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Effect of IoT Integration in Construction Industry: Structural Equation Modeling Approach

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This study aims to identify and analyze the key factors influencing the successful integration of Internet of Things (IoT) technology in the construction industry to enhance building efficiency and user experience. The integration of IoT technology in buildings has the potential to significantly improve operational efficiency, sustainability, and user satisfaction. However, achieving effective implementation requires a comprehensive understanding of various influencing factors. To develop a structural model elucidating the components critical for IoT integration in the construction sector. Amixed-methods approach was employed, combining qualitative interviews with 12 IoT experts and quantitative surveys involving 112 participants in a preliminary survey and 184 in a main survey. Data were analyzed using exploratory factor analysis (EFA) and structural equation modeling (SEM). The findings highlight the significant impact of data-driven decision-making ($\beta = 0.163$, $p < 0.001$), energy management ($\beta = 0.242$, $p < 0.001$), integration with interconnected systems ($\beta = 0.104$, $p < 0.001$), personalized user experiences ($\beta = 0.247$, $p < 0.001$), and predictive maintenance ($\beta = 0.241$, $p < 0.001$) on optimizing IoT utilization in buildings. The model demonstrates a good fit with a predictive relevance measure ($Q^2 = 0.197$). The study provides valuable insights for industry professionals and scholars, offering a framework to guide future IoT technology applications in construction to achieve enhanced efficiency and user satisfaction.

Keywords: Internet of Things (IoT), Buildings, Efficiency, User experience, Structural equation modeling, Data-driven decisions.

1. Introduction

Digital technologies support effective economics in various sectors. The report published by the World Economic Forum stated that this digitalization process could add $13.6 trillion to the value of businesses across the world in the next decade [1]. It would mean a significant $1.2 trillion addition to the economic growth of the United States by incorporating state-of-the-art digital technologies: the IoT, machine learning, and cloud computing. In fact, these two phenomena are developing with the facilitation of digital technologies [2]. A forecast based on the report of the European Commission is that the acceptance of digital technologies in Europe has the potential to create an additional 1.25 million jobs in the year 2025 [3]. The IoT acts as the enabling technology of communication inside smart buildings; hence, different devices and systems can integrate and coordinate. Such devices are embedded with sensors and actuators which capture and forward data for analysis. In predictive maintenance, IoT data may detect equipment failures or inefficiencies to enable timely intervention, argued by researcher [4]. Its IoT applications in smart buildings promote digitalization of physical structures, with beneficial outcomes in operational efficiency and user satisfaction [5].

This is despite the fact that the IoT in intelligent buildings is a subject whose corpus of scholarly works keeps on developing, and various indications are that much more work is called for on the individual elements and mechanisms that make it a practical tool in enhancing operating efficiency and improving user satisfaction. Works of previous studies have tended to concentrate on the advantages of IoT in intelligent buildings [6]. It is also necessary to carry out the necessary empirical research using strict quantitative methods in order to precisely determine the degree of impact brought about by the introduction of the IoT. Understanding the organizational and human issues that affect the effectiveness of the Internet of Things has been less well addressed, which has traditionally been dominated by academic research focused on its technical aspects [7]. In-depth analysis of the psychological and social implications of deploying IoT may provide insights into elements influencing increased effectiveness and user happiness [8]. In fact, the underlying components, quantifiable repercussions, and social aspects with regard to IoT in intelligent buildings are very important and need to be investigated as one aspect of overcoming gaps.

This research investigates the functionality of IoT technology for Intelligent Buildings. The focus is on improving user happiness and operational effectiveness. to enhance identify the primary capabilities and technologies enabled by IoT in terms of intelligent buildings that are most valuable for enhancing productivity and user satisfaction. This research extends the existing body of knowledge. First, the contribution of IoT has already been pointed out by previous works, enhancing both the efficiency and users' happiness of intelligent buildings. This study tries to present a holistic approach, triggering into the specific elements and processes that support this achievement. The second novelty within this work is the application of SEM for the quantitative analysis of relationships existing between IoT, building efficiency, and user experience. In the present study, SEM has been adopted as a methodological strategy for the accomplishment of an in-depth statistical analysis, whose aim is to quantify the exact and direct influence that IoT exerts on the targeted objectives. It improves the validity and reliability of these results and hence enhances the assessments framework. The study is a novelty because it provides empirical data to support the claims on the effectiveness of IoT in the creation of intelligent structures that improve operational efficiency and user satisfaction.

2. Related Work

The Internet of Things has been a game changer in many sectors, most especially the construction and building sectors. A building-or IoT integration with the integration of different tools and technology in buildings can increase productivity and user experience [9]. The following literature study will review the current research and developments in the sector to improve the efficacy in buildings and user experience thereof accordingly [10]. Results of the study have nailed that it assists in attaining sustainable behaviors, cost reduction, and the improvement of energy efficiency [11]. Comfort, productivity, and well-being of occupants are severely affected by IEQ. IoT makes it possible to monitor and control various parameters, like temperature, humidity, air quality, and light [12]. Other works focused on the integration of IoT and advanced sensing methodologies to allow real-time monitoring and adaptive control of Indoor Environmental Quality, showing an increase in occupant satisfaction and overall performance of the building [13].

IoT integration allows for the development of occupant-centric applications related to user experience and convenience [14]. Examples will be intelligent lighting systems that incorporate adaptive settings for preferring occupants, occupancy patterns, and levels of available natural light [15]. This involved IoT technology to control an intelligent lighting system. Although there are a lot of benefits involved, the IoT inherently introduces several security and privacy concerns [16]. Access to IoT devices and data by unauthorized parties, along with breaches, has emerged as a significant peril to IoT application development. An earlier work was conducted to study IoT-enabled building structures concerning the security challenges therein and to propose some security frameworks to reduce all potential risks involved in using IoT in buildings [17]. A proposed strategy was presented that uses data from the IoT in model development and making predictions about occupant behaviour [18]. It presents a framework for defective detection and diagnosis in HVAC systems using IoT detectors. It showed the efficiency of IoT-enabled sensors identifying anomalies that would improve overall system performance [19]. The research work connected solar panels to IoT-based potential energy control; preventive maintenance application built around the use of IoT data analytics.

A search of documents in the Scopus database was done between the year 2018 to 2023, with the title, abstract, or keywords containing "IoT" AND "data OR analytics" AND "predictive OR maintenance". The search provided 3,704 document results, which discussed a total of 3,304 publications from the chosen year range of 2018 to 2023. It also looked at the distribution in regard to years within this period, with 871 documents representing the highest number of publications in the year 2022. The contributing countries/territories also formed a core basis for analysis, dominated by Indian contributions with 860 publications, next to China, which had 454 documents, as featured in Figure 1.

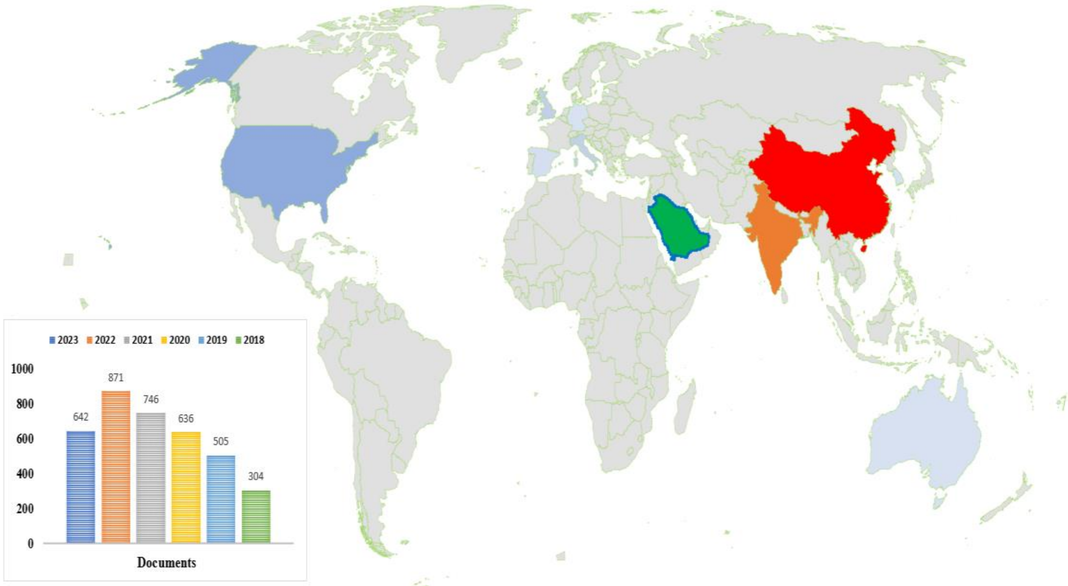

Figure 1: Documents by Year and Countries

VOS viewer software was used to see and analyses the network of publications in order to further map the bibliometric data collected from Scopus. Through network analysis, this enabled identifying significant research subjects, prominent authors, and developing patterns across time. Relevant results from the previous five years were then retrieved and analyzed from the over 250 most relevant publications discovered within the chosen publication period. The network analysis revealed the expansion of research focus areas and output connected to the use of IoT data analytics for predictive maintenance applications. Figure 2 depicts cluster mapping of co-occurring terms from publications in VOS viewer, which indicated prominent research issues addressed such as predictive maintenance, machine learning, IoT sensors, and anomaly detection. The size of keywords represented the frequency with which they appeared, while closely related terms formed different clusters based on semantic similarity and co-occurrence in articles. The essential keywords of dense clusters reflecting important study fields were highlighted in the density view. The overlay visualization demonstrated the progression of subjects throughout time. Keywords connecting distinct clusters reflected overlapping domains that drew more attention. The use of key phrase cabbage plots revealed primary and sub-themes. Insights on author keywords gave views on how researchers categories domains. The VOS viewer's network analysis permitted methodical investigation of the literature, finding key subjects. This gave insight into the evolution of research interest and output connected to the use of IoT analytics for predictive maintenance applications during the last five years.

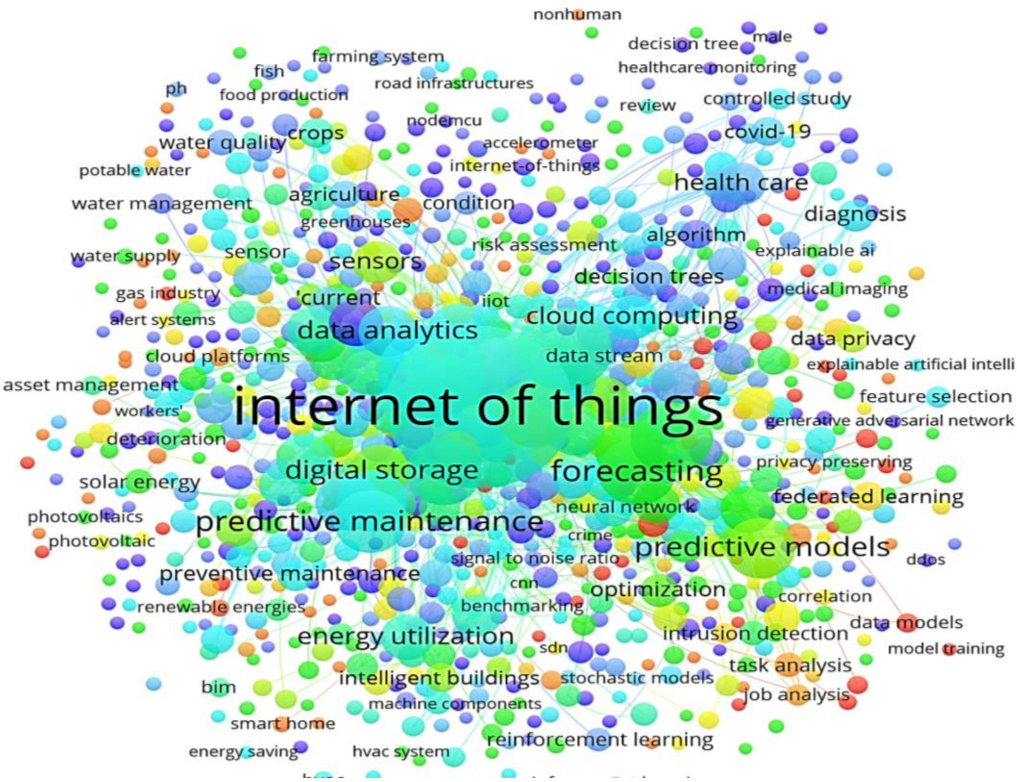

Figure 2: Visualization of Searched Keywords

The results of this bibliometric analysis showed that the use of IoT sensor data and machine learning analytics improved equipment dependability through predictive failure detection and reduced unexpected outage occurrences. Maintenance tasks could be scheduled proactively based on real-time performance monitoring. The current research sought to build upon these insights by investigating how IoT-enabled technologies and data-driven approaches could also be applied to increase building energy efficiency and optimize building operations and management through continuous remote monitoring [20]. The results of this analysis showed that energy usage and associated expenditures have significantly decreased. An investigation was made on how IoT technology may be used to solicit input from building inhabitants about its problems. This investigation's findings showed that the use of IoT technology raised tenant satisfaction and well-being levels [21].

Present research investigates the integration of IoT devices with HVAC systems that deal with heating, ventilation, and air conditioning using sophisticated algorithms. This will provide dynamic and adaptive control to improve energy efficiency while maintaining optimal occupant comfort. Application of IoT-based safety measures in buildings, as discussed in the present research, uses sensors, cameras, and algorithms to enhance security and prevent unauthorized entry .This study explored how real-time visualization could be carried out based on data from the internet of things. The volume of material already in existence underlines how important it is to harness the technology of IoT for furthering the efficiency of buildings and for optimizing user experience. Integration of IoT technology into building systems makes possible various features to be enabled: robotics, management of energy, indoor environmental quality monitoring, occupant-centric applications, data analytics, and maintenance planning. Future research will overcome these challenges and conduct their investigation into the potential IoT technologies may have within the construction industry. The mixed-method approach allowed me to combine qualitative results from interviews with experts, in conjunction with quantitative data from surveys and statistical analyses [22].

The interview itself consists of twelve in-depth interviews with renowned professionals specializing in IoT and building industries; making qualitative data very rich, thereby giving much valued insight into the factors that affect such IoT implementation. The next step was to conduct a pilot test to quantitatively gather data from 112 participants, which allowed refining the survey questionnaire and identification of relevant factors to be investigated. Following that, EFA was applied to identify and cluster significant factors to enact IoT effectively in buildings. Finally, SEM has been used to develop an integrated structural model that can explain the elements affecting IoT implementation. Elaborating on these research methods allowed assurance of a staunch and structured approach to conducting qualitative inquiry into the research objectives and translating into useful conclusions.

3. Methodology

The angle used in this study is a mixed-methods research design that captures the factors contributing, during the implementation of IoT technology, to enhancements in the efficiency of buildings and improving user experiences. This study carries out a comprehensive analysis of the literature review and a panel of 12 in-depth interviews with highly distinguished professionals in IoT and the construction industry. These experts have been handpicked based on their experience and expertise in the delivery of IoT technology implementation and construction practices.

The experience of the experts varied in a wide set of disciplines related to: IoT technology, construction engineering, architecture, building management, and sustainable development. Their insights proved very valuable in pinpointing the key variables and success factors needed for the implementation of IoT technology in buildings. As stated previously, the data were used to develop a comprehensive inventory of variables leading to good outcomes in carrying out IoT technology within buildings [23]. The outcome was followed by a pilot survey with the application of a quantitative survey questionnaire and the implementation of exploratory factor analysis in order to elucidate significant factors and their categorization into construction. Later, a main survey questionnaire was applied, with SEM analysis applied to building a structural model, which contains a predefined influence on the implementation of IoT in buildings. In addition to expert interviews, the success factors identified were verified in a very careful procedure for their reliability and validity [24]. The process generated cross-referencing of insights gained through interviews with existing literature on implementing IoT technology in buildings, peer review by professionals and researchers, consensus discussions amongst the original panel of experts, a pilot survey to gather feedback through the construction sector, statistical analysis using techniques like EFA-SEM. The methodology chart is indicated in Figure 1, while Table 1 presents all factors identified by interviews and literature reviews.

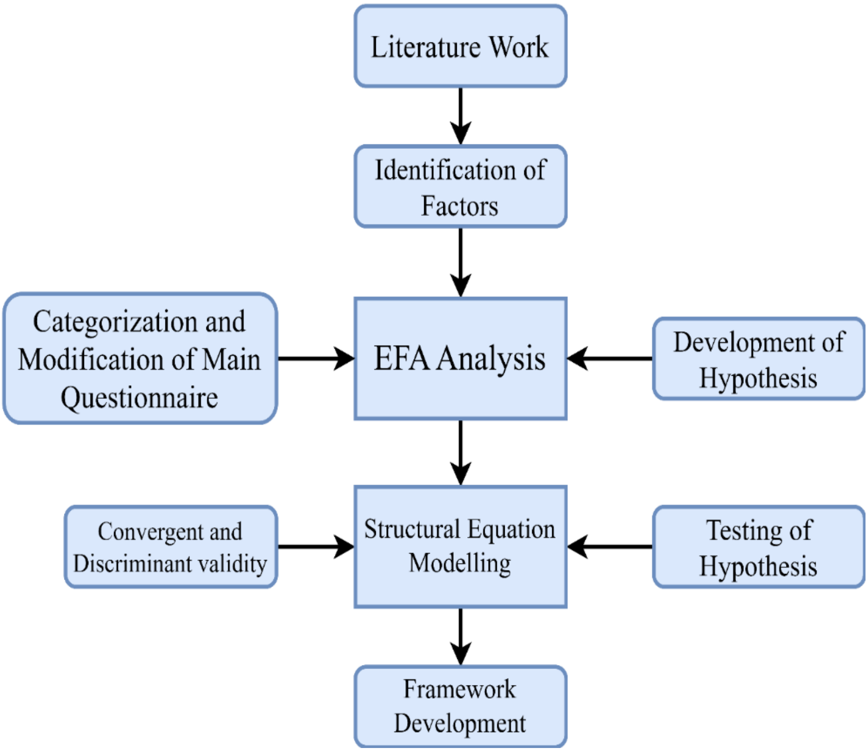

Figure 3 Flowchart of research method

Table 1 Identified success factors

Sr. No	Variables for Implementing IOT to enhanced efficiency and user experience in buildings	References
IOT-EU1	Remote monitoring and predictive analytics facilitate proactive energy management and optimization.	[25]
IOT-EU2	Algorithms for predictive analytics examine IoT data to identify patterns and trends, thereby facilitating proactive maintenance planning and scheduling.	Interview
IOT-EU3	Integrating the IOT with renewable energy sources increases energy efficiency and decreases reliance on nonrenewable resources.	[26]
IOT-EU4	Predictive maintenance optimizes resource allocation by concentrating efforts on apparatus requiring attention, resulting in cost savings and enhanced productivity.	[27]
IOT-EU5	IoT data facilitates continuous development, enabling building administrators to make informed decisions and increase the user experience.	[28]
IOT-EU6	IoT enables intelligent alarm systems to detect and report security violations or suspicious activities to occupants and authorities.	[29]
IOT-EU7	Integration with renewable energy sources enables buildings to manage and utilize sustainable energy in an efficient manner.	[30]
IOT-EU8	In buildings, data-driven decision-making based on IoT-generated data improves maintenance strategies and asset management.	Interview
IOT-EU9	IoT facilitates the incorporation of surveillance cameras, sensors, and video analytics for real-time threat detection and proactive response.	Interview
IOT-EU10	Connected access control systems provide enhanced security through centralized management, remote access control, and real-time access point monitoring.	Interview

IOT-EU11	Integrating the IOT with smart infrastructure enables demand response programs, optimizing building energy consumption.	[31]
IOT-EU12	Integrating the IOT with smart appliances enables remote control and automation, improving convenience and energy efficiency.	[32]
IOT-EU13	Integration with intelligent meters facilitates accurate invoicing and real-time monitoring of energy consumption.	Interview
IOT-EU14	IOT-based data decision-making optimizes building performance by highlighting inefficiencies and enhancement opportunities.	[33]
IOT-EU15	Participation in demand response programs enables buildings to optimize energy consumption during peak demand or high energy costs.	[34]
IOT-EU16	The IOT enables real-time energy monitoring, allowing occupants and facility administrators to trace energy consumption and identify optimization opportunities.	[35]
IOT-EU17	Automating building systems based on the occupants' preferences improves convenience and user satisfaction.	Interview
IOT-EU18	Predictive maintenance enhances the safety and comfort of building occupants by preventing equipment malfunctions that could disrupt building operations.	Interview
IOT-EU19	Resource allocation is optimized by analyzing energy consumption, occupancy patterns, and space utilization data.	[36]
IOT-EU20	Integrating intelligent assistants enables users to interact with building systems via voice commands or mobile interfaces.	[19]

4. Data Collection

There were two unique phases to the data gathering method for this research project. In this respect, the pilot survey was carried out by 112 people who had been randomly selected from the construction industry. The internet distribution approach was used for collecting the replies of the above-mentioned people. Overall, 184 people participated in the main questionnaire survey, and they had been selected to maintain all the sample characteristics as for those in the pilot survey. Following estimation, an acceptable sample size was estimated to be 170 participants. In real sense, a total of 250 questionnaires were distributed by the researchers [37]. Questionnaires collected according to the inclusion criteria for validity and usable validly were 184 in number from which data analysis was done. Data collection approaches used in this research aimed at having a significant number of respondents and an effective way of gathering essential information. In all, 184 valid questionnaires were collected and used for the analysis. The determination of the sample size considered the diversity and representativeness of the construction sector, taking into consideration participants of various roles and expertise related to IoT technology in buildings. Although it may not be representative of the entirety, the research study employed statistical software to conduct EFA and SEM in order to extract meaningful insight from the data collected. It should be underlined that though the sample size was robust for the purpose of the present study, there is a possibility of limitation with regard to capturing the whole spectrum of opinions within the construction sector.

5. Exploratory Factor Analysis (EFA)

EFA is a statistical method that deals with the analysis of the relationship between variables for their underlying latent component or structure. In this research, data from the pilot survey were analyzed using EFA [38]. Therefore, this research makes it easier to identify and categorize essential components related to deploying IoT technology in buildings. EFA has been conducted to explore and identify those significant factors that are strongly influencing the IoT deployment performance by identifying the relationships between variables [39]. In this way, the analysis provided indications over the underlying structure of the data and set the ground for the next steps of the investigation.

6. Structure Equation Modelling (SEM)

SEM is a statistical methodology that scrutinizes intricate associations among variables and evaluates theoretical frameworks. The data collected from the pilot survey was then subjected to SEM analysis in the present study. The above-mentioned thus facilitated the development of an integrated framework which captures the different elements that influence the successful integration of IoT technology within building structures [40]. Using SEM, several of these factors could be gleaned as it assessed the direct and indirect effects of this relationship that existed between the observable and latent variables with much clarity. This analysis conducted had, in turn, facilitated the ease with which we were able to assess the overall applicability of the model and the importance of the linkages to better our understanding of the elements that go into the effective application of IoT in buildings.

7. Results and Analysis

1 Exploratory Factor Analysis (EFA)

The rotated component matrix resulting from the factor analysis is presented in Table 2. The table presents the loadings of variables on each component. The six components have been designated as Activities 1 to 6. The rows show the elements of improving user experience via the Internet of Things (IoT-EU). The loadings show the strength of the relationship among each variable and each component. Further research did not include the variables IOT-EU8 and IOT-EU18 because of their low load or cross-loading errors. Additionally, each component's eigenvalues and the percentage of variance that each one contributes to the model's variance are presented.

Table 2 Matrix of rotating components

Activities	1	2	3	4	5	6
IOT-EU11	.853					
IOT-EU12	.785					
IOT-EU7	.737					
IOT-EU13	.698					
IOT-EU16		.819				
IOT-EU1		.776				
IOT-EU3		.721				
IOT-EU15		.681				
IOT-EU9			.787			
IOT-EU10			.741			
IOT-EU6			.673			
IOT-EU2				.770		
IOT-EU4				.740		
IOT-EU14					.722	

IOT-EU19					.685	
IOT-EU5					.613	
IOT-EU17						.723
IOT-EU20						.693
Eigen Values	4.432	4.275	3.732	3.124	2.777	2.143
% Variance	14.323	13.315	12.622	11.114	9.201	8.122
Excluded Variables= IOT-EU8; IOT-EU18 due to low loading or cross-loading errors.						

Table 3 presents the designated constructs identified in the study and their respective reliability statistics. The constructs are Integration with Smart Grid and Devices, Energy Management, Enhanced Security, Predictive Maintenance, Data-Driven Decision Making, and Personalized Experiences. The reliability coefficients, denoted by the code IOT-EU followed by the corresponding construct number, indicate the internal consistency or reliability of the items within each construct. Greater internal consistency is suggested by higher reliability coefficients [6]. The table serves the purpose of establishing the reliability of the constructs and showcasing the resilience of the measurement scales employed in assessing the success factors associated with the implementation of IoT in buildings.

Table 3 Named constructs with reliability statistics

Construct	Code	Reliability
Integration with Smart Grid & Devices	IOT-EU11	.859
	IOT-EU12	
	IOT-EU7	
	IOT-EU13	
Energy Management	IOT-EU16	.827
	IOT-EU1	
	IOT-EU3	
	IOT-EU15	
Enhanced Security	IOT-EU9	.789
	IOT-EU10	
	IOT-EU6	
Predictive Maintenance	IOT-EU2	.767
	IOT-EU4	
Data-Driven Decision Making	IOT-EU14	.715
	IOT-EU19	
	IOT-EU5	
Personalized Experiences	IOT-EU17	.712
	IOT-EU20	

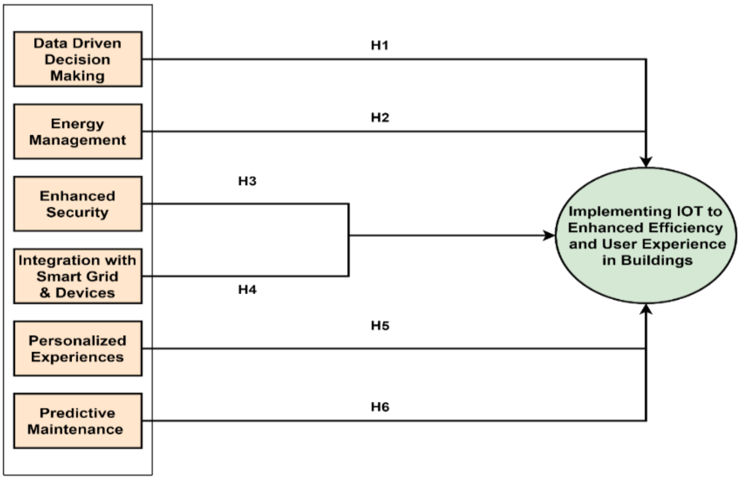

Figure 4 Hypothesized framework

According to Figure 4 and EFA analysis results, the following six hypotheses were formulated, indicating the influence of success factors and impact on implementing IoT to enhance building efficiency and user experience. The six hypotheses presented in Figure 2, derived from the exploratory factor analysis (EFA) results, are underpinned by a combination of empirical evidence from the literature and the identified success factors from our study's data. Each hypothesis reflects a theoretical understanding of how specific success factors influence the implementation of IoT to enhance building efficiency and user experience. Firstly, the hypothesis on data-driven decision-making posits that it positively influences IoT implementation, echoing prior research emphasizing the importance of data-driven approaches in optimizing building operations. Similarly, the energy management hypothesis aligns with literature highlighting the crucial role of energy management systems in utilizing IoT technologies for improved efficiency. Together, these hypotheses provide a rigorous basis for understanding the relationships between success factors and IoT implementation in buildings, synthesizing both theoretical principles and empirical findings to contribute to the broader understanding of IoT technology's impact in construction.

- H1: Data-driven decision-making positively impacts the implementation of IoT to enhance efficiency and user experience in buildings.

- H2: Energy management positively impacts the implementation of IoT to enhance efficiency and user experience in buildings.

- H3: Enhanced security positively impacts the implementation of IoT to enhance efficiency and user experience in buildings.

- H4: Integration with intelligent grids and devices positively impacts cloud computing implementation for high-rise buildings.

- H5: Personalized experiences positively impact the implementation of cloud computing for high-rise buildings.

- H6: Predictive maintenance positively impacts the implementation of cloud computing for high-rise buildings.

2 Demographics

The demographic frequency of the participants in the study is presented in Table 4. The table encompasses three distinct categories: Profession, Organization, and Buildings Industry Experience. Within the Profession category, the data presents the frequencies and corresponding percentages of participants belonging to various occupations, namely Quantity Surveyor, Architect, Civil Engineer, M&E Engineer, Project Manager, and Others. The Organization category presents data on the frequencies and percentages of individuals classified as Contractor, Consultant, and Client. The category of Buildings Industry Experience presents frequencies and percentages pertaining to various ranges of experience.

Furthermore, the table presents data on participants' familiarity with digital technologies, specifically the IoT. The frequencies and corresponding percentages are provided for both affirmative (Yes) and negative/uncertain (No/Maybe) responses [41]. The demographic insights thoroughly comprehend the participant characteristics of their professional backgrounds, organizational roles, industry experience, and familiarity with IoT technologies.

Table 4 Demographic frequency of participants

Grouping	Classification	Frequency	%
Occupation	Quantity Surveyor	23	11.8
	Architect	21	9.8
	Civil Engineer	69	40.5
	M&E Engineer	16	6.5
	Project Manager	36	20.3
	Other	19	11.1
Organization	Contractor	72	40.5
	Consultant	71	39.2
	Client	41	20.3
Buildings Industry Experience	0-5 Years	54	22.9
	6-10 Years	53	32.7
	11-15 Years	44	31.4
	16-20 Years	15	5.9
	Over 20 Years	18	7.2
Knowledge of Digital Technologies (IOT)	Yes	165	87.6
	No/Maybe	19	12.4

8. Structure Equation Modelling (SEM)

1 Measurement Model

The reliability and validity statistics for the model are shown in Table 5. The table includes the following constructions: energy management, enhanced security, preventative maintenance, data-driven decision-making, and tailored experiences are some of the benefits of integrating smart devices with the grid. Some of the statistical indicators offered include loadings, the variance inflation factor (VIF), Cronbach's alpha (CA), composite reliability (CR), and average variance extracted (AVE) [42]. The loadings reflect the strength of the relationship between each variable and its related construct. The variance inflation factor (VIF) is a statistical method for detecting if variables are multicollinear. Two measures are used to assess a construct's internal consistency: Cronbach's alpha (CA) and composite reliability (CR) [43].

On the other hand, average variance extracted (AVE) quantifies the proportion of variance accounted for by the construct [44]. There is no longer any mention of the factors that were left out of the study. The aforementioned data demonstrate the model's validity and dependability in evaluating the constructions connected to IoT deployment in buildings.

Table 5 Statistics for model validity and dependability

Construct	Code	Loadings	VIF	CA	CR	AVE
Integration with Smart Grid & Devices	IOT-EU11	0.869	2.606	0.731	0.838	0.636
	IOT-EU12	Deleted	1.974	-	-	-
	IOT-EU7	0.852	1.526	-	-	-
	IOT-EU13	0.654	1.368	-	-	-
Energy Management	IOT-EU16	Deleted	1.719	0.88	0.943	0.892
	IOT-EU1	0.950	1.760	-	-	-
	IOT-EU3	0.939	1.661	-	-	-
	IOT-EU15	Deleted	1.048	-	-	-
Enhanced Security	IOT-EU9	0.616	1.760	0.73	0.76	0.518
	IOT-EU10	0.681	2.606	-	-	-
	IOT-EU6	0.843	1.048	-	-	-
Predictive Maintenance	IOT-EU2	0.711	1.876	0.752	0.752	0.604
	IOT-EU4	0.839	1.056	-	-	-
Data-Driven Decision Making	IOT-EU14	0.826	1.475	0.804	0.884	0.717
	IOT-EU19	0.822	1.920	-	-	-
	IOT-EU5	0.891	2.606	-	-	-
Personalized Experiences	IOT-EU17	0.922	1.974	0.793	0.906	0.828
	IOT-EU20	0.897	1.526	-	-	-

The results of the Fornell-Larcker criteria analysis, which assesses the discriminant validity between the constructs, are shown in Table 6. In accordance with the aforementioned standards, it is anticipated that the average extracted variance (AVE) for every element will be larger than its correlation with other constructs. It is possible to draw the conclusion that all constructs meet the requirements for discriminant validity based on the obtained findings. This is shown by the reality that the mean variance abstracted (AVE) values surpass the associations with other constructs, confirming the constructs' uniqueness [45].

Table 6 Fornell Larker criteria results

Construct	DD	EM	ES	SG	PE	PM
Data-Driven Decision Making=DD	0.847					
Energy Management=EM	0.364	0.945				
Enhanced Security=ES	0.413	0.179	0.720			
Integration with Smart Grid & Devices=SG	0.331	0.213	0.207	0.798		
Personalized Experiences=PE	0.298	0.191	0.196	0.206	0.910	
Predictive Maintenance=PM	0.526	0.595	0.641	0.323	0.182	0.777

Table 7 shows data related to the assessment of discriminant validity between components through Heterotrait-Monotrait (HTMT). The table shows, for each pair of constructs, the HTMT values. It is predicted that the HTMT values should be below 1 to prove discriminant validity and to show that the investigated constructs are different. The findings indicate that all the values for HTMT are less than 1, and therefore, the constructs have excellent discriminant validity [35]. This would, therefore mean that Data-Driven Decision Making (DD), Energy Management (EM), Enhanced Security (ES), Integration with Smart Grid & Devices (SG), Personalized Experiences (PE), and Predictive Maintenance (PM) constructs bear distinct characteristics from one another within the model.

Table 7 HTMT statistics

Construct	DD	EM	ES	SG	PE	PM
Data-Driven Decision Making=DD						
Energy Management=EM	0.427					
Enhanced Security=ES	0.542	0.773				
Integration with Smart Grid & Devices=SG	0.412	0.255	0.294			
Personalized Experiences=PE	0.357	0.075	0.83	0.276		
Predictive Maintenance=PM	0.252	0.206	0.101	0.628	0.48	

The cross-loadings between the variables and constructs in the model are presented in Table 8. The constructs Data-Driven Decision Making (DD), Energy Management (EM), Enhanced Security (ES), Integration with Smart Grid & Devices (SG), Personalized Experiences (PE), and Predictive Maintenance (PM) are influenced by the variables IOT-EU14, IOT-EU19, IOT-EU5, IOT-EU1, IOT-EU3, IOT-EU9, IOT-EU10, IOT-EU6, IOT-EU11, IOT-EU13, IOT-EU7, IOT-EU17, IOT-EU20, IOT-EU2, and IOT-EU4 through cross-loading. The significance of the relationships between all the variables and the constructs is shown in the table. Higher numbers suggest a stronger association [41]. The cross-loadings observed in this study offer valuable insights into the individual contributions of each variable to the various constructs, thereby facilitating a more comprehensive comprehension of the associations within the conceptual model.

Table 8 Cross ladings

Variables	DD	EM	ES	SG	PE	PM
IOT-EU14	0.826	0.271	0.338	0.227	0.201	0.41
IOT-EU19	0.822	0.286	0.317	0.292	0.228	0.421
IOT-EU5	0.891	0.356	0.388	0.315	0.312	0.211
IOT-EU1	0.351	0.95	0.243	0.172	0.222	0.266
IOT-EU3	0.335	0.939	0.258	0.234	0.291	0.246
IOT-EU9	0.254	0.142	0.616	0.12	0.184	0.235
IOT-EU10	0.275	0.223	0.681	0.153	0.24	0.29
IOT-EU6	0.351	0.315	0.843	0.172	0.215	0.266
IOT-EU11	0.311	0.172	0.255	0.869	0.172	0.27
IOT-EU13	0.193	0.234	-0.004	0.654	0.234	0.176
IOT-EU7	0.268	0.223	0.153	0.852	0.213	0.3
IOT-EU17	0.351	0.195	0.243	0.172	0.922	0.266
IOT-EU20	0.18	0.269	0.59	0.205	0.897	0.239
IOT-EU2	0.291	0.356	0.388	0.315	0.312	0.711
IOT-EU4	0.18	0.269	0.59	0.205	0.297	0.839
DD= Data Driven Decision Making; EM=Energy Management; ES= Enhanced Security; SG= Integration with Smart Grid & Devices; PE=Personalized Experiences; PM= Predictive Maintenance						

2 Structure Path Analysis

The findings of the path analysis for each hypothesis are displayed in Table 9. The present study investigates the potential associations between the constructs of decision-making diversity (DD), emotional management (EM), ethical sensitivity (ES), social goals (SG), psychological empowerment (PE), and performance motivation (PM), and the outcome variable of IoT. The table presents the original sample values (O), sample mean values (M), standard deviations (STDEV), t-statistics, p-values, and the outcomes of each hypothesis. The t-statistics indicate the significance of the relationships under examination, whereas the p-values are utilized to ascertain whether the hypotheses are accepted or rejected [9]. Based on the obtained results, all hypotheses are deemed acceptable as the p-values are statistically significant (p=0), indicating that the constructs substantially influence the outcome variable, IoT. Figure 3 indicates the model with path coefficients and significance, while Figure 4 presents the path coefficients with t-statistics.

Table 9 Path analysis results

Hypothesis	Constructs	(O)	(M)	(STDEV)	T statistics	P values	Outcomes
H1	DD -> IOT	0.163	0.161	0.014	11.905	0	Accepted
H2	EM -> IOT	0.242	0.241	0.007	33.721	0	Accepted
H3	ES -> IOT	0.232	0.232	0.008	30.965	0	Accepted
H4	SG -> IOT	0.104	0.105	0.017	6.063	0	Accepted
H5	PE -> IOT	0.247	0.246	0.008	30.776	0	Accepted
H6	PM -> IOT	0.241	0.239	0.005	46.202	0	Accepted
DD= Data Driven Decision Making; EM=Energy Management; ES= Enhanced Security; SG= Integration with Smart Grid & Devices; PE=Personalized Experiences; PM= Predictive Maintenance (O)= Original sample; (M)=Sample mean; (STDEV) =Standard deviation							

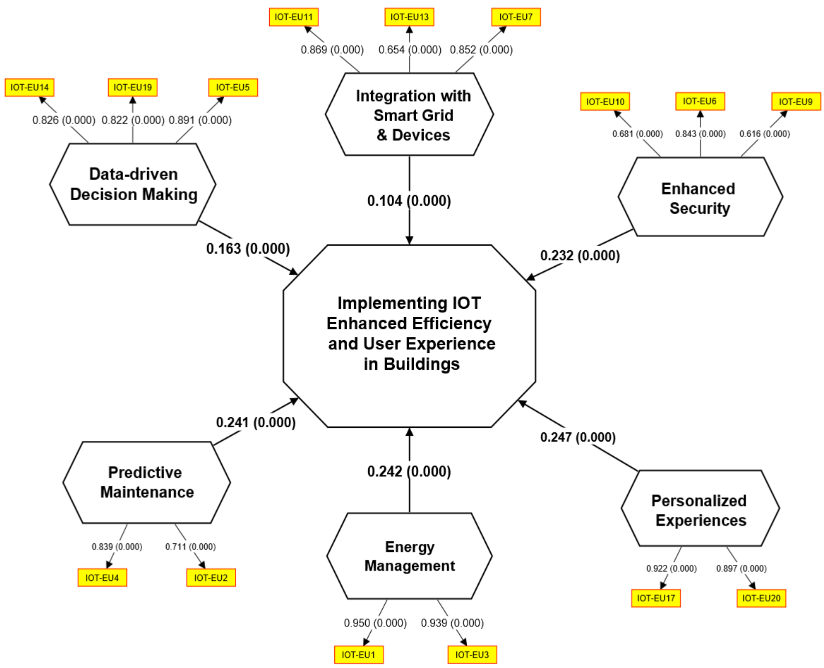

Figure 5 Model indicating path significance and path coefficients.

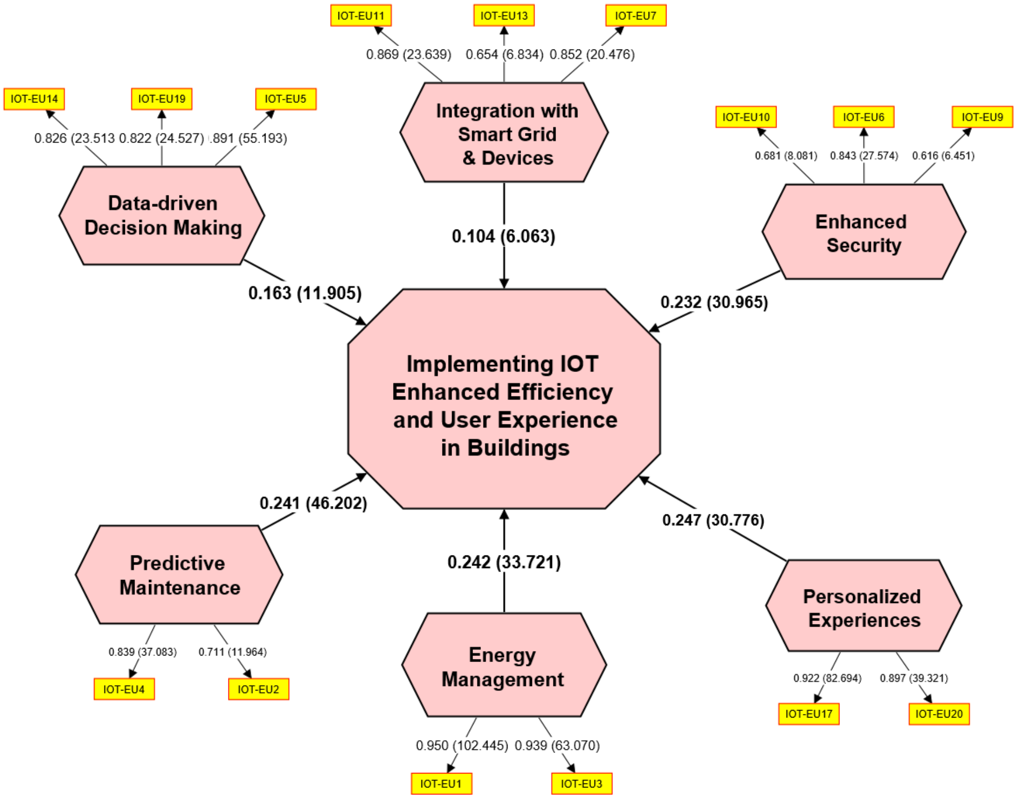

Figure 6 Model indicating path significance and t-statistics

The predictive relevance measures of the model are presented in Table 10. The table presents three key components: the Sum of Squares due to the Model (SSO), the Sum of Squares due to Error (SSE), and the predictive relevance measure Q^2. Q^2 is computed as the difference between 1 and the ratio of SSE to SSO. The predictive relevance measure Q^2 evaluates the model's capacity to predict and elucidate the dependent variable [41]. In this instance, the model utilized for implementing the IoT to improve efficiency and enhance the user experience within buildings exhibits a Q^2 value of 0.197. This value suggests that the model possesses a moderate level of predictive significance in elucidating the variability observed in the outcome variable [46].

Table 10 Model predictive relevance

Predictive Relevance	SSO	SSE	Q^2(=1-SSE/SSO)
Implementing IOT Enhanced Efficiency and User Experience in Buildings.	4320.000	3467.775	0.197

9. Discussion

The research findings offer empirical evidence in favor of the hypotheses pertaining to the utilization of IoT technology to improve operational effectiveness and user satisfaction within architectural structures.

H1: The hypothesis positing that the utilization of data-driven decision-making has a positive effect on implementing IoT technology, leading to improved efficiency and user experience in buildings, is corroborated. The results of the path analysis indicate a statistically significant and positive association between data-driven decision-making and the implementation of IoT technology ($t = 11.905$, $p < 0.001$). This discovery is consistent with prior research emphasizing the significance of utilizing data-driven decision-making to optimize building operations and enhance user experiences [47].

H2: The hypothesis proposing a positive relationship between energy management and the implementation of IoT is also corroborated. The results of the path analysis indicate a statistically significant and positive association between energy management and the adoption of IoT technology ($t = 33.721$, $p < 0.001$). This discovery aligns with previous studies highlighting the significance of energy management systems in utilizing IoT technologies to optimize energy usage and improve building efficiency [37].

H3: The study's findings support the hypothesis suggesting that increased security has a positive impact on the adoption of IoT. The results of the path analysis indicate a statistically significant positive association between increased security measures and the adoption of IoT technology ($t = 30.965$, $p < 0.001$). This observation is consistent with prior scholarly works that underscore the significance of implementing robust security protocols in IoT implementations to safeguard data and infrastructure [48].

H4: The hypothesis positing a positive relationship between integrating smart grids and devices and implementing IoT for high-rise buildings is confirmed. The results of the path analysis indicate a statistically significant and positive association between the level of integration with smart grid and devices and the implementation of the Internet of Things ($t = 6.063$, $p < 0.001$). This discovery further supports prior studies highlighting the advantages of incorporating IoT technologies into intelligent grid infrastructure to enhance energy management efficiency and optimize building operations [49].

H5: The hypothesis positing that the implementation of personalized experiences positively impacts the adoption of IoT in high-rise buildings is corroborated. The results of the path analysis indicate a statistically significant and positive association between personalized experiences and the adoption of IoT technology ($t = 30.776$, $p < 0.001$). This discovery aligns with previous research that emphasizes the significance of personalization in augmenting user satisfaction and engagement within intelligent building environments [13].

H6: The hypothesis positing a positive relationship between predictive maintenance and the implementation of IoT in high-rise buildings is corroborated. The results of the path analysis indicate a statistically significant and positive association between the utilization of predictive maintenance and the adoption of IoT technology ($t = 46.202$, $p < 0.001$). This discovery is consistent with prior studies highlighting the advantages of utilizing IoT technologies for predictive maintenance, which ultimately enhances building performance and decreases maintenance expenses [17].

These six hypotheses set during this research correspond not only to the literature but also bear important practical implications for engineering practice in implementing the IoT in buildings. In order to make this present analysis even more lucid and, therefore, useful for actionable insights to inform practice, there is a need to explain how each hypothesis applies to concrete recommendations for realization within an engineering entity. To expound, for instance, H1 on data-driven decision-making, engineering entities could make optimum strategy development concerning building operations like HVAC and lighting through predictive maintenance based on real-time analytics of data from IoT-generated data. This brings in H2 on energy management; it postulates that an integration of IoT with an energy management system ensures better resource utilization, consumption of energy, and operation cost optimization. Smart Energy Monitoring can be engaged to track and analyze energy consumption patterns in real-time. Engineering entities should always go for proactive implementation and measures that would lead to optimization in energy matters. On the contrary, H3 Enhanced Security refers to the implementation of a robust cybersecurity policy to integrate IoT devices with developed security systems for protection of infrastructure of buildings from probable cyber threats and unauthorized access. H4 smart grid integration and devices are necessary to upgrade energy management practices through dynamic load balancing and demand response mechanisms that enhance grid stability and resilience. According to H5, in a building automation system, the personal experience is crucial where the services will be tailor-made and suit each user's needs, therefore raising the level of use satisfaction and comfort. H6: Predictive Maintenance-once there is proactive monitoring and maintenance of the building equipment through IoT-enabled predictive analytics, which reduces downtime while optimizing asset performance. In addition, formulating the implementation strategies while studying the feasibility and effectively integrating all the stakeholders can help to seamlessly embed in the systems the IoT technologies. Moreover, IoT deployments need continuous monitoring and evaluation for iterative working out of the performance of the system and resolution of emerging challenges. Embedding these recommendations and guidelines on analysis allows engineering entities to exploit all the potential from IoT technology to maximum efficiency in building and user experience, ensuring a sustainable intelligent built environment. Cumulatively, these findings represent more significant additions to the accrued knowledge in this area of empirical evidence on the accrued positive impact of data-driven decision-making, energy management, enhanced security, integration with the smart grid and devices, personalization, and predictive maintenance in the implementation of IoT in buildings to enhance efficiency through effective user experience. The results from this present study confirm and extend the previous research into this subject area, highlighting the unique contribution that the high-rise building setting offers to the industry of construction.

10. Conclusion and Limitations

This study investigated those variables that could best describe the successful implementation of IoT technology in enhancing efficiency and improving users' satisfaction in buildings within the construction industry. It was observed from this study that the drivers of successful implementation of IoT technologies in buildings include data-driven decision-making, effective energy management, enhanced security, ease of integration with smart grids and devices, customized user experience, and proactive and predictive maintenance. Results of this research contribute significantly to the existing body of research by providing insightful information about several elements affecting successful use of IoT technology in a tall building setting.

10.1 Conclusion

The conclusions of the study have serious management implications, since such elements elevate building operations-if integrated-in the line of energy efficiency, strengthening of security, offering personalized services, and enhancement of preventive maintenance. Building managers can enhance the efficiency of the usability in buildings by infusing technology of the IoT and implementing tactics that correspond with such aspects. The limitations of this study must, therefore, be conceded: the context-specific effects of the findings and reliance on self-reported data. Inter-relationships and possible moderating or mediating effects among the components found should be studied in future research to transcend these limitations. This study considerably furthers the knowledge base on IoT use in buildings. This chapter provides useful information to managers in the building sector who can use IoT technology to improve efficiency and enhance user experience.

10.2 Limitations of Study

While this study has been useful for gaining insight into the successful implementation of IoT technology in buildings within a construction sector framework, there are some limitations that need to be considered as influencing generalization and robustness in the findings. These are a sample size based on a particular sampling from respondents in the construction industry. While efforts had been made to ensure the sample was representative, findings might therefore not be fully generalizable either to other geographic regions or sectors within the construction industry. The findings also rely heavily on self-reported data through questionnaires, and as such, the responses may well introduce biases and inaccuracies into the data, with an associated consequence for result validity. Furthermore, while the mixed-methods approach adopted for this study allowed an investigation into both depth and breadth of factors underpinning the implementation of IoT, there might have been other original variables/perspectives not aspired to. These limitations in the present study can be further addressed in future research with larger and more diversified samples, objective measures of IoT implementation success, and with alternative research approaches.

Further, based on the findings and implications of this research study, future directions of research could be drawn. First, the possible long-term effects of this IoT technology on building performance and user satisfaction might point to valuable information about problems of sustainability and scalability concerning IoT deployments in construction. Further, the study of how the IoT interacts with other emerging technologies, such as AI and blockchain, can unlock even more significant possibilities to make buildings more resilient and efficient. Further, considering the socio-economic and cultural drivers for the ultimate adoption and acceptance of IoT technologies in different contexts may further enrich such complex dynamics. Lastly, the analysis of regulatory frameworks and standards influencing IoT diffusion in buildings may provide policies for best practices to industries. Given the limitations of this review and the identified gaps in research, further contributions could be undertaken in this developing body of knowledge on IoT in construction and innovation in building design and management practices.

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