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Research article

Deterrents to the IoT for smart buildings and infrastructure development: A partial least square modeling approach

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ABSTRACT

Implementing Internet of things (IoT) technology in the context of intelligent buildings and infrastructure development has garnered significant attention within the construction sector. Nonetheless, the implementation of IoT could be improved by assessing various barriers. The purpose of this study was to examine the obstacles related to the adaptation of IoT techniques within the construction sector, as well as the effects on the advancement of intelligent building and infrastructure systems. The study employed a mixed-method approach involving exploratory factor analysis (EFA) and structural equation modeling (SEM) to determine six types of barriers: knowledge, technical, standardization, creativity, complexity, and economics. The study revealed that the implementation of IoT for developing smart construction and infrastructure in the construction sector was significantly influenced by all six constructs. The results of this study offer significant ramifications for the field. The study underscores the necessity for heightened consciousness and instruction regarding the advantages of implementing IoT. The study posits that the technical barriers, including interoperability, modernization of legacy infrastructure, and coordination and collaboration difficulties, require attention from the industry. The study highlights the significance of establishing industry-wide standards and protocols for implementing IoT and regulatory and legal frameworks. Finally, the study underscores the necessity for augmented funding and financing options for IoT endeavors. Subsequent study endeavors may expand upon the present findings by delving into the barriers encountered by alternative sectors and nations and assessing the efficacy of the suggested measures in this investigation.

1. Introduction

Internet of Things (IoT) revolutionizes the global building sector by providing intelligent systems for developing smart structures and infrastructure. Construction is a significant contributor to the economy, accounting for 4.5 % of the country's gross domestic product. Much study has been conducted in recent decades on smart infrastructures, neighborhoods, towns, and structures [1,2]. Even

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though researchers have looked at similar topics from a variety of angles, including this one is still being investigated. The topic entails adapting technologies and knowledge from multiple disciplines [3,4]. Smart buildings, neighborhoods, and cities are currently isolated and categorized in terms of technology and application advancement due to the operational constraints of current IoT applications and the uneven incorporation of sensor networks into buildings, communities, and cities [5]. One of the most basic and significant elements of the natural world in which humans live is such as buildings. Increased integration of advanced technology into structures and their systems has given rise to the concept of smart buildings, in which the complete cycle of a building can be minorly managed for comfort, price- and resource efficiency, and ease [6]. Smart buildings (also known as intelligent buildings) can only be realized using new technologies, such as the deployment of sensors, the design, and creation of big data, analytics, cloud, and cloud computing, the development of software engineering, algorithms for interaction between humans and computers, etc. As one of the difficulties of smart construction is managing an intricate network of interrelated functional objects in various building elements, the development of the IoT is one of the most prevalent areas among these technologies that support them [7–9]. With IoT, there is a tremendous opportunity to progress toward the desired objectives. The literature provides multiple definitions for the technology, given the variety of IoT stakeholders and applications [10,11]. On the technological front, IoT is the convergence of three main paradigms: the Things-oriented vision, the Internet-oriented vision, and the Semantic-oriented vision.

IoT's architecture is designed to endow all objects with identifying, sensing, networking, and computational capabilities, allowing them to interchange and share information and develop advanced Internet-based services. As a result, the interconnectedness would allow smart independence, background-aware adaptive choices, and a deeper knowledge of intricate systems [12,13]. These abilities accomplish smart buildings' objectives, including incorporating ambient intelligence, by establishing a global network that supports ubiquitous computation and context awareness among devices. A rapid increase in connected devices has been observed in the past five years [14,15]. Cisco states that in 2010, the number of connected devices per Internet user exceeded six and predicted that by 2020, 50 billion linked gadgets would be used globally, up from 20 billion. IoT is the evolutionary result of several extant technologies, including wireless sensor networks (WSN) and machine-to-machine (M2M) communication [16,17]. The IoT has two effects: Integration of sensing, storage, network, processing, and computation capabilities into commonplace objects (e.g., home appliances, doors, windows, lighting, smoke detectors, etc.) and bringing them online, even though they may not have been designed with these capabilities [18,19]. This is contrary to many Internet-connected devices (smartphones, laptops, etc.) originally designed to be Internet-connected [20,21]. Second, integration of networks containing the objects. This would render their network accessible.

IoT's ambient intelligence enables all objects to comprehend their environments, engage in meaningful interactions with people, and aid in making choices. Even though studies still face technological obstacles to advance, implement, and ultimately mature IoT, the technique is anticipated to apply to numerous industries, including healthcare, manufacturing, retail, agriculture, industrial automation, etc. [22,23]. However, the emphasis studies currently place on developing IoT application solutions for the building sector could be increased [24,25]. This is because most efforts are presently focused on developing IoT technology, i.e., in computer science and electrical engineering. However, collaboration with other fields of study, such as civil engineering or construction technology, is also necessary to determine the issues and difficulties that would be resolved or improved by using IoT and thus promote the adaptability of IoT in smart buildings [24,25].

Furthermore, a study on the adaptation of IoT uncovers additional potential issues and study directions for IoT's technological and methodological advancement. In recent years, IoT has begun to penetrate the building sector as a new trend. Studies and practitioners are examining the advantages and disadvantages of the Internet of Things by actual application [18,26,27]. To demonstrate the competitive edge and emerging trend of IoT, several businesses, like IBM and Intel, have already begun to release smart building goods to the public [22,23]. Thus, understanding how to incorporate IoT into this sector to develop smart buildings is crucial [28,29]. The present study requires a thorough examination and evaluation of Internet of Things applications to all relevant areas of potential construction, despite the existence of surveys for IoT-based smart buildings [30,31].

Moreover, as interest in transdisciplinary research expands, an analytical assessment could provide a fresh basis for civil, construction, and architectural engineering studies [32,33]. Consequently, even though An in-depth knowledge of the technical specifications and possible application fields to the construction industry is crucial for completing improvement aspects of IoT and speeding up the creation of connected buildings because the whole IoT sector is driven by technology and is impacted by a top-down strategy [34,35].

The objective of this study is to employ Structural Equation Modelling (SEM) in order to evaluate the obstacles present in the building sector. Structural Equation Modelling (SEM) is a statistical methodology that enables the exploration of intricate associations between variables, offering a comprehensive framework for the simultaneous analysis of both measurement and structural models. The integration of Structural Equation Modelling (SEM) in the research facilitates a thorough evaluation of the obstacles encountered in the deployment of IoT for the advancement of smart buildings and infrastructure. This methodology facilitates a more comprehensive comprehension of the interconnectedness between different obstacles and offers a quantitative assessment of their effects, thereby augmenting the study's validity and rigour. Providing a precise definition of SEM is crucial in order to facilitate comprehension of its significance within the research context, particularly for readers who may not be familiar with the term. The aim is to gain a deeper understanding of the factors that impede the successful implementation of IoT technology for the development of smart buildings and infrastructure.

Although previous studies have identified the hurdles to IoT application in the building sector, they have yet to utilize SEM to identify the complex relationships between the numerous factors that influence IoT adoption [11,36].

In addition, this study is crucial because it shed light on the factors that must be addressed to promote the application of IoT and accelerate the advancement of smart constructions and infrastructure. Policymakers, industry leaders, and studies interested in promoting the application of IoT in the building sector find this study's findings useful [37].

In addition, this research contributes to the growing body of literature on the barriers to IoT adoption in the building sector. This subject has become increasingly essential in recent years. This study will fill a void in the literature on IoT adoption in emergent markets by identifying the barriers to IoT adoption in the building sector.

Overall, the originality of this study lies in its use of SEM to evaluate the barriers to IoT adoption in the building sector, its focus on the first research of its kind, and its potential to contribute to the literature on IoT adoption barriers in the building sector. This study's findings will provide valuable insight into the barriers that prevent IoT applications in building sector. The findings will inform policymakers and industry leaders about the most important factors that must be addressed to promote the adoption of IoT and accelerate the advancement of smart buildings and infrastructure. This study seeks to contribute to understanding IoT adoption barriers in the building sector and provide policymakers and industry executives with recommendations for overcoming these barriers. Following are the key contribution of this study.

- This study identifies and analyses six important hurdles—knowledge, technical, standardisation, creativity, complexity, and economics—that affect the use of IoT in smart construction and infrastructure development within the building industry.
- The research provides significant recommendations for industry practitioners by shedding light on the unique obstacles encountered by the construction sector in implementing IoT technology. These insights may be found in the study's findings.
- This study proposes a rigorous technique that may be utilized in comparable scenarios to analyze obstacles to the adoption of IoT by applying a mixed-method approach that combines exploratory factor analysis and structural equation modelling. The research was carried out by combining the two methods.
- The results contribute to a greater knowledge of the essential reasons that are impeding the deployment of IoT, which enables stakeholders to make choices based on accurate information and build effective strategies to overcome these hurdles.
- The findings of this study are a useful resource not only for policymakers, industry leaders, and other researchers in who are interested in encouraging the use of IoT in smart building and infrastructure development, but also for researchers in other locations that are confronting issues.

2. Related work

Despite their potential to increase efficiency, productivity, and safety, the building sector has been reluctant to implement IoT technologies. Several studies, including one on the building sector, have investigated the barriers and barriers to adopting IoT in the building sector [19,26,32]. Numerous factors, such as cost, security, lack of skills and expertise, interoperability, and resistance to change, have been identified in these studies as barriers to the adoption of IoT [27,38].

Chung et al. (2023) [32] analyzed the factors that influence the adoption of IoT in building sector. The cost of IoT adoption was the most significant barrier, followed by a need for knowledge and education about IoT technologies. The study also revealed that construction professionals needed knowledge and skills to implement and maintain IoT systems.

(Dosumu & Uwayo (2023) [39] conducted a second study on the barriers to IoT application in the building sector, concentrating on security concerns. As construction initiatives entail confidential information such as building designs, financial information, and employee data, the study discovered that security concerns were a significant barrier to adoption. The study recommended that the industry implement a risk-based approach to IoT security that prioritizes the protection of critical assets and data.

Khurshid et al. (2023) [3] analyzed the challenges to IoT applications in the building industry, focusing on interoperability issues. The absence of interoperability standards and protocols was a significant barrier to IoT adoption, as various IoT systems could not communicate with one another. The study recommended that the industry employ standardized protocols and platforms to assure interoperability.

In addition, Liu et al. (2022) [16] investigated the barriers associated with IoT adoption in the Australian building sector. The study discovered that resistance to change was a significant barrier to IoT adoption, as construction professionals were reluctant to employ unfamiliar technologies. The study suggests that the industry educates and trains construction professionals on the advantages of IoT systems.

Kazmi & Sodangi (2022) [40] examined the challenges in applying IoT in the building sector, concentrating on the shortage of comprehension of IoT technology and its potential benefits. The study discovered that construction professionals needed the knowledge and skills to comprehend IoT technologies' advantages and how they could be implemented in construction projects.

Baghalzadeh Shishehgarkhaneh et al. (2022) [41]investigated IoT application in the Chinese building sector. According to the study, the need for defined business models and the cost-effectiveness of IoT technologies were significant barriers to adoption. The study suggests that the business sector establishes defined business models and adoption strategies for IoT technologies.

Sarkar et al. (2022) [24]investigated the barriers to IoT adoption in the building sector, concentrating on the need for more awareness and comprehension of IoT technologies. The study found that construction professionals needed to gain the knowledge and skills to implement and maintain IoT systems and that education and training were required to promote adoption.

Zhong (2022) [17] investigated the barriers to implementing IoT in the building sector, concentrating on the absence of interoperability standards and protocols. According to the study, the lack of standardization hindered the integration of IoT systems with existing construction technologies, resulting in interoperability issues. To promote integration and interoperability, the study recommended the development of standardized protocols and platforms.

Fredriksson et al. (2022) [19] investigated the barriers to IoT adoption in the Saudi Arabian building sector, concentrating on the shortage of collaboration and trust between stakeholders. As a result of a lack of trust and collaboration between stakeholders, construction professionals were reluctant to exchange information and data, according to the study. The study suggests developing trust-building strategies to encourage collaboration and data sharing.

These studies illustrate the complexity and diversity of the challenges to IoT applications in the building sector, including the building sector [19,36]. The comparison of research is given in Table 1 where the research gap is identified. By identifying these barriers, policymakers and industry leaders can devise strategies and policies to surmount them and encourage the building sector's adoption of IoT technologies.

3. Methodology

The study design employed for evaluating the impediments to the application of IoT in the context of smart buildings and infrastructure development within the building sector was a mixed-method methodology, as indicated in Fig. 1. The study commenced with a thorough examination of existing literature, highlighting prospective barriers to IoT application in the context of intelligent building and infrastructure development. Furthermore, the study interviewed 10 construction engineering professionals to supplement the literature review with expert opinions [51,57,58].

Subsequently, a preliminary survey was administered to assess the dependability and authenticity of the survey instrument. The results were subjected to Exploratory Factor Analysis (EFA) to detect any possible shortcomings in the questionnaire [43,56]. The questionnaire for the main survey was modified based on the pilot survey results. Subsequently, the main survey was carried out. The primary survey obtained information from a broader population of professionals in the construction sector.

The utilization of Structural Equation Modeling (SEM) enabled the examination of information gathered from the primary survey, thereby facilitating a more comprehensive comprehension of the correlation between the recognized barriers and the application of IoT in the advancement of smart buildings and infrastructure [54,59]. Ultimately, the Structural Equation Model (SEM) validation was executed to authenticate the soundness and consistency of the model formulated in the present investigation [49,60,61].

This choice was made in order to provide a comprehensive understanding of the obstacles that stand in the way of IoT implementation within the context of smart building and infrastructure development in the construction industry. This technique makes it possible to systematically investigate these roadblocks in terms of their identification, analysis, and connections to one another. To guarantee that the sample is representative of the construction industry, a random sampling procedure was used for selecting participants for data collection. This helped to ensure that the sample was accurate. In order to determine the reliability and validity of the questionnaire, the pilot survey included 128 participants from the relevant industry. After that, a main questionnaire survey was conducted and it had 213 participants. This survey collected data from a larger community of construction professionals in the country. The data acquired using this method guarantees that an accurate representation of the many aspects of the industry has been obtained. The process of data gathering, beginning with the pilot survey and continuing through the main survey, took a total of three months to complete. This timeframe was chosen in order to achieve a satisfactory compromise between the acquisition of exhaustive data and the effectiveness of operating procedures.

The methodology adopted for this research comprised a thorough examination of existing literature, consultations with experts, a preliminary survey, a primary survey, Structural Equation Modeling (SEM) analysis, and validation of the SEM model. This approach facilitated a comprehensive evaluation of the barriers to the application of IoT technology in the building sector.

Table 1
Comparison of existing studies

Sr. #	Findings	Methodology	Difference/Gap	References
1	Discusses IoT applications in smart buildings, including energy management and security.	Literature review and case studies	Limited discussion on IoT implementation challenges.	[19,42,43]
2	Identifies knowledge and financial constraints as significant barriers to IoT adoption.	Survey and statistical analysis	Limited examination of technical barriers.	[17,44,45]
3	Emphasizes the importance of industry-wide standards for successful IoT implementation.	Literature review and expert interviews	Lacks exploration of economic barriers.	[12,46,47]
4	Highlights the need for fostering creativity in IoT-driven solutions.	Qualitative analysis and case studies	Limited discussion on standardization challenges.	[34,48,49]
5	Identifies complexities such as data management and integration in IoT projects.	Case studies and expert interviews	Does not delve into economic constraints.	[23,50,51]
6	Discusses the financial implications of IoT adoption in construction projects.	Cost-benefit analysis and surveys	Limited focus on knowledge-related barriers.	[52–54]
7	Examines IoT integration in building maintenance, emphasizing its benefits.	Literature review and field surveys	Minimal exploration of creativity-related hurdles.	[3,33,40]
8	Shows how IoT can enhance sustainability in construction practices.	Case studies and environmental assessments	Neglects standardization challenges.	[6,22,27]
9	Identifies security challenges associated with IoT implementation in smart buildings.	Security audits and expert interviews	Limited discussion on economic constraints.	[11,24,32]
10	Discusses IoT adoption in the building sector, emphasizing its growth potential.	Surveys and statistical analysis	Does not delve into creativity-related barriers.	[39,55,56]

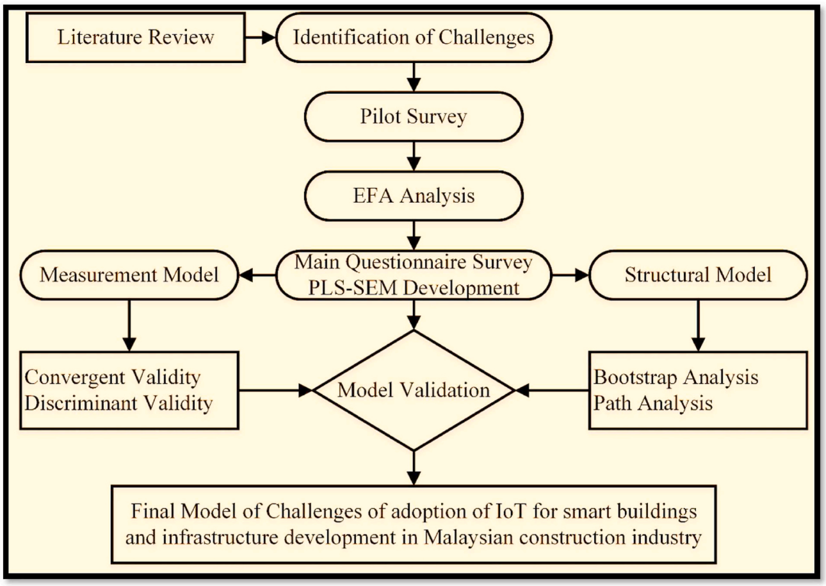

Fig. 1. Flowchart of study method.

3.1. *Identification of barriers*

A literature review was conducted utilizing articles from reputable sources such as MDPI, Science Direct, Web of Science, and Google Scholar to ascertain the barriers to IoT adoption in building sector. The review of relevant literature has identified possible barriers to implementing IoT technology in the context of smart buildings and infrastructure development [47,50]. To enhance the literature review, interviews were conducted with 10 construction engineering professionals to obtain expert opinions [7,46,57]. The identification of the primary 17 barriers to the adoption of IoT in the building sector was based on the results of a comprehensive literature review and insights from industry experts, as shown in Table 2. In general, the identification of these barriers has served as a valuable initial step towards conducting further analysis of the impediments to the adoption of IoT in the building sector.

3.2. *Data collection*

The study's data collection process comprised two surveys: a pilot survey and a primary questionnaire survey. The preliminary survey comprised inquiries about the 17 barriers identified in the literature review and through consultations with experts. The study employed a 5-point Likert scale to gauge the participants' responses, and the sample comprised 128 individuals employed in the building sector. The decision to gather data using a Likert scale with five points was taken in order to find a balanced medium between the need for granularity and the need for ease of use [20,55]. It offers sufficient variety between replies to be able to capture subtleties

Table 2
Barriers to implementation of IoT.

Barriers	Description	References
C1	Risk of data intrusions, cyberattacks, and violations of data privacy.	[62,63]
C2	Lack of industry-wide IoT implementation standards and protocols.	[27,64]
C3	Data security and privacy issues are of concern.	[38,65]
C4	Change aversion and unwillingness to embrace new technologies.	[44,66]
C5	IoT implementation's long-term benefits take time to quantify.	[45,67]
C6	Lack of knowledge and comprehension of IoT benefits.	[48,68]
C7	Complexities in scalability and interoperability.	[36,61]
C8	Concerns for the environment and sustainability in IoT implementation.	[39,69]
C9	Integration difficulties with current building management systems.	[33,40]
C10	More funding and financing alternatives are needed for IoT initiatives.	[26,70]
C11	Potential interoperability issues between various IoT platforms and devices.	[32,42]
C12	Implementation and infrastructure expenses.	[22,55]
C13	Regulatory and legal ambiguity.	[23,71]
C14	Industry fragmentation with coordination and collaboration difficulties.	[72,73]
C15	Complexities in data management, analysis, and decision-making.	[37,74]
C16	Legacy infrastructure modernization difficulties.	[75,76]
C17	Skills shortage in IoT technologies.	[41,77]

in the participants' thoughts while yet being simple enough for responders to comprehend and complete. This scale has seen extensive usage in a variety of research projects, including those concerned with the adoption of technology, the impediments that stand in its way, and attitudes [10,60]. The primary purpose of the pilot survey was to assess the dependability and accuracy of the questionnaire while also detecting any potential concerns with the inquiries [27,67].

The outcomes of the pilot survey informed the development of the primary questionnaire survey. The primary survey instrument comprised the difficulties emanating from the pilot survey analyses and employed a 5-point Likert scale to assess the respondents' reactions. The main survey comprised 213 participants with similar characteristics to the pilot survey sample. To ensure the representativeness of the building sector sample, random sampling was employed in both surveys.

3.3. Exploratory factor analysis (EFA)

An EFA was performed to analyze the reliability and validity of the pilot survey questionnaire. The purpose of the EFA was to ascertain the fundamental factors that contribute to the barriers encountered in the adoption of IoT technology within the construction sector. The suitability of the sample for factor analysis was assessed by conducting the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity [3,61]. The KMO test evaluates the adequacy of correlation among variables for conducting factor analysis. The Bartlett test of sphericity is a statistical procedure used to determine whether the correlation matrix significantly deviates from an identity matrix.

After the administered assessments, a rotated component matrix utilizing varimax rotation was employed to ascertain the latent factors. Varimax rotation aims to streamline the components' loadings by maximizing the variance of the squared loadings [16,25]. The internal consistency of the questionnaire was evaluated by measuring Cronbach's alpha. Cronbach's alpha is a statistical method used to evaluate the internal consistency and reliability of a set of items or questions. It is utilized to determine whether the items in the set measure the same underlying construct. In general, the EFA facilitated the enhancement of the questionnaire and yielded significant revelations regarding the fundamental factors that contribute to the impediments to the adoption of IoT in the construction sector.

3.4. Structure equation modelling (SEM)

The study utilized SEM to analyze the primary questionnaire survey findings. The purpose was to evaluate the hypotheses and explore the connections among the recognized barriers to the implementation of IoT in the construction sector. The study sample comprised 213 participants employed in the construction sector who shared comparable demographic attributes with the pilot survey cohort [31,48].

The computation of the Average Variance Extracted (AVE) was conducted as a means of evaluating convergent validity [35,78]. The discriminant validity assessment was conducted by utilizing the Fornell-Larcker criterion. This criterion involves examining whether the square root of the AVE for each construct surpasses the correlation between that particular construct and other constructs present within the model. The Heterotrait-Monotrait ratio (HTMT) was employed to evaluate the discriminant validity [58,73].

The study employed path analysis to investigate the variables' interrelationships and evaluate the proposed hypotheses. Ultimately, the model's predictive relevance was evaluated to gauge its capacity for forecasting future outcomes [10,13]. In general, the utilization of SEM analysis offered a thorough methodology for evaluating the hypotheses and exploring the connections among the recognized barriers to IoT adoption construction sector [65,77]. The analysis facilitated the evaluation of the model's convergent and discriminant validity and its predictive significance. The findings were utilized to pinpoint opportunities for enhancement and to propose tactics for surmounting the barriers to the implementation of IoT in the construction sector.

3.5. Model validation survey

In order to authenticate the findings of this study, a validation survey was administered to 12 professionals with expertise in the building sector. This survey aimed to evaluate the precision and pertinence of the recognized barriers to the application of IoT in the industry, along with the suitability of the suggested approaches to surmount these barriers.

The validation survey comprised five inquiries about the research's purpose and the model's ultimate validation. The objective of the inquiry was to assess the viewpoints of specialists regarding the significance and pertinence of the recognized barriers, the suitability of the suggested approaches, and the practicality of executing these approaches within the construction sector. Following are the five validation questions.

1. Rate the importance of the identified barriers to the implementation of IoT in smart buildings and infrastructure development.
2. To what extent do you agree with the model proposed help to overcome barriers to IoT application in the building sector?
3. Rate how well do you believe the identified barriers align with your own experiences and observations in IoT implementation for smart buildings and infrastructure development?
4. This study is useful for the proposed model of barriers to IoT application in the building sector?
5. Do you think this study is reasonable in its objective achievements.

The selection of experts was based on their significant expertise and knowledge in the vicinity of construction and the adoption of IoT technology [34,76]. An online platform was used to conduct the survey, and the collected responses were analyzed to ascertain the consensus among the specialists. In general, the survey conducted for validation purposes yielded significant insights regarding the identified barriers and the suggested approaches to surmount them. The feedback was utilized to enhance the model and augment the precision and pertinence of the study's results.

4. Results and analysis

4.1. Reliability analysis

The findings presented in Table 3 demonstrate that the pilot survey questionnaire was deemed reliable in assessing the 17 barriers that affect the application of IoT within the construction sector. The Cronbach's alpha coefficients for each variable (C1–C17) exceeded the acceptable threshold of 0.7, with values ranging from 0.712 to 0.889. The statement mentioned above implies that the pilot survey's inquiries were uniform in their evaluation of the barriers associated with the application of IoT. The outcomes suggest that the preliminary survey questionnaire proved to be a dependable instrument for detecting and quantifying the barriers to the implementation of IoT in the construction sector. The present reliability analysis engenders assurance in the authenticity of the outcomes of the pilot survey. It proposes that the recognized barriers can be further scrutinized and assimilated into the primary questionnaire survey [5,8,35,73].

4.2. Exploratory factor analysis (EFA)

The outcomes of the KMO and Bartlett's test of sphericity are presented in Table 4. These tests were performed as a component of the EFA on the pilot survey questionnaire. The KMO measure of sampling adequacy yielded a value of 0.726, signifying that the sample size and variables utilized in the analysis were sufficient for conducting the exploratory factor analysis [2,10,45]. A threshold of 0.6 or higher is deemed an acceptable value. Furthermore, Bartlett's test of sphericity was performed to examine the null hypothesis that the correlation matrix represents an identity matrix, indicating that the variables are not correlated. The examination findings revealed an estimated chi-square statistic of 153.376 with 136 degrees of freedom and a p-value of 0, signifying that the correlation matrix deviated significantly from an identity matrix. The aforementioned indicates the presence of non-zero correlations among the variables, thereby rendering them appropriate for factor analysis. In general, the findings support the application of EFA in scrutinizing the data obtained from the preliminary survey.

The rotated component matrix derived from the exploratory factor analysis (EFA) performed on the pilot survey questionnaire outcomes is presented in Table 5. This analysis aimed to identify the barriers that hinder the implementation of IoT in the advancement of smart buildings and infrastructure in construction sector. This study employed the varimax rotation technique to extract the components, and six components were identified based on the eigenvalue criterion. It demonstrates that a significant proportion of the encountered difficulties exhibited high factor loadings on their respective components, implying good convergent validity [4,17,67]. The challenge denoted as C11 was excluded from further analysis due to the absence of a factor loading greater than 0.5 on any of the components.

The utilization of the rotated component matrix facilitates the identification of the interrelationships among the barriers. The high factor loadings observed on Component 4 for barriers C4, C5, and C16 suggest a correlation with the absence of standards and interoperability. The results suggest that Barriers C6, C1, and C17 exhibit significant factor loadings on Component 1, which implies a correlation with insufficient technical proficiency and knowledge. The findings from the exploratory factor analysis (EFA) indicate that the barriers to the adoption of IoT in the construction sector can be classified into six distinct components [10,30,57]. These components may serve as a framework to inform the formulation of effective policies and strategies to mitigate the identified barriers.

Table 3
Reliability statistics.

Variables	CA (Extraction)
C1	0.823
C2	0.851
C3	0.819
C4	0.789
C5	0.772
C6	0.715
C7	0.889
C8	0.845
C9	0.813
C10	0.723
C11	0.703
C12	0.729
C13	0.761
C14	0.863
C15	0.829
C16	0.711
C17	0.712

Table 4
KMO and Bartlett's test.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.726
Bartlett's Test of Sphericity	Approx. Chi-Square	153.376
	df	136
	Sig.	0

Table 5
Rotated component matrix.

Challanges	1	2	3	4	5	6
C6	0.901					
C1	0.883					
C17	0.535					
C14		0.748				
C16		0.652				
C7		0.622				
C9		0.591				
C3			0.765			
C13			0.718			
C2			0.643			
C5				0.917		
C4				0.898		
C15					0.863	
C8					0.791	
C12						0.804
C10						0.644
C11*						

Table 6 presents data regarding the overall variance accounted for in the pilot survey questionnaire. The first column of the presented data displays the initial eigenvalues of each component, whereas the second column indicates the percentage of variance explained by each component. The cumulative percentage of variance explained by each component is presented in the third column, wherein the magnitude of variance increases with the inclusion of each successive component. According to Tables 5 and it can be observed that the initial six components account for 65.8 % of the overall variance present in the data. The residual constituents exhibit significantly reduced eigenvalues and contribute a lesser proportion of the variability [1,40,52]. This analysis facilitates determining the optimal number of components retained in the final exploratory factor analysis model. The scree plot is presented in Fig. 2 to indicate the components concerning their Eigen values more clearly.

Table 7 presents the barriers to implementing IoT initiatives across six constructs. These constructs are knowledge, technical, standardization, creativity, complexity, and economics. Each of these constructs presents specific barriers, as described below.

The knowledge construct comprises barriers related to understanding IoT's benefits, the risk of data breaches and privacy violations, and a shortage of IoT technology skills. The mean values for this construct range from 2.58 to 3.23, indicating that these barriers

Table 6
Total variance explained.

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.604	21.199	21.199	2.235	13.144	13.144
2	1.961	11.535	32.734	1.984	11.67	24.814
3	1.667	9.805	42.539	1.913	11.256	36.07
4	1.471	8.652	51.191	1.834	10.788	46.858
5	1.374	8.085	59.276	1.83	10.762	57.62
6	1.11	6.53	65.806	1.392	8.186	65.806
7	0.988	5.811	71.617			
8	0.808	4.752	76.369			
9	0.769	4.525	80.894			
10	0.64	3.764	84.658			
11	0.601	3.533	88.192			
12	0.552	3.249	91.441			
13	0.451	2.655	94.096			
14	0.415	2.441	96.537			
15	0.266	1.563	98.1			
16	0.223	1.311	99.411			
17	0.1	0.589	100			

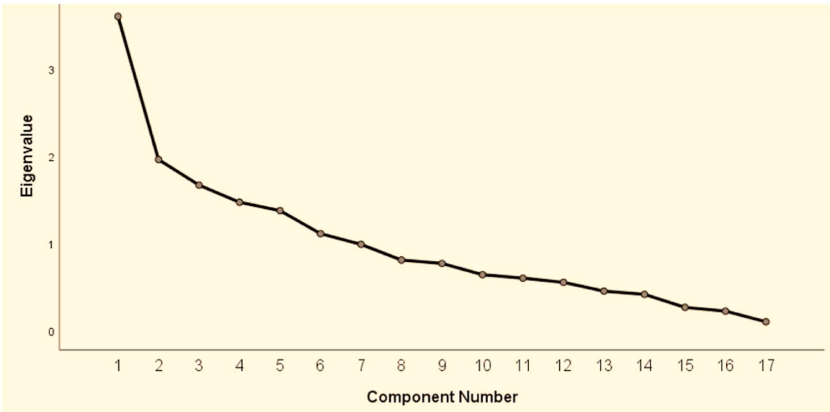

Fig. 2. Scree plot

Table 7
Barriers with named constructs.

Construct	Barriers	Description	Mean
Knowledge	C6	Lack of knowledge and comprehension of IoT benefits.	2.58
	C1	Risk of data intrusions, cyberattacks, and violations of data privacy.	3.23
	C17	Skills shortage in IoT technologies.	3.13
Technical	C14	Industry fragmentation with coordination and collaboration difficulties.	2.46
	C16	Legacy infrastructure modernization difficulties.	2.71
	C7	Complexities in scalability and interoperability.	2.63
	C9	Integration difficulties with current building management systems.	2.63
Standardization	C3	Data security and privacy issues are of concern.	3.23
	C13	Regulatory and legal ambiguity.	3.27
	C2	Lack of industry-wide IoT implementation standards and protocols.	2.92
Creativity	C5	IoT implementation's long-term benefits take time to quantify.	3.53
	C4	Change aversion and unwillingness to embrace new technologies.	3.11
Complexity	C15	Complexities in data management, analysis, and decision-making application.	2.41
	C8	Concerns for the environment and sustainability in IoT implementation.	2.82
Economic	C12	Implementation and infrastructure expenses.	3.24
	C10	More funding and financing alternatives are needed for IoT initiatives.	3.27

are moderately significant [61].

The technical construct includes barriers related to industry fragmentation, difficulties in legacy infrastructure modernization, scalability, interoperability, and integration with existing building management systems. The mean values for this construct range from 2.46 to 2.71, indicating that these barriers are relatively moderate.

The standardization construct includes data security and privacy barriers, regulatory and legal ambiguity, and the lack of industry-wide IoT implementation standards and protocols. The mean values for this construct range from 2.92 to 3.27, indicating that these barriers are moderately significant.

The creativity construct encompasses barriers related to difficulties quantifying IoT's long-term benefits and changes in aversion or reluctance to embrace new technologies. The mean values for this construct range from 3.11 to 3.53, indicating that these barriers are moderately significant [11].

The complexity construct covers barriers related to data management, analysis, decision-making applications, and concerns for the environment and sustainability in IoT implementation. The mean values for this construct range from 2.41 to 2.82, indicating that these barriers are relatively moderate.

The economic construct includes barriers to implementation and infrastructure expenses, as well as the limited availability of funding and financing alternatives for IoT initiatives. The mean values for this construct range from 3.24 to 3.27, indicating that these barriers are moderately significant [31,73].

The barriers to implementing IoT initiatives are diverse and can be broadly categorized into six constructs. The mean values suggest that these barriers are moderately significant and require careful consideration and planning to address successfully.

The following six hypotheses are devised following the hypothesized framework presented in Fig. 3.

H1. Knowledge barriers create a significant impact on the application of IoT for smart construction along with infrastructure development in the building sector

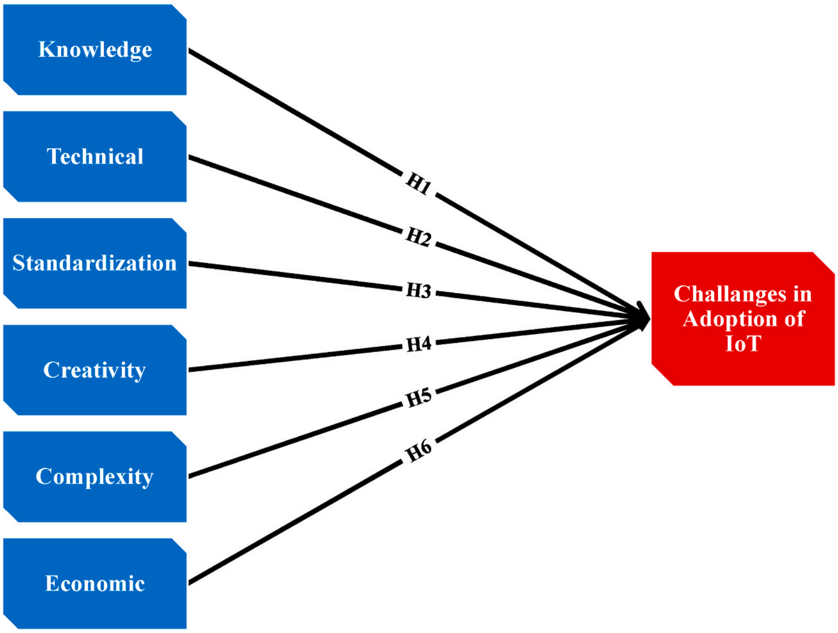

Fig. 3. Hypothesized framework.

oAccording to this hypothesis, the lack of understanding and awareness regarding IoT technology within the building industry may limit the proper deployment of the technology in smart construction and the development of infrastructure.

H2. Technical barriers create a significant impact on the application of IoT for smart construction along with infrastructure development in the building sector

oThe conclusion drawn from H2 is that the implementation of IoT in smart building and infrastructure projects may face significant difficulties due to a number of technical barriers. These concerns include problems with interoperability, ageing infrastructure, and difficulty in coordination.

H3. Standardization barriers create a significant impact on the application of IoT for smart constructions along with infrastructure development in the building sector

oThis hypothesis proposes that the lack of industry-wide standards and protocols for Internet of Things deployment might be a barrier to the development of smart buildings and infrastructure within the construction sector.

H4. Creativity barriers create a significant impact on the application of IoT for smart constructions along with infrastructure development in the building sector

oAccording to hypothesis, difficulties associated with innovation and creativity may impede efforts to fully exploit the potential offered by Internet of Things (IoT) technology in order to improve intelligent building and infrastructure.

H5. Complexity barriers create a significant impact on the application of IoT for smart construction along with infrastructure development in the building sector.

oThis hypothesis suggests that the complexities involved with adopting IoT, such as data management, integration, and the complexity of the system, might be major barriers to achieving success in smart construction and infrastructure projects. These projects include those that include the building of roads and bridges.

H6. Economic barriers create a significant impact on the application of IoT for smart construction along with infrastructure development in the building sector oIt is hypothesized that the adoption and deployment of IoT technology for smart construction and infrastructure projects in the building industry may be hindered by financial restrictions and insufficient choices for financing the projects.

4.3. Demographics

The survey respondents' educational qualifications, years of experience, and professions are depicted in Fig. 4. The data indicates that a significant proportion of the participants possess a master's degree (56 %), followed by 22 % holding a Ph.D. and 20 % obtaining a bachelor's degree. None of the participants indicated possessing a high school diploma, and no individuals belong to the “Others” classification. Regarding experience, most participants, constituting 31 %, possess 5–10 years of experience, while those with 0–5 years of experience closely follow, accounting for 22 % of the respondents. Furthermore, the data reveals that 18 % of the participants have experience ranging from 11 to 15 years.

Similarly, 19 % of the respondents have an experience of 16–20 years, and 10 % of the participants have an experience exceeding 20 years. Regarding occupation, the majority of participants, comprising 55 %, are engaged in civil engineering, whereas 25 % are involved in architecture. Furthermore, it is noteworthy that 10 % of the participants hold the project manager position, and an equal percentage of 10 % are responsible for safety management. Notably, none of the participants have indicated belonging to the “Others” classification in terms of their occupation. The data, as mentioned above, can prove valuable in comprehending the demographic characteristics of the participants in the survey and acquiring a deeper understanding of the viewpoints and encounters they could contribute to the study.

4.4. Structure equation modelling (SEM)

4.4.1. Measurement model

The statistical reliability and validity of the model are presented in Table 8. The assessment aims to determine the reliability and validity of the constructs utilized in the model for measuring the difficulties encountered in the implementation of IoT. As mentioned earlier, the table comprises seven columns, namely construct, barriers, loadings, Variance Inflation Factor (VIF), Cronbach's alpha, composite reliability, and AVE.

The loadings column displays the correlation between each construct and its corresponding barriers. A positive relationship exists between the loading value and the degree of association between the construct and its corresponding barriers. The VIF column displays the degree of multicollinearity among the constructs. A VIF value exceeding 1.5 signifies the existence of multicollinearity [16,33,39]. The column about Cronbach's alpha assesses the internal consistency of the constructs under consideration. A Cronbach's alpha value of 0.7 or greater indicates good reliability. The column depicting composite reliability presents the reliability of the constructs as a composite measure. A value of 0.7 or greater is indicative of good reliability. The AVE metric quantifies the extent to which the constructs account for the observed variance, with a threshold of 0.5 or greater indicating satisfactory convergent validity [19,74].

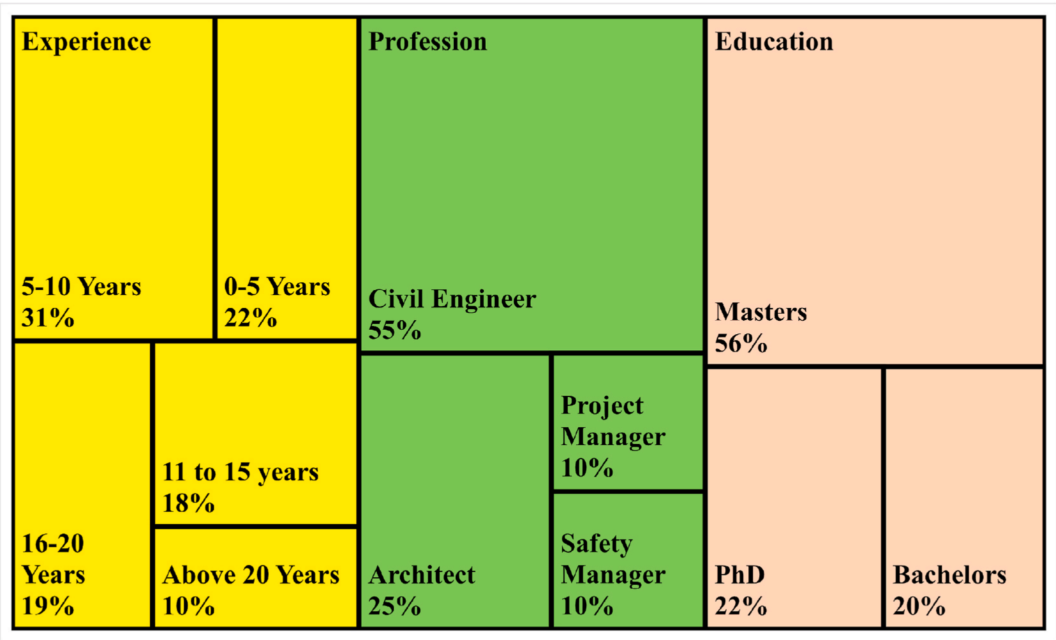

Fig. 4. Demographics.

Table 8
Model reliability and validity statistics.

Construct	Barriers	Loadings	VIF	Cronbach Alpha	Composite Reliability	AVE
Knowledge	C6	0.971	2.5	0.937	0.97	0.941
	C1	0.969	1.13	–	–	–
	C17	**Deleted**	1.13	–	–	–
Technical	C14	0.709	1.25	0.707	0.768	0.525
	C16	0.771	1.144	–	–	–
	C7	0.691	1.43	–	–	–
	C9	**Deleted**	1.14	–	–	–
Standardization	C3	0.850	1.25	0.721	0.841	0.725
	C13	0.853	2.20	–	–	–
	C2	**Deleted**	2.20	–	–	–
Creativity	C5	0.942	2.15	0.85	0.93	0.869
	C4	0.922	1.18	–	–	–
Complexity	C15	0.866	1.43	0.711	0.873	0.775
	C8	0.895	2.5	–	–	–
Economic	C12	0.966	1.13	0.699	0.763	0.631
	C10	0.574	1.13	–	–	–

Table 7 presents evidence that the constructs utilized in the model exhibit strong reliability and validity. Certain constructs, namely C2, C17 and C9, were excluded from the analysis due to their low loading values. No evidence of multicollinearity was detected. The internal consistency of most constructs was deemed satisfactory, as evidenced by Cronbach's alpha and composite reliability values exceeding 0.7. The obtained AVE values were greater than 0.5, suggesting that the measures' convergent validity was satisfactory. The overall trend of the model reliability and validity statics is indicated in Fig. 5.

The Fornell-Larcker criteria results for the six constructs in the study are presented in Table 9. The presented tabular data displays the correlation coefficients among the various constructs, forming a matrix of numerical values. The diagonal elements of the matrix correspond to under root of the mean AVE for every construct. As per the Fornell-Larcker criterion, it is recommended that the AVE of a construct should surpass the maximum correlation it shares with any other construct present in the matrix. The present analysis reveals that the diagonal values surpass the corresponding correlation coefficients, signifying the constructs' adequate discriminant validity [26,36]. The matrix values indicate that the correlation between Complexity and Creativity is the highest, yet it remains below the threshold, signifying that the constructs are distinct. The Fornell-Larcker criteria demonstrate that the measurement model exhibits convergent and discriminant validity.

Table 10 displays the outcomes of the heterotrait-monotrait ratio (HTMT) statistics, a technique utilized to evaluate the discriminant validity of the constructs. The diagonal elements exhibit values of 0.7 or lower, which suggests that the constructs possess satisfactory discriminant validity. Nevertheless, certain elements located off the diagonal surpass the suggested threshold of 0.9, implying the existence of possible concerns regarding discriminant validity. The HTMT values for the pairs of constructs, namely Creativity-Economic, Economic-Knowledge, Standardization-Knowledge, Technical-Economic, and Technical-Standardization, are below 0.9. This suggests that there is significant discriminant validity between these pairs of constructs [34,70]. This proposition

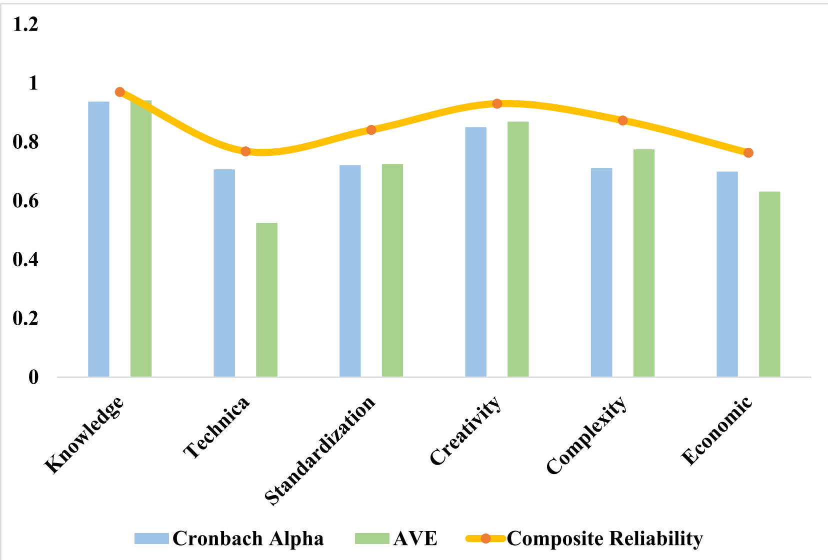

Fig. 5. Comparison of model reliability and validity statistics.

Table 9
Fornell Larker criteria results.

Construct	Complexity	Creativity	Economic	Knowledge	Standardization	Technical
Complexity	0.88					
Creativity	0.091	0.932				
Economic	0.125	0.188	0.794			
Knowledge	0.077	0.181	0.185	0.97		
Standardization	0.044	0.139	0.269	0.418	0.851	
Technical	0.021	0.193	0.291	0.328	0.315	0.725

Table 10
HTMT statistics.

Construct	Complexity	Creativity	Economic	Knowledge	Standardization	Technical
Complexity						
Creativity	0.121					
Economic	0.333	0.248				
Knowledge	0.142	0.2	0.218			
Standardization	0.084	0.187	0.461	0.547		
Technical	0.228	0.282	0.449	0.447	0.542	

implies the possibility of a certain degree of convergence between the constructs or that they are assessing similar latent constructs. Further investigation of potential issues and consideration of possible solutions, such as redefining constructs or incorporating additional measures to enhance discriminant validity, may be warranted by studies [54,63].

Table 11 displays the cross-loadings of the variables within the model, denoting the degree to which each variable aids in measuring each construct. The diagonal elements of the matrix indicate the loadings of individual variables on their respective constructs, and it is expected that these loadings would exhibit a higher magnitude in comparison to the loadings on other constructs. In general, the findings indicate that the variables exhibit a high degree of loading on their corresponding constructs, thereby providing evidence in favor of the convergent validity of the model. Nevertheless, certain cross-loadings are also observable, suggesting possible discriminant validity concerns. As an illustration, C15 exhibits a comparatively elevated loading on the construct of creativity, thereby implying that it may also be assessing certain facets of the aforementioned construct [66,79]. Additional inquiry is required to ascertain the significance of this matter. However, the comprehensive outcomes offer some corroboration for the authenticity of the measurement framework.

4.4.2. Structure path analysis

Table 12 presents the outcomes of the path analysis, which demonstrate the connections between the six latent constructs and the dependent variable, namely, challenges to implementing the IoT. The findings indicate that the six constructs have a significant impact on the barriers to the implementation of the IoT. The study found a statistically significant and positive correlation ($\beta = 0.239$, $p < 0.001$) between the level of complexity and the barriers encountered during the implementation of IoT technology. This implies that there is a positive relation between the level of complexity and barriers encountered in the implementation of IoT technology. The study found that IOT implementation barriers have positive and significant relationships with various factors, including Creativity ($\beta = 0.254$, $p < 0.001$), Economic ($\beta = 0.244$, $p < 0.001$), knowledge ($\beta = 0.341$, $p < 0.001$), Standardization ($\beta = 0.292$, $p < 0.001$), and Technical ($\beta = 0.344$, $p < 0.001$). The findings suggest that the issue of collinearity does not hold significant weight in the present analysis, given that all constructs exhibit collinearity values that are less than 1.5. This implies that the constructs exhibit a degree of differentiation and are not strongly interrelated [12,62]. In summary, the findings indicate that a multitude of factors, including

Table 11
Cross ladings.

Variables	Complexity	Creativity	Economic	Knowledge	Standardization	Technical
C15	**0.866**	0.107	0.06	−0.038	0.08	0.064
C8	**0.895**	0.056	0.155	0.163	0.003	−0.021
C5	0.064	**0.942**	0.182	0.199	0.168	0.207
C4	0.108	**0.922**	0.169	0.134	0.085	0.148
C10	−0.146	0.077	**0.574**	0.052	0.17	−0.019
C12	0.189	0.192	**0.966**	0.196	0.255	0.34
C1	0.043	0.18	0.162	**0.969**	0.393	0.331
C6	0.106	0.171	0.196	**0.971**	0.416	0.306
C13	−0.001	0.081	0.221	0.405	**0.853**	0.285
C3	0.077	0.156	0.238	0.306	**0.85**	0.252
C14	−0.084	0.117	0.168	0.342	0.217	**0.709**
C16	0.105	0.254	0.26	0.235	0.226	**0.771**
C7	0.008	0.011	0.198	0.124	0.25	**0.691**

Table 12
Path analysis results.

Hypothesis	Path	β	SE	t-values	p-values	VIF	Results
H1	Complexity - > IOT Implementation Barriers	0.239	0.018	13.588	<0.001	1.025	✓
H2	Creativity - > IOT Implementation Barriers	0.254	0.018	14.274	<0.001	1.079	✓
H3	Economic - > IOT Implementation Barriers	0.244	0.020	12.221	<0.001	1.169	✓
H4	Knowledge - > IOT Implementation Barriers	0.341	0.021	16.171	<0.001	1.296	✓
H5	Standardization - > IOT Implementation Barriers	0.292	0.021	13.838	<0.001	1.305	✓
H6	Technical - > IOT Implementation Barriers	0.344	0.021	16.489	<0.001	1.243	✓

complexity, creativity, economic considerations, knowledge, standardization, and technical aspects, significantly impact the barriers that impede the application of IoT technology. The aforementioned results align with prior scholarly investigations that have recognized these factors' significance in achieving effective IoT implementation.

The findings of this study hold significant ramifications for enterprises seeking to integrate IoT technologies. By comprehensively comprehending the factors that contribute to hindrances in implementation, organizations can undertake measures to mitigate these factors and augment the probability of successful implementation [45,55]. Organizations should prioritize simplifying technology and reducing complexity, enhancing knowledge and expertise in IoT, standardizing processes and procedures, and allocating resources toward technical infrastructure. The findings presented in Table 11 on path analysis offer significant insights into the determinants of barriers to implementing IoT. The results underscore the significance of considering various factors during the implementation of IoT and propose that entities should adopt a holistic strategy to tackle barriers to implementation.

Table 13 presents the results of the predictive relevance analysis of the model, utilizing the SSO, SSE, and Q2 metrics. The acronym SSO denotes the summation of squares of observed values, while SSE stands for the summation of squares of errors. Q2, on the other hand, represents the predictive relevance of the model, which is determined by subtracting the ratio of SSO to SSE from 1. The SSO value for the implementation barriers of IoT was determined to be 4811.000, while the SSE value was calculated to be 3864.172. As a result, the Q2 value was found to be 0.197. This statement implies that the model exhibits a moderate level of predictive capability in elucidating the range of barriers encountered in implementing IOT. Although the Q2 value is not notably elevated, it still suggests a significant association between the independent and dependent variables within the model [15,53]. Consider that additional variables beyond the model's scope could impact the hindrances to implementing IOT. Therefore, it may be necessary to conduct further studies to enhance the model's predictive capability [12,56].

4.4.3. Model validation

The findings of the validation survey conducted among 12 respondents are presented in Table 14. The survey aimed to evaluate the pertinence of the identified barriers to IoT adoption in the building sector, the proposed strategies to address these barriers, the significance of adopting IoT technologies, the feasibility of the proposed strategies, and other potential barriers to IoT adoption. The participants generally provided favorable evaluations regarding the recognized barriers, suggested approaches, and significance of implementing IoT, as indicated by the mean values ranging from 4.08 to 4.42 on a scale of 5. The data reveal discrepancies in the individual reactions, as evidenced by the standard deviations ranging from 0.75 to 0.92. The respondents deemed the identified barriers pertinent to adopting IoT in the building sector, as indicated by a mean score of 4.33. The participants also agreed to the proposed strategies to overcome the barriers, as indicated by a mean score of 4.17. The statement implies that the strategies are deemed viable in tackling the barriers to adopting IoT [31,76]. The participants acknowledged the significance of integrating IoT technologies in advancing smart buildings and infrastructure, as evidenced by a mean score of 4.25. This suggests recognizing the possible advantages of implementing IoT technology within the construction sector.

The respondents rated the proposed strategies' feasibility favorably, as evidenced by a mean score of 4.17. This implies that the proposed tactics are perceived as feasible and attainable. Ultimately, the participants offered additional perspectives regarding prospective barriers to the implementation of IoT within the construction sector. As mentioned earlier, the aforementioned responses hold potential utility in pinpointing additional study domains and formulating tactics to tackle the barriers.

5. Discussion

Knowledge construct includes "C6 Lack of knowledge and comprehension of IoT benefits", "C1 Risk of data intrusions, cyber-attacks, and violations of data privacy", and "C17 Skills shortage in IoT technologies". The hypothesis, "H1: Knowledge barriers create a significant impact on the application of IoT for smart construction and infrastructure development in the building sector", is fully accepted considering the outcomes of SEM analysis. The discovery that barriers to knowledge have a significant impact on the application of IoT for the advancement of smart construction and infrastructure in building sector is in line with a prior study on the

Table 13
Model predictive relevance.

Predictive relevance analysis of model	SSO	SSE	Q^2 (=1- SSO/SSE)
IOT Implementation Barriers	4811.000	3864.172	0.197

Table 14
Validation results.

Respondent	1	2	3	4	5	6	7	8	9	10	11	12	Mean	SD
Q1	4	4	4	5	3	5	3	5	5	4	5	5	4.33	0.75
Q2	3	4	5	5	3	4	3	5	5	5	4	4	4.17	0.80
Q3	5	3	3	5	3	5	3	5	5	4	5	5	4.25	0.92
Q4	4	4	4	3	3	5	5	5	4	3	4	5	4.08	0.76
Q5	3	5	3	5	5	4	5	5	5	5	5	3	4.42	0.86

function of knowledge in adopting technology. Empirical study has indicated that a deficiency in comprehension and awareness of the advantages and drawbacks of technology may impede its implementation. Moreover, the insufficiency of proficient personnel to execute and administer the technology can impact its adoption. The distinctive aspect of this study lies in its particular emphasis on the construction sector which presents distinct barriers and features. This research highlights the importance of knowledge barriers in adopting IoT in the building sector [9,80]. This information can be valuable for industry professionals and policymakers, as it emphasizes prioritizing knowledge acquisition and skill development to facilitate IoT adoption.

The technical construct includes "C14 Industry fragmentation with coordination and collaboration difficulties", "C16 Legacy infrastructure modernization difficulties", "C7 Complexities in scalability and interoperability", and "C9 Integration difficulties with current building management systems". The hypothesis, "H2: Technical barriers create a significant impact on the application of IoT for smart construction and infrastructure development in the building sector", is fully accepted considering the outcomes of SEM analysis. The discovery that technical barriers substantially influence IoT implementation in advancing smart constructions and infrastructure within the construction sector aligns with a prior study that has recognized technical hindrances to adopting IoT. Amade & Nwakanma (2021) [43]conducted a study that revealed that technical barriers, including interoperability and integration with legacy systems, were major impediments to the adoption of IoT in the construction sector. This study's distinctive contribution lies in its concentration on building sector and its recognition of particular technical barriers exclusive to this setting, such as industry fragmentation and coordination [24,56]. The results indicate that resolving these technical barriers will be crucial for the productive implementation of IoT within the building industry of and may hold significance for other industries that encounter similar barriers.

Standardization construct includes "C3 Data security and privacy issues are of concern", C13 Regulatory and legal ambiguity", and "C2 Lack of industry-wide IoT implementation standards and protocols". The hypothesis, "H3: Standardization barriers create a significant impact on the application of IoT for smart buildings along with infrastructure development in the building sector", is fully accepted considering the outcomes of SEM analysis. The discovery that the hindrances posed by standardization have a notable effect on the integration of IoT to develop smart buildings and infrastructure within the construction sector is consistent with prior investigations on the adoption of IoT in various other industries. The study has indicated that the absence of uniformity and compatibility can impede the acceptance of IoT owing to barriers in assimilating devices and systems from diverse vendors. The study makes a distinctive contribution by pinpointing particular barriers pertinent to the construction sector, specifically those associated with data security, privacy apprehensions, and regulatory uncertainty [47,75]. The barriers above underscore the significance of formulating industry-wide standards and protocols that cater to the distinctive requirements and regulations of the construction sector.

Creativity construct includes "C5 IoT implementation's long-term benefits are difficult to quantify" and "C4 Change aversion and unwillingness to embrace new technologies". The hypothesis, "H4: Creativity barriers create a significant impact on the application of IoT for smart construction along with infrastructure development in the building sector", is fully accepted considering the outcomes of SEM analysis. The present study's discovery that creativity barriers considerably affect the implementation of IoT for developing smart buildings and infrastructure in the construction sector aligns with a prior study that underscores the significance of organizational culture and attitudes toward innovation. This research's distinctive role lies in identifying particular barriers to creativity that impact the industry, including barriers related to quantifying long-term benefits and resistance to change. The barriers above may hold particular significance within the construction sector, which has a historical tendency towards risk aversion and a reluctance to integrate novel technological advancements swiftly [11,32]. Comprehending these barriers can provide insight into formulating tactics that facilitate novelty and surmount opposition to alteration [20,57]. Hence, the present study's identification of barriers to creativity and their influence on the adoption of IoT in the construction sector is a significant addition to the existing body of knowledge.

Complexity construct includes "C15 Complexities in data management, analysis, and decision-making application" and "C8 Concerns for the environment and sustainability in IoT implementation". The hypothesis, "H5: Complexity barriers create a significant impact on the application of IoT for smart construction along with infrastructure development in the building sector", is fully accepted considering the outcomes of SEM analysis. The results of the complex construct in this investigation align with a prior scholarly inquiry on the difficulties encountered during the adoption of IoT in diverse sectors. The study's distinctive contribution lies in its concentration on the building sector, which has yet to be extensively studied in this domain. The results indicate that complexity-related barriers, including data management, analysis, decision-making, and environmental sustainability concerns, significantly influence IoT adoption in smart buildings and infrastructure development. The barriers mentioned above can be mitigated by devising suitable data management systems and executing sustainable practices within the construction sector [3,63]. The findings of this investigation offer significant perspectives for professionals, policymakers, and scholars in the construction sector who aim to encourage the integration of IoT technology in the construction domain.

The economic construct includes "C12 "Implementation and infrastructure expenses," and C10 Few funding and financing alternatives are available for IoT initiatives". The hypothesis, "H6: Economic barriers create a significant impact on the application of IoT for smart construction along with infrastructure development in the building sector", is fully accepted considering the outcomes of SEM analysis. The present study underscores the economic impediments to the application of IoT for the construction industry, such as costs associated with implementation and infrastructure, as well as the need for more funding and financing options. These findings align with prior studies on the barriers to IoT integration in this industry [44,68]. The study is endowed with a distinctive outlook owing to the particular context of the building sector. The results indicate that the economic difficulties significantly influence the implementation of IoT to construct intelligent buildings and develop infrastructure. This underscores the necessity for innovative financing and cost-sharing approaches to surmount these difficulties [13,61]. This study offers significant perspectives for policymakers, industry experts, and other relevant parties engaged in advancing the implementation of IoT technologies within the construction sector.

Numerous construction companies encounter limitations in budget allocation for the implementation of IoT technologies. For instance, a construction company of modest size may encounter difficulties in allocating a substantial portion of its financial resources towards the investment in infrastructure, devices, and implementation of IoT technology. In order to address this challenge, it is possible to explore innovative financing approaches, such as leasing options, pay-*as*-you-go models, or shared investment schemes. These approaches enable organizations to leverage IoT technologies without requiring initial capital investment, thereby enhancing the viability of adopting and implementing IoT solutions.

The Uncertainty Surrounding Return on Investment (ROI) An economic apprehension faced by construction firms pertains to the ambiguity surrounding the return on investment (ROI) of IoT expenditures. Quantifying and measuring the long-term financial benefits of integrating the IoT in the construction sector pose significant challenges. In order to surmount this obstacle, it is possible to integrate inventive financial strategies with performance-based agreements or outcome-based payment frameworks. These mechanisms establish a connection between the financial returns and the outcomes or operational efficiencies that are attained as a result of implementing the IoT. Construction companies can enhance their confidence in investing in IoT projects by ensuring that the financial incentives are aligned with the tangible performance improvements facilitated by IoT technologies.

The aforementioned examples serve to underscore the significance of employing inventive financial methods and cost-sharing tactics in order to tackle the economic obstacles linked to the implementation of IoT in the construction industry. By utilizing these strategies, construction firms can effectively address financial limitations, effectively control infrastructure costs, minimize uncertainties surrounding return on investment, and tap into supplementary funding channels to facilitate the seamless integration and deployment of IoT technologies.

6. Empirical and theoretical contributions

The current study makes significant empirical and theoretical advancements in the domain of IoT adoption within the building industry. This study employs empirical research methods to identify and comprehensively analyze six key obstacles that impede the implementation of IoT technology in the building sector. The barriers in question encompass a range of factors, including knowledge, technical expertise, standardization, creativity, complexity, and economic considerations. The results provide significant insights for policymakers, industry experts, and scholars in order to formulate effective strategies and solutions to address these obstacles.

This research study provides empirical evidence that supports the significant impact of the identified barriers on the adoption of IoT technology in building sector. The research employs Structural Equation Modeling (SEM) analysis to validate the impact, which is consistent with previous studies that have identified comparable obstacles in different industries, such as the construction sector. This study offers unique insights by specifically emphasizing the obstacles encountered by the construction industry.

The research paper additionally provides an all-encompassing theoretical framework that facilitates comprehension of the obstacles linked to the adoption of IoT in the building industry. The framework comprises six constructs that delineate the primary obstacles to the adoption of IoT technology. Theoretical frameworks possess the capacity to function as a guiding principle for forthcoming research endeavors pertaining to the adoption of IoT within the construction sector. Furthermore, the utility of this technology transcends the confines of the construction sector and holds potential advantages for other industries encountering comparable obstacles in the adoption of IoT technologies.

In brief, this study makes a substantial academic contribution by identifying and analyzing the obstacles to the adoption of IoT technology in the building sector. The study presents empirical evidence, substantiates the impact of these obstacles, and proposes a theoretical framework that can serve as a guiding principle for future investigations. By acknowledging and overcoming these obstacles, policymakers, industry experts, and academics can facilitate the effective adoption of IoT technologies, not only within the construction sector but also in other industries encountering comparable difficulties.

In the course of the research, each and every hypothesis was validated. Each hypothesis was supported by empirical evidence gathered through the research methodology, indicating that all six types of barriers (knowledge, technical, standardisation, creativity, complexity, and economics) have a significant impact on the application of IoT for smart construction and infrastructure development in the building sector. These barriers include standardisation, creativity, complexity, and economics. Within the scope of the research, the data and analysis showed strong evidence for the effect that these constraints have on the adoption of IoT technology. As a consequence of this, none of the assumptions were found to be incorrect, and the outcomes of the research confirmed that it is essential to overcome these obstacles in order to successfully adopt IoT in the construction industry.

7. Managerial suggestions

This paper offers significant insights into the difficulties encountered when implementing IoT technology for the purpose of developing smart buildings and infrastructure. To optimize comprehension and facilitate effective decision-making, it is imperative for managers to prioritize the augmentation of their knowledge regarding IoT technologies and the advantages they offer. The objective of fostering knowledge among employees about the IoT can be accomplished through the implementation of training programs and workshops. It is advisable for companies to contemplate engaging in partnerships with other entities within their respective industries as a means to effectively tackle technical and standardization obstacles. Through collaborative efforts, it is possible to establish industry-wide implementation standards and protocols, thereby fostering interoperability, scalability, and security. In order to surmount economic obstacles, it is imperative for managers to engage in an exploration of alternative financing models and funding options. This may entail the exploration of public-private partnerships, examination of government-funded financing initiatives, and implementation of crowdfunding initiatives.

In order to ascertain and quantify the lasting advantages of integrating the IoT in the construction industry, it is imperative to employ innovative methodologies and approaches for measurement. In order to adequately evaluate the long-term benefits of implementing IoT technologies, it is essential to adopt novel project evaluation methodologies and formulate appropriate metrics. It is imperative for managers to acknowledge the significance of integrating environmental and sustainability considerations into the integration of IoT technology within the construction industry. The comprehensive examination of the entire lifecycle of IoT technologies, encompassing their manufacturing and disposal processes, is necessary to effectively address and minimize their environmental impact. By adopting the aforementioned managerial recommendations, companies can effectively address the challenges associated with the implementation of IoT and facilitate the advancement of intelligent buildings and infrastructure within the nation.

8. Limitations and future implications

The present study acknowledges specific limitations that warrant attention in subsequent research endeavors in order to augment the overall quality and scope of the investigation. The study's sample size was restricted to only 12 participants, which raises concerns regarding the extent to which the findings can be applied to the wider building sector. Subsequent inquiries ought to encompass a broader and more heterogeneous cohort, in order to enhance the generalizability and validity of the findings. Furthermore, the research primarily concentrated on the obstacles associated with the implementation of Internet of Things (IoT) technology within the construction industry, neglecting to investigate the potential advantages and prospects that may arise from its adoption. Future studies should focus on exploring the benefits and potential of implementing the Internet of Things (IoT), while also devising strategies to maximize these advantages while minimizing the accompanying difficulties.

One additional constraint pertains to the exclusion of cultural and societal variables that could potentially impact the adoption of IoT technologies within the construction industry. To obtain a comprehensive understanding of the impact of IoT adoption, it is recommended that future research focuses on investigating various variables, including attitudes towards technology, risk aversion, and the prevailing innovation culture. Furthermore, the study failed to address the ethical implications related to the implementation of Internet of Things (IoT) in the construction industry. Future inquiries should conduct a comprehensive analysis of the ethical ramifications associated with the subject matter, encompassing aspects such as the preservation of data confidentiality, implementation of robust security protocols, and the potential impact on both the workforce and the broader community. By acknowledging these constraints and investigating these prospective ramifications, it will enhance the holistic comprehension of the obstacles, prospects, and ethical aspects associated with the deployment of IoT for intelligent structures and infrastructure advancement.

There are a number of interesting avenues that may be pursued in the field of Internet of Things (IoT) research in the future for the purpose of developing smart buildings and infrastructure To begin, there is a window of opportunity to carry out comparison studies across other industries. The goal of these research is to acquire a more in-depth knowledge of how the adoption of IoT and the hurdles to its adoption vary across diverse sectors other than construction. These kinds of research might shed light on problems that are unique to a certain sector and encourage the exchange of information and new ideas. Long-term effect evaluation is another potential path for further study in the future. It is possible to get useful insights for both practitioners and policymakers by investigating the long-term advantages and ever-changing issues connected with the implementation of IoT in smart buildings and infrastructure over an extended period of time. In addition, the protection of users' privacy and data when using IoT devices is of the utmost importance. In light of the proliferation of Internet of Things (IoT) systems, researchers have the opportunity to investigate novel methods that may strengthen security and protect individuals' privacy inside smart buildings while maintaining the data and device integrity. In addition, the emphasis of research in the future might shift towards regulatory and policy frameworks. In order to facilitate the successful adoption of IoT in the construction industry, one of the most important roles that can be played is evaluating the efficiency of current rules and proposing specific regulatory measures.

9. Conclusion

This study offers a comprehensive understanding of the challenges that the construction industry has when attempting to apply IoT technology for the purpose of developing smart infrastructure and buildings thanks to the information provided by this research. The research that was carried out for the purpose of this study was effective in identifying six key roadblocks that stand in the way of growth in the sector. A lack of suitable experience, technological restrictions, issues connected to standardisation, obstructions to innovation, complexity in the subject matter, and economic restraints are some of the hurdles that must be overcome. The results of the structural equation modelling (SEM) investigation showed that these obstacles have a substantial influence on the adoption of IoT technology. The aforementioned results provide a substantial addition to the existing body of research about the use of Internet of Things (IoT) technology within the realm of building infrastructure thanks to the fact that they show how IoT may improve building efficiency. Policymakers and professionals working in the sector stand to gain significant insights from the identification of obstacles, which will enable them to build focused strategies for the barriers' reduction.

In addition to that, the findings of this study provide important new insights on the primary elements that have a bearing on the inclusion of Internet of Things technologies within the construction sector. The results that have been presented here may serve as a point of reference for further research that are carried out in this specific subject. The results of this research have significant repercussions for managers, as they underline the significance of allocating resources to training and development programmes with the objective of enhancing workers' grasp of the Internet of Things (IoT) as well as their identification of the benefits that are connected with it. In addition, the study highlights the relevance of industry stakeholders working together to develop all-encompassing standards and protocols prior to the introduction of the internet of things (IoT). It is vital that businesses demonstrate a proactive position in adopting emerging technologies, and governments should participate in a comprehensive analysis of alternative funding and financing arrangements in order to successfully enable the implementation of Internet of Things initiatives.

The use of a cross-sectional study design and the use of a relatively small sample size are the two aspects of the research that might be categorized as its limiting factors. Future research efforts may want to think about increasing the sample size and using a longitudinal investigative strategy to investigate the issues encountered by the construction industry over a longer period of time in order to solve these constraints. These are some of the options that may be considered. In addition, future research efforts may prioritize the development of strategies targeted at overcoming the hurdles described in this study, therefore allowing the efficient integration of IoT technologies in the arena of building construction. These strategies might be developed in order to overcome the barriers elucidated in this study.

Ethics

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

Ahsan Waqar: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Nasir Shafiq:** Resources, Methodology, Investigation, Data curation. **Idris Othman:** Supervision, Software, Resources, Project administration. **Saleh Hamed Alsulamy:** Writing – review & editing, Visualization, Project administration, Data curation, Conceptualization. **Abdullah Mohammed Alshehri:** Writing – original draft, Validation. **Ibrahim Idris Falqi:** Software, Formal analysis, Data curation, Conceptualization.

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.

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