Asian Architect. Build Eng. (2007), https://doi.org/10.3130/jaabe.6.65.

[4] I. Othman, A. Idrus, M. Napiah, Human resource management in the construction of a sustainable development project: towards successful completion, WIT Trans. Ecol. Environ. (2012), https://doi.org/10.2495/EID120161.

[5] H. Begić, M. Galić, A systematic review of construction 4.0 in the context of the BIM 4.0 premise, Buildings (2021), https://doi.org/10.3390/BUILDINGS11080337.

[6] Q. Chen, H. Feng, B. Garcia de Soto, Revamping construction supply chain processes with circular economy strategies: a systematic literature review, J. Clean. Prod. (2022), https://doi.org/10.1016/j.jclepro.2021.130240.

[7] Y. Dong, H. Zhang, L. Li, Mechanism construction of human resource management based on blockchain technology, J. Syst. Sci. Inf. (2021), https://doi.org/10.21078/JSSI-2021-310-11.

[8] W. Widyanty, A. Daito, S. Riyanto, D. Nusraningrum, Gaining a competitive advantage through strategic human resource management in Indonesian construction industry, Manag. Sci. Lett (2020), https://doi.org/10.5267/j.msl.2020.2.010.

[9] F. Susilowati, H. Prawenti, E. Puspitasari, Human resource management patterns in Indonesia's construction companies, J. Appl. Eng. Sci. (2021), https://doi.org/10.5937/jaes0-29474.

[10] U.S. Igwe, S.F. Mohamed, M.B.M.D. Azwarie, Recent technologies in construction; A novel search for total cost management of construction projects, IOP Conf. Ser. Mater. Sci. Eng. (2020), https://doi.org/10.1088/1757-899X/884/1/012041.

[11] Y. Gamil, M.A. Abdullah, I. Abd Rahman, M.M. Asad, Internet of things in construction industry revolution 4.0: recent trends and challenges in the Malaysian context, J. Eng. Des. Technol. (2020), https://doi.org/10.1108/JEDT-06-2019-0164.

[12] T.J. Lin, N.M. Aziz, Embracing the digital twin for construction monitoring and controlling to mitigate the impact of COVID-19, J. Des. Built. Environ. 22 (3) (2022) 40–59.

[13] K. Khurshid, A. Danish, M.U. Salim, M. Bayram, T. Ozbakkaloglu, M.A. Mosaberpanah, An in-depth survey demystifying the internet of things (IoT) in the construction industry: unfolding new dimensions, Sustainability (2023), https://doi.org/10.3390/su15021275.

[14] A. Katiyar, P. Kumar, A review of internet of things (IoT) in construction industry: building a better future, Int. J. Adv. Sci. Comput. Eng. (2021), https://doi.org/10.30630/ijasce.3.2.53.
[15] T. Lin, Z. Huan, Y. Shi, X. Yang, Implementation of a smart contract on a consortium blockchain for IoT applications, Sustain. Times (2022), https://doi.org/10.3390/su14073921.
[16] U.H. Madanayake, R.D. Seidu, B.E. Young, Investigating the skills and knowledge requirements for iot implementation in construction, in: Proceedings of the International Conference on Industrial Engineering and Operations Management, 2020.
[17] R. Maqbool, M.R. Saiba, S. Ashfaq, Emerging industry 4.0 and Internet of Things (IoT) technologies in the Ghanaian construction industry: sustainability, implementation challenges, and benefits, Environ. Sci. Pollut. Res. (2022), https://doi.org/10.1007/s11356-022-24764-1.
[18] M.R. Patruni, P. Saraswathi, Securing Internet of Things devices by enabling Ethereum blockchain using smart contracts, Build. Serv. Eng. Res. Technol. (2022), https://doi.org/10.1177/01436244221078933.
[19] P.S. Micheev, K.A. Muraviev, E.V. Rezchikova, K.V. Selivanov, Designing smart pulse flow meters using diversion analysis, Int. J. Electr. Comput. Eng. (2023), https://doi.org/10.11591/ijece.v13i2.pp1338-1345.
[20] Y. Qi, Influence of psychological capital construction on human resource management from the perspective of employee engagement, Rev. Argent. Clin. Psicol. (2020), https://doi.org/10.24205/03276716.2020.273.
[21] V. Villa, B. Naticchia, G. Bruno, K. Aliev, P. Piantanida, D. Antonelli, Iot open-source architecture for the maintenance of building facilities, Appl. Sci. (2021), https://doi.org/10.3390/app11125374.
[22] K.A.K. Raja, D. Murali, Resource management in construction project, Int. J. Sci. Res. Publ. (2020), https://doi.org/10.29322/ijsrp.10.05.2020.p10130.
[23] S.S. Darvazeh, F.M. Mooseloo, S. Aeini, H.R. Vandchali, E.B. Tirkolaee, An integrated methodology for green human resource management in construction industry, Environ. Sci. Pollut. Res. (2022), https://doi.org/10.1007/s11356-022-20967-8.
[24] X. Wang, S. Wang, X. Song, Y. Han, IoT-based intelligent construction system for prefabricated buildings: study of operating mechanism and implementation in China, Appl. Sci. (2020), https://doi.org/10.3390/APP10186311.
[25] H. Kusimo, et al., Optimisation of resource management in construction projects: a big data approach, World J. Sci. Technol. Sustain. Dev. (2019), https://doi.org/10.1108/WJSTSD-05-2018-0044.
[26] A. Opoku, V. Ahmed, G. Ofori, Realising the sustainable development goals through organisational learning and efficient resource management in construction, Resour. Conserv. Recycl. (2022), https://doi.org/10.1016/j.resconrec.2022.106427.
[27] H. Sun, Z. Liu, Research on intelligent dispatching system management platform for construction projects based on digital twin and BIM technology, Adv. Civ. Eng. (2022), https://doi.org/10.1155/2022/8273451.
[28] K. Rajhans, V. Bhavsar, Impending need of sustainable human resource management practices in construction industry: evidence from India, Int. J. Constr. Manag. (2023), https://doi.org/10.1080/15623599.2022.2050569.
[29] A. Waqar, A.H. Qureshi, W.S. Alaloul, Barriers to building information modeling (BIM) deployment in small construction projects: Malaysian construction industry, Sustain. Times 15 (3) (2023), https://doi.org/10.3390/su15032477.
[30] A. Srivastava, et al., Imperative role of technology intervention and implementation for automation in the construction industry, Adv. Civ. Eng. (2022), https://doi.org/10.1155/2022/6716987.
[31] R.S. Vasilyev, K.Y. Losev, A.G. Cheprasov, D.T. Bektash, BIM and QR-codes interaction on a construction site, J. Phys. Conf. (2020), https://doi.org/10.1088/1742-6596/1425/1/012089.
[32] A. Waqar, H. Almujibah, Factors Influencing Adoption of Digital Twin Advanced Technologies for Smart City Development : Evidence from Malaysia, 2023, https://doi.org/10.3390/buildings13030775.
[33] G. Pereira, M. Parente, J. Moutinho, M. Sampaio, Fuel consumption prediction for construction trucks: a noninvasive approach using dedicated sensors and machine learning, Infrastructures (2021), https://doi.org/10.3390/infrastructures6110157.
[34] J. Watson, S. Thomas, T. Goodfellow, Groundwater resource management during construction dewatering, Sustain. Water Resour. Manag. (2022), https://doi.org/10.1007/s40899-022-00678-1.
[35] I.S. Vasilca, M. Nen, O. Chivu, V. Radu, C.P. Simion, N. Marinescu, The management of environmental resources in the construction sector: an empirical model, Energies (2021), https://doi.org/10.3390/en14092489.
[36] A. Waqar, M.B. Khan, N. Shafiq, K. Skrzypkowski, K. Zagórski, A. Zagórska, Assessment of challenges to the adoption of IOT for the safety management of small construction projects in Malaysia: structural equation modeling approach, Appl. Sci. 13 (5) (2023), https://doi.org/10.3390/app13053340.
[37] A. Waqar, I. Othman, J.C. Pomares, Impact of 3D printing on the overall project success of residential construction projects using structural equation modelling, Int. J. Environ. Res. Public Health (2023), https://doi.org/10.3390/ijerph20053800.
[38] A. Waqar, I. Othman, N. Shafiq, M.S. Mansoor, Applications of AI in oil and gas projects towards sustainable development: a systematic literature review, Artif. Intell. Rev. (2023) 0123456789, https://doi.org/10.1007/s10462-023-10467-7.
[39] S. Wu, Intelligent communication management terminal in the construction of human resource management mode, Wirel. Commun. Mob. Comput. (2021), https://doi.org/10.1155/2021/7106104.