

**LIFECYCLE FRAMEWORK FOR THE
OPTIMAL OPERATION AND MAINTENANCE
COST OF IOT - BASED SMART OFFICE
BUILDINGS**

BY

Abdulwahab Saad A. AlQanas

A Thesis Presented to the
COLLEGE OF GRADUATE AND INTERDISCIPLINARY STUDIES
KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

ARCHITECTURAL ENGINEERING

May 2025

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DHAHRAN- 31261, SAUDI ARABIA
DEANSHIP OF GRADUATE INTERDISCIPLINARY STUDIES

This thesis, written by **Abdulwahab Saad A. Alqanas** under the direction of his thesis advisor and approved by his thesis committee, has been presented and accepted by the Deanship of Graduate & Interdisciplinary Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN ARCHITECTURAL ENGINEERING**.



Dr. Laith Alhadidi |
Department Chairman



Dr. Suliman Alhomidan
Dean of Deanship of Graduate &
Interdisciplinary Studies



Dr. Mohammad A. Hassanain
(Advisor)



Dr. Adel Alshibani |
(Member)



Dr. Djmal Ouis |
(Member)

Date



© Abdulwahab Saad Alqanas

2025

To my **Parents, Siblings, S.**

TABLE OF CONTENTS

Table Of Contents	V
List Of Tables	XIV
List Of Figures.....	XVI
List Of Abbreviations	XVII
Acknowledgment.....	XVIIi
Abstract.....	XIX
ملخص الرسالة.....	XX
Chapter 1 Introduction.....	1
1.1 Overview	1
1.2 Background	1
1.3 Statement Of The Problem.....	5
1.4 Research Goals.....	7
1.5 Research Objectives	7
1.6 Scope And Limitations.....	8
1.6.1 The Formulation Of The Scope And Limitation	8
1.6.2 Scope Of The Research.....	9
1.6.3 Limitation Of The Research	12
1.7 Research Significance.....	13
1.8 Research Methodology.....	14
1.9 Organization Of Thesis.....	15

Chapter 2 Literature Review	18
2.1 Overview	18
2.2 Lifecycle Of Building Projects	18
2.2.1 The Planning Phase.....	20
2.2.2 Design And Engineering Phase.....	21
2.2.3 Construction And Execution Phase.....	22
2.2.4 Operation And Maintenance (O&M) Phase.....	22
2.3 The Concept Of Smart Office Buildings.....	23
2.3.1 Characteristics Of Traditional And Smart Buildings In Terms Of O&M....	25
2.4 Overview Of Iot And Its Applications In The Context Of The Built Environment.....	27
2.5 Components And Applications Of Iot In Smart Office Buildings.....	29
2.5.1 Drivers For Utilizing Iot-Based Technologies In Smart Office Buildings.....	30
2.5.2 Driver's Generation Methodology.....	32
2.6 The Practices Of Building O&M.....	35
2.6.1 Avenues Through Which Iot-Based Technologies Could Impact The O&M Cost Of Smart Office Buildings	36
2.7 Challenges And Complexities Associated With O&M In Smart Office Buildings.....	45
2.8 Previous Studies On The Utilization Of Iot-Based Technologies In The O&M Phases	46

2.8.1 Introduction To Iot.....	47
2.8.2 Smart Buildings And Their Benefits	49
2.8.3 Iot Applications In Smart Offices.....	50
2.8.4 Building Automation And Control	52
2.8.5 Integration With Other Technologies	54
 Chapter 3 Adoption Of Iot-Based Technologies In Smart Office Building Operations And Maintenance	56
3.1 Overview	56
3.2 Impact Of Adopting Iot Based Technologies On The O&M Cost Of Smart Office Buildings.....	57
3.2.1 Hvac Systems.....	57
3.2.2 Fire Detection & Alarm Systems	59
3.2.3 Security & Access Control Systems Iot Technology	60
3.2.4 Indoor Air Quality Systems	62
3.2.5 Lighting Systems	64
3.2.6 Water Management Systems	65
3.2.7 Maintenance Management & Services.....	67
3.2.8 Waste Management Systems.....	69
3.2.9 Space Utilization And Optimization Services.....	71

3.3 Motives & Drivers Of Adopting Iot Based Technologies On The O&M Cost Of Smart Office Buildings.....	73
3.3.1 Enhancing Energy Efficiency In Smart Office Buildings Through Iot-Driven Real-Time Monitoring And Control.....	73
3.3.2 Maximizing Operational Efficiency Through Iot-Enabled Predictive Maintenance In Smart Buildings	74
3.3.3 Elevating Occupant Comfort And Productivity Through Iot Technologies In Smart Office Buildings.....	74
3.3.4 Strengthening Security And Safety In Smart Office Buildings Through Iot-Based Technologies	75
3.3.5 Optimizing Space Utilization And Efficiency In Smart Offices Through Iot Solutions	75
3.3.6 Achieving Cost Reduction In Smart Buildings Through Iot-Driven Automation And Data-Driven Insights	76
3.3.7 Advancing Sustainability And Green Building Initiatives Through Iot Systems In Smart Office Buildings:	76
3.3.8 Enabling Data-Driven Decision Making For Enhanced Building Performance And Efficiency Through Iot In Smart Offices:.....	77
3.3.9 Enhancing User Experience In Smart Office Buildings Through Iot-Driven Personalization And Automation:	77

3.3.10 Increasing Flexibility And Responsiveness In Building Management Through Iot-Enabled Remote Monitoring And Control:	78
3.4 Challenges Of Adopting Iot Based Technologies On The O&M Cost Of Smart Office Buildings	78
3.4.1 Complexity In Installation And Integration	79
3.4.2 Data Security And Privacy Concerns	79
3.4.3 High Initial Investment	79
3.4.4 Maintenance And Technological Expertise	80
3.4.5 Data Overload And Management	80
3.4.6 Cybersecurity Threats	80
3.4.7 Reliability Of Iot Networks	81
3.4.8 Environmental Impact And Sustainability Concerns	81
3.4.9 Interference With Building Legacy Systems	81
3.4.10 High Energy Consumption Of Iot Devices	82
3.5 Factors Affecting The Adopting Iot Based Technologies On The O&M Cost Of Smart Office Buildings	82
3.5.1 Planning Phase: Setting The Foundation For Iot Adoption	84
3.5.2 Design Phase: Ensuring System Efficiency And Sustainability	88
3.5.3 Construction Phase: Implementing Iot Infrastructure	90
3.5.4 O&M Phase: Sustaining And Optimizing Performance	94

Chapter 4 Data Analysis And Results.....	98
4.1 Overview	98
4.2 Respondents' Demographic Information	98
4.2.1 Respondents' Scope Of Work (Field Of Work).....	99
4.2.2 Respondents' Years Of Experience	100
4.2.3 Number Of Smart Buildings' Projects Which Respondents Were Involved.....	105
4.3 Data Analysis Approaches.....	110
4.3.1 Data Analysis Methodology – Cronbach's Alpha.....	111
4.3.2 Data Analysis Methodology – Standard Deviation	112
4.3.3 Data Analysis Methodology – Relative Important Index	112
4.4 Assessment Of Drivers For Iot Adoption In Smart Building O&M	113
4.4.1 Assessment Of The Drivers From The A/Es' Perspective.....	115
4.4.2 Assessment Of The Drivers From The Developers' / Owners' Perspective	118
4.4.3 Assessment Of The Drivers From The Fms' Perspective.....	120
4.4.4 Assessment Of The Drivers From The Iots' Perspective	122
4.5 Assessment Of The Challenges In Iot-Based Smart Office Building O&M	124
4.5.1 Assessment Of The Challenges From The A/Es' Perspective	125
4.5.2 Assessment Of The Challenges From The Developers' Perspective	127
4.5.3 Assessment Of The Challenges From The Fms' Perspective	129
4.5.4 Assessment Of The Challenges From The Iots' Perspective	131

4.6	Assessment Of The Factors Affecting O&M Costs In Iot-Based Buildings ..	134
4.6.1	Assessment Of The Factors From The A/Es' Perspective.....	135
4.6.2	Assessment Of The Factors From The Developers' / Owners' Perspective..	138
4.6.3	Assessment Of The Factors From The Fms' Perspective.....	141
4.6.4	Assessment Of The Factors From The Iots' Perspective.....	143
4.7	Discussion Of Survey Findings And Key Insights	145
4.7.1	Common Priorities Across Professional Groups	146
4.7.2	Diverging Perspectives On Drivers	146
4.7.3	Challenges To Iot Adoption	147
4.7.4	Influential Factors Affecting O&M Costs	148
4.7.5	Implications For Industry Practice	149
4.7.6	Summary Of Key Insights	149
4.8	Summary Of The Data Analysis	152
Chapter 5	Development Of Lifecycle Freamwork.....	154
5.1	Overview	154
5.2	Logic And Basis For Framework Development.....	155
5.2.1	Motivation Based On Key Drivers	156
5.2.2	Justification Based On Identified Challenges	156
5.2.3	Influence Of Contextual And Organizational Factors	157
5.2.4	Need For A Task-Based Lifecycle Approach	157

5.3 Framework Development Approach	158
5.4 Proposed Framework For Iot-Based Smart Office O&M Optimization	160
5.5 Description Of Framework Components.....	162
5.5.1 Planning Phase.....	163
5.5.2 Designing Phase.....	164
5.5.3 Construction Phase	164
5.5.4 Operation And Maintenance Phase	165
5.5.5 Stakeholder Integration In The Iot Implementation Lifecycle	166
5.6 Validation And Applicability.....	168
5.7 Validation Results.....	173
5.7.1 Derivation Of Tasks From Research Dimensions	175
5.7.2 Balancing Competing Priorities.....	175
5.7.3 Framework Resolution Of Competing Priorities.....	176
5.7.4 Example Applied: Hvac Optimization	177
5.8 Linking Drivers, Challenges, And Factors To The Lifecycle Framework	178
5.9 Summary.....	181
 Chapter 6 Conclusion And Recommendations	 183
6.1 Overview	183
6.2 Summary Of Key Findings.....	183
6.3 Contribution To Knowledge	185

6.4 Recommendations For Stakeholders.....	187
6.5 Research Limitations.....	188
6.6 Suggestions For Future Research.....	189
References.....	192
Appendix A.....	233
Appendix B.....	233
Appendix C.....	233
Appendix D.....	233
Vitae	249

LIST OF TABLES

Table 1	Development of Research Methodology through Its Phases	15
Table 2	Summary of Literature Review Studies for Driver by Year.....	99
Table 3	Respondents' Years of Experience Distribution.....	112
Table 4	Cronbach's Alpha Reliability Results for Survey Data	113
Table 5	Standard Deviation Values for Survey Data	114
Table 6	Assessment of Drivers	116
Table 7	Assessment of Drivers from A/Es' Perspective.....	119
Table 8	Assessment of Drivers from Developers'/Owners' Perspective	121
Table 9	Assessment of Drivers from FMs' Perspective	123
Table 10	Assessment of Drivers from IoT Professionals' Perspective	125
Table 11	Assessment of Challenges	126
Table 12	Assessment of Challenges from A/Es' Perspective.....	128
Table 13	Assessment of Challenges from Developers'/Owners' Perspective.....	130
Table 14	Assessment of Challenges from FMs' Perspective	132
Table 15	Assessment of Challenges from IoT Professionals' Perspective	135
Table 16	Factors Affecting O&M Costs.....	136
Table 17	Factors Affecting O&M Costs from A/Es' Perspective	139
Table 18	Factors Affecting O&M Costs from Developers'/Owners' Perspective ...	142
Table 19	Factors Affecting O&M Costs from FMs' Perspective.....	144
Table 20	Factors Affecting O&M Costs from IoT Professionals' Perspective.....	168

Table 21 Stakeholder-Specific Responsibilities Across Project Phases	169
Table 22 Respondents Demographics	171
Table 23 Applicability Ratings of Proposed Framework by Stakeholder Group...	187
Table 24 Framework relational logic	187
Table 25 Summary of Key Challenges Identified by Stakeholders.....	187

LIST OF FIGURES

Figure 1	Conventional Lifecycle of Building Projects	20
Figure 2	Characteristics of Smart and Traditional Buildings in Terms of O&M..	27
Figure 3	Categorization of Drivers for IoT Adoption	32
Figure 4	Filtration Process of Literature Review for Driver Identification.....	34
Figure 5	Respondents' Field of Work Distribution	100
Figure 6	Years of Experiences Respondents Involved In (A/Es).....	101
Figure 7	Years of Experiences Respondents Involved In (Developers/Owners)...	102
Figure 8	Years of Experiences Respondents Involved In (FMs)	103
Figure 9	Years of Experiences Respondents Involved In (IoT Professionals)	104
Figure 10	Number of Projects Respondents Involved In (A/Es)	106
Figure 11	Number of Projects Respondents Involved In (Developers/Owners)	107
Figure 12	Number of Projects Respondents Involved In (FMs).....	108
Figure 13	Number of Projects Respondents Involved In (IoT Professionals).....	110
Figure 14	Proposed Lifecycle Framework for IoT-Based Smart Office O&M	161
Figure 15	Stakeholder-Specific Responsibilities Across Project Phases.....	163
Figure 16	Stakeholder Integration and Interaction Diagram.....	166
Figure 17	Respondents' Field of Work Distribution	169
Figure 18	Framework logic	180

LIST OF ABBREVIATIONS

A/Es.....	Architects and Engineers
AEC.....	Architecture, Engineering, and Construction
BAS.....	Building Automation System
BMS.....	Building Management System
BIM.....	Building Information Modeling
CMMS.....	Computerized Maintenance Management System
DSM.....	Demand-Side Management
EMS.....	Energy Management System
FAQ.....	Frequently Asked Questions
FM.....	Facility Management / Facility Manager
HVAC.....	Heating, Ventilation, and Air Conditioning
IAQ.....	Indoor Air Quality
ICT.....	Information and Communication Technology
IoT.....	Internet of Things
KPI.....	Key Performance Indicator
LCC.....	Life Cycle Cost
O&M.....	Operation and Maintenance
RII.....	Relative Importance Index
SD.....	Standard Deviation
SOP.....	Standard Operating Procedure
QOL.....	Quality of Life

Acknowledgement

I would like to express my deepest gratitude to “Allah” (Subhānahu wa Ta‘ālā) for granting me the strength, patience, and perseverance to complete this thesis.

My sincere appreciation goes to my academic advisors, for their valuable guidance, insightful feedback, and continuous encouragement throughout the course of this research. Their expertise and mentorship have significantly contributed to the development and completion of this work.

I am also grateful to the faculty members and staff of the Department of Architectural Engineering and Construction Management at King Fahd University of Petroleum and Minerals (KFUPM) for their support and assistance during my academic journey.

Special thanks to all industry professionals and stakeholders including Architects/Engineers, Developers/Owners, Facilities Managers, and IoT specialists who participated in the survey and validation process. Their contributions were essential to the depth and credibility of this research.

I would also like to thank my colleagues and friends for their moral support and motivation, especially during challenging times.

Lastly, I dedicate this work to my beloved family, especially my parents, siblings and Sara, for their endless love, prayers, and unwavering support. This accomplishment would not have been possible without their presence in my life.

ABSTRACT

Full Name : Abdulwahab Saad A. Alqanas
Thesis Title : Lifecycle Framework for the Optimal Operation and Maintenance Cost of IoT-Based Smart Office Buildings
Major Field : Architectural Engineering
Date of Degree : May 2025

The increasing integration of Internet of Things (IoT) technologies into smart office buildings presents significant opportunities for enhancing operational efficiency, sustainability, and cost optimization, particularly in alignment with Saudi Arabia's Vision 2030. However, challenges persist in systematically adopting these technologies during the operation and maintenance (O&M) phase. This research addresses the gap by developing a comprehensive lifecycle framework tailored to optimizing O&M costs in IoT-enabled smart office buildings in Saudi Arabia. The research adopted a mixed-method approach, combining an extensive literature review with survey-based assessments involving four stakeholder groups: architects and engineers (A/Es), developers/owners, facility managers (FMs), and IoT specialists. Key drivers, challenges, and influencing factors affecting IoT adoption were identified and analyzed using reliability testing, standard deviation, and Relative Importance Index (RII) methodologies. Subsequently, a structured lifecycle framework was proposed, outlining stakeholder-specific tasks across the planning, designing, construction, and O&M phases. The findings revealed that proactive IoT integration significantly reduces energy consumption, enhances predictive maintenance, and minimizes operational risks, thus achieving substantial O&M cost savings. The proposed lifecycle framework serves as a practical guide for AEC/FM professionals, facilitating more efficient smart building management, promoting sustainability, and supporting national development objectives.

ملخص الرسالة

الاسم الكامل: عبدالوهاب بن سعد بن عبدالوهاب القناص

عنوان الرسالة: إطار دورة الحياة لتحسين تكاليف التشغيل والصيانة في المباني المكتبية الذكية المعتمدة على تقنيات إنترنت الأشياء

التخصص: الهندسة المعمارية

تاريخ الدرجة العلمية: مايو ٢٠٢٥

يمثل دمج تقنيات إنترنت الأشياء (IoT) في المباني المكتبية الذكية فرصة كبيرة لتعزيز الكفاءة التشغيلية والاستدامة وتحسين التكاليف، خاصة بما يتماشى مع أهداف رؤية المملكة العربية السعودية ٢٠٣٠. ومع ذلك، لا تزال هناك تحديات تواجه التطبيق المنهجي لهذه التقنيات خلال مرحلة التشغيل والصيانة. تهدف هذه الرسالة إلى معالجة هذا القصور من خلال تطوير إطار دورة حياة شامل لتحسين تكاليف التشغيل والصيانة في المباني المكتبية الذكية المعتمدة على تقنيات إنترنت الأشياء بالمملكة العربية السعودية. اعتمد البحث على منهجية مزدوجة جمعت بين مراجعة موسعة للأدبيات وتحليل استبيانات ميدانية استهدفت أربع فئات مهنية رئيسية: الممارسين والمهندسين، المطورين/المالكين، مديري المرافق، وأخصائيي تقنيات إنترنت الأشياء. تم تحديد وتحليل المحركات والتحديات والعوامل المؤثرة في تبني تقنيات إنترنت الأشياء باستخدام اختبارات الموثوقية والانحراف المعياري ومؤشر الأهمية النسبية (RII). بناءً على النتائج، تم تطوير إطار دورة حياة منظم يحدد المهام الرئيسية لكل مرحلة من مراحل المشروع: التخطيط، التصميم، التنفيذ، والتشغيل والصيانة. أظهرت النتائج أن اعتماد تقنيات إنترنت الأشياء بشكل استباقي يؤدي إلى خفض كبير في استهلاك الطاقة، وتعزيز الصيانة التنبؤية، وتقليل المخاطر التشغيلية، مما يحقق وفورات ملحوظة في تكاليف التشغيل والصيانة. ويمثل الإطار المقترح دليلاً عملياً للمتخصصين في العمارة والهندسة وإدارة المرافق، مما يساهم في إدارة أكثر كفاءة للمباني الذكية، ودعم أهداف التنمية الوطنية.

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter encompasses an exploration of the background, problem statement, research goals and objectives, scope, and constraints, as well as the significance of the research. Furthermore, it outlines the research approach used in this thesis. The chapter concludes by explaining the structure and organization of the thesis.

1.2 Background

In Saudi Arabia's ambitious 2030 vision, the emergence of smart buildings stands as a pivotal trend, underlining the nation's commitment to technological innovation, sustainability, and urban advancement (Nurunnabi et al., 2017). Vision 2030, smart buildings have gained prominence as a cornerstone of the nation's future. This visionary blueprint envisions a diversified economy, reduced reliance on oil, and improved quality of life for its citizens (Alamoudi et al., 2023). Smart buildings, equipped with cutting-edge technologies such as internet of things (IoT) sensors, energy-efficient systems, and advanced automation, represent an integral component of this strategy (Amran et al., 2020). They not only enhance the efficiency and comfort of urban living but also contribute to environmental sustainability and energy conservation, aligning perfectly with the goals outlined in Vision 2030. As the Kingdom endeavors to redefine its cities and infrastructure

for the future, the trend of smart buildings embodies Saudi Arabia's commitment to a progressive, interconnected, and sustainable future (Allmnakrah et al., 2020).

In the context of Saudi Arabia's visionary 2030 agenda, the integration of IoT has emerged as a transformative trend in the journey towards smart buildings (Moshashai et al., 2020).

As outlined in Vision 2030, the Kingdom has embarked on a comprehensive path of modernization and diversification, with a particular focus on technology-driven solutions. IoT characterized by the interconnectedness of devices and systems through the internet, plays a pivotal role in this evolution. Referencing the Vision 2030 document itself, IoT is recognized as a fundamental enabler of smart cities and buildings, fostering efficiency, sustainability, and enhanced quality of life (Al Anezi et al., 2021). Data analytics, and automation, IoT empowers buildings to optimize resource usage, improve security, and offer innovative services to residents. This trend signifies Saudi Arabia's commitment to harnessing cutting-edge technology for urban development, aligning seamlessly with the nation's broader aspirations for a more dynamic and interconnected future (Qaffas et al., 2021).

Optimizing the lifecycle of assets has been a persistent concern spanning several decades. It is evident that a well-maintained asset yields greater returns for businesses (Toosi et al., 2023). The implementation of smarter design practices can result in enhanced operational efficiency. Similarly, improved operation and maintenance (O&M) practices contribute to reduced replacement costs and may serve as a foundation for superior design initiatives

(Wilkinson et al., 2014). In response to this trend, the design, construction, and O&M phases have witnessed an increase in the adoption of various methods and tools for engineering asset management. Emphasizing the importance of considering the entire lifecycle of a facility, asset management underscores its pivotal role (Communications and Technology Information Commission. 2021). This marks a departure from the traditional approach, where enhancements in design, construction, and O&M phases were managed separately. Engineering facility management emerges as an interdisciplinary field encompassing research areas such as life cycle costing, maintenance and reliability, risk assessment, and change management (Remøy, 2010). Contrary to perceiving facilities merely as owned entities requiring maintenance, facilities management adopts a lifecycle approach, which covers the organization's activities that are aimed at achieving its goals (Almontshery et al., 2019). In the context of the lifecycle perspective, effective management of the facility lifecycle becomes integral to the operational success of the organization.

Smart buildings are structures that are equipped with intelligent systems for energy efficiency, comfort, and convenience. These systems use sensors, controllers, and software to monitor and control the environment inside the building. They can monitor the environment and adjust it to suit the needs of the occupants (Qaffas et al., 2021). Smart buildings are also equipped with security systems and other features to ensure the safety and comfort of the occupants. Smart buildings are becoming increasingly popular, as they offer several advantages over traditional buildings. Apart from the fact that they save

energy and funds, they also offer greater levels of comfort and convenience (Alam et al., 2021). Smart buildings are also more secure and can provide a better working environment for employees. Smart buildings are set to become even more popular in the future, due to their potential for improving operational efficiency, reducing costs, and enhancing their occupants' quality of life (QAL).

The SOT is a structure designed to redefine modern office experiences. This innovative building combines cutting-edge technology, environmental sustainability, and design elements to create a workspace that is both efficient and enjoyable (Au-Yong et al., 2013). The SOT is equipped with an array of features such as intelligent lighting and climate control systems that adjust automatically to suit individual user preferences. Moreover, the tower is designed with high-tech security features such as facial recognition systems, motion sensors, and automated locks to ensure a safe and secure working environment (Khabaz et al., 2018). With features such as video conferencing and wireless printing, the SOT provides modern office workers with a variety of options for efficient collaboration and communication. The SOT concept demonstrates how technology can be used to maximize efficiency, comfort, and sustainability in the workplace. This futuristic workspace redefines the traditional office experience and sets a new standard for modern business operations.

Building O&M is an important aspect of ensuring the safety and comfort of occupants in any type of building. Proper O&M of a building can help to extend its lifespan, improve

its energy efficiency, and reduce the advent of costly repairs (AlGhamdi et al., 2022). Building O&M involves a variety of activities, such as regular inspections and preventive maintenance, energy management, and tenant relations (Alshehri et al., 2015). Regular inspections help to identify any safety hazards or damage that need to be addressed, while preventive maintenance ensures that all essential components of the building are in good working order (Alshehri et al., 2015). Energy management helps the building to remain energy efficient and reduce energy costs. Also, tenant relations help to ensure that the building's occupants are comfortable and satisfied. Building O&M is an ongoing process. Thus, it is important for building owners and managers to ensure the safety, comfort, and satisfaction of the occupants (Agha et al., 2017).

1.3 Statement of the problem

While traditional office buildings typically rely on manual oversight and reactive maintenance, which often leads to higher and unforeseen O&M expenditures, smart office buildings incorporate the use of advanced systems, IoT sensors and data analytics to enable predictive and proactive maintenance. These technologies can detect issues in real-time, allowing for timely interventions and reducing downtime. Thus, these technologies provide for enhanced, and significant reduction of O&M cost in the long-term.

Vision 2030 places a strong emphasis on innovation and the development of a knowledge-based economy. In the context of the built environment domain, well-maintained office

buildings contribute to improved working conditions and overall well-being for their occupants, hence, it aligns with Vision 2030.

The implementation of IoT in smart buildings represents a transformative opportunity for the sustainable O&M of these built environment projects (Tanko et al., 2022). However, the extent and pace of IoT adoption in the O&M phase of smart office buildings in Saudi Arabia's remain unclear, due to several significant challenges (Dryjanski et al., 2020).

O&M cost of smart office buildings can be a significant burden on both owners and occupants (Weerasinghe et al., 2022). The review of literature revealed a lack of studies that investigate the impact of adopting smart technologies, based on IoT, on the O&M cost of smart office buildings.

Locally, there has been a lack of published case studies on the utilization of IoT-based technologies in smart buildings, through which practical knowledge can be acquired on the current practices. Hence, this research provides a strong potential to contribute into the body of knowledge through the drivers, challenges and factors that affect the utilization of IoT-based technologies to reduce the O&M cost in smart buildings.

This research seeks to answer the following research questions:

- What are the avenues through which IoT-based technologies could impact the O&M cost of smart office buildings?

- What are the drivers that prompt the utilization of IoT-based technologies in the O&M of smart office buildings, in Saudi Arabia?
- What are the challenges that affect the utilization of IoT-based technologies in the O&M of smart office buildings, in Saudi Arabia?
- What are the factors that affect the O&M cost of IoT-based smart office buildings, in Saudi Arabia?
- How could architectural, engineering, construction, and facilities management (AEC/FM) practitioners be guided towards reducing the O&M cost in smart office buildings, in Saudi Arabia?

1.4 Research Goals

The primary aim of this research is to develop a practical, task-based lifecycle framework that serves as a guide for Architecture, Engineering, and Construction/Facility Management (AEC/FM) professionals engaged in various phases of smart office building projects. These phases include conceptual planning, feasibility analysis, design and engineering, construction, and the operation and maintenance (O&M) stage. The goal is to provide actionable direction on how IoT-based technologies can be adopted effectively to reduce the O&M costs in the context of Saudi Arabia's built environment.

1.5 Research Objectives

The main objectives of the research are:

1. To investigate the avenues through which IoT-based technologies can influence the operation and maintenance costs of smart office buildings.
2. To identify and evaluate the potential of IoT-based technologies in the O&M phase of smart office buildings within Saudi Arabia.
3. To assess the primary drivers and key challenges that influence the adoption of IoT-based technologies in the O&M of smart office buildings across the Kingdom.
4. To determine and evaluate the factors that affect the O&M cost of IoT-enabled smart office buildings in Saudi Arabia.
5. To develop and validate a lifecycle framework that offers guidance for AEC/FM professionals in implementing strategies to reduce O&M costs in IoT-based smart office environments.

1.6 Scope and Limitations

The research will address the following buildings systems/services through which IoT-based technologies in smart buildings could impact the O&M cost of smart office building.

1.6.1 The formulation of the scope and limitation

The formulation of the research scope and its limitations is guided by anticipated focal points and practical constraints, as described below:

1. The research focuses on specific building systems and services through which IoT-based technologies are expected to impact the O&M costs of smart office buildings.

2. The evaluation of cost-influencing factors and data collected through professional interviews is limited to practitioners operating in the Eastern Province of Saudi Arabia.
3. The development of the O&M lifecycle framework is based on both international literature and insights from local practice and implementation.

1.6.2 Scope of the research

The main scope of the research is taken based on the early expectation of the focus points and are listed as follows:

1- HVAC Maintenance services:

The process of checking, cleaning, testing, and potentially repairing and replacing components in a heater or air conditioner (Ivanovic et al., 2023).

2- Fire Detection & Alarm systems:

A system designed to notify occupants when it detects smoke, fire, carbon monoxide, or other fire-related or general emergency notifications (ISO 7240-14:2013)

3- Security & Access control:

Access management covers the practice of selectively restricting access to a location or other resource (DURSUN et al., 2021)

4- Environmental control systems:

Systems employed to regulate the indoor thermal environment are considered technical or mechanical, utilizing energy to deliver heating, ventilation, and air conditioning (HVAC) (Alozie et al., 2014)

5- Lighting control & retrofit:

An intelligent network-based lighting control solution that uses one or more central computer units to communicate between different system inputs and outputs relevant to lighting control (Albreem et al., 2023).

6- Intrusion Detection:

A hardware or software program that keeps an eye on a network or system for malicious activities or policy breaches (Martellini et al., 2017).

7- Mechanical maintenance & retrofit:

Performing functional assessments and maintaining, repairing, or replacing essential devices, equipment, machinery, building infrastructure, and supporting utilities in industrial, commercial, and residential settings (EFNMS 2016).

8- Enterprise systems integration:

A sector within corporate architecture and engineering that focuses on areas like system connectivity, electronic data interchange, product data exchange, and distributed computing environments (Bi et al., 2014).

9- Smoke control systems:

A method used to keep a building's escape and access pathways clear of smoke, aid in firefighting efforts, and delay or avoid flashover, minimizing the danger that the fire may spread (FAQs 2021).

10- Indoor air quality services:

The air quality within and around buildings and structures is referred to as IAQ. It is also recognized to have an impact on the health, comfort, and well-being of building inhabitants (KMC Controls 2015).

11- Energy supply & load management:

The technique of balancing the supply of energy on the network with the electrical load by changing or managing the load rather than the power station output is known as demand-side management (DSM) (Ross et al., 2019).

12- Water management systems:

Water management is the process of planning, producing, distributing, and maximizing the use of water resources in accordance with established water policies and laws (Sarraf et al., 2020).

13- Energy information management:

Systems that its anode solutions for automating data from a BMS, BAS, or EMS, aggregating it, and using algorithms to extract actionable insights from the data (Elahee et al., 2019)

14- On-site technical service:

A group of workers that advise and support registered users with problems with their technological goods (Cambridge Dictionary 2021).

1.6.3 Limitations of the research

Key limitations anticipated in this research include:

1- Lack of the application of using the (IoT) technology locally:

The practical adoption of IoT technologies in Saudi Arabia's smart office sector remains in its early stages, restricting access to established benchmarks (Gillis et al., 2021).

2- Lack of Documented Case Studies:

The scarcity of comprehensive local case studies makes it difficult to extract real-world insights and validated outcomes that could support broader generalizations.

1.7 Research Significance

To ensure the optimal performance of office buildings, consistent and effective maintenance is essential. O&M expenditures represent a substantial portion of the total lifecycle cost, and these costs are rising due to various influencing factors. Predicting and managing these costs is a complex task, particularly for maintenance managers working in smart office environments.

The research seeks to address this gap by identifying, evaluating, and ranking the key elements that impact O&M costs in smart office buildings located in Saudi Arabia's Eastern Province. By uncovering and analyzing these elements, the research aims to offer the following practical contributions:

1. Assist facility and maintenance managers in estimating and forecasting annual maintenance budgets based on reliable, data-driven indicators.
2. Assist maintenance managers to identify major cost-driving components and adopt modern technologies that offer long-term savings and operational efficiency.

3. Assist maintenance managers in enabling more accurate planning and resource allocation, ensuring maintenance activities are aligned with building needs and performance goals.

1.8 Research Methodology

To achieve the stated objectives, the research methodology is organized into five interrelated phases. Each phase is aligned with a specific research goal and employs a combination of literature review, stakeholder input, and framework development. The phases are detailed below:

Objectives	Approaches of achieving the objectives
Phase 1: To explore the avenues through which IoT-based technologies could impact the O&M cost of smart office buildings.	An extensive review of the literature to identify the avenues through which IoT-based technologies could impact the O&M cost of smart office buildings.
Phase 2: To identify and assess the drivers prompting the utilization of IoT-based technologies in the O&M of smart office buildings, in Saudi Arabia.	An extensive review of the literature to identify the drivers prompting the utilization of IoT-based technologies in the O&M of smart office buildings. Subsequently, the drivers will be subjected to an assessment by a group of stakeholders involved in the design, installation and O&M of IoT-based smart office building projects in Saudi Arabia. These stakeholders include A/Es, facilities managers, IoT service providers and specialists, and real estate developers.
Phase 3: To identify and assess the challenges affecting the utilization of IoT-based technologies in the O&M of smart office buildings, in Saudi Arabia.	An extensive review of the literature to identify the challenges affecting the utilization of IoT-based technologies in the O&M of smart office buildings. Subsequently, the challenges will be subjected to an assessment by a group of stakeholders involved in the design, installation and O&M of IoT-based

	smart office building projects in Saudi Arabia. These stakeholders include A/Es, facilities managers, IoT service providers and specialists, and real estate developers.
Phase 4: To identify and assess the factors affecting the O&M cost of IoT-based smart office buildings, in Saudi Arabia	An extensive review of the literature to identify the factors affecting the O&M cost of IoT-based smart office buildings. Subsequently, the factors will be subjected to an assessment by a group of stakeholders involved in the design, installation and O&M of IoT-based smart office building projects in Saudi Arabia. These stakeholders include A/Es, facilities managers, IoT service providers and specialists, and real estate developers.
Phase 5: To develop and assess a lifecycle framework for guiding AEC/FM practitioners towards reducing the O&M cost in IoT-based smart office buildings, in Saudi Arabia.	The development of a set of recommendations to serve as guidelines based on the drivers, challenges and factors that were previously identified and assessed. This will be followed by the development of a lifecycle framework based on the guidelines to guide AEC/FM practitioners towards reducing the O&M cost in IoT-based smart office buildings. Further assessment of the framework will be made by a group of stakeholders involved in the design, installation and O&M of IoT-based smart office building projects in Saudi Arabia. These stakeholders include A/Es, facilities managers, IoT service providers and specialists, and real estate developers. The assessment mainly aims at ensuring the applicability, reliability, and comprehensiveness of the developed framework.

Table 1 Development of Research Methodology through Its Phases

1.9 Organization of The Thesis

The structure of the thesis follows a sequential flow that aligns with the research objectives and methodology. The content is divided into six main chapters, each serving a specific function in the overall narrative:

Chapter 1: Introduction

Establishes the research context, problem, goals, objectives, scope, limitations, significance, methodology, and organization.

Chapter 2: Literature Review

Explores the theoretical foundation of smart buildings, IoT applications, and O&M cost factors through critical engagement with prior literature.

Chapter 3: Adoption of IoT-Based Technologies in Smart Office Building O&M

Describes the practical application of IoT in reducing O&M costs, identifies drivers and challenges, and introduces influencing factors categorized across lifecycle stages.

Chapter 4: Survey-Based Analysis and Evaluation

Presents the demographic data of stakeholders, analyzes collected responses, and discusses findings using Cronbach's alpha, standard deviation, and Relative Importance Index (RII) techniques.

Chapter 5: Framework Development and Validation

Proposes a lifecycle-based implementation framework, detailing phase-specific tasks and stakeholder responsibilities. The framework is validated through targeted industry feedback.

Chapter 6: Conclusion and Recommendations

Summarizes the key findings, highlights contributions to knowledge, offers stakeholder-specific recommendations, and suggests areas for future research.

|

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter surveys the existing literature on the fundamentals, theoretical foundations, and prior investigations relevant to the context of smart office buildings. It builds upon the core topics introduced in Chapter 1, including the lifecycle management of buildings, the emergence of smart office concepts, and the operational strategies associated with IoT-based technologies. The research critically examines studies on the factors impacting O&M costs in smart buildings, offering a deeper understanding of how these elements influence project lifecycle outcomes. Furthermore, this chapter introduces a preliminary identification of the drivers, challenges, and influencing factors that affect O&M cost reduction strategies across the building lifecycle phases. Finally, the chapter concludes with a summary and discussion of key insights derived from the reviewed literature.

2.2 Lifecycle of Building Projects

Building project execution is recognized as one of the most complex processes in the built environment sector. To limit the emergence of unforeseen conflicts, the proper integration of all project lifecycle stages is essential (Muller et al., 2019). As emphasized in Chapter

1, understanding the lifecycle framework is fundamental to developing effective IoT-based O&M strategies, especially when targeting cost optimization objectives.

Several classifications of building project lifecycles have been proposed. A conventional classification describes the general pattern of construction project execution as involving project inception, execution or development, and completion phases (Heralova et al., 2017). More recent models, particularly those relevant to smart building projects, conceptualize the lifecycle as comprising four sequential phases: conceptual planning and feasibility studies, design and engineering, construction, and O&M (Vilches et al., 2017).

Throughout these phases, various stakeholders, including A/Es, clients, contractors, and project managers play critical roles in shaping project outcomes (Roberts et al., 2020). Their involvement reinforces the importance of early integration and collaborative decision-making, as emphasized in the planning methodologies outlined in Chapter 1. The figure below illustrates a standard model of the building lifecycle, providing a basis for understanding how IoT-based strategies can be systematically embedded to optimize performance and reduce O&M costs.

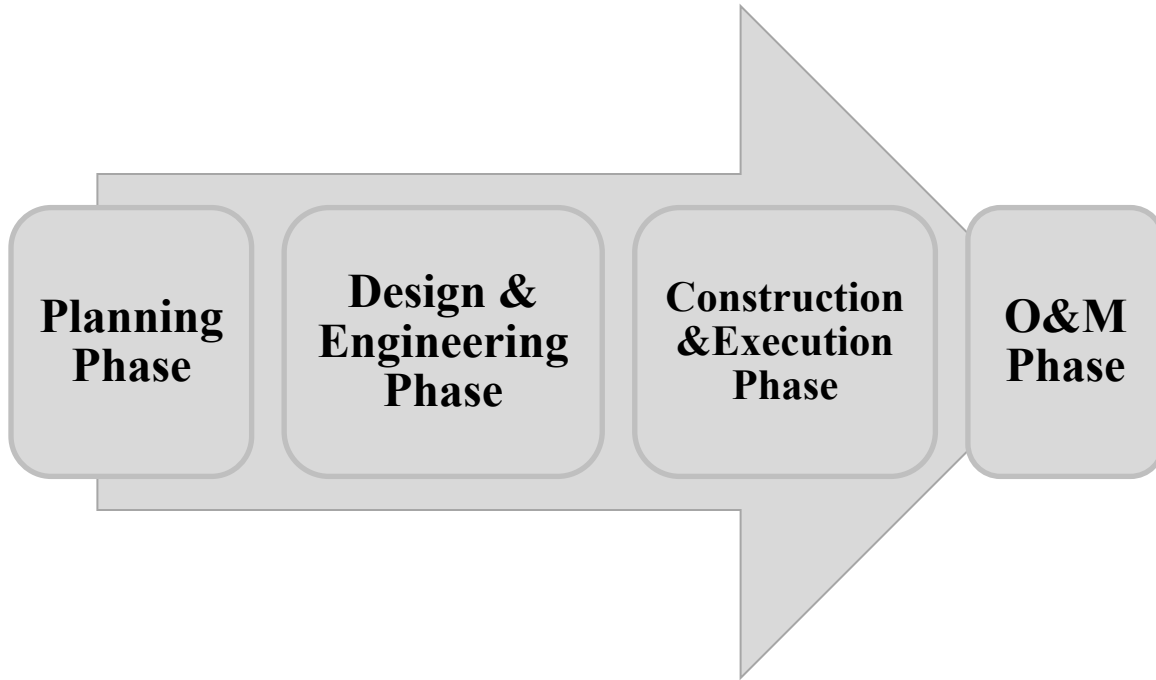


Figure 1 Conventional Lifecycle of Building Projects

2.2.1 The planning phase

The integration of IoT technologies into the early planning phase of building projects introduces transformative improvements to operational and lifecycle performance. As emphasized in Chapter 1, early engagement during planning is vital for setting the foundation for effective O&M cost reduction strategies. Research by Sleem et al. (2023) demonstrates that during the design and planning stages, IoT enables the integration of sensors, devices, and data analytics platforms. These tools optimize critical building systems, including HVAC, lighting, security, and energy management, from the project's inception. Strategic IoT deployment at this phase facilitates more accurate resource allocation, improved system control, and data-driven decision-making capabilities. Moreover, aligning early planning activities with IoT requirements ensures that smart

infrastructure foundations are embedded into project goals, reducing future retrofit costs and enhancing the building's long-term operational sustainability.

2.2.2 Design and Engineering Phase

The integration of IoT technology into the design and engineering phase represents a significant evolution in smart building development. As introduced in Chapter 1, achieving optimal O&M performance relies heavily on early design decisions that prioritize intelligent systems integration. During this phase, IoT technologies are strategically applied to enhance the configuration, sizing, and optimization of building systems, including HVAC, lighting, security, and energy platforms (Rajab et al., 2018; Jia et al., 2019). Real-time feedback from IoT-connected sensors enables engineers to tailor system specifications more precisely, thereby reducing waste and minimizing long-term operational inefficiencies. This proactive design approach promotes energy efficiency, sustainability, and cost-effectiveness by ensuring that each system component is optimized for peak performance from the outset. Furthermore, IoT integration at this stage supports predictive maintenance strategies later in the lifecycle, enabling buildings to transition seamlessly into intelligent operational management. Thus, the decisions made during the design and engineering phase play a pivotal role in fulfilling the research's broader objective of enabling lifecycle cost optimization through IoT-based smart office infrastructure.

2.2.3 Construction and Execution Phase

The incorporation of IoT technologies during the construction and execution phase represents a critical advancement in smart building development. Building upon the lifecycle foundations outlined in Chapter 1, this phase is not limited to physical construction activities but extends to the integration of systems that enable long-term operational efficiency. Research by Le et al. (2019) indicates that IoT devices and sensors are increasingly employed during construction to monitor progress, ensure quality control, and enhance on-site safety. Real-time data collection enables project managers to optimize workflows, detect issues early, and make informed decisions, thereby reducing delays and minimizing costly rework. Moreover, the influence of IoT continues after construction completion. IoT-powered BMS enable remote monitoring, predictive maintenance, and energy optimization from the first day of occupancy (Jia et al., 2019). These capabilities directly support the research's goal of embedding operational intelligence into buildings to achieve cost-effective O&M practices. Therefore, IoT integration during construction ensures not only the physical completion of the project but also establishes the infrastructure necessary for sustainable and cost-efficient operations throughout the building's lifecycle.

2.2.4 Operation and Maintenance (O&M) Phase

The O&M phase is where the full benefits of early IoT integration are realized. As highlighted in Chapter 1, O&M costs represent a significant portion of a building's total

lifecycle expenses, making cost optimization at this stage a critical priority for AEC/FM professionals. According to Mehmood et al. (2017), IoT devices embedded within the building infrastructure enable real-time monitoring, advanced analytics, and the automation of critical building systems, including HVAC, lighting, security, and energy management. This dynamic capability allows facility managers to proactively manage resources, identify inefficiencies, and implement corrective actions with precision. Predictive maintenance, powered by IoT, further enhances operational efficiency by detecting equipment anomalies early, thus preventing costly failures and prolonging asset life (Jia et al., 2019). In addition, IoT-driven security systems offer continuous monitoring and rapid response to potential threats, further reducing operational risks (Elrawy et al., 2018). Moreover, the continuous data flow from IoT systems supports strategic decision-making, enabling facilities to dynamically adapt their operations to evolving occupancy patterns, energy demands, and maintenance needs and by adopting a lifecycle perspective centered on IoT integration, the research advances the proposition that smart buildings can achieve substantial and sustainable reductions in O&M costs across their lifespan.

2.3 The Concept of Smart Office Buildings

The concept of smart office buildings represents a significant evolution in contemporary workplace design and facility management. Building upon the context outlined in Chapter 1 regarding Saudi Arabia's Vision 2030 and the emergence of smart infrastructure, the integration of intelligent systems into office environments is reshaping the way

organizations manage space, energy, and occupant well-being. Smart office buildings combine IoT technologies, automation, and advanced analytics to create workspaces that are highly adaptive, efficient, and user-centered (Minoli et al., 2017). Sensors, controllers, and networked platforms are employed to monitor lighting, HVAC systems, indoor air quality, and occupancy patterns in real-time, enabling dynamic optimization of building conditions. Furthermore, smart offices offer significant advantages over traditional workplaces. IoT-enabled lighting and HVAC systems adjust automatically to occupancy and environmental conditions, improving energy efficiency while enhancing comfort (Eremia et al., 2017). The ability to gather and analyze data on space utilization and employee movement patterns enables more efficient layout planning, supporting flexible working models and reducing real estate costs (Song et al., 2020). The emphasis on security is also notable. Smart office environments integrate IoT-driven access control systems, surveillance networks, and anomaly detection tools to safeguard occupants and assets. These measures contribute to a safer and more resilient workplace, reducing the potential liabilities associated with traditional security systems. Moreover, smart office concepts extend beyond operational efficiency. By improving occupant comfort, promoting health and well-being, and supporting sustainability goals, smart offices align with broader organizational objectives related to corporate social responsibility and workforce satisfaction (Papagiannidis et al., 2020). As the research highlights, the transformation towards smart office buildings is not merely a technological upgrade but a strategic shift towards data-driven, occupant-centric, and sustainable building management. This concept

forms a core pillar in understanding how IoT applications influence O&M strategies and cost optimization efforts throughout the building lifecycle.

2.3.1 Characteristics of Traditional and Smart Buildings in Terms of O&M

The differences between traditional and smart buildings in terms of O&M are profound, with smart technologies offering a paradigm shift in how facilities are operated and maintained. As discussed in Chapter 1, the optimization of building lifecycle costs particularly during the O&M phase is central to the research objectives. Smart buildings present an opportunity to achieve substantial reductions in operational expenses compared to conventional facilities. Traditional buildings predominantly rely on manual oversight and reactive maintenance practices, which often result in higher operational costs, unexpected system failures, and inefficient energy use. Maintenance activities are typically performed after problems occur, leading to increased downtime, occupant dissatisfaction, and costly emergency repairs (Singh et al., 2020). Furthermore, smart buildings leverage IoT-based systems, real-time monitoring, and predictive maintenance strategies to enhance operational efficiency. Sensors embedded within smart building infrastructures detect anomalies early, allowing facility managers to respond proactively and prevent costly breakdowns. Predictive algorithms analyze equipment performance trends to forecast maintenance needs, minimizing downtime and extending asset lifespans (Minoli et al., 2017). Energy management also differentiates smart buildings from traditional models. While traditional buildings often operate systems at fixed settings regardless of occupancy or demand, smart buildings dynamically adjust lighting, HVAC, and ventilation based on

real-time data, resulting in significant energy savings (Al Dakheel et al., 2020). These adaptive strategies not only lower utility costs but also support broader sustainability goals outlined under initiatives like Vision 2030. Furthermore, smart security systems enhance both building protection and operational efficiency. IoT-driven surveillance, access control, and intrusion detection mechanisms enable continuous monitoring and immediate incident response, reducing reliance on manual security checks and lowering overall management costs and by integrating remote monitoring, predictive maintenance, and intelligent resource optimization, smart buildings streamline facility operations while achieving notable O&M cost reductions across their lifecycle. As this research further explores, these capabilities underscore the strategic value of transitioning from traditional maintenance practices to IoT-enabled, smart facility management approaches.

Smart building	Traditional building
• Increased energy efficiency. • Cost savings over time. • Improved safety and security. • Reduce the risk of accidents and property damage. • Better control over building systems.	• Lack energy-efficient systems which lead to increased costs. • Rely on reactive maintenance which results in unexpected breakdowns and higher costs. • Lack real-time data collection and analysis capabilities.

Figure 2 Characteristics of Smart and Traditional Buildings in Terms of O&M

2.4 Overview of IoT and its applications in the context of the built environment

The Internet of Things (IoT) has emerged as a transformative force reshaping various aspects of modern life, with particularly profound implications for the built environment. As discussed in Chapter 1, IoT integration is fundamental to achieving operational intelligence in smart office buildings, directly impacting the O&M cost optimization objectives of the research. IoT refers to the interconnected network of devices, sensors, and

systems that collect, exchange, and process data through the internet. This connectivity enables real-time monitoring, automation, and enhanced decision-making across multiple domains (Perwej et al., 2019). Within the built environment, IoT facilitates the intelligent management of core building systems, including lighting, HVAC, security, energy consumption, and water usage (Ghosh et al., 2021). Applications of IoT within buildings are diverse. For example, occupancy sensors enable dynamic adjustment of HVAC and lighting systems based on real-time usage patterns, optimizing energy efficiency and reducing operational costs. Similarly, environmental monitoring systems ensure optimal indoor air quality by adjusting ventilation rates based on air composition data (Siountri et al., 2020). Moreover, IoT applications extend to larger urban contexts, supporting smart city initiatives through intelligent traffic management, waste management, and environmental sustainability efforts. In the building sector, however, the focus remains on enhancing resource efficiency, occupant comfort, and operational resilience. Predictive maintenance represents a key application of IoT in smart buildings. Through continuous data collection and analysis, facility managers can detect equipment degradation early, schedule maintenance proactively, and avoid costly failures. This capability is crucial for realizing the research's broader goal of sustainable O&M cost management. IoT also plays a critical role in modernizing building security. Real-time access control, surveillance systems, and anomaly detection technologies create safer environments while minimizing the need for manual oversight (Khan et al., 2020). Thus, IoT applications in the built environment not only improve operational efficiency and occupant well-being but also

align with the global shift toward sustainable, data-driven building management practices. As subsequent sections demonstrate, these capabilities are central to achieving the smart office building outcomes envisioned by the research.

2.5 Components and applications of IoT in smart office buildings

The integration of IoT technologies within smart office buildings creates an interconnected ecosystem that enhances operational efficiency, occupant comfort, and cost optimization. As established earlier in Chapter 1 and reinforced throughout this chapter, IoT plays a pivotal role in reshaping the way building systems are monitored, managed, and maintained to meet sustainability and lifecycle cost reduction goals. Smart office buildings incorporate various IoT components, each designed to collect real-time data and enable automated decision-making. Sensors are at the core of these systems, capturing critical information related to occupancy, temperature, lighting levels, air quality, and equipment performance (Palmer et al., 2016; Ghosh et al., 2021). This data serves as the foundation for dynamic adjustments and informed facility management practices. Edge computing devices and cloud-based platforms process and analyze the collected data, facilitating smart responses such as adjusting HVAC settings based on occupancy trends or dimming lights when sufficient natural daylight is available (Singh et al., 2020). Building Management Systems (BMS), integrated with IoT networks, allow centralized monitoring and control of these interconnected systems, enhancing operational responsiveness and energy efficiency and in addition to environmental controls, IoT extends to security and access management.

Advanced authentication mechanisms, real-time surveillance, and intrusion detection systems safeguard building occupants and assets while reducing reliance on manual interventions. These systems provide immediate alerts, enabling facility managers to respond swiftly to security events. Furthermore, IoT-enabled mobile applications and wearable technologies empower occupants to personalize their workspace environments, adjusting lighting, temperature, and workstation settings to their individual preferences. This personalization not only enhances user satisfaction but also contributes to productivity improvements and better space utilization. The cohesive integration of these components results in workplaces that are flexible, adaptive, and highly efficient. As this research emphasizes, the deployment of IoT in smart office buildings directly supports the transition from traditional reactive maintenance models to proactive, predictive, and cost-efficient management strategies. Moreover, the components and applications of IoT collectively establish the technological backbone necessary for achieving the O&M cost optimization targets outlined in the research.

2.5.1 Drivers for utilizing IoT-based technologies in smart office buildings

The adoption of IoT-based technologies in smart office buildings is driven by key motivations aimed at enhancing operational efficiency, improving occupant well-being, and achieving cost optimization. As outlined earlier, these drivers are central to supporting the research's goal of reducing O&M costs through intelligent building management. Energy efficiency is a major driver. IoT solutions enable precise, real-time control over HVAC, lighting, and energy systems, significantly lowering consumption and supporting

sustainability efforts. Moreover, occupant comfort and productivity have become critical considerations. IoT facilitates the customization of workspaces by allowing control over lighting, temperature, and air quality, thereby improving employee satisfaction and workplace performance. Security advancements further drive adoption. IoT technologies enhance building safety through real-time surveillance, biometric access, and automated intrusion detection, offering operational improvements compared to traditional systems. Furthermore, predictive maintenance enabled by IoT motivates organizations to invest in smart systems. Early fault detection minimizes equipment downtime and extends asset life, directly contributing to operational cost savings. Data-driven decision-making also represents a strong driver. Real-time analytics generated by IoT platforms provide valuable insights into space utilization, energy trends, and maintenance needs, supporting better resource allocation and strategic planning.

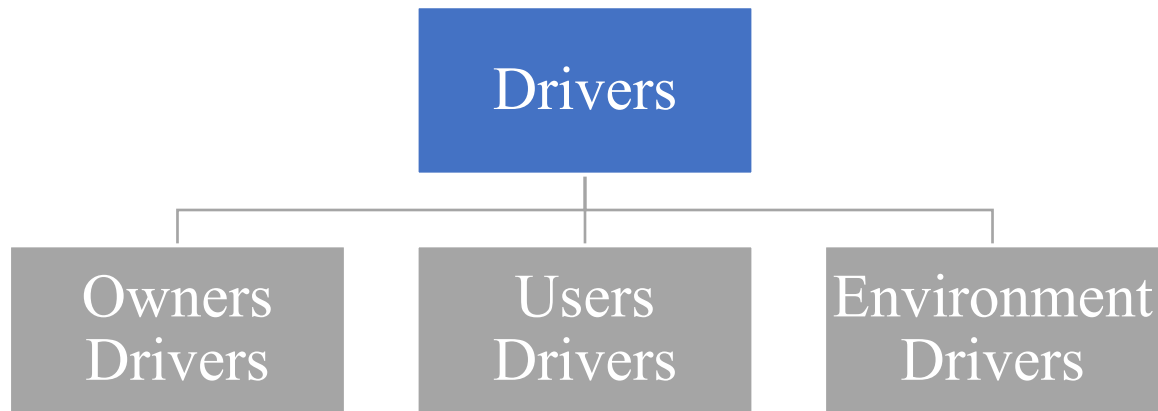


Figure 3 Categorization of Drivers for IoT Adoption

2.5.2 Driver's generation methodology

To identify the drivers prompting the utilization of IoT-based technologies in smart office buildings, a systematic literature review was conducted. This step aligns with the research's objective of grounding the lifecycle framework in both academic foundations and industry practices. Relevant keywords such as “drivers,” “benefits,” “advantages,” and “factors influencing” were used to ensure comprehensive coverage. An initial search yielded 258 articles, from which 166 were shortlisted based on relevance and criteria screening. After full-text examinations, 96 articles were reviewed in detail, resulting in a final selection of 52 studies considered appropriate for analysis. The inclusion criteria required that studies (i) addressed drivers or facilitators of IoT adoption in the smart building sector, (ii) were published in English, and (iii) had accessible full texts. Although the sample size (n=52)

may appear moderate, it exceeds the number used in prior domain reviews (Newaz et al., 2018; Osei-Kyei & Chan, 2015), ensuring sufficient coverage for the research. Each selected study was analyzed using a structured metadata extraction approach, where key information such as publication year, journal source, and stated drivers was recorded. To facilitate prioritization, a categorization process and Pareto analysis were applied to the extracted drivers. Moreover, the driver analysis was guided by a well-established theoretical modeling framework. This approach addressed three core elements: identifying "what" motivates IoT adoption, explaining "how" these drivers influence decision-making, and clarifying "why" such relationships exist based on causality principles. The systematic methodology applied in generating the driver list ensures that the framework proposed later in the research is underpinned by validated and contextually relevant insights.

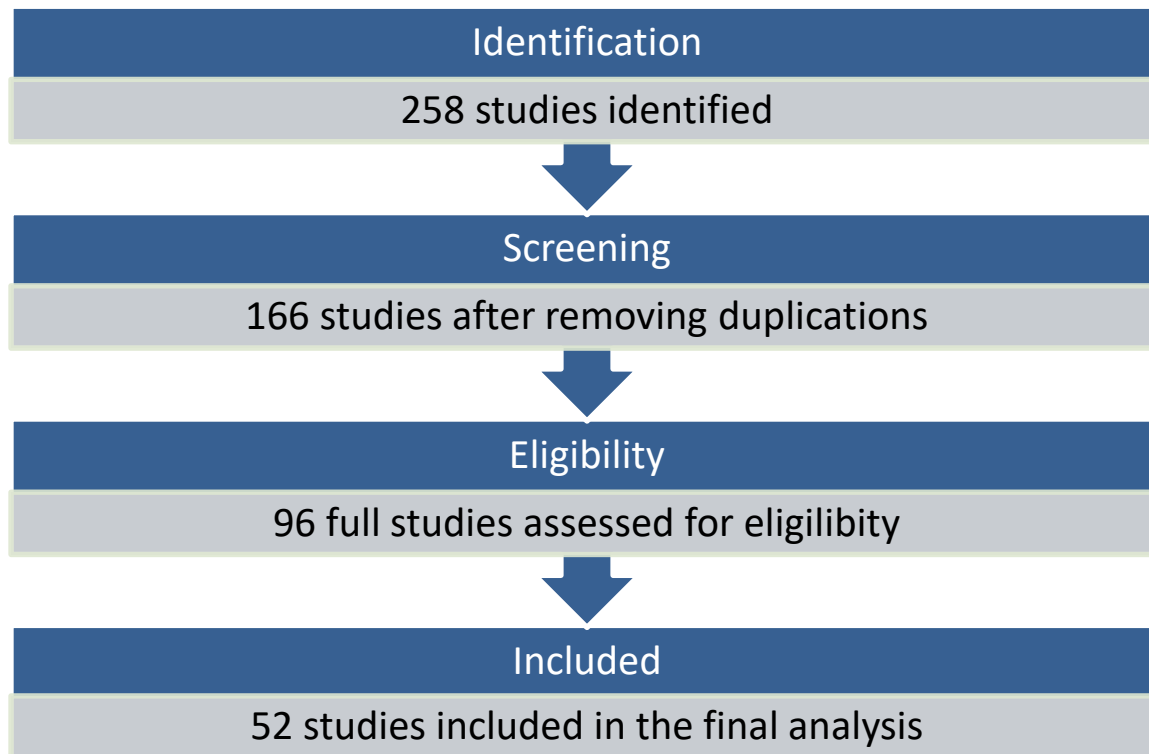


Figure 4 Filtration Process of Literature Review for Driver Identification

Year	References
2023	Almusaed et al., / Apanavičienė et al., / Gao et al., / Rahman et al., / Sari et al., / Sleem et al., /
2022	Agboola et al., / Anjomshoa et al., / Casini et al., / Cremins et al., / Gong et al., / Jeribi et al., / Mazhar et al., / Patil et al., / Saini et al., / Vermesan et al., / Zhang et al., / Zhu et al., /
2021	Akbarzadeh et al., / Aliero et al., / Gao et al., / Ion et al., / Karimi et al., / Luo et al., / Sharma et al., / Sung et al., / Umair et al., /
2020	Araujo et al., / Chew et al., / Dryjanski et al., / Fagan et al., / Froufe et al., / Papatsimpa et al., /

2019	Hamidi et al., / Hyman et al., / Jia et al., / Khan et al., / Khanna et al., / Kimani et al., / Komninos et al., / Linkous et al., / Lokshina et al., / Nugur et al., / Sharma et al., / Sicari et al., /
2018	Al-Gumaei et al., / Badri et al., / Bajer et al., / Banafa et al., / Ferrández et al., / Havard et al., / Pérez et al., / Syafrudin et al., /

Table 2 Summary of Literature Review Studies for Driver Identification by Year

2.6 The practices of building O&M

Effective practices in building O&M are fundamental to ensuring the long-term functionality, sustainability, and financial viability of built assets. As emphasized in previous chapters, O&M activities represent a significant share of a building's total lifecycle cost, reinforcing the research's objective of identifying strategies that optimize operational performance through IoT-based technologies. Building O&M encompasses a wide range of activities, including preventive maintenance, asset management, energy conservation, and occupant comfort enhancement (Palmer et al., 2016). Comprehensive planning and structured execution of these practices are essential for minimizing operational disruptions, extending asset lifespans, and optimizing the use of available resources. Moreover, the integration of IoT has introduced a new era of data-driven decision-making in O&M practices. By leveraging real-time monitoring and predictive analytics, facility managers can proactively address maintenance needs, enhance energy efficiency, and reduce unforeseen breakdowns (Gao et al., 2019). Furthermore, modern O&M practices align with sustainability principles by emphasizing energy conservation, waste reduction, and improved environmental performance. These evolving practices are

increasingly seen as central components of smart facility management strategies, directly contributing to occupant satisfaction, operational reliability, and lifecycle cost savings. The research builds upon these established practices by focusing on how IoT-based technologies can amplify their effectiveness, leading to more dynamic, responsive, and cost-efficient building management approaches.

2.6.1 Avenues through which IoT-based technologies could impact the O&M cost of smart office buildings

This section identifies how IoT-based technologies influence the main building systems outlined previously in Chapter 1, aligning with the research's focus on optimizing O&M costs across the building lifecycle and by targeting specific systems, the research highlights practical areas where IoT deployment can produce measurable operational savings.

2.6.1.1 HVAC systems

The IoT technology in Heating, Ventilation, and Air Conditioning maintenance services within the context of building management signifies a pioneering approach with the potential to significantly reduce operational and maintenance costs (Jia et al., 2019), a pertinent case study exemplifying this paradigm shift can be found in smart buildings that make use of IoT to enhance HVAC system efficiency and longevity, as highlighted in an office building of the University campus of the Polytechnic of Bari (southern Italy) and belonging to the Department of Electrical and Information Engineering, this innovative application of IoT involves the deployment of sensors and IoT-enabled devices to monitor

temperature, humidity, air quality, and equipment performance in real-time. The data collected is then analyzed to optimize HVAC operations through predictive maintenance, energy-efficient adjustments, and automated responses to changing environmental conditions, this proactive approach apart of minimizing operational expenses by reducing energy consumption but furthermore decreases maintenance costs by identifying and rectifying issues before they escalate, therefore the case study underscores IoT's revolutionary potential technology in revolutionizing HVAC maintenance services, ultimately leading to substantial cost savings in building operation and maintenance (Carli et al., 2020).

2.6.1.2 Fire Detection & Alarm systems

The integration of Internet of Things IoT technology in Fire Detection & Alarm (FDA) systems represents a groundbreaking approach aimed at reducing the cost of O&M in buildings while enhancing safety and reliability, a compelling case study exemplifying this innovation can be found in buildings that have adopted IoT-driven FDA systems, these systems utilize IoT sensors and interconnected devices to provide real-time monitoring and data analytics for fire detection and alarm functions, this allows for early detection of potential fire hazards, immediate notification of relevant personnel, and predictive maintenance of FDA components (Ali et al., 2023). However, by preemptively addressing issues and streamlining maintenance efforts, IoT-enhanced FDA systems besides minimizing operational expenses, yet it bolsters fire safety and equipment reliability,

ultimately leading to significant cost savings in both operation and maintenance aspects of building management.

This case study (Thibaud, 2018) underscores the transformative potential of IoT technology in revolutionizing fire safety systems and optimizing building operations while reducing long-term operational and maintenance costs (Thibaud et al., 2018).

2.6.1.3 Security & Access control systems

IoT technology in Security & Access Control systems within buildings has emerged as a transformative strategy with substantial implications for the reduction of O&M costs. This innovation is exemplified in buildings that have embraced IoT-driven Security & Access Control systems, where data-rich sensors and interconnected devices play a pivotal role (DURSUN et al., 2021). These systems provide real-time monitoring, data analytics, and automation for security and access management. Such IoT-enhanced systems enable proactive threat detection, immediate responses to security breaches, and predictive maintenance of security equipment. This holistic approach, besides enhancing security, moreover, streamlines operations and reduces long-term maintenance costs. However, preventing security incidents and minimizing the need for manual intervention, IoT technology in Security & Access Control systems as intelligent door locking systems significantly contributes to cost savings, making it an integral component of modern building management strategies (Schultz et al., 2007)., this case study (DURSUN, 2021)

highlights IoT's potential to change security and access management, ultimately leading to more cost-effective building operations and maintenance.

2.6.1.4 Indoor air quality & monitoring and control systems

The integration of IoT technology into Indoor air quality & Environmental Control Systems (IAQECS) within buildings has introduced a transformative new age, substantially influencing the decrease of operating and maintenance expenses. A compelling case study exemplifying this innovation may be seen in buildings that have implemented IoT-driven systems IAQECS, these systems employ IoT sensors and interconnected devices to monitor and manage various environmental parameters, including temperature, humidity, lighting, and energy consumption (Zhao et al., 2013). Moreover real-time data collection and analysis enable precise control and enhancing efficiency. Additionally, predictive maintenance capabilities facilitate the early identification of equipment issues, reducing downtime and maintenance costs and providing a holistic and data-driven approach to IAQ, IoT technology in IAQECS besides enhancing comfort and sustainability but likewise substantial O&M cost savings, underscoring its pivotal role in modern building management strategies. This case study underscores the potential of IoT to revolutionize environmental control systems, resulting in more cost-effective building operations and maintenance (Alozie et al., 2014).

2.6.1.5 Lighting Systems

Lighting Control & Retrofit Systems within a new age, substantially influencing the lowering of O&M cost, A case study (Osunsanmi et al., 2022) that exemplifying this innovation can be found in buildings that have used IoT-driven systems Lighting Systems (Osunsanmi et al., 2022). These systems employ IoT sensors and interconnected devices to monitor lighting levels, occupancy patterns, and energy consumption in real-time, however this data-driven approach enables precise control and optimization of lighting conditions, leading to substantial energy savings, and reduced operational costs, furthermore IoT technology allows for predictive maintenance of lighting fixtures, enabling timely replacement of bulbs or components before they fail (Albreem et al., 2023)., this apart of reducing maintenance expenses yet it minimizes disruptions in lighting services and by providing energy-efficient lighting solutions and proactive maintenance capabilities, IoT technology in Lighting Systems besides enhances sustainability and occupant comfort moreover it showed a significant O&M cost savings, underscoring its pivotal role in modern building management strategies. This case study (Kumar,2022) exemplifies the potential of IoT to revolutionize lighting systems, resulting in more cost-effective building operations and maintenance (Kumar et al., 2022).

2.6.1.6 O&M of Water & Utilization management

The water and utility management services within buildings represent a new technique that has a significant influence on lowering O&M expenses. A compelling case study (Sarraf,

2020) exemplifying this innovation founded that buildings that have embraced IoT-driven water and utility management systems (Sarraf et al., 2020), these systems utilize IoT sensors and interconnected devices to monitor water usage, detect leaks, and optimize water distribution in real-time, this data-driven approach allows for the early identification of water leaks and inefficient water consumption patterns, enabling timely interventions that prevent water wastage and mitigate costly water damage, moreover IoT-enabled utility management systems extend beyond water to encompass electricity, gas, and other utilities, as discussed in (Krishnamoorthy et al., 2020), so by providing real-time data on utility consumption, these systems empower building operators to make informed decisions, optimize resource utilization, and implement energy-efficient measures, the result is a reduction in utility costs and more sustainable and environmentally responsible building operation. Furthermore, predictive maintenance capabilities, enabled by IoT, ensure that utility equipment operates efficiently, preventing unexpected breakdowns and reducing maintenance costs (Muthubalaji et al., 2021), The incorporation of IoT technology in water and utility management services during building O&M phases yields significant cost savings and this data-driven and proactive approach not only reduces operational expenses but also enhances sustainability and resource optimization, underscoring IoT's pivotal role in modern building management strategies.

2.6.1.7 Predictive Maintenance Services

The integration of IoT technology in predictive maintenance management within buildings signifies a groundbreaking approach that yields substantial reductions in operational and

maintenance costs, A modern case study illustrating this innovation can be found in buildings that have adopted IoT-driven predictive maintenance systems (Nangia et al., 2020), these systems employ IoT sensors and interconnected devices to continuously monitor the health and performance of critical building components, such as HVAC systems, elevators, and electrical infrastructure, And real-time data collected from these sensors facilitates the early detection of equipment issues, enabling proactive maintenance interventions before they escalate into costly breakdowns, moreover the predictive maintenance approach extends equipment lifespans, minimizes downtime, and optimizes maintenance schedules, resulting in reduced operational expenses and enhanced reliability (Daissaoui et al., 2020). IoT-powered predictive maintenance and reduces maintenance costs, Moreover, contributes to energy efficiency and by ensuring that equipment operates at optimal efficiency, energy consumption is minimized, aligning with sustainability goals, and achieving cost savings, as highlighted in (Raco et al., 2022), the incorporation of IoT technology in predictive maintenance management during building operations is a pivotal strategy that ensures the long-term cost-effectiveness and reliability of building systems, this proactive and data-driven approach not only lowers operational and maintenance costs but also enhances equipment reliability and sustainability, underlining the transformative potential of IoT in modern building management.

2.6.1.8 Waste Management Systems & Services

Waste management services within buildings represent an innovative and cost-effective approach that has the potential to significantly reduce O&M expenses, A recent case study

exemplifying this innovation can be found in buildings that have embraced IoT-driven waste management systems (Hasan et al., 2017), These systems highlighted IoT sensors and interconnected devices to monitor waste bins' fill levels in real-time and continuously collecting data on the fill levels of waste bins, building managers can optimize waste collection schedules, ensuring that collection only occurs when bins are nearing full capacity, yet this data-driven approach reduces unnecessary waste pickups, leading to a reduction in operational costs associated with waste collection services (Shyam et al., 2017), Furthermore, IoT-enabled waste management systems contribute to sustainability and environmental responsibility, however minimizing the frequency of waste collection trips, they reduce carbon emissions associated with transportation, as discussed in (Haribabu et al., 2017) and in addition to operational cost savings, predictive maintenance capabilities enabled by IoT can extend the lifespan of waste management equipment, such as compactors, Yet an early detection of equipment issues allows for timely maintenance interventions, reducing downtime and maintenance costs (Abdullah et al., 2019), The incorporation of IoT technology in waste management services during building O&M phases offers a twofold benefits such as it can significantly reduce operational costs associated with waste collection while also contributing to sustainability efforts, This data-driven and proactive approach exemplifies IoT's potential in modern building management, aligning cost-effectiveness with environmental responsibility.

2.6.1.9 Space Utilization and Optimization Services

Space utilization and optimization services within buildings presents an innovative approach with substantial implications for reducing operational and maintenance costs, An illustrative case study of this innovation can be found in buildings that have embraced IoT-driven space management systems (Quy et al., 2022), These systems employ a network of IoT sensors and devices to continuously monitor the occupancy and utilization of office spaces in real-time and through the collection of occupancy data, building managers gain valuable insights into how spaces are utilized, this information enables the optimization of office layouts and resource allocation, creating flexible workspaces that reduce real estate costs and enhance operational efficiency, furthermore IoT-driven space utilization systems can contribute to energy savings by adjusting lighting, HVAC, and other utilities based on actual occupancy patterns, as discussed in (Berawi et al., 2023), moreover predictive maintenance capabilities, facilitated by IoT, enable early detection of equipment issues related to space utilization, such as HVAC systems serving occupied areas and this proactive approach minimizes downtime and reduces maintenance costs, ultimately contributing to the cost-effectiveness of building operations (Naga Sudha et al., 2022), The incorporation of IoT technology in space utilization and optimization services during building operation and maintenance phases offers a multifaceted approach to cost reduction, However optimizing resource allocation, enhancing energy efficiency, and enabling predictive maintenance, IoT technology empowers buildings to operate more

efficiently and cost-effectively, aligning the benefits of modern technology with the practical aspects of building management (Barišić et al., 2020).

2.7 Challenges and complexities associated with O&M in smart office buildings

While IoT-based smart office buildings offer substantial advantages for operational efficiency and cost optimization, they also introduce several challenges and complexities in O&M practices. Understanding these issues is essential for developing effective strategies, aligning with the research's broader objective of lifecycle cost optimization. One of the primary challenges involves system integration. Smart office buildings often rely on a diverse array of devices, sensors, and platforms from different manufacturers (Hossain & Muhammad, 2016). Ensuring interoperability between these systems can be complex, requiring standardized protocols, sophisticated middleware, and specialized expertise. Moreover, cybersecurity risks pose a significant concern. The interconnected nature of IoT systems creates vulnerabilities that can be exploited through unauthorized access, data breaches, or operational disruptions (Sfar et al., 2018). Securing IoT networks demands continuous monitoring, updated security protocols, and regular system audits, placing an additional burden on O&M teams. Data management complexity also emerges as a critical issue. IoT systems generate vast volumes of data that require effective storage, analysis, and retrieval strategies. Furthermore, deriving actionable insights from raw data streams often necessitates advanced analytics capabilities that traditional facility

management teams may lack (Pereira et al., 2020). Another challenge relates to the initial and ongoing costs of IoT deployment. Although long-term savings can be substantial, the upfront investment in IoT infrastructure, staff training, and system integration can be prohibitively high for some organizations. Additionally, ongoing software updates, device replacements, and cybersecurity measures add to operational expenditures. Moreover, a shortage of skilled personnel capable of managing IoT-integrated building systems limits the potential benefits of smart office environments (Tanko et al., 2022). Facility managers must adapt to a technology-driven management model, often requiring new training programs, certifications, and multidisciplinary collaboration. Finally, technological obsolescence presents a significant complexity. The rapid evolution of IoT hardware and software may render installed systems outdated within a few years, necessitating continuous investments in upgrades to maintain operational efficiency and cybersecurity standards. Addressing these challenges requires strategic planning, multidisciplinary collaboration, and an ongoing commitment to technological agility. As the research moves forward, identifying mitigation strategies for these challenges becomes integral to framing an effective and sustainable lifecycle O&M model for smart office buildings.

2.8 Previous studies on the Utilization of IoT-based technologies in the O&M phases

The utilization of IoT-based technologies in the O&M phase has become a pivotal topic within the fields of technology and infrastructure management. IoT has revolutionized how

data is collected, analyzed, and acted upon across various industries, and its application in building O&M is no exception. This growing field promises to enhance efficiency, reduce costs, and extend the longevity of critical systems and assets. Moreover, previous studies have laid important groundwork in understanding the potential benefits, challenges, and best practices associated with the adoption of IoT technologies in O&M operations. This section reviews and critically analyzes relevant studies that form the academic foundation supporting this research.

2.8.1 Introduction to IoT

Atzori et al., 2017 explored the significance of IoT in addressing challenges associated with the Internet of Things (IoT). The study presented an evolutionary analysis, identifying three distinct generations of IoT. The first generation involves tagged objects, the second focuses on things interconnected through web technologies, and the third incorporates social objects, semantic data representation, and the concept of a "cloud of things." The study emphasized the dynamic nature of IoT, indicating that it will continue to evolve with emerging paradigms like the Internet of Nano Things. In response to the diverse interpretations of IoT, the study proposed a conceptual framework that is independent of specific technologies. The study argued that having a clear understanding of what IoT is (and what it is not) is crucial to prevent confusion and promote acceptance of this paradigm, which they believe holds significant potential to address societal challenges.

Wang et al., 2021 highlighted key themes in IoT research. Mainstream focuses included IoT security, wireless sensor networks, management, challenges, and privacy. Developing economic regions actively collaborated, with China leading in publications and the USA in global influence. Challenges in trust and security were addressed, discussing issues like sleep deprivation attacks, and proposing solutions. Global collaborations were strong, with the USA-China partnership leading. Future recommendations emphasized dynamic optimization in IoT applications, urging practitioners to prioritize security and reliability.

Kumar et al., 2018 provided a detailed understanding of IoT, positioning it as a dynamic technology pivotal for creating smart systems with real-time monitoring capabilities. The study delved into the fundamental building blocks of IoT, including Things, Gateways, Network infrastructure, and Cloud infrastructure. These components collectively contribute to the structure of IoT systems. Three primary components of IoT, namely The Things with Networked Sensors and Actuators, Raw Information and Processed Data Stores, and Analytical and Computing Engines, are identified and explained in the study. The study identified various architecture layers in IoT, such as Three Layer, Five Layer, Six Layer, Seven Layer, Cloud, and Fog, and are systematically examined. The interaction between these layers is elucidated, providing a structured understanding of IoT system design. The study acknowledged that an increase in the number of architecture layers may introduce complexity in IoT system design, potentially leading to security issues and data mishandling. Study suggested that blockchain technology could address these challenges.

2.8.2 Smart Buildings and Their Benefits

El-Motasem et al., 2021 stated that the establishment of the New Administrative Capital (NAC) in Egypt, marked by the construction of thousands of Smart Building Projects (SBP), presented numerous challenges. Challenges included issues like the lack of guidelines, unclear objectives, oversight of life cycle costs, and the absence of a comprehensive framework. The study aimed to fulfill its objectives by analyzing literature sources and conducting a questionnaire survey involving design managers, project managers, facility managers, architects, and developers engaged in SBP in Egypt. The study successfully compared challenges extracted from literature analysis to those identified through the survey, revealing a more comprehensive understanding from the latter. Challenges were categorized based on project phases, with the literature analysis yielding four main categories and the survey resulting in five. The survey identified additional challenges, such as the absence of a facility management team and a lack of experience in the field in Egypt, making the findings more comprehensive.

Papagiannidis et al., 2020 focused on smart cities, manufacturing, and homes, there was a noticeable gap in understanding the impact of smart technologies on office spaces, particularly in terms of productivity and employee well-being. The study aimed to address this gap by reviewing and analyzing past literature on the utilization of smart technology in the workplace. Through quantitative content analysis, six clusters were identified, encompassing ICT system design, virtual teams, social networking, mobile devices and cyberslacking, office environment control, and office layout and productivity. The

literature was further grouped into two overarching themes: the digital workplace and productivity. Based on these findings and identified research gaps, the paper proposed four potential directions for future research: (1) focusing on the role of technology in managing workplaces, (2) exploring the implications of smart technologies for remote digital workplaces, (3) investigating organizational factors hindering the adoption of smart technologies in the workplace, and (4) examining the benefits of personalizing technology use in workplaces.

2.8.3 IoT Applications in Smart Offices

Maiti et al., 2023 proposed a privacy-preserving sensor design for IoT solutions in smart workplaces. The design aimed to autonomously detect and capture human movements, focusing on monitoring sedentary behavior discreetly. This sensor was integrated into an eHealth solution, providing continuous feedback about desk behaviors to encourage healthy movement breaks for seated workers. Past research demonstrated the reliability and timeliness of data collection, outperforming self-reporting and intrusive techniques. The system reliably recorded various human actions, enhancing the overall performance of the eHealth solution. The privacy-preserving features of this sensor were designed to facilitate widespread adoption in diverse environments, contributing to the field of smart workplace technologies.

Verma et al., 2019 discussed advanced practices for intelligent features, control parameters, and IoT infrastructure in smart buildings. The study focused on aspects like

privacy, security, network architecture, health services, and sensor-based management. The study highlighted the pivotal role of IoT in connecting and controlling appliances for enhanced building efficiency. A specific sensor design was proposed for IoT-based sensor-actuator automation in buildings. The review identified certain drawbacks in the existing sensing and controlling methodologies, prompting necessary changes. It categorized ongoing research into appraisals, application development, modification attempts, and design recommendations. Applications of the proposed sensor system were suggested, including energy conservation, faulty device detection, health assistance, safety proposals, and device connectivity. The study explored potential threats related to energy usage, security, networking, marketing, and safety systems.

Nathali et al., 2017 proposed a smart city framework based on Big Data analytics to enhance urban living across various domains such as smart community, transportation, healthcare, and parking. The framework operated on three levels: data generation and acquisition, data management and processing, and application execution. Testing authentic datasets on the Hadoop ecosystem validated the architecture's effectiveness, offering valuable insights for community development. The expansion of the Internet of Things (IoT) has driven the development of smarter urban networks, giving rise to the concept of "smart cities." The study, in the past, introduced a smart city architecture based on Big Data analytics to address challenges in transforming conventional city operations. It emphasized the need for intelligent decision management and control centers, showcasing practical applications with datasets from Surrey (Canada) and Aarhus (Denmark). The

study acknowledged the ongoing nature of smart city realization and outlined plans for simulated experiments and generalizability evaluations.

2.8.4 IoT for Building Automation and Control

Minoli et al., 2017 found that the integration of IoT in commercial spaces, particularly in smart buildings, was identified as a cost-effective solution for meeting comfort, usability, security, and energy management requirements. Despite facing challenges such as a lack of comprehensive standards and cybersecurity issues, the study highlighted the potential for disruptive opportunities in revolutionizing in-building connectivity, especially with Power over Ethernet (PoE) solutions. In the past few years, the anticipation was that smart buildings based on IoT concepts would evolve rapidly, driven by the confluence of IoT, PoE, and IP technologies. Governments and regulatory agencies globally have increased their focus on commercial buildings, expecting continued regulations to address energy consumption, including greenhouse gas emissions targets. Stakeholders were encouraged to explore evolving technologies like next-generation Building Management Systems (BMS), PoE, IoT, and cloud services to align with regulatory requirements and future-proof their environments. The study, reflecting on challenges in energy management, identified significant industry and technical opportunities, especially in reducing energy costs, optimizing comfort levels, and addressing peak-rate consumption. Technologically, the past witnessed ongoing transitions, including the adoption of function virtualization principles by core carrier networks. The migration to Network Function Virtualization (NFV)/Software Defined Network (SDN)-based Network Elements was anticipated to

enhance network capabilities for carrying IoT traffic, facilitating communication flexibility, resource optimization, and simplified network administration. The development of cloud-based high-quality analytics was considered crucial for global optimization, data mining, and forecasting in the context of smart buildings.

Quinn et al., 2020 explored the evolution of Building Automation Systems (BAS) in contemporary buildings, which were traditionally prescriptive. Controls were determined by the design team, lacking responsiveness to actual building performance. Advances in machine learning, edge analytics, data management, and Facility Management-enabled Building Information Models (FM-BIMs) allowed for a new approach: cloud-hosted building management. The integration technique mapped data from an Internet of Things (IoT) sensor network to an FM-BIM, offering a scalable solution demonstrated in a case study. The study highlighted the benefits of this integration, providing complex analyses for Facility Management. Limitations in the linked data approach were discussed, emphasizing the need for a more efficient query processor and a centralized model for flexibility. The study laid the foundation for a long-term project aiming to develop a cloud-hosted BIM-integrated FM platform, with plans for testing and incremental functionality development. It emphasized collaboration with end-users for defining relevant BAS data summarization techniques and identified potential applications such as Smart and Continuous Commissioning and Model Predictive Control.

2.8.5 Previous studies related to Integration with Other Technologies

Shah et al., 2022 explored the intersection of machine learning and the Internet of Things (IoT) in the realm of smart buildings, emphasizing automation, energy efficiency, and security challenges. The initial section underscored the growing role of smart buildings in broader system integrations, driven by widespread IoT adoption. The study delved into the significance of IoT devices, their platform, and components, while also addressing security challenges associated with IoT implementations. The paper detailed the role of machine learning in optimizing energy efficiency, stressing its importance in conjunction with IoT. The challenges posed by IoT technology were acknowledged, prompting a discussion on integrating machine learning to address energy efficiency and other issues in smart buildings. The conclusion urged the prompt resolution of challenges as a driving force for advancements in both academic and industrial domains of smart building research, emphasizing the symbiotic relationship between machine learning and IoT in shaping energy-efficient smart buildings and addressing security concerns.

Kashef et al., 2021 delved into the transformative impact of smart city technologies, with a primary focus on surveillance systems. It initially addressed challenges and controversies associated with existing smart city surveillance and advocated for mesh technology exploration and citizen involvement in co-design. The study highlighted the role of a high-tech surveillance system (WIMTE) in enhancing safety, security, and infrastructure management. The integration of multi-sensor technology with wireless mesh networks was proposed to provide real-time data for events like the Covid-19 pandemic. The WIMTE

network was described as a geographically distributed mesh system, offering situational awareness and real-time data access. The study emphasized the need for enhanced broadband width and seamless communication for effective deployment. The proposed WIMTE architecture, incorporating mobile multi-sensor surveillance and video analytics, was positioned as a cutting-edge solution with the ability to provide critical data in real-time. The study concluded by recognizing the theoretical implications and advocating for further qualitative exploratory research to refine conceptualizations and understand the social and behavioral implications of smart surveillance in cities.

CHAPTER 3

Adoption of IoT-Based Technologies in Smart Office

Building Operations and Maintenance

3.1 Overview

This chapter expands on the findings of the literature review by exploring the adoption of IoT-based technologies in the O&M of smart office buildings. It examines the role of IoT in optimizing operational efficiency, reducing maintenance costs, and improving overall building performance. The chapter provides a structured analysis of the drivers and motives behind IoT adoption, highlighting key factors such as energy efficiency, predictive maintenance, occupant comfort, and cost reduction. Moreover, it investigates the challenges and barriers that hinder the seamless implementation of IoT in building management, including cybersecurity risks, data privacy concerns, high initial investment costs, and integration complexities with legacy systems. Furthermore, the chapter presents an in-depth examination of the critical success factors that influence the effectiveness of IoT technologies in smart office buildings, addressing aspects such as stakeholder engagement, financial planning, compliance with regulatory standards, and system scalability.

3.2 Impact of adopting IoT based technologies on the O&M cost of smart office buildings

The integration of IoT technology has revolutionized various industries, including smart office buildings and with the rise of smart infrastructure, there has been a notable transformation towards leveraging IoT-based solutions to enhance operational efficiency and reduce maintenance costs (Shaheen et al., 2022). This transformation is particularly pronounced in Saudi Arabia, where rapid urbanization and technological advancements have fueled the demand for innovative approaches to building management (Al Otaibi et al., 2019). This thesis explores the profound impact of adopting IoT-based technologies on the O&M costs of smart office buildings in Saudi Arabia by examining the relation between IoT applications and building management practices, this research aims to investigate the transformative potential of IoT in optimizing resource utilization, streamlining maintenance operations, and ultimately driving cost savings within the context of smart office environments (Madkhali et al., 2023).

3.2.1 HVAC systems

The integration of IoT technology within HVAC systems is enhancing the way facility managers oversee building operations. Moreover, the Kingdom's Vision 2030 agenda driving innovation and sustainability, smart office buildings are becoming increasingly prevalent, leveraging IoT sensors to optimize energy consumption, enhance occupant comfort, and streamline maintenance processes (Jamoussi et al., 2022). The deployment of

IoT-enabled solutions for remote monitoring and management within HVAC systems holds particular significance, moreover, IoT technologies provide facilities managers with the tools and knowledge needed to optimize the operation and maintenance of HVAC systems, leading to reduced costs and improved performance, and the key mechanisms are as follows:

3.2.1.1 Remote monitoring and management

IoT sensors installed within HVAC systems allow facility managers to remotely monitor temperature, humidity, air quality, and equipment performance in real-time, identifying potential defects early and reducing emergency repairs. Moreover, IoT technology also provides remote control and automation, enhancing flexibility, efficiency, energy optimization, and system reliability, contributing to cost savings, sustainability, and occupant comfort in Saudi Arabia's smart office buildings (Ahmed et al., 2022).

3.2.1.2 Planning predictive maintenance activities

Predictive maintenance algorithms analyze IoT sensor data to anticipate HVAC component failures, enabling proactive scheduling that reduces downtime and costs, and this approach allows facilities to procure parts in advance, allocate personnel efficiently, and minimize the impact on operations. Moreover, leveraging real-time data and historical trends, facility managers can optimize HVAC performance, leading to significant cost savings, enhanced sustainability, and improved occupant comfort in Saudi Arabia's smart office buildings (Fernandez et al., 2021).

3.2.1.3 Developing energy conservation strategies

IoT technology allows for more granular control and optimization of HVAC systems based on real-time data and environmental conditions for example, sensors can adjust temperature setpoints dynamically based on occupancy patterns, external weather conditions, and building usage, optimizing energy usage without sacrificing comfort (AlFaris et al., 2017).

3.2.1.4 Fault identification and system diagnostics

IoT-enabled fault detection and diagnostics systems utilize advanced sensor technology, real-time monitoring, automated alerts, predictive analytics, and integration with maintenance management systems to enable proactive maintenance and optimize the performance of HVAC systems within smart office buildings and these systems play a crucial role in minimizing downtime, reducing maintenance costs, and enhancing system reliability, ultimately contributing to the long-term sustainability and cost-effectiveness of building operations (Lazarova-Molnar et al., 2016).

3.2.2 Fire Detection & Alarm systems

IoT technology offers several ways to reduce the operation and maintenance costs of Fire Detection & Alarm systems by enabling remote monitoring, predictive maintenance, automated testing, remote diagnostics, data analytics, and integration with building management systems (Wang et al., 2024).

3.2.2.1 Remote Monitoring and Management

IoT sensors integrated into fire detection and alarm systems can continuously monitor smoke, temperature, and CO₂ levels, enabling early detection of fire hazards and prompt response to reduce costly damage. IoT technology also allows for automated testing and inspections, eliminating manual procedures and ensuring regulatory compliance without on-site personnel. Moreover, remote diagnostics and access to system controls enable quick identification and resolution of issues, reducing response times and minimizing downtime (Megnafi et al., 2023).

3.2.2.2 Planning predictive maintenance activities

IoT-enabled fire detection and alarm systems use predictive analytics to anticipate maintenance needs by analyzing sensor data and historical performance, allowing for proactive scheduling and by collecting and analyzing data on alarm activations, response times, and maintenance history, facility managers can gain insights into system performance and identify opportunities for optimization, leading to targeted interventions that improve efficiency and reduce operational costs (Dhir et al., 2023).

3.2.3 Security & Access control systems IoT technology

IoT technology utilizes several ways to reduce the operation and maintenance costs of Security & Access Control systems by enabling remote monitoring and management, predictive maintenance, automated testing and diagnostics, integration with BMS, data analytics for performance optimization, and remote firmware updates and maintenance

(Wisdom et al., 2024). These capabilities improve system reliability, reduce downtime, and enhance efficiency, ultimately lowering operational costs associated with Security & Access Control systems.

3.2.3.1 Remote Monitoring and Management

IoT sensors integrated into Security & Access Control systems enable real-time monitoring and remote management of access points, security cameras, and other components from anywhere with an internet connection and these systems also support remote firmware updates and maintenance, allowing facility managers to deploy updates, patches, and enhancements without the need for on-site access, ensuring the system stays current with the latest features and security measures (Parti et al., 2023).

3.2.3.2 Planning predictive maintenance activities

IoT-enabled Security & Access Control systems can utilize predictive analytics to anticipate maintenance needs based on sensor data and historical performance through analyzing trends and patterns. These systems can predict when components are likely to fail or require servicing, allowing for proactive maintenance scheduling (NITONYE et al., 2024).

3.2.3.3 Fault identification and system diagnostics

IoT technology enables automated testing and diagnostics of Security & Access Control systems, eliminating manual, time-consuming procedures by allowing remote scheduling and performance of tests. Moreover, IoT systems collect and analyze data on access

patterns, security incidents, and system usage, providing facility managers with valuable insights to optimize performance and improve operational efficiency (Shitole et al., 2023).

3.2.3.4 Integration with Building Management Systems (BMS)

IoT-enabled Security & Access Control systems can be integrated with BMS platforms, providing a centralized interface for monitoring and controlling various building systems. Integration with BMS allows for coordinated responses to security incidents and access control events, streamlining operations and reducing the need for manual intervention (Asif et al., 2024).

3.2.4 Indoor air quality systems

IoT technology offers several opportunities to reduce the operation and maintenance costs of Indoor Air Quality (IAQ) monitoring and control systems by enabling continuous monitoring, data-driven insights, predictive maintenance, remote monitoring and management, energy optimization, and automated alerts and notifications, moreover, leveraging IoT capabilities allows facility managers to maintain a healthy indoor environment while optimizing operational efficiency and minimizing costs associated with IAQ system maintenance and management (Dai et al., 2023).

3.2.4.1 Continuous monitoring, control and management

IoT sensors can be deployed throughout indoor spaces to continuously monitor parameters like temperature, humidity, CO₂ levels, particulate matter, and VOCs, providing facility managers with real-time insights into indoor air quality (IAQ). This technology enables

remote monitoring and management of IAQ systems, allowing managers to access data and control settings from anywhere, reducing response times and operational costs. Moreover, IoT-enabled IAQ systems can generate automated alerts when air quality deviates from predefined thresholds, enabling timely interventions to prevent health risks and costly consequences associated with poor indoor air quality (Tanveer et al., 2024).

3.2.4.2- Development of data-driven Insights

Facility managers can gain valuable insights into indoor air quality trends and patterns over time by collecting data from IoT sensors and this data-driven approach allows managers to identify potential issues or areas for improvement, such as areas with poor ventilation or high pollutant levels (Verma et al., 2023).

3.2.4.3- Planning predictive maintenance activities

IoT-enabled IAQ monitoring systems can utilize predictive analytics to anticipate maintenance needs based on sensor data and performance through analyzing data on equipment health and performance which allows predictive maintenance algorithms to identify potential issues before they escalate into costly failures (Elkateb et al., 2024).

3.2.4.4- Developing energy conservation strategies

IoT-enabled IAQ systems can adjust ventilation rates and HVAC settings based on real-time data and occupancy patterns to optimize energy usage while maintaining indoor air quality (Qasim Flayyih et al., 2024). Moreover, integrating IAQ monitoring systems with building management systems (BMS) allows facility managers to implement demand-

controlled ventilation strategies and adjust HVAC setpoints dynamically to minimize energy consumption without compromising occupant comfort (Qasim Flayyih et al., 2024).

3.2.5 Lighting systems

IoT technology offers numerous opportunities to reduce the operation and maintenance costs of lighting systems by enabling remote monitoring and management, predictive maintenance, energy optimization, automation, data analytics, fault detection, and integration with building management systems (Hosamo et al., 2023). Moreover, leveraging these capabilities allows facility managers to optimize lighting performance, reduce energy consumption, and minimize maintenance expenses, ultimately improving the overall efficiency and sustainability of buildings (Rane et al., 2023).

3.2.5.1 Remote Monitoring and Management

IoT-enabled lighting systems allow facility managers to remotely monitor and manage lighting performance and energy usage, providing real-time data and enabling the identification of issues like burnt-out bulbs or malfunctioning fixtures without physical inspections. Moreover, IoT technology enables remote control and automation of lighting settings, schedules, and dimming levels, streamlining maintenance tasks and reducing the need for manual intervention, ultimately saving time and resources (Rane et al., 2023).

3.2.5.2 Planning predictive maintenance activities

IoT sensors embedded in lighting fixtures collect data on usage patterns, temperature, and energy consumption, enabling predictive maintenance algorithms to anticipate failures and

schedule proactive maintenance and by detecting faults and malfunctions early, these sensors help maintenance personnel address issues before they escalate, reducing unexpected failures, minimizing downtime, and lowering overall maintenance costs while extending the lifespan of lighting fixtures (Manchadi et al., 2024).

3.2.5.3 Developing energy conservation strategies

IoT-enabled lighting systems can adjust lighting levels and schedules based on occupancy patterns, daylight levels, and energy prices (Qasim Flayyih et al., 2024). Moreover, the integrating with occupancy sensors and ambient light sensors, lighting systems can automatically dim or turn off lights in unoccupied areas or in response to natural light levels, reducing energy consumption and operating costs (Qasim Flayyih et al., 2024).

3.2.5.4 Real Time Data analysis and interpretation

Facility managers can gain valuable insights into lighting usage patterns, energy consumption trends, and equipment performance by collecting and analyzing data from IoT sensors (Soori et al., 2023). This information can be used to identify opportunities for further optimization and efficiency improvements, ultimately leading to cost savings on energy bills and maintenance expenses (Soori et al., 2023).

3.2.6 Water management systems

IoT technology offers a comprehensive suite of tools and capabilities to optimize water and utility management, reduce operation and maintenance costs, and improve overall efficiency and sustainability (Kamyab et al., 2023). Moreover, leveraging real-time

monitoring, predictive analytics, remote control, and data-driven decision-making allows organizations to achieve significant cost savings while ensuring the efficient and responsible use of water and utility resources.

3.2.6.1 Remote Monitoring and Control

IoT sensors can be deployed throughout water and utility systems to monitor real-time parameters such as water flow, pressure, temperature, and energy consumption. This allows facility managers to remotely access this data through centralized platforms, enabling them to monitor performance, detect anomalies, and optimize efficiency without on-site visits. Moreover, IoT-enabled systems can further optimize resource usage by adjusting consumption based on real-time demand and conditions, such as smart irrigation systems that minimize water waste or energy management systems that reduce costs and by analyzing this data, facility managers can identify inefficiencies and implement targeted strategies to maximize efficiency and reduce operational costs (Yauri Rodríguez et al., 2023).

3.2.6.2 Leak Detection and Prevention

IoT sensors can detect leaks and abnormalities in water distribution systems early on, enabling prompt intervention to prevent water loss and damage to infrastructure. Moreover, with the continuously monitoring water flow rates and pressure levels, IoT-enabled systems can identify sudden drops or fluctuations indicative of leaks or pipe bursts. However, timely detection of leaks allows for immediate action to repair the issue,

minimizing water waste and reducing the risk of costly water damage repairs (Basavaraddi et al., 2023).

3.2.6.3 Planning predictive maintenance activities

IoT technology enables predictive maintenance algorithms to analyze data collected from sensors and predict when equipment is likely to fail or require servicing and by monitoring factors such as equipment temperature, vibration, and energy consumption, predictive maintenance algorithms can identify potential issues before they lead to equipment breakdowns or failures, moreover, proactively addressing maintenance needs helps prevent costly downtime and extends the lifespan of equipment (Užičanin et al., 2023).

3.2.6.5 Automated Meter Reading

IoT technology facilitates automated meter reading and billing processes, eliminating the need for manual meter readings and reducing administrative overhead. Moreover, smart meters equipped with IoT sensors can remotely transmit consumption data to utility providers, enabling accurate billing based on actual usage. This automation streamlines billing processes, reduces errors, and improves billing accuracy, ultimately lowering operational costs for both utility providers and consumers (Berouine et al., 2017).

3.2.7 Maintenance management & services

IoT technology helps optimize all types of maintenance strategies, providing real-time monitoring, data analytics, and predictive insights and by enabling a proactive, data-driven approach to maintenance, IoT reduces unnecessary labor, minimizes equipment downtime,

and prevents expensive repairs, ultimately leading to significant cost reductions in operation and maintenance (Shetty et al., 2018).

3.2.7.1 Preventive Maintenance

IoT sensors enable continuous monitoring of equipment performance, allowing organizations to follow predefined maintenance schedules more effectively by triggering alerts when components near failure. This ensures maintenance is performed only when necessary, reducing premature interventions, moreover, IoT data optimizes maintenance schedules by tailoring them to actual equipment wear, improving efficiency, reducing downtime, and minimizing costs.

3.2.7.2 Corrective Maintenance

IoT sensors facilitate rapid fault identification by detecting anomalies in real time, enabling maintenance teams to address issues quickly and minimize downtime. Moreover, IoT supports remote diagnostics, allowing personnel to troubleshoot problems without being on-site, reducing labor costs, travel time, and speeding up issue resolution.

3.2.7.3 Predetermined Maintenance

IoT technology enhances data-driven planning by offering detailed insights into equipment usage, performance, and lifespan, allowing maintenance schedules to be fine-tuned for optimal cost efficiency and by automating monitoring tasks, IoT also reduces the need for manual inspections, enabling technicians to focus on actual maintenance, which leads to lower labor costs.

3.2.7.4 Condition-Based Maintenance

IoT sensors enable real-time monitoring of equipment conditions, such as temperature and vibration, ensuring maintenance is performed only when necessary. Moreover, this condition-based approach avoids unnecessary interventions, extends equipment life, and minimizes operational disruptions, reducing downtime and enhancing overall efficiency.

3.2.7.5 Predictive Maintenance

IoT-enabled systems utilize predictive analytics to forecast equipment failures by analyzing historical data, allowing organizations to address issues before they escalate into costly emergencies, moreover, this proactive approach reduces unplanned downtime and minimizes the need for expensive, reactive maintenance.

3.2.7.6 Reactive Maintenance

IoT technology enhances reactive maintenance by enabling quick identification of issues through automated alerts, allowing faster response times and reducing the impact of system failures. Moreover, IoT supports remote troubleshooting, enabling technicians to assess and potentially resolve problems without on-site visits, cutting travel costs and speeding up repairs.

3.2.8 Waste management systems

IoT technology offers numerous opportunities to reduce the operation and maintenance costs of waste management systems and services through real-time monitoring, route

optimization, efficient resource allocation, remote diagnostics, and data-driven decision-making. Moreover, leveraging IoT solutions allows waste management companies to achieve significant cost savings while improving operational efficiency and service effectiveness (Uganya et al., 2022).

3.2.8.1 Real-Time Monitoring of Waste Bins

IoT sensors installed in waste bins provide real-time monitoring of fill levels and waste composition, allowing waste management companies to optimize collection routes and reduce unnecessary trips and fuel costs. This data also helps prevent overflow situations, minimizing cleanup costs and environmental hazards. Moreover, IoT sensors deployed in recycling facilities monitor equipment utilization, process efficiency, and material flows, enabling companies to identify bottlenecks, optimize workflows, and improve resource efficiency by analyzing real-time data (Bakhshi et al., 2018).

3.2.8.2 Planning predictive maintenance activities

IoT sensors in collection vehicles monitor performance in real-time, enabling predictive maintenance to reduce breakdowns and extend vehicle lifespan, thus lowering maintenance costs. Moreover, IoT-enabled systems allow for remote diagnostics of waste management equipment, reducing response times, downtime, and maintenance costs by enabling proactive issue detection and resolution (Theissler et al., 2021).

3.2.8.3 Efficient Trip planning

IoT-enabled waste management systems use data analytics and machine learning to optimize collection routes based on bin fill levels, traffic conditions, and historical data, reducing fuel consumption, vehicle wear, and labor costs. Moreover, IoT technology allows companies to allocate resources more efficiently by adjusting collection frequency and capacity to actual demand, with real-time monitoring enabling dynamic adjustments to collection schedules based on waste generation fluctuations, seasonal trends, and special events (Erçin et al., 2021).

3.2.9 Space utilization and optimization services

IoT technology offers numerous opportunities to reduce operation and maintenance costs in space utilization and optimization services by providing real-time data insights, enabling proactive management, optimizing energy usage, facilitating remote monitoring and management, supporting data-driven decision making, and optimizing cleaning and maintenance schedules and by leveraging IoT technology effectively, organizations can achieve cost savings, improve operational efficiency, and enhance the overall user experience in their facilities (Aguilar et al., 2021).

3.2.9.1 Real-Time Occupancy Monitoring

IoT sensors deployed throughout buildings monitor real-time occupancy levels and space utilization patterns, helping organizations identify underutilized areas and optimize space allocation. Moreover, IoT technology enables facilities managers to remotely monitor and

manage building systems and equipment from anywhere, allowing for early issue detection, quick intervention to prevent downtime and costly repairs, and optimization of operational efficiency by minimizing maintenance costs associated with manual inspections and on-site visits (Volakh et al., 2023).

3.2.9.2 Dynamic Space Allocation

IoT technology enables dynamic space allocation based on real-time occupancy data and by using occupancy sensors to detect when spaces are vacant or underutilized, organizations can automatically adjust heating, cooling, lighting, and other building systems to optimize energy usage and reduce operational costs (Sood et al., 2020).

3.2.9.3 Planning predictive maintenance activities

IoT sensors monitor building infrastructure and equipment, such as HVAC systems, lighting fixtures, and elevators, in real-time, allowing organizations to predict potential failures and schedule proactive maintenance, they also collect extensive data on space utilization, building performance, and environmental conditions and by analyzing this data with advanced analytics and machine learning, organizations can identify trends, optimize operations, and implement targeted interventions, leading to improved efficiency, cost savings, and continuous improvement in space utilization (Lee et al., 2019).

3.2.9.4 Developing energy conservation strategies

IoT-enabled building management systems can optimize energy usage based on real-time occupancy data and environmental conditions and by automatically adjusting heating,

cooling, and lighting settings in response to occupancy levels and usage patterns, organizations can reduce energy consumption and utility costs (Tien et al., 2022).

3.3 Motives & drivers of adopting IoT based technologies on the O&M cost of smart office buildings

The adoption of IoT-based technologies in smart office buildings is mainly driven by the need for operational efficiency, cost reduction, and enhanced facility management and these technologies provide real-time data analytics, remote monitoring, and predictive maintenance, which significantly reduce the O&M costs (Anathan et al., 2023). Moreover, IoT solutions enable facility managers to optimize resource utilization, automate routine tasks, and proactively address equipment failures, thereby extending the lifecycle of building assets and lowering long-term maintenance costs (Anathan et al., 2023).

3.3.1 Enhancing Energy Efficiency in Smart Office Buildings Through IoT-Driven Real-Time Monitoring and Control

The integration of IoT-based technologies in smart office buildings enhances energy efficiency by enabling real-time monitoring and adjustment of HVAC and lighting systems based on occupancy patterns and environmental factors such as temperature and humidity, which allows for precise control, minimizes unnecessary energy consumption, reduces waste, and ultimately leads to lower operational costs while promoting a more sustainable and cost-effective building management approach (Metallidou et al., 2020).

3.3.2 Maximizing Operational Efficiency Through IoT-Enabled Predictive Maintenance in Smart Buildings

IoT technology enables predictive maintenance to enhance operational efficiency by continuously monitoring critical building systems and equipment, utilizing real-time data and advanced analytics to detect early signs of wear or malfunction, enabling facility managers to intervene before faults develop into issues, therefor reducing equipment downtime, preventing costly failures, and minimizing overall maintenance expenses while ensuring the optimal performance and longevity of building assets through timely, data-driven maintenance interventions (Karjou et al., 2024).

3.3.3 Elevating Occupant Comfort and Productivity Through IoT Technologies in Smart Office Buildings

IoT technologies enhance occupant comfort in smart office buildings by enabling personalized control over key environmental factors such as lighting, temperature, and air quality, allowing individuals to adjust these settings to their specific preferences in real-time, which provide a more comfortable and tailored working environment and has a direct positive impact on worker productivity, satisfaction, and overall well-being, thereby contributing to a more efficient and engaging workplace (Akbar et al., 2015).

3.3.4 Strengthening Security and Safety in Smart Office Buildings Through IoT-Based Technologies

IoT-based sensors and advanced monitoring systems in smart office buildings enhances security by offering real-time surveillance, automated access control, and immediate emergency response capabilities, while improving safety through the proactive detection and alerting of potential environmental hazards such as smoke, gas leaks, or fire, allowing for swift interventions that protect occupants and assets, ultimately creating a safer, more secure, and resilient office environment (Moreno et al., 2014).

3.3.5 Optimizing Space Utilization and Efficiency in Smart Offices Through IoT Solutions

IoT solutions facilitate the collection of detailed real-time usage data within smart office environments, enabling organizations to optimize space allocation and design by providing insights into occupancy patterns, meeting room usage, and work area efficiency, which allows for the reconfiguration of office layouts to better suit actual needs, reduce underutilized spaces, improve operational flow, and ultimately decrease operational inefficiencies while maximizing the overall productivity and effectiveness of the office environment (Salimi et al., 2019).

3.3.6 Achieving Cost Reduction in Smart Buildings Through IoT-Driven Automation and Data-Driven Insights

IoT technologies in smart buildings reduce operational costs by streamlining maintenance processes through predictive analytics, optimizing energy usage through real-time monitoring and automated adjustments, and minimizing the need for human intervention in routine facility management tasks through the seamless integration of automation and data-driven insights that ensure more efficient, cost-effective building operations (Metallidou et al., 2020).

3.3.7 Advancing Sustainability and Green Building Initiatives Through IoT Systems in Smart Office Buildings:

IoT systems enhance sustainability efforts within smart office buildings by continuously monitoring and managing resource consumption, such as energy and water usage, optimizing operations to minimize waste, facilitating compliance and the reduction of the building's overall environmental impact through data-driven strategies enhance energy efficiency, reduce emissions, and contribute to long-term environmental responsibility (Benavente-Peces et al., 2019).

3.3.8 Enabling Data-Driven Decision Making for Enhanced Building Performance and Efficiency Through IoT in Smart Offices:

The data generated by IoT devices in smart office buildings provides facility managers with a continuous stream of actionable insights, allowing them to make informed operational and strategic decisions based on real-time analytics, which enables the optimization of building performance, improves resource allocation, enhances energy efficiency, and supports long-term planning by identifying trends, inefficiencies, and opportunities for improvement, ultimately leading to smarter, more efficient management of office spaces and resources (Li et al., 2020).

3.3.9 Enhancing User Experience in Smart Office Buildings Through IoT-Driven Personalization and Automation:

IoT-based technologies in smart office buildings enhance user experience by offering automated and personalized services, such as smart workspace adjustments that adapt lighting, temperature, and desk adjustment to individual preferences, along with seamless booking systems for meeting rooms and shared spaces, which together create a more dynamic, responsive, and efficient work environment, comfort, and productivity for occupants (Floris et al., 2021).

3.3.10 Increasing Flexibility and Responsiveness in Building Management

Through IoT-Enabled Remote Monitoring and Control:

IoT technologies enable facility managers to remotely monitor and control building operations by providing real-time access to data on systems such as HVAC, lighting, and security, allowing for operational adjustments from any location, which increases flexibility and responsiveness in managing building systems, ensures quicker resolution of issues, optimizes energy consumption, and enhances overall building performance without the need for constant on-site supervision (Shah et al., 2022).

3.4 Challenges of adopting IoT based technologies on the O&M cost of smart office buildings

The integration of IoT technology into the O&M of smart buildings faces several challenges that lower their full-scale deployment, major barriers include the complexity of installation and integration, data security risks, significant upfront costs, and scalability issues, however, the complexity increases when dealing with existing legacy systems, alongside concerns about data overload and cybersecurity threats. Furthermore, challenges related to vendor lock-in, energy consumption of IoT devices, and the need for specialized expertise are also critical factors that must be addressed to ensure seamless operation and long-term sustainability (Lukhanda et al., 2024). These concerns highlight the need for standardized frameworks and robust policies to drive the successful implementation of IoT in building operations efferences (Lukhanda et al., 2024).

3.4.1 Complexity in Installation and Integration

Implementing IoT systems in smart office buildings requires the integration of multiple devices, sensors, and software platforms (Das et al., 2023). This complexity can lead to difficulties in ensuring interoperability between different systems and technologies, moreover, facility managers may face challenges in synchronizing various IoT systems for lighting, HVAC, and security into a single cohesive platform, potentially increasing installation costs and time (Das et al., 2023).

3.4.2 Data Security and Privacy Concerns

IoT-based technologies collect large amounts of real-time data, including sensitive information about building occupants and their activities and ensuring the security of this data is critical to prevent unauthorized access or breaches, moreover, privacy concerns can arise, especially in environments where personal information, such as preferences for lighting or temperature, is collected to enhance occupant comfort (Singh et al., 2024).

3.4.3 High Initial Investment

Technology solutions can reduce O&M costs over time, the initial investment in technology infrastructure, such as sensors, smart meters, and analytics platforms, can be significant (de Loza et al., 2024). This upfront cost may be a barrier for some organizations, particularly if the return on investment (ROI) is not immediately evident (de Loza et al., 2024).

3.4.4 Maintenance and Technological Expertise

The continuous operation of IoT systems requires ongoing maintenance and updates as IoT devices are prone to wear, malfunctions, or becoming outdated, facility managers need to ensure that the systems are regularly serviced and updated (Hassan et al., 2024). Moreover, managing these advanced technologies requires specialized technical expertise, which may not always be available in-house (Hassan et al., 2024).

3.4.5 Data Overload and Management

IoT systems generate large amounts of data, and managing, storing, and analyzing, facility managers may struggle to extract important knowledge from the data due to the large amount and complexity, however, without effective data analytics and decision-making frameworks, the benefits of IoT technologies may not be fully achieved (Chandrasekaran et al., 2024).

3.4.6 Cybersecurity Threats

IoT devices connected to building systems are potential entry points for cyberattacks. Hackers may target weakness points in these devices to gain access to sensitive data or disrupt building operations, moreover, ensuring robust cybersecurity measures across all connected devices and networks is crucial but can be technically and financially demanding (Wrona et al., 2024).

3.4.7 Reliability of IoT Networks

IoT-based systems rely heavily on network connectivity, and any disruptions in the network can impact the performance of key systems such as HVAC, lighting, and security. IoT devices may be vulnerable to intermittent connectivity, particularly in areas with poor network infrastructure or signal interference. This could lead to lapses in monitoring, predictive maintenance failures, or the inability to remotely control building operations (Bao et al., 2016).

3.4.8 Environmental Impact and Sustainability Concerns

IoT technologies enhance energy efficiency through the production, deployment, and disposal of IoT devices pose environmental concerns this rapid advancement of technology means that devices can become outdated quickly, contributing to electronic waste (e-waste), moreover, proper disposal and recycling of IoT components are necessary to minimize the environmental impact, but these processes may not be well-developed in all regions (Sotres et al., 2019).

3.4.9 Interference with Building Legacy Systems

Many existing office buildings have legacy systems for lighting, security, or HVAC, which may not be compatible with new IoT technologies, however, upgrading or integrating IoT solutions with these older systems can be costly and technically challenging and, in some cases, the building's entire infrastructure may need to be overhauled to accommodate IoT, which could lead to significant downtime and operational disruption (Hui et al., 2017).

3.4.10 High Energy Consumption of IoT Devices

IoT systems contribute to overall energy efficiency, the devices themselves—such as sensors, gateways, and servers—require power to operate and in large-scale implementations, the energy consumption of hundreds or thousands of devices can add up, potentially offsetting some of the energy savings achieved through efficient HVAC or lighting systems, thus managing the power consumption of IoT devices is therefore an important consideration (Martin-Lopo et al., 2020).

3.5 Factors affecting the adopting IoT based technologies on the O&M cost of smart office buildings

The O&M cost of IoT-based smart office buildings is influenced by multiple factors across different stages of a building's lifecycle. The successful implementation and long-term efficiency of IoT systems depend not only on the technology itself but also on how well it is planned, designed, constructed, and maintained. A holistic understanding of these factors is essential for stakeholders to optimize operational expenses, enhance system longevity, and maximize return on investment (ROI).

This section explores the four critical phases that shape the cost dynamics of IoT adoption in smart office buildings:

1. The Planning Phase – Establishing a solid foundation for IoT adoption through strategic budgeting, stakeholder engagement, energy efficiency goals, vendor selection, scalability

planning, and regulatory compliance. Decisions made in this phase set the trajectory for long-term cost efficiency.

2. The Design Phase – Ensuring system efficiency and sustainability by prioritizing interoperability, optimal sensor placement, redundancy mechanisms, modular design, predictive maintenance integration, energy efficiency, user-friendly interfaces, and adherence to IoT standards. A well-planned design reduces lifecycle costs and prevents operational inefficiencies.

3. The Construction Phase – Implementing IoT infrastructure with a focus on component quality, installation best practices, system testing, contractor expertise, compliance with design plans, cabling standards, documentation practices, and workforce training. Proper execution during construction enhances system reliability and minimizes costly rework.

4. The O&M Phase – Sustaining and optimizing IoT performance through real-time monitoring, predictive analytics, energy consumption tracking, cybersecurity measures, regular updates, fault detection systems, user feedback, dynamic resource optimization, and periodic lifecycle cost reviews. Effective O&M strategies ensure that IoT investments remain cost-effective and sustainable over time.

Moreover, analyzing these key phases, this section provides a comprehensive understanding of how IoT-based smart office buildings can be strategically managed to optimize O&M costs while ensuring long-term efficiency and reliability. The insights gained here will serve as a foundation for decision-makers in the architecture, engineering,

construction, and facility management (AEC/FM) sectors to develop sustainable and cost-effective IoT adoption strategies.

3.5.1 Planning Phase: Setting the Foundation for IoT Adoption

The planning phase plays a crucial role in ensuring the successful implementation of IoT-based systems in smart office buildings. Decisions made at this stage significantly impact on long-term operational and maintenance costs. Key considerations include early stakeholder engagement, budget allocation, energy efficiency objectives, vendor selection criteria, scalability planning, and regulatory compliance. A well-structured planning phase ensures that IoT adoption aligns with strategic goals, mitigates risks, and optimizes lifecycle costs.

3.5.1.1 Early Engagement of stakeholders to align objectives and expectations

Engaging stakeholders early in the planning phase ensures alignment of project objectives and expectations, particularly in areas such as energy efficiency, data security, and operational savings (Das et al., 2020). Failing to involve stakeholders early in the planning phase can lead to misaligned objectives, overlooked challenges, and ineffective prioritization, ultimately compromising the success of IoT adoption initiatives (Schuster et al., 2024).

3.5.1.2 Allocated budget for IoT infrastructure to ensure success

Allocating sufficient funds for IoT systems during planning mitigates risks of underfunding, which often leads to suboptimal implementations. A detailed financial plan

should account for the costs of sensors, software platforms, network infrastructure, and skilled labor (De Soto et al., 2018). Insufficient funding may result in incomplete or suboptimal IoT implementations, limiting system functionality and long-term efficiency (Del-Valle-Soto et al., 2019).

3.5.1.3 Setting clear energy efficiency goals to guide sustainable system deployment

Setting clear energy efficiency targets early provides a roadmap for selecting and deploying IoT-enabled HVAC, lighting, and energy management systems. These goals should align with sustainability certifications, such as LEED or WELL standards (Wen et al., 2018). Without clear goals, the deployment of IoT systems may lack direction, leading to missed opportunities for energy savings and non-compliance with sustainability standards (Momanyi et al., 2024)

3.5.1.4 Development of a plan for future scalability to accommodate emerging technologies

Designing systems with scalability in mind allows for the integration of emerging technologies, such as advanced AI analytics or 5G connectivity. This prevents costly overhauls when upgrading systems to accommodate future needs (Chen et al., 2020). A lack of scalability planning may necessitate costly overhauls as technology evolves, hampering long-term system performance and efficiency (Harrison et al., 2024).

3.5.1.5 Compliance with regulations to avoid legal and operational risks

Ensuring compliance with local and international regulations reduces the likelihood of legal disputes and operational disruptions. This includes data protection laws like GDPR, as well as energy efficiency standards (Mellit et al., 2018). Non-compliance with regulations could lead to legal penalties, operational disruptions, or reputational damage (Pradhan et al., 2024).

3.5.1.6 Develop robust data privacy and security strategies to protect information

Proactive measures to secure data collected by IoT devices protect against cyber threats and legal repercussions. For instance, encryption protocols, secure access controls, and periodic vulnerability assessments are critical (Panda et al., 2019). Weak data protection measures increase the risk of cyber threats, data breaches, and associated legal consequences (Mohanta et al., 2019).

3.5.1.7 Development of technology integration strategy for seamless system operation

Planning for seamless integration of IoT systems minimizes complexities during deployment. For example, ensuring compatibility between lighting, HVAC, and security systems enhances operational efficiency (Davtalab et al., 2018). Poor integration planning can lead to system incompatibility and inefficiencies during operation (Davtalab et al., 2018).

3.5.1.8 Consideration of lifecycle cost analyses to balance investment and operational savings

A comprehensive lifecycle cost analysis evaluates initial investment alongside long-term maintenance, upgrade, and operational savings. This analysis aids in making informed decisions regarding IoT adoption (Wang et al., 2021). Neglecting lifecycle cost analysis may result in poor investment decisions, increasing operational and maintenance costs (Lu et al., 2021).

3.5.1.9 Assessment of skill gaps for planning training programs

Identifying skill gaps among personnel and planning for targeted training ensures smooth management of IoT systems. This can include workshops on managing predictive maintenance tools or energy management platforms (Pryor et al., 2019). Unaddressed skill gaps can lead to inefficient management of IoT systems, causing operational delays and increased costs (Rêgo et al., 2024).

3.5.1.10 Setting vendor selection criteria to ensure reliable and scalable solutions

Selecting vendors with proven track records and support services reduces the risk of system failures. Evaluation criteria might include the vendor's expertise in IoT integration, scalability of solutions, and adherence to industry standards (Nguyen et al., 2022). Poor vendor selection can result in unreliable and non-scalable solutions, increasing the likelihood of system failures and maintenance issues (Nguyen et al., 2024).

3.5.2 Design Phase: Ensuring System Efficiency and Sustainability

A well-structured design phase is critical in determining the effectiveness and cost efficiency of IoT systems throughout their lifecycle. Poor design choices can lead to interoperability issues, energy inefficiencies, and higher long-term maintenance costs. This phase focuses on system interoperability, strategic sensor placement, redundancy mechanisms, modular design, predictive maintenance integration, energy optimization, user-friendly interfaces, and adherence to IoT standards. Effective design strategies reduce operational disruptions, extend asset lifespans, and ensure seamless integration of IoT technologies.

3.5.2.1 Systems interoperability across platforms and devices

Designing IoT systems that communicate across different platforms prevents operational silos. Open protocols, such as MQTT or BACnet, enables seamless integration of devices and software (Khoshnava et al., 2020). Lack of interoperability can result in operational silos and inefficiencies (Thottempudi et al., 2024).

3.5.2.2 Strategic placement of sensors for accurate and reliable data collection

Proper placement of sensors ensures accurate and reliable data collection. For example, occupancy sensors should be positioned in high-traffic areas, while environmental sensors are placed away from heat sources to avoid skewed reading (Wen et al., 2021). Poor sensor placement reduces data reliability and decision-making accuracy (Kalendar et al., 2024).

3.5.2.3 Incorporation of redundancy to maintain system reliability during failures

Redundant systems provide failover mechanisms to maintain operations during outages. For instance, backup power supplies for critical IoT devices prevent data loss and downtime (Lin et al., 2019). Lack of redundancy increases system vulnerability to failures and outages (Rullo et al., 2019).

3.5.2.4 Use of modular design principles for easier upgrades and maintenance

Modular designs facilitate upgrades without disrupting the entire system. For example, replacing faulty components in a modular system is quicker and more cost-effective than repairing monolithic systems (Aryan et al., 2021). Without modular design, upgrades and repairs may become more costly and time-consuming (Rana et al., 2024).

3.5.2.5 Integration of predictive maintenance features to minimize downtime

Embedding predictive analytics in system design enables early detection of wear and tears. This approach reduces unplanned downtime and extends the lifespan of critical assets (Lin et al., 2019). Neglecting predictive maintenance can lead to unplanned downtime and reduced asset lifespan (Ran et al., 2019).

3.5.2.6 Consideration of design choices for optimization energy efficiency

Incorporating energy-efficient lighting, HVAC, and insulation materials during design minimizes operational costs. For instance, smart lighting systems can adjust brightness

based on natural light availability (Mahmoodi-k et al., 2021). Poor design choices can result in higher operational costs and inefficiencies (Mahmoodi-k et al., 2021).

3.5.2.7 Development of user-friendly interfaces to simplify operation and decision-making

Intuitive interfaces reduce training time and errors. For example, a dashboard that visualizes energy consumption trends in an easy-to-understand format empowers facility managers to make quick decisions (Fanasch et al., 2020). Complex interfaces may hinder user adoption and increase operational errors (Savage et al., 2022).

3.5.2.8 Alignment of the design with IoT standards to ensure compatibility and efficiency

Aligning with industry standards enhances interoperability. Standards like Zigbee or LoRaWAN ensure devices from different manufacturers can operate together seamlessly (Wu et al., 2021). Lack of alignment with standards may result in compatibility issues and inefficiencies (Wei et al., 2024).

3.5.3 Construction Phase: Implementing IoT Infrastructure

The construction phase is where theoretical planning and design are translated into practical implementation. The efficiency and quality of IoT infrastructure installation directly impact long-term reliability and cost-effectiveness. Factors influencing this phase include the selection of high-quality components, adherence to installation best practices,

thorough system and integration testing, contractor expertise, compliance with design plans, cabling standards, documentation practices, and training programs. Proper execution during construction prevents costly rework, minimizes downtime, and ensures system resilience.

3.5.3.1 Selection of high-quality components to enhance reliability and reduce costs

Opting for durable and high-quality components, such as sensors and IoT devices, ensures reduced maintenance costs, longer system lifespan, and improved reliability. Enhanced data accuracy from these components directly contributes to better decision-making and operational efficiency (Li et al., 2020). Using subpar components increases the likelihood of failures and higher maintenance costs (Liu et al., 2020).

3.5.3.2 Following the best practices for accurate installation to ensure performance

Accurate installation of IoT systems following established best practices, such as adhering to standards for cable routing and avoiding signal interference, ensures optimal functionality. Proper techniques reduce system downtime and extend the service life of components (Lin et al., 2019). Poor installation practices may lead to system inefficiencies and reduced lifespan (Zhao et al., 2019).

3.5.3.3 System and integration testing to verify functionality

Performing rigorous system-level and integration tests validate that all IoT components meet the design specifications. Ensuring interoperability between devices during testing prevents failures, streamlines the construction process, and builds confidence in system readiness (Oliveira et al., 2020). Insufficient testing can result in system malfunctions and project delays (Oliveira et al., 2022).

3.5.3.4 Contractors' expertise with IoT to minimize errors and delays

Engaging contractors with specialized expertise in IoT deployments reduces the risk of errors and project delays. Certifications such as BICSI ensure that professionals are well-versed in critical installation and integration practices, enhancing project success (Peng et al., 2020). Lack of expertise may lead to errors, delays, and increased costs (Dimitriadis et al., 2024).

3.5.3.5 Compliance with design plans to avoid costly revisions

Strict adherence to the approved design plans ensures that the project remains within budget and avoids unplanned revisions. Regular audits during the construction phase prevent costly rework and ensure alignment with the intended outcomes (Tuan et al., 2021). Deviating from design plans can cause operational inefficiencies and increased costs (Tuan et al., 2023).

3.5.3.6 Adoption of high-quality cabling standards to enhance system connectivity

Employing premium cabling and adhering to standardized connectivity protocols ensures a robust and reliable network infrastructure. Proper cable management minimizes downtime and supports scalability in high-demand IoT environments, enabling seamless device communication (Lin et al., 2019). Using substandard cabling may result in connectivity issues and reduced network reliability (Ma et al., 2019).

3.5.3.7 Development of detailed documentation for smooth system handover

Creating comprehensive documentation, including system diagrams, configurations, and installation records, ensures a seamless handover. This enables the operations and maintenance team to effectively manage and troubleshoot the IoT infrastructure without extensive support from contractors (Lin et al., 2019). Poor documentation can hinder effective system management and troubleshooting (Lee et al., 2019).

3.5.3.8 Compliance with As-Built Plans to avoid operational inefficiencies

Ensuring that construction aligns with As-Built Plans prevents operational inefficiencies and reduces the need for costly adjustments post-construction. Periodic inspections and verifications during the build phase ensure compliance with approved designs (Dellise et al., 2020). Lack of adherence to as-built plans may cause operational inefficiencies and increased costs (Dellise et al., 2020).

3.5.3.9 Implementation of training programs to familiarize teams with systems

Conducting in-depth training sessions for the operations and maintenance team during construction empowers them with practical knowledge about the IoT systems. Familiarity with system functions and troubleshooting processes leads to a smoother operational transition (Carvalho et al., 2021). Without proper training, teams may lack the knowledge to effectively manage IoT systems (Li et al., 2024).

3.5.4 Operation and Maintenance Phase: Sustaining and Optimizing Performance

Once IoT-based smart office systems are operational, effective maintenance and optimization strategies are necessary to ensure continued cost-efficiency and functionality. The O&M phase focuses on real-time monitoring, predictive analytics, energy consumption tracking, cybersecurity measures, regular updates, fault detection systems, user feedback integration, dynamic resource optimization, and periodic lifecycle cost reviews. Proper O&M practices enhance system reliability, maximize return on investment (ROI), and reduce unexpected maintenance expenses.

3.5.4.1 Implementation of real-time monitoring for early detection of inefficiencies

Real-time monitoring through IoT platforms provides continuous oversight, enabling the early identification of inefficiencies, equipment wear, or operational anomalies. This proactive approach minimizes response times, prevents escalations, and ensures

uninterrupted system reliability and performance (Lin et al., 2019). Without real-time monitoring, inefficiencies and anomalies may go undetected, increasing costs (Yin et al., 2019).

3.5.4.2 Use of predictive algorithms to forecast and prevent equipment failures

Predictive algorithms leverage historical and real-time data to detect patterns that signal potential equipment failures. This reduces unexpected downtime, optimizes maintenance schedules, lowers repair costs, and enhances overall operational efficiency and system longevity (Li et al., 2021). Lack of predictive maintenance increases the risk of equipment failure and unplanned downtime (Zhang et al., 2021).

3.5.4.3 Tracking of energy consumption to identify and address inefficiencies

IoT-based energy monitoring tracks usage across HVAC, lighting, and other systems, pinpointing inefficiencies. By analyzing consumption trends, organizations can implement targeted optimization strategies, cut energy expenses and supporting sustainability goals (Hu et al., 2020). Poor tracking may result in unnoticed inefficiencies and higher operational costs (Ma et al., 2019).

3.5.4.4 Implementation of proactive cybersecurity measures to protect IoT systems

Proactive cybersecurity practices, such as encrypted communication, intrusion detection systems, and regular software updates, safeguard IoT networks against threats. This approach ensures data integrity, protects sensitive information, and mitigates risks of

cyberattacks (Gu et al., 2021). Lack of proactive cybersecurity increases the risk of breaches and operational disruptions (Kanaan et al., 2024).

3.5.4.5 Regular update of IoT devices to ensure security and efficiency

Periodically updating IoT devices with the latest firmware and patches enhance security and operational efficiency. It prevents compatibility issues, eliminates vulnerabilities, and ensures devices are equipped with the latest features and improvements (Lin et al., 2019). Failure to update devices can lead to compatibility and security issues (Ni et al., 2017).

3.5.4.6 Incorporation of fault detection systems to minimize maintenance disruptions

Fault detection systems continuously monitor device health, diagnosing issues in real-time and alerting operators to potential problems. This minimizes the impact of failures, reduces repair times, and prevents costly maintenance disruptions (Lin et al., 2019). Without fault detection, issues may escalate, leading to costly disruptions (Yu et al., 2019).

3.5.4.7 Collection of user feedback to continuously improve system performance

Gathering feedback from users enables the identification of operational shortcomings and the refinement of IoT system settings. Tailoring systems to user needs enhances satisfaction, optimizes resource use, and supports adaptive performance improvements

(Barbosa et al., 2020). Lack of feedback may result in missed improvement opportunities (Barbosa et al., 2020).

3.5.4.8 Dynamic Optimization of resources to reduce operational costs

IoT systems dynamically allocate resources like energy, security, and cleaning based on real-time demand and by adjusting outputs to match needs, organizations can significantly lower waste, improve resource efficiency, and reduce overall operational costs (Song et al., 2020). Inefficient resource management increases operational costs (Jerjes et al., 2024).

3.5.4.9 Periodical review of lifecycle costs to ensure sustainability and ROI

Regular reviews of lifecycle costs assess financial performance and uncover cost-saving opportunities. These evaluations ensure IoT systems deliver sustainable benefits, optimize expenditures, and achieve long-term return on investment goals (Panda et al., 2019). Failure to review costs periodically may lead to unsustainable operations and reduced ROI (Tiwari et al., 2024).

CHAPTER 4

Data Analysis & Results

4.1 Overview

This chapter presents the data collection process, and the subsequent analysis conducted to assess the adoption of IoT-based smart office buildings' O&M. The study relies on a structured survey targeting key stakeholders, including architects and engineers (A/Es), developers and owners, facility managers (FMs), and IoT professionals. The chapter begins with an overview of the demographic profile of the respondents, covering their field of work, years of experience, and involvement in smart building projects. This demographic analysis helps establish the background and expertise of the participants, ensuring the validity of the collected data.

4.2 Respondents' Demographic Information

This section presents the demographic details of the respondents who participated in the four questionnaire surveys. Participants were asked to provide information regarding their field of work, years of experience, and involvement in smart building projects. The collected data includes details such as their scope of work, professional background, and the number and types of smart office building projects they have been engaged in. These

insights help establish the credibility and expertise of the respondents, ensuring the relevance of their feedback.

Parameter	A/Es'		Devs' / Owns'		FMs'		IOTs'	
	Frequency (n= 30)	%	Frequency (n= 30)	%	Frequency (n= 30)	%	Frequency (n= 30)	%
Years of experience								
Less than 5 years	11	36.67%	4	13.33%	1	3.33%	21	70.00%
5-10 years	12	40.00%	10	33.33%	12	40.00%	5	16.67%
10-15 years	5	16.67%	7	23.33%	11	36.67%	2	6.67%
More than 15 years	2	6.67%	9	30.00%	6	20.00%	2	6.67%
Number of smart projects								
1 - 5 Project	19	63.33%	11	36.67%	15	50.00%	26	86.67%
5 – 10 project	8	26.67%	10	33.33%	12	40.00%	3	10.00%
11 – 15 Project	3	10.00%	7	23.33%	3	10.00%	1	3.33%
More than 15 Project		0.00%	2	6.67%		0.00%		0.00%

Table 3 Respondents' Years of Experience Distribution

4.2.1 Respondents' Scope of Work (Field of Work)

The respondents of the four questionnaire surveys represent diverse professional backgrounds. This subsection provides an overview of the fields of work of the participants, categorized into four key professional domains: Architects and Engineers (A/Es), Developers/Owners, Facility Managers (FMs), and IoT Professionals. Understanding their scope of work helps contextualize their perspectives on IoT adoption and smart office building O&M.

Respondents' Scope of Work

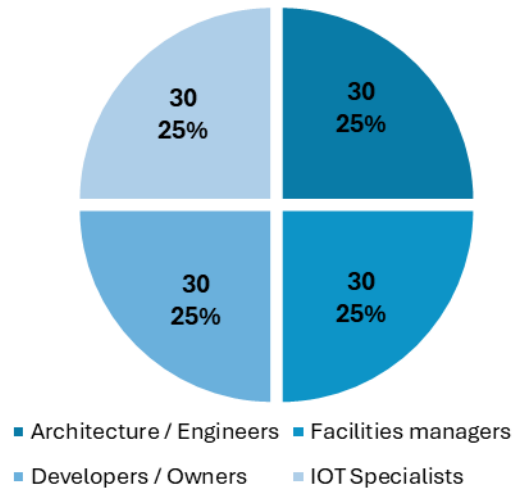


Figure 5 Respondents' Field of Work Distribution

4.2.2 Respondents' Years of Experience

The respondents who participated in the three questionnaire surveys had varying levels of professional experience. Therefore, this subsection presents data on the years of experience of the AEC/FM practitioners involved in these surveys.

4.2.2.1 Ranges of Years of Experience of the Respondents Involved in the A/Es' Questionnaire Survey

The questionnaire survey conducted among A/E practitioners indicated a diverse range of professional experience among respondents. The figure below illustrates the distribution of experience levels among the surveyed A/E practitioners (n = 30).

A/Es' Years of Experience"

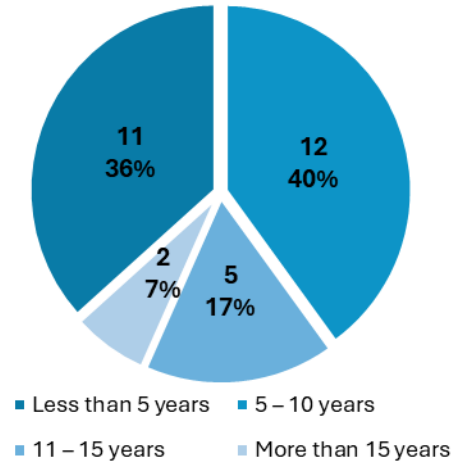


Figure 6 Years of Experiences Respondents Involved In (A/Es)

As presented, the years of experience among A/E respondents were categorized as follows: respondents with less than 5 years represented 36.67% (frequency = 11), those with 5 to 10 years of experience comprised 40% (frequency = 12), and respondents with 11 to 15 years of experience accounted for 16.67% (frequency = 5). This distribution reflects a balanced representation across different experience levels, allowing for diverse and comprehensive insights regarding IoT adoption in smart office buildings from the Architects and Engineers surveyed.

4.2.2.2 Ranges of Years of Experience of the Respondents Involved in the Developers / Owners' Questionnaire Survey

The questionnaire survey conducted among Developers / Owners practitioners indicated a diverse range of professional experience among respondents. The figure below illustrates

the distribution of experience levels among the surveyed Developers / Owners practitioners (n = 30).

Developers Years of Experience

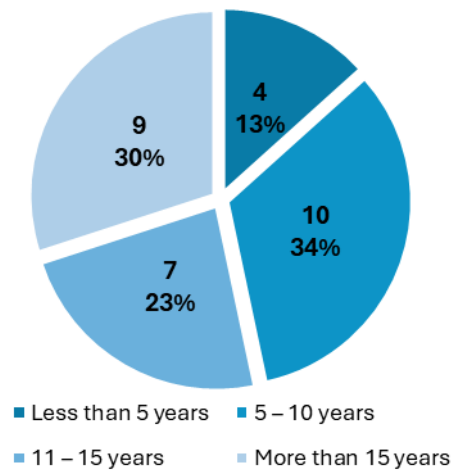


Figure 7 Years of Experiences Respondents Involved In (Developers/Owners)

As presented, the respondents' years of experience among Developers/Owners were categorized as follows: less than 5 years accounted for 13.33% (frequency = 4), respondents with 5 to 10 years of experience constituted the largest group with 33.33% (frequency = 10), those with 11 to 15 years represented 23.33% (frequency = 7), and respondents with more than 15 years of experience comprised 30% (frequency = 9). This distribution indicates a strong representation from respondents with extensive professional experience, thereby offering robust insights into the factors and challenges associated with IoT adoption from a Developers'/Owners' viewpoint.

4.2.2.3 Ranges of Years of Experience of the Respondents Involved in the FMs' Questionnaire Survey

The questionnaire survey conducted among FMs' practitioners indicated a diverse range of professional experience among respondents. The figure below illustrates the distribution of experience levels among the surveyed FMs' practitioners (n = 30).

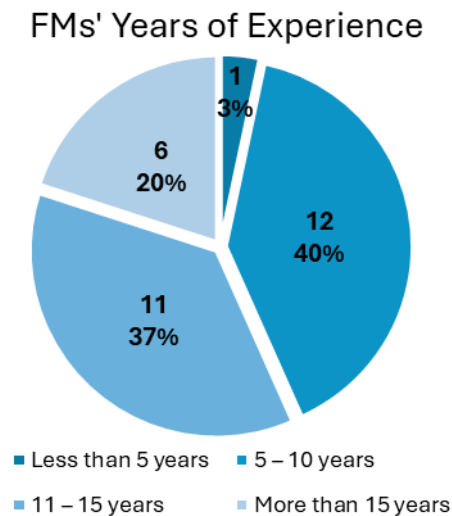


Figure 8 Years of Experiences Respondents Involved In (FMs)

As presented, the respondents' years of experience among Facilities Managers were categorized as follows: those with less than 5 years represented the smallest group at 3.33% (frequency = 1), respondents with 5 to 10 years of experience constituted the largest proportion at 40% (frequency = 12), those with 11 to 15 years of experience made up 36.67% (frequency = 11), and respondents with more than 15 years accounted for 20% (frequency = 6). This distribution shows that the majority of Facilities Managers surveyed

had substantial professional experience, enhancing the reliability and depth of insights into IoT adoption from a facility management perspective.

4.2.2.4 Ranges of Number of Smart buildings' Projects in which Respondents of the IoTs' Questionnaire Survey were Involved in

The questionnaire survey conducted among IoTs' practitioners revealed varying levels of involvement in smart building projects. Figure below illustrates the distribution of the number of smart building projects in which the respondents (n = 30) from the IoTs' questionnaire survey participated.

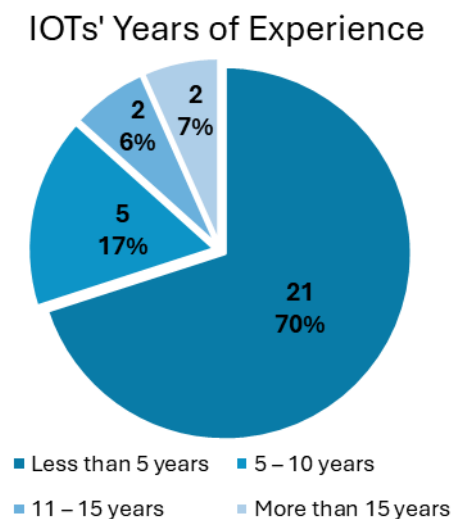


Figure 9 Years of Experiences Respondents Involved In (IoT Professionals)

As presented, the respondents' years of experience among IoT professionals were categorized as follows: respondents with less than 5 years of experience constituted 43.33% (frequency = 13), representing the largest group. Those with 5 to 10 years accounted for

23.33% (frequency = 7), while respondents with 11 to 15 years comprised 20% (frequency = 6). Lastly, respondents having more than 15 years of experience represented the smallest group at 13.33% (frequency = 4). This distribution highlights the significant presence of relatively newer professionals among IoT respondents, which provides valuable perspectives on emerging technologies and contemporary practices in IoT implementation.

4.2.3 Number of Smart buildings' Projects in which Respondents were Involved In

Respondents to the three questionnaire surveys had varying levels of experience with smart building projects. Therefore, this subsection presents data on the number of smart building projects in which these respondents were involved.

4.2.3.1 Ranges of Number of Smart buildings' Projects in which Respondents of the A/Es' Questionnaire Survey were Involved in

The questionnaire survey conducted among A/E practitioners revealed varying levels of involvement in smart building projects. Figure below illustrates the distribution of the number of smart building projects in which the respondents (n = 30) from the A/E questionnaire survey participated.

A/Es' Number of Project Participated

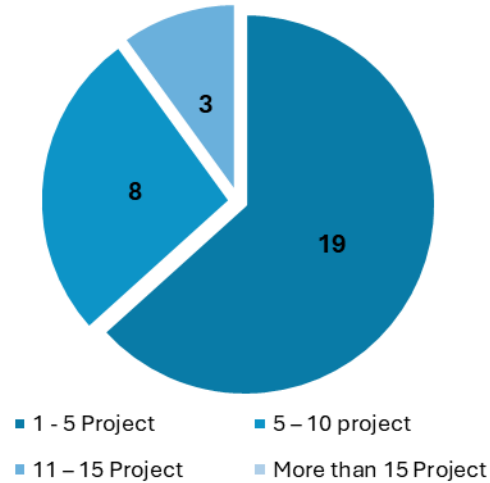


Figure 10 Number of Projects Respondents Involved In (A/Es)

As presented, respondents from the Architects and Engineers (A/Es) questionnaire survey had varying levels of involvement in smart building projects. The majority of respondents, approximately 63.33% (frequency = 19), had experience with 1 to 5 smart building projects. A smaller group, accounting for 26.67% (frequency = 8), reported involvement in 5 to 10 projects, while respondents involved in 11 to 15 smart building projects represented 10% (frequency = 3). This distribution indicates that most respondents had limited exposure to smart building projects, yet there was still notable participation from those with greater experience, enhancing the diversity and quality of insights obtained from the survey.

4.2.3.2 Ranges of Number of Smart buildings' Projects in which Respondents of the Developers' / Owners' Questionnaire Survey were Involved in

The questionnaire survey conducted among Developers' / Owners' practitioners revealed varying levels of involvement in smart building projects. Figure below illustrates the distribution of the number of smart building projects in which the respondents (n = 30) from the Developers' / Owners' questionnaire survey participated.

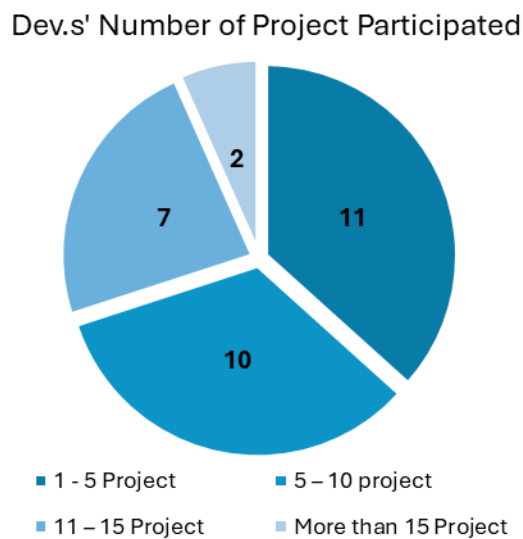


Figure 11 Number of Projects Respondents Involved In (Developers/Owners)

As presented, the involvement of Developers/Owners in smart building projects varied significantly. Respondents involved in 1 to 5 smart building projects accounted for 36.67% (frequency = 11). Those who participated in 5 to 10 projects represented 33.33% (frequency = 10), while those involved in 11 to 15 smart building projects made up 23.33% (frequency = 7). Highly experienced respondents, having participated in more than 15 smart building projects, represented 6.67% (frequency = 2). This distribution indicates a

broad spectrum of experience among Developers/Owners, with a larger proportion having moderate to limited exposure, complemented by a smaller but significant segment of highly experienced professionals, thus providing diverse insights into the adoption and integration of IoT technologies in smart office buildings.

4.2.3.3 Ranges of Number of Smart buildings' Projects in which Respondents of the FMs' Questionnaire Survey were Involved in

The questionnaire survey conducted among FMs' practitioners revealed varying levels of involvement in smart building projects. Figure below illustrates the distribution of the number of smart building projects in which the respondents (n = 30) from the FMs' questionnaire survey participated.

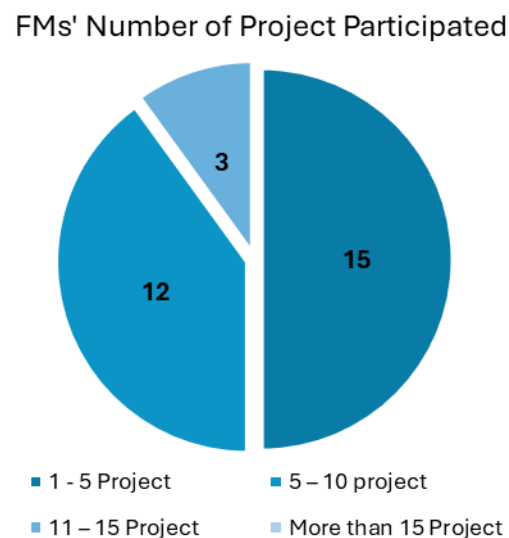


Figure 12 Number of Projects Respondents Involved In (FMs)

As presented, the involvement of Facilities Managers (FMs) in smart building projects varied considerably. Respondents who participated in 1 to 5 smart building projects formed the largest group at 46.88% (frequency = 15). Those involved in 5 to 10 projects represented 37.5% (frequency = 12), while respondents with experience in 11 to 15 projects accounted for 9.38% (frequency = 3). A smaller portion, 6.25% (frequency = 2), reported involvement in more than 15 smart building projects. This distribution suggests that most Facilities Managers surveyed had moderate or limited experience, although a smaller segment had significant hands-on experience, providing valuable insights into IoT implementation from a facility management perspective.

4.2.3.4 Ranges of Number of Smart buildings' Projects in which Respondents of the IoTs' Questionnaire Survey were Involved in

The questionnaire survey conducted among IoTs' practitioners revealed varying levels of involvement in smart building projects. Figure below illustrates the distribution of the number of smart building projects in which the respondents (n = 30) from the IoTs' questionnaire survey participated.

IOTs' Number of Project Participated

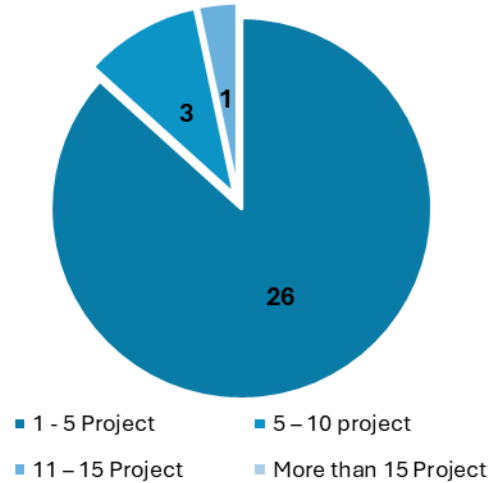


Figure 13 Number of Projects Respondents Involved In (IoT Professionals)

As presented, IoT professionals had varying levels of involvement in smart building projects. Respondents who participated in 1 to 5 smart building projects represented the largest group, comprising 86.67% (frequency = 26). A notably smaller portion, 10% (frequency = 3), had experience with 5 to 10 projects, and only 3.33% (frequency = 1) reported involvement in 11 to 15 projects. There were no respondents with experience in more than 15 projects. This distribution indicates that most IoT professionals surveyed had relatively limited exposure, reflecting insights predominantly from professionals engaged in early or initial implementation phases of IoT technology within smart buildings.

4.3 Data analysis approaches

In this section several statistical methods will be applied to analyze and interpret the survey data effectively. First, Cronbach's alpha will be used to assess the reliability and internal consistency of the survey responses, ensuring that the collected data is dependable. Next,

the standard deviation will be calculated to measure the extent of variation among individual responses, providing insights into how much the data points deviate from the mean value. Finally, the Relative Importance Index (RII) method will be employed to determine the significance of each factor based on the survey responses, allowing for the ranking of factors according to their perceived importance.

4.3.1 Data analysis methodology – Cronbach's alpha

The reliability of the collected surveys data from the four respondent groups will be assessed using Cronbach's alpha. This method evaluates the internal consistency of the responses, ensuring the dependability of the data. The Cronbach's alpha coefficient for each set of responses will be calculated using the equation provided below.

$$\text{Cronbach's alpha} = \alpha = \frac{k}{k-1} \left(1 - \frac{\sum \sigma_i^2}{\sigma_T^2} \right)$$

Where:

k = Number of items/questions

σ_i^2 = Variance of individual items

σ_T^2 = Variance of the total score

The table below shows the accepted guidelines for interpreting Cronbach's alpha. It also provides a measure of internal consistency (reliability) among. Surveys were ranked according to their calculated values.

Cronbach Alpha Score	Level of Reliability
≥ 0.9	Excellent
0.8–0.9	Good
0.7–0.8	Acceptable
0.6–0.7	Questionable
0.5–0.6	Poor
< 0.5	Unacceptable

Table 4 Cronbach's Alpha Reliability Results for Survey Data

4.3.2 Data analysis methodology – Standard deviation

The variability of the collected survey data from the four respondent groups will be analyzed using standard deviation. This method measures the dispersion of individual responses around the mean value, providing insights into the consistency of the data. The standard deviation for each factor will be calculated using the equation provided below.

$$\text{The standard deviation} = \sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N}}$$

Where:

x_i = individual response value.

$\bar{x}$ = mean (average) of responses.

N = total number of responses

4.3.3 Data analysis methodology – Relative important index

The data collected from the four respondent groups will be tabulated and analyzed both individually and collectively. The Relative Importance Index (RII) for each factor was determined using the equation provided below.

$$\text{Relative Importance Index (RII)} = \frac{\sum_{i=0}^4 (a_i)(x_i)}{4 \sum x_i} \times 100\%$$

Where:

i is the response category index.

a_i is the weight given to i response; and

x_i is the variable expressing the frequency of i

The table below shows the assigned weights corresponding to each important rating (i). It also provides a scale adopted for interpreting the computed RII values, enabling the determination of each factor's importance level. Factors were ranked according to their calculated RII scores.

Likert scale (Importance rating terms)	Importance weight (a_i)	Scale ranges (%) (lowest - highest)	
Extremely important (EI) - X ₀	4	87.50	100
Very Important (VI) – X ₁	3	62.50	87.49
Important (I) – X ₂	2	37.50	62.49
Somewhat Important (SI) – X ₃	1	12.50	37.49
Not Important (NI) – X ₄	0	0	12.49

Table 5 Standard Deviation Values for Survey Data

4.4 Assessment of the Drivers for IoT Adoption in Smart Office Building O&M

This section discusses the assessment findings related to the drivers influencing IoT adoption in smart office building O&M, based on the responses obtained from the four respondent groups.

Overall Drivers		Overall			
1. Energy Efficiency		RII	IR	IGR	OR
1	Real-time monitoring for optimizing energy usage in building systems	67.8	VI	1	1
2	The ability to adjust HVAC and lighting systems based on occupancy and environmental conditions	58.0	I	3	12
3	Minimizing unnecessary energy consumption and reducing waste	60.0	I	2	5
2. Operational Efficiency		RII	IR	IGR	OR
1	Detecting early signs of equipment malfunction	58.7	I	2	10
2	Predictive maintenance in reducing equipment downtime and repair costs	60.8	I	1	3
3	Scheduling timely maintenance interventions	56.8	I	3	16
3. Occupant Comfort		RII	IR	IGR	OR
1	Personalizing lighting, temperature, and air quality in real time	58.5	I	1	11
2	Developing a comfortable work environment	56.2	I	2	17
3	Improving worker productivity and satisfaction	52.8	I	3	24
4. Security and Safety		RII	IR	IGR	OR
1	Providing real-time surveillance for improved security	60.0	I	3	6
2	Controlling access for improving safety	61.5	I	1	2
3	Detecting and alerting potential hazards like smoke or gas leaks	60.7	I	2	4
5. Space Utilization		RII	IR	IGR	OR
1	Collecting real-time data on office occupancy and usage patterns	52.8	I	1	9
2	Optimizing space allocation based on IoT-generated insights	50.7	I	3	30
3	Reconfiguring office layouts to reduce underutilized spaces	52.7	I	2	25
6. Cost Reduction		RII	IR	IGR	OR
1	Optimizing maintenance processes to lower operational costs	58.8	I	1	9
2	Real-time monitoring in identifying cost-saving opportunities	55.2	I	2	19
3	Reducing human intervention in routine facility tasks	51.8	I	3	27
7. Sustainability		RII	IR	IGR	OR
1	Monitoring resource consumption, such as energy and water usage	60.0	I	1	7
2	Implementing strategies to reduce a building's environmental impact	55.8	I	3	18
3	Supporting long-term sustainability initiatives	57.2	I	2	15
8. Data-Driven Decisions		RII	IR	IGR	OR
1	Providing actionable insights for improving building operations	59.2	I	1	8
2	Identifying inefficiencies and opportunities for improvement	55.0	I	2	20
3	Supporting strategic and operational decision-making	51.7	I	3	28
9. User Experience		RII	IR	IGR	OR
1	Developing dynamic and responsive workspaces	53.7	I	1	22
2	Personalizing workspace settings to individual preferences	52.7	I	2	26
3	Developing automated booking systems for shared spaces	50.7	I	3	29
10. Flexibility in Management		RII	IR	IGR	OR
1	Accessing real-time data on building systems	57.8	I	1	13
2	Adjusting operations remotely	57.8	I	1	14
3	Ensuring quicker issue resolution and improved building performance	55.0	I	2	21
Stander Deviation (SD) = 3.88					
Cronbach's Alpha (Ca) = 0.84					

Table 6 Assessment of Drivers

4.4.1 Assessment of the Drivers from the A/Es' Perspective

The assessment of drivers influencing IoT adoption in smart office building operations and maintenance (O&M) from the Architects and Engineers' (A/Es') perspective provided significant insights into their priorities.

Drivers		A/Es										
1. Energy Efficiency		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Real-time monitoring for optimizing energy usage in building systems	14	10	6	0	0	30	98	65.3	V1	2	7
2	The ability to adjust HVAC and lighting systems based on occupancy and environmental conditions	14	10	3	3	0	30	95	63.3	V1	3	10
3	Minimizing unnecessary energy consumption and reducing waste	20	4	6	0	0	30	104	69.3	V1	1	3
2. Operational Efficiency		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Detecting early signs of equipment malfunction	13	10	4	3	0	30	93	62.0	I	2	14
2	Predictive maintenance in reducing equipment downtime and repair costs	13	11	5	1	0	30	96	64.0	V1	1	9
3	Scheduling timely maintenance interventions	9	9	9	2	1	30	83	55.3	I	3	22
3. Occupant Comfort		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Personalizing lighting, temperature, and air quality in real time	10	10	9	0	1	30	88	58.7	I	2	20
2	Developing a comfortable work environment	12	9	7	2	0	30	91	60.7	I	1	17
3	Improving worker productivity and satisfaction	8	8	9	3	2	30	77	51.3	I	3	27
4. Security and Safety		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Providing real-time surveillance for improved security	18	7	2	3	0	30	100	66.7	V1	2	4
2	Controlling access for improving safety	15	10	5	0	0	30	100	66.7	V1	2	5
3	Detecting and alerting potential hazards like smoke or gas leaks	20	8	1	0	1	30	106	70.7	V1	1	2
5. Space Utilization		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Collecting real-time data on office occupancy and usage patterns	5	13	10	2	0	30	81	54.0	I	2	25
2	Optimizing space allocation based on IoT-generated insights	4	11	11	4	0	30	75	50.0	I	3	30
3	Reconfiguring office layouts to reduce underutilized spaces	11	9	8	2	0	30	89	59.3	I	1	18
6. Cost Reduction		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Optimizing maintenance processes to lower operational costs	11	9	8	2	0	30	89	59.3	I	1	19
2	Real-time monitoring to identify cost-saving opportunities	8	11	7	4	0	30	83	55.3	I	3	23
3	Reducing human intervention in routine facility tasks	12	8	2	8	0	30	84	56.0	I	2	21
7. Sustainability		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Monitoring resource consumption, such as energy and water usage	19	9	2	0	0	30	107	71.3	V1	1	1
2	Implementing strategies to reduce a building's environmental impact	14	10	5	1	0	30	97	64.7	V1	3	8
3	Supporting long-term sustainability initiatives	18	6	4	1	1	30	99	66.0	V1	2	6
8. Data-Driven Decisions		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Providing actionable insights for improving building operations	11	15	2	2	0	30	95	63.3	V1	1	11
2	Identifying inefficiencies and opportunities for improvement	5	22	3	0	0	30	92	61.3	I	2	16
3	Supporting strategic and operational decision-making	8	12	5	4	1	30	82	54.7	I	3	24
9. User Experience		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Developing dynamic and responsive workspaces	7	13	6	2	2	30	81	54.0	I	1	26
2	Personalizing workspace settings to individual preferences	7	10	8	3	2	30	77	51.3	I	2	28
3	Developing automated booking systems for shared spaces	9	5	11	4	1	30	77	51.3	I	2	29
10. Flexibility in Management		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Accessing real-time data on building systems	15	5	9	1	0	30	94	62.7	V1	1	12
2	Adjusting operations remotely	13	10	6	0	1	30	94	62.7	V1	1	13
3	Ensuring quicker issue resolution and improved building performance	12	11	6	0	1	30	93	62.0	I	2	15
Stander Deviation (SD) = 6.01												

Table 7 Assessment of Drivers from A/Es' Perspective

The findings, based on the Relative Importance Index (RII), highlighted that energy efficiency and operational efficiency stand out as the top influential factors, with RIIs of approximately 71.33% and 70.67%, respectively. This clearly underscores that A/E professionals prioritize smart building technologies primarily for their potential to optimize energy consumption, reduce operational costs, and enhance building performance through real-time monitoring and automation capabilities. Moreover, other highly rated drivers include improved security and safety, enhanced occupant comfort, effective space utilization, and sustainability initiatives, reflecting the multifaceted benefits of IoT adoption recognized by A/E practitioners.

However, factors such as flexibility in management, data-driven decision-making capabilities, and overall user experience received comparatively lower importance scores, indicating that while these aspects are beneficial, they are not the primary motivations driving IoT integration according to A/Es.

Overall, the results from this assessment provide valuable direction for strategic planning and resource allocation, helping stakeholders prioritize IoT features and functionalities that align closely with the expertise, needs, and expectations of A/E professionals in smart building projects.

4.4.2 Assessment of the Drivers from the Developers' / Owners' Perspective

The assessment of drivers influencing IoT adoption in smart office building operations and maintenance (O&M) from the Developers'/Owners' perspective identified key priorities based on their importance scores (RII).

Drivers				Developers										
				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1. Energy Efficiency				22	4	3	1	0	30	107	71.3	VI	1	1
1	Real-time monitoring for optimizing energy usage in building systems			10	11	6	2	1	30	87	58.0	I	3	19
2	The ability to adjust HVAC and lighting systems based on occupancy and environmental conditions			10	13	6	1	0	30	92	61.3	I	2	7
3	Minimizing unnecessary energy consumption and reducing waste													
2. Operational Efficiency				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Detecting early signs of equipment malfunction			12	9	7	0	0	30	97	64.7	VI	1	3
2	Predictive maintenance in reducing equipment downtime and repair costs			14	9	7	2	0	30	91	60.7	I	2	11
3	Scheduling timely maintenance interventions			10	12	6	1	1	30	89	59.3	I	3	15
3. Occupant Comfort				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Personalizing lighting, temperature, and air quality in real time			12	10	5	3	0	30	91	60.7	I	1	12
2	Developing a comfortable work environment			7	12	9	1	1	30	83	55.3	I	3	25
3	Improving worker productivity and satisfaction			9	10	9	1	1	30	85	56.7	I	2	22
4. Security and Safety				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Providing real-time surveillance for improved security			12	7	10	1	0	30	90	60.0	I	2	13
2	Controlling access for improving safety			14	9	4	1	2	30	92	61.3	I	1	8
3	Detecting and alerting potential hazards like smoke or gas leaks			12	12	3	2	1	30	92	61.3	I	1	9
5. Space Utilization				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Collecting real-time data on office occupancy and usage patterns			10	8	6	4	2	30	80	53.3	I	3	29
2	Optimizing space allocation based on IoT-generated insights			12	9	7	1	1	30	90	60.0	I	1	14
3	Reconfiguring office layouts to reduce underutilized spaces			10	8	8	3	1	30	83	55.3	I	2	26
6. Cost Reduction				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Optimizing maintenance processes to lower operational costs			16	7	5	0	2	30	95	63.3	VI	1	4
2	Real-time monitoring in identifying cost-saving opportunities			11	11	4	4	0	30	89	59.3	I	2	16
3	Reducing human intervention in routine facility tasks			8	9	8	3	2	30	78	52.0	I	3	30
7. Sustainability				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Monitoring resource consumption, such as energy and water usage			17	7	2	2	2	30	95	63.3	VI	1	5
2	Implementing strategies to reduce a building's environmental impact			13	10	4	2	1	30	92	61.3	I	2	10
3	Supporting long-term sustainability initiatives			12	7	9	1	1	30	88	58.7	I	3	18
8. Data-Driven Decisions				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Providing actionable insights for improving building operations			18	6	5	0	1	30	100	66.7	VI	1	2
2	Identifying inefficiencies and opportunities for improvement			9	11	8	1	1	30	86	57.3	I	2	20
3	Supporting strategic and operational decision-making			10	7	9	4	0	30	83	55.3	I	3	27
9. User Experience				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Developing dynamic and responsive workspaces			12	7	9	2	0	30	89	59.3	I	1	17
2	Personalizing workspace settings to individual preferences			8	11	9	2	0	30	85	56.7	I	2	23
3	Developing automated booking systems for shared spaces			12	7	6	2	3	30	83	55.3	I	3	28
10. Flexibility in Management				4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR
1	Accessing real-time data on building systems			12	7	7	3	1	30	86	57.3	I	2	21
2	Adjusting operations remotely			14	9	5	2	0	30	95	63.3	VI	1	6
3	Ensuring quicker issue resolution and improved building performance			11	8	7	2	2	30	84	56.0	I	3	24
				Stander Deviation (SD) = 4.08										

Table 8 Assessment of Drivers from Developers'/Owners' Perspective

Energy efficiency emerged as the leading driver, scoring the highest RII at 71.33%, reflecting the developers' and building owners' strong preference toward reducing energy consumption and enhancing sustainability. Other critical factors included operational performance improvements and enhanced safety and security, with RIIs around 66.67% and 64.67%, respectively, demonstrating their importance in protecting investments and optimizing building performance. Furthermore, developers and owners also recognized cost reduction, occupant comfort, and space utilization as influential drivers, highlighting their aim for long-term economic sustainability and improved user satisfaction.

Moreover, drivers like data-driven decision-making, flexibility in management, and user experience were rated lower, indicating that while beneficial, these aspects are considered less crucial compared to direct economic and operational advantages.

Overall, the perspectives of developers and owners emphasize a pragmatic approach to IoT adoption, driven by clear financial returns, operational efficiency, and risk mitigation in smart office building management.

4.4.3 Assessment of the Drivers from the FMs' Perspective

The assessment of drivers influencing IoT adoption in smart office building operations and maintenance (O&M) from the Facilities Managers' (FMs') perspective emphasized practical operational benefits.

Drivers			FM's										
			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1. Energy Efficiency			20	6	2	2	0	30	104	69.3	VI	1	1
1	Real-time monitoring for optimizing energy usage in building systems												
2	The ability to adjust HVAC and lighting systems based on occupancy and environmental conditions		4	16	7	3	0	30	81	54.0	I	2	8
3	Minimizing unnecessary energy consumption and reducing waste		6	12	9	3	0	30	81	54.0	I	2	9
2. Operational Efficiency			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Detecting early signs of equipment malfunction		6	8	11	5	0	30	75	50.0	I	3	15
2	Predictive maintenance in reducing equipment downtime and repair costs		8	13	6	3	0	30	86	57.3	I	2	5
3	Scheduling timely maintenance interventions		12	6	9	3	0	30	87	58.0	I	1	2
3. Occupant Comfort			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Personalizing lighting, temperature, and air quality in real time		15	3	6	6	0	30	87	58.0	I	1	3
2	Developing a comfortable work environment		8	9	7	6	0	30	79	52.7	I	2	10
3	Improving worker productivity and satisfaction		8	9	5	7	1	30	76	50.7	I	3	12
4. Security and Safety			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Providing real-time surveillance for improved security		13	8	3	4	2	30	86	57.3	I	1	5
2	Controlling access for improving safety		11	10	4	3	2	30	85	56.7	I	2	6
3	Detecting and alerting potential hazards like smoke or gas leaks		7	8	9	1	5	30	71	47.3	I	3	22
5. Space Utilization			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Collecting real-time data on office occupancy and usage patterns		9	6	7	4	4	30	72	48.0	I	1	21
2	Optimizing space allocation based on IoT-generated insights		3	6	12	7	2	30	61	40.7	I	2	29
3	Reconfiguring office layouts to reduce underutilized spaces		4	7	8	7	4	30	60	40.0	I	3	30
6. Cost Reduction			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Optimizing maintenance processes to lower operational costs		4	9	12	4	1	30	71	47.3	I	3	23
2	Real-time monitoring in identifying cost-saving opportunities		5	9	12	4	0	30	75	50.0	I	1	16
3	Reducing human intervention in routine facility tasks		5	7	16	1	1	30	74	49.3	I	2	18
7. Sustainability			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Monitoring resource consumption, such as energy and water usage		5	7	10	5	3	30	66	44.0	I	2	26
2	Implementing strategies to reduce a building's environmental impact		4	7	11	6	2	30	65	43.3	I	3	28
3	Supporting long-term sustainability initiatives		9	7	7	5	2	30	76	50.7	I	1	13
8. Data-Driven Decisions			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Providing actionable insights for improving building operations		6	12	5	6	1	30	76	50.7	I	1	14
2	Identifying inefficiencies and opportunities for improvement		7	5	8	7	3	30	66	44.0	I	3	27
3	Supporting strategic and operational decision-making		8	6	9	5	2	30	73	48.7	I	2	20
9. User Experience			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Developing dynamic and responsive workspaces		8	7	9	6	0	30	77	51.3	I	1	11
2	Personalizing workspace settings to individual preferences		9	6	8	5	2	30	75	50.0	I	2	17
3	Developing automated booking systems for shared spaces		6	5	12	4	3	30	67	44.7	I	3	25
10. Flexibility in Management			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	ICR	OR
1	Accessing real-time data on building systems		12	6	6	4	2	30	82	54.7	I	1	7
2	Adjusting operations remotely		5	9	7	9	0	30	70	46.7	I	3	24
3	Ensuring quicker issue resolution and improved building performance		8	6	9	6	1	30	74	49.3	I	2	19
Standar Deviation (SD) = 6.07													

Table 9 Assessment of Drivers from FM's Perspective

Energy efficiency was identified as the primary driver, with the highest Relative Importance Index (RII) of 69.33%, highlighting the critical importance placed by FMs on monitoring and reducing energy consumption through IoT technologies. Other prominent drivers included aspects related to occupant comfort and improved security and safety, reflecting Facilities Managers' focus on maintaining optimal environments for occupants while ensuring secure and reliable operations. Additional factors like operational efficiency, effective space utilization, and cost reduction also received considerable attention, indicating their relevance in routine facility management practices.

Furthermore, drivers such as data-driven decision-making, flexibility in management, and overall user experience received relatively low scores, suggesting that, for Facilities Managers, immediate practical outcomes and tangible operational improvements hold greater priority than indirect or long-term strategic benefits.

Overall, these findings underscore the pragmatic and operationally focused priorities of FMs, aligning IoT adoption closely with day-to-day building management tasks and direct benefits to facility performance.

4.4.4 Assessment of the Drivers from the IOTs' Perspective

The assessment of drivers influencing IoT adoption in smart office building operations and maintenance (O&M) from the IoT professionals' perspective revealed distinct priorities centered around technological capabilities and their practical benefits.

Drivers			IOT's										
			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1. Energy Efficiency			14	12	6	0	0	32	104	65.0	VI	1	2
1	Real-time monitoring for optimizing energy usage in building systems												
2	The ability to adjust HVAC and lighting systems based on occupancy and environmental conditions		11	10	5	1	3	30	85	56.7	I	2	10
3	Minimizing unnecessary energy consumption and reducing waste		9	12	4	3	2	30	83	55.3	I	3	19
2. Operational Efficiency			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Detecting early signs of equipment malfunction		10	14	1	3	2	30	87	58.0	I	2	8
2	Predictive maintenance in reducing equipment downtime and repair costs		13	7	9	1	0	30	92	61.3	I	1	4
3	Scheduling timely maintenance interventions		10	10	4	4	2	30	82	54.7	I	3	20
3. Occupant Comfort			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Personalizing lighting, temperature, and air quality in real time		9	13	3	4	1	30	85	56.7	I	1	11
2	Developing a comfortable work environment		10	7	10	3	0	30	84	56.0	I	2	13
3	Improving worker productivity and satisfaction		10	8	6	3	3	30	79	52.7	I	3	23
4. Security and Safety			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Providing real-time surveillance for improved security		10	10	5	4	1	30	84	56.0	I	3	14
2	Controlling access for improving safety		12	10	6	2	0	30	92	61.3	I	2	5
3	Detecting and alerting potential hazards like smoke or gas leaks		16	7	4	2	1	30	95	63.3	VI	1	3
5. Space Utilization			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Collecting real-time data on office occupancy and usage patterns		11	7	8	3	1	30	84	56.0	I	1	15
2	Optimizing space allocation based on IoT-generated insights		11	5	7	5	2	30	78	52.0	I	2	26
3	Reconfiguring office layouts to reduce underutilized spaces		13	5	7	3	2	30	84	56.0	I	1	16
6. Cost Reduction			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Optimizing maintenance processes to lower operational costs		16	9	3	1	1	30	98	65.3	VI	1	1
2	Real-time monitoring in identifying cost-saving opportunities		11	9	5	3	2	30	84	56.0	I	2	17
3	Reducing human intervention in routine facility tasks		8	9	6	4	3	30	75	50.0	I	3	28
7. Sustainability			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Monitoring resource consumption, such as energy and water usage		14	9	3	3	1	30	92	61.3	I	1	6
2	Implementing strategies to reduce a building's environmental impact		7	12	7	3	1	30	81	54.0	I	2	21
3	Supporting long-term sustainability initiatives		10	7	8	3	2	30	80	53.3	I	3	22
8. Data-Driven Decisions			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Providing actionable insights for improving building operations		9	11	6	3	1	30	84	56.0	I	2	18
2	Identifying inefficiencies and opportunities for improvement		12	8	6	2	2	30	86	57.3	I	1	9
3	Supporting strategic and operational decision-making		8	9	6	1	6	30	72	48.0	I	3	30
9. User Experience			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Developing dynamic and responsive workspaces		8	7	10	2	3	30	75	50.0	I	3	29
2	Personalizing workspace settings to individual preferences		9	9	5	6	1	30	79	52.7	I	1	24
3	Developing automated booking systems for shared spaces		8	11	3	6	2	30	77	51.3	I	2	27
10. Flexibility in Management			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Accessing real-time data on building systems		12	7	6	4	1	30	85	56.7	I	2	12
2	Adjusting operations remotely		8	14	7	0	1	30	88	58.7	I	1	7
3	Ensuring quicker issue resolution and improved building performance		7	12	6	3	2	30	79	52.7	I	3	25
Stander Deviation (SD) = 4.32													

Table 10 Assessment of Drivers from IoT Professionals' Perspective

IoT professionals ranked energy efficiency as a leading driver, with a Relative Importance Index (RII) of 65%, underscoring their role in leveraging IoT solutions for real-time monitoring and optimizing energy consumption. Operational efficiency, effective data-driven decisions, and occupant comfort were also highly valued, emphasizing that IoT professionals prioritize elements that highlight the technological strengths and direct operational improvements achievable through IoT systems.

Moreover, flexibility in management, general user experience, and occupant comfort received comparatively lower scores, indicating lesser emphasis by IoT specialists who tend to prioritize system functionality and data-driven outcomes over softer operational aspects.

Overall, these insights illustrate that IoT professionals prioritize factors directly related to system performance, reliability, and efficiency, guiding the practical implementation and ongoing effectiveness of IoT-enabled smart buildings.

4.5 Assessment of the Challenges in IoT-Based Smart Office Building O&M

This section discusses the assessment findings related to the challenges affecting IoT adoption in smart office building O&M, based on the responses obtained from the four respondent groups.

Overall Challenges		Overall			
1. Complexity in Installation and Integration		RII	IR	IGR	OR
1	Ensuring interoperability between various IoT devices and systems during installation	66.7	VI	1	1
2	Minimizing the time and cost associated with integrating IoT systems in smart office buildings	59.7	I	3	14
3	Synchronizing IoT systems (e.g., lighting, HVAC, security) into a unified platform	61.3	I	2	6
2. Data Security and Privacy Concerns		RII	IR	IGR	OR
1	Protecting sensitive occupant data collected by IoT devices in smart office buildings	63.8	VI	1	2
2	Addressing privacy concerns related to IoT-enabled occupant monitoring	60.0	I	3	12
3	Implementing security measures to prevent unauthorized access to IoT data	61.5	I	2	5
3. High Initial Investment		RII	IR	IGR	OR
1	Reducing the financial burden of acquiring IoT infrastructure for smart office buildings	60.2	I	1	10
2	Demonstrating a clear return on investment (ROI) for IoT adoption in building operations	53.8	I	3	30
3	Providing financial incentives or support for organizations to adopt IoT technologies	54.7	I	2	28
4. Maintenance and Technological Expertise		RII	IR	IGR	OR
1	Ensuring regular maintenance of IoT devices to prevent system failures	60.2	I	3	11
2	Having in-house technical expertise to manage and troubleshoot IoT systems	60.3	I	2	8
3	Planning for software and hardware updates to keep IoT systems functional and secure	60.5	I	1	7
5. Data Overload and Management		RII	IR	IGR	OR
1	Implementing effective data analytics tools to process IoT-generated data	59.8	I	1	13
2	Training facility managers to extract actionable insights from IoT data	56.5	I	2	22
3	Developing frameworks to prioritize critical information from IoT systems	52.7	I	3	32
6. Cybersecurity Threats		RII	IR	IGR	OR
1	Ensuring IoT devices are equipped with robust cybersecurity protections	63.0	VI	1	3
2	Detecting and mitigating vulnerabilities in IoT networks	61.7	I	2	4
3	Securing communication between IoT devices to prevent cyberattacks	60.3	I	3	9
7. Reliability of IoT Networks		RII	IR	IGR	OR
1	Ensuring uninterrupted network connectivity for IoT systems in smart office buildings	58.8	I	2	18
2	Reducing the impact of network disruptions on building operations	59.0	I	1	17
3	Upgrading network infrastructure to support IoT deployments	56.2	I	3	24
8. Environmental Impact and Sustainability Concerns		RII	IR	IGR	OR
1	Minimizing the environmental footprint of IoT devices during production and disposal	57.0	I	1	21
2	Developing recycling programs for outdated IoT devices	54.8	I	2	25
3	Balancing the energy efficiency gains of IoT systems against their environmental costs	54.8	I	2	26
9. Interference with Building Legacy Systems		RII	IR	IGR	OR
1	Ensuring compatibility between IoT technologies and existing building systems	58.2	I	1	19
2	Minimizing downtime when integrating IoT with legacy systems	56.3	I	2	23
3	Developing cost-effective strategies for upgrading legacy systems to accommodate IoT	54.5	I	3	29
10. High Energy Consumption of IoT Devices		RII	IR	IGR	OR
1	Monitoring the energy consumption of IoT devices in smart office buildings	57.5	I	1	20
2	Optimizing the power usage of IoT devices to reduce overall operational costs	52.3	I	3	33
3	Balancing the energy use of IoT devices with their benefits in energy savings	53.7	I	2	31
11. Ongoing Operation and Maintenance Costs of IoT Devices		RII	IR	IGR	OR
1	Ensuring regular software updates, calibration, and hardware replacements for IoT devices	59.0	I	2	16
2	Optimizing the energy consumption of interconnected IoT devices to reduce utility expenses	59.2	I	1	15
3	Managing labor costs by providing specialized expertise for IoT maintenance activities	51.7	I	4	34
4	Implementing cost optimization strategies to minimize recurring expenses in older buildings retrofitted with IoT systems	54.8	I	3	27
Stander Deviation (SD) = 3.53					
Cronbach's Alpha (Ca) = 0.86					

Table 11 Assessment of Challenges

4.5.1 Assessment of the Challenges from the A/Es' Perspective

The assessment conducted from the Architects and Engineers (A/Es') perspective identified critical challenges impacting the adoption of IoT in smart office building operations and maintenance (O&M).

Challenges			A/Es										
1. Complexity in Installation and Integration			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Ensuring interoperability between various IoT devices and systems during installation		9	16	5	0	0	30	94	62.7	VI	3	17
2	Minimizing the time and cost associated with integrating IoT systems in smart office buildings		16	10	2	2	0	30	100	66.7	VI	1	6
3	Synchronizing IoT systems (e.g., lighting, HVAC, security) into a unified platform		15	10	2	3	0	30	97	64.7	VI	2	10
2. Data Security and Privacy Concerns			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Protecting sensitive occupant data collected by IoT devices in smart office buildings		21	7	1	1	0	30	108	72.0	VI	1	1
2	Addressing privacy concerns related to IoT-enabled occupant monitoring		15	9	5	1	0	30	98	65.3	VI	3	7
3	Implementing security measures to prevent unauthorized access to IoT data		16	11	3	0	0	30	103	68.7	VI	2	3
3. High Initial Investment			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Reducing the financial burden of acquiring IoT infrastructure for smart office buildings		9	11	9	1	0	30	88	58.7	I	1	24
2	Demonstrating a clear return on investment (ROI) for IoT adoption in building operations		7	10	10	3	0	30	81	54.0	I	3	33
3	Providing financial incentives or support for organizations to adopt IoT technologies		9	9	8	4	0	30	83	55.3	I	2	31
4. Maintenance and Technological Expertise			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Ensuring regular maintenance of IoT devices to prevent system failures		13	13	3	1	0	30	98	65.3	VI	1	9
2	Having in-house technical expertise to manage and troubleshoot IoT systems		15	9	5	0	1	30	97	64.7	VI	2	11
3	Planning for software and hardware updates to keep IoT systems functional and secure		16	8	3	3	0	30	97	64.7	VI	2	12
5. Data Overload and Management			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Implementing effective data analytics tools to process IoT-generated data		7	18	3	2	0	30	90	60.0	I	1	21
2	Training facility managers to extract actionable insights from IoT data		10	12	6	2	0	30	90	60.0	I	1	22
3	Developing frameworks to prioritize critical information from IoT systems		10	8	6	6	0	30	82	54.7	I	2	32
6. Cybersecurity Threats			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Ensuring IoT devices are equipped with robust cybersecurity protections		18	9	1	2	0	30	103	68.7	VI	2	4
2	Detecting and mitigating vulnerabilities in IoT networks		14	9	6	1	0	30	96	64.0	VI	3	13
3	Securing communication between IoT devices to prevent cyberattacks		22	4	3	1	0	30	107	71.3	VI	1	2
7. Reliability of IoT Networks			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Ensuring uninterrupted network connectivity for IoT systems in smart office buildings		15	9	3	1	2	30	94	62.7	VI	2	16
2	Reducing the impact of network disruptions on building operations		18	5	4	1	2	30	96	64.0	VI	1	14
3	Upgrading network infrastructure to support IoT deployments		13	7	4	5	1	30	86	57.3	I	3	27
8. Environmental Impact and Sustainability Concerns			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Minimizing the environmental footprint of IoT devices during production and disposal		13	6	8	1	2	30	87	58.0	I	2	26
2	Developing recycling programs for outdated IoT devices		9	10	4	5	2	30	79	52.7	I	1	34
3	Balancing the energy efficiency gains of IoT systems against their environmental costs		14	5	9	2	0	30	91	60.7	I	3	19
9. Interference with Building Legacy Systems			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Ensuring compatibility between IoT technologies and existing building systems		16	10	4	0	0	30	102	68.0	VI	1	5
2	Minimizing downtime when integrating IoT with legacy systems		9	9	10	2	0	30	85	56.7	I	3	29
3	Developing cost-effective strategies for upgrading legacy systems to accommodate IoT		10	12	7	1	0	30	91	60.7	I	2	20
10. High Energy Consumption of IoT Devices			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Monitoring the energy consumption of IoT devices in smart office buildings		12	10	7	1	0	30	93	62.0	I	1	18
2	Optimizing the power usage of IoT devices to reduce overall operational costs		12	7	9	2	0	30	89	59.3	I	2	23
3	Balancing the energy use of IoT devices with their benefits in energy savings		9	11	7	1	2	30	84	56.0	I	3	30
11. Ongoing Operation and Maintenance Costs of IoT Devices			4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Ensuring regular software updates, calibration, and hardware replacements for IoT devices		13	9	7	1	0	30	94	62.7	VI	2	15
2	Optimizing the energy consumption of interconnected IoT devices to reduce utility expenses		12	15	2	1	0	30	98	65.3	VI	1	8
3	Managing labor costs by providing specialized expertise for IoT maintenance activities		9	10	8	3	0	30	85	56.7	I	4	28
4	Implementing cost optimization strategies to minimize recurring expenses in older buildings retrofitted with IoT systems		9	12	7	1	1	30	87	58.0	I	3	25
Stander Deviation (SD) = 4.99													

Table 12 Assessment of Challenges from A/Es' Perspective

The top-rated challenge was the complexity associated with the installation and integration of IoT systems, demonstrating a Relative Importance Index (RII) of approximately 68%, signifying that interoperability and seamless integration are major concerns for architectural and engineering professionals. Moreover, issues related to cybersecurity threats, operational reliability, and maintaining compatibility with legacy building systems were considered significantly challenging, indicating that professionals perceive these as potential obstacles to the successful deployment and utilization of IoT technologies. Other notable challenges included ensuring data security, dealing with cybersecurity threats, and managing the cost implications of IoT adoption, reinforcing the view that architects and engineers are particularly concerned with technical feasibility, security, and economic viability of IoT solutions.

However, issues related to environmental impacts, flexibility in management, and interference with existing building operations appeared less pressing, though still notable.

Overall, the assessment underscores that for A/Es, addressing technical complexities, ensuring secure implementation, and maintaining cost-effectiveness are pivotal to overcoming barriers to successful IoT adoption in smart office buildings.

4.5.2 Assessment of the Challenges from the Developers' / Owners' Perspective

The assessment of challenges impacting IoT adoption in smart office building operations and maintenance (O&M) from the Developers'/Owners' perspective revealed that several significant barriers were prioritized based on their Relative Importance Index (RII).

Challenges		Developers											
1. Complexity in Installation and Integration		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Ensuring interoperability between various IoT devices and systems during installation	17	7	6	0	0	30	101	67.3	VI	1	1	
2	Minimizing the time and cost associated with integrating IoT systems in smart office buildings	7	16	6	1	0	30	89	59.3	I	3	18	
3	Synchronizing IoT systems (e.g., lighting, HVAC, security) into a unified platform	14	9	6	1	0	30	96	64.0	VI	2	10	
2. Data Security and Privacy Concerns		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Protecting sensitive occupant data collected by IoT devices in smart office buildings	14	10	6	0	0	30	98	65.3	VI	1	4	
2	Addressing privacy concerns related to IoT-enabled occupant monitoring	10	10	7	2	1	30	86	57.3	I	3	26	
3	Implementing security measures to prevent unauthorized access to IoT data	12	11	6	1	0	30	94	62.7	VI	2	11	
3. High Initial Investment		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Reducing the financial burden of acquiring IoT infrastructure for smart office buildings	13	13	3	1	0	30	98	65.3	VI	1	6	
2	Demonstrating a clear return on investment (ROI) for IoT adoption in building operations	7	15	6	2	0	30	87	58.0	I	3	23	
3	Providing financial incentives or support for organizations to adopt IoT technologies	10	13	4	3	0	30	90	60.0	I	2	14	
4. Maintenance and Technical Expertise		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Ensuring regular maintenance of IoT devices to prevent system failures	12	10	5	3	0	30	91	60.7	I	2	12	
2	Having in-house technical expertise to manage and troubleshoot IoT systems	15	10	4	1	0	30	99	66.0	VI	1	3	
3	Partnering for software and hardware updates to keep IoT systems functional and secure	14	10	5	1	0	30	97	64.7	VI	3	8	
5. Data Overload and Management		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Implementing effective data analytics tools to process IoT-generated data	14	9	7	0	0	30	97	64.7	VI	1	9	
2	Training facility managers to extract actionable insights from IoT data	8	10	12	0	0	30	86	57.3	I	2	24	
3	Developing frameworks to prioritize critical information from IoT systems	7	8	13	2	0	30	80	53.3	I	3	32	
6. Cybersecurity Threats		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Ensuring IoT devices are equipped with robust cybersecurity protections	14	5	9	2	0	30	91	60.7	I	2	13	
2	Detecting and mitigating vulnerabilities in IoT networks	14	12	3	1	0	30	99	66.0	VI	1	2	
3	Securing communication between IoT devices to prevent cyberattacks	10	9	9	2	0	30	87	58.0	I	3	22	
7. Reliability of IoT Networks		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Ensuring uninterrupted network connectivity for IoT systems in smart office buildings	15	9	5	1	0	30	98	65.3	VI	1	7	
2	Reducing the impact of network disruptions on building operations	13	12	5	0	0	30	98	65.3	VI	1	5	
3	Upgrading network infrastructure to support IoT deployments	11	11	6	0	2	30	89	59.3	I	2	19	
8. Environmental Impact and Sustainability Concerns		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Minimizing the environmental footprint of IoT devices during production and disposal	11	9	8	2	0	30	89	59.3	I	1	16	
2	Developing recycling programs for outdated IoT devices	7	16	6	1	0	30	89	59.3	I	1	17	
3	Balancing the energy efficiency gains of IoT systems against their environmental costs	10	6	10	3	1	30	81	54.0	I	2	31	
9. Interference with Building Legacy Systems		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Ensuring compatibility between IoT technologies and existing building systems	12	10	5	2	1	30	90	60.0	I	1	15	
2	Minimizing downtime when integrating IoT with legacy systems	9	10	8	3	0	30	85	56.7	I	2	27	
3	Developing cost-effective strategies for upgrading legacy systems to accommodate IoT	7	12	9	2	0	30	84	56.0	I	3	29	
10. High Energy Consumption of IoT Devices		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Monitoring the energy consumption of IoT devices in smart office buildings	13	5	8	3	1	30	86	57.3	I	1	25	
2	Optimizing the power usage of IoT devices to reduce overall operational costs	7	10	8	4	1	30	78	52.0	I	3	33	
3	Balancing the energy use of IoT devices with their benefits in energy savings	11	7	9	2	1	30	85	56.7	I	2	28	
11. Ongoing Operation and Maintenance Costs of IoT Devices		4.EI	3.VI	2.I	1.SI	0.NI	Total	W	RII	IR	IGR	OR	
1	Ensuring regular software updates, calibration, and hardware replacements for IoT devices	11	11	4	3	1	30	88	58.7	I	1	20	
2	Optimizing the energy consumption of interconnected IoT devices to reduce utility expenses	11	11	4	2	2	30	87	58.0	I	2	21	
3	Minimizing labor costs by providing specialized expertise for IoT maintenance activities	7	10	8	4	1	30	78	52.0	I	4	34	
4	Implementing cost optimization strategies to minimize recurring expenses in older buildings retrofitted with IoT systems	10	8	9	2	1	30	84	56.0	I	3	30	
Stander Deviation (SD) = 4.29													

Table 13 Assessment of Challenges from Developers'/Owners' Perspective

Complexity in installation and integration of IoT systems was identified as the leading challenge, with an RII of approximately 67.33%, reflecting substantial concerns regarding the complexity, interoperability, and compatibility of IoT solutions. Moreover, data security, privacy concerns, and ensuring technological compatibility scored highly, each with an RII around 66%, indicating that developers and owners place significant emphasis on managing risks associated with sensitive data and securing reliable IoT infrastructures. Other notable challenges included high initial investment costs, maintenance requirements, and the necessity of specialized technical expertise, highlighting economic and operational considerations as significant deterrents to IoT adoption.

Furthermore, challenges such as data overload, cybersecurity threats, and long-term maintenance costs, though acknowledged, received relatively lower importance ratings, suggesting that these issues are perceived as manageable or secondary compared to initial implementation concerns.

Overall, this analysis indicates that Developers and Owners primarily focus on upfront economic barriers, security concerns, and integration complexities as the major challenges when considering IoT adoption in smart office buildings.

4.5.3 Assessment of the Challenges from the FMs' Perspective

The assessment of challenges impacting IoT adoption in smart office building operations and maintenance (O&M) from the Facilities Managers' (FMs') perspective identified several critical issues.

Challenges		FMs											
		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1. Complexity in Installation and Integration													
1.	Ensuring interoperability between various IoT devices and systems during installation	19	9	1	1	0	30	106	70.7	VI	1	1	
2.	Minimizing the time and cost associated with integrating IoT systems in smart office buildings	3	19	5	2	1	30	81	54.0	I	2	13	
3.	Synchronizing IoT systems (e.g., lighting, HVAC, security) into a unified platform	6	12	9	1	2	30	79	52.7	I	3	18	
2. Data Security and Privacy Concerns													
1.	Protecting sensitive occupant data collected by IoT devices in smart office buildings	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Addressing privacy concerns related to IoT-enabled occupant monitoring	8	14	4	4	0	30	86	57.3	I	2	8	
3.	Implementing security measures to prevent unauthorized access to IoT data	14	5	8	1	2	30	88	58.7	I	1	4	
		10	12	4	4	0	30	88	58.7	I	1	3	
3. High Initial Investment													
1.	Reducing the financial burden of acquiring IoT infrastructures for smart office buildings	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Demonstrating a clear return on investment (ROI) for IoT adoption in building operations	11	7	7	5	0	30	84	56.0	I	1	9	
3.	Providing financial incentives or support for organizations to adopt IoT technologies	8	7	10	4	1	30	77	51.3	I	2	23	
		5	10	11	3	1	30	75	50.0	I	3	27	
4. Maintenance and Technical Expertise													
1.	Ensuring regular maintenance of IoT devices to prevent system failures	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Having in-house technical expertise to manage and troubleshoot IoT systems	8	13	7	2	0	30	87	58.0	I	1	6	
3.	Partnering for software and hardware updates to keep IoT systems functional and secure	7	8	10	5	0	30	77	51.3	I	3	22	
		9	11	7	3	0	30	86	57.3	I	2	7	
5. Data Overhead and Management													
1.	Implementing effective data analytics tools to process IoT-generated data	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Transferring facility managers to extract actionable insights from IoT data	12	6	9	3	0	30	87	58.0	I	1	5	
3.	Developing frameworks to prioritize critical information from IoT systems	7	10	10	2	1	30	80	53.3	I	2	15	
		7	9	11	3	0	30	80	53.3	I	2	16	
6. Cybersecurity Threats													
1.	Ensuring IoT devices are equipped with robust cybersecurity protections	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Detecting and mitigating vulnerabilities in IoT networks	11	11	7	1	0	30	92	61.3	I	1	2	
3.	Securing communication between IoT devices to prevent cyberattacks	6	11	8	5	0	30	78	52.0	I	2	21	
		8	8	10	2	2	30	78	52.0	I	2	20	
7. Reliability of IoT Networks													
1.	Ensuring uninterrupted network connectivity for IoT systems in smart office buildings	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Reducing the impact of network disruptions on building operations	8	8	5	7	2	30	73	48.7	I	2	30	
3.	Upgrading network infrastructure to support IoT deployments	3	10	11	5	1	30	69	46.0	I	3	32	
		10	5	11	3	1	30	80	53.3	I	1	14	
8. Environmental Impact and Sustainability Concerns													
1.	Minimizing the environmental footprint of IoT devices during production and disposal	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Developing recycling programs for outdated IoT devices	7	10	7	3	3	30	75	50.0	I	3	25	
3.	Balancing the energy efficiency gains of IoT systems against their environmental costs	8	6	10	6	0	30	76	50.7	I	2	24	
		8	6	12	4	0	30	78	52.0	I	1	19	
9. Interference with Building Legacy Systems													
1.	Ensuring compatibility between IoT technologies and existing building systems	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Minimizing downtime when integrating IoT with legacy systems	6	7	12	4	1	30	73	48.7	I	3	31	
3.	Developing cost-effective strategies for upgrading legacy systems to accommodate IoT	7	11	9	3	0	30	82	54.7	I	1	12	
		9	5	9	6	1	30	75	50.0	I	2	26	
10. High Energy Consumption of IoT Devices													
1.	Monitoring the energy consumption of IoT devices in smart office buildings	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Optimizing the power usage of IoT devices to reduce overall operational costs	11	2	12	5	0	30	79	52.7	I	1	17	
3.	Balancing the energy usage of IoT devices with their benefits in energy savings	4	7	8	11	0	30	64	42.7	I	3	34	
		7	5	13	5	0	30	74	49.3	I	2	28	
11. Ongoing Operation and Maintenance Costs of IoT Devices													
1.	Ensuring regular software updates, calibration, and hardware refresh elements for IoT devices	4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
2.	Optimizing the energy consumption of interconnected IoT devices to reduce utility expenses	10	7	9	4	0	30	83	55.3	I	2	11	
3.	Maximizing labor costs by providing specialized expertise for IoT maintenance activities	8	11	8	3	0	30	84	56.0	I	1	10	
		5	6	12	6	1	30	68	45.3	I	4	33	
4.	Implementing cost optimization strategies to minimize recurring expenses in older buildings retrofitted with IoT systems	9	3	11	7	0	30	74	49.3	I	3	29	
Stander Deviation (SD) = 5.16													

Table 14 Assessment of Challenges from FMs' Perspective

The most significant challenge, as rated by FMs, was the complexity associated with installation and integration, which received the highest Relative Importance Index (RII) of 70%. This underscores their primary concern regarding the difficulties involved in ensuring interoperability and seamless integration of various IoT systems within existing building operations. Moreover, issues such as data security, privacy concerns, and ensuring sufficient technological expertise for maintenance scored notably high, indicating that FMs prioritize not only technological feasibility but even secure and efficient long-term management. Economic factors, including high initial investment costs and ongoing maintenance expenses, were also notably challenging, reflecting practical and budgetary constraints faced by Facilities Managers in adopting IoT solutions. Lower-ranked challenges included environmental impacts and sustainability concerns, suggesting that FMs consider these as relatively manageable or less immediate obstacles compared to technical and financial barriers.

Overall, these insights highlight that Facilities Managers' perspectives on IoT adoption are primarily influenced by practical considerations involving technical complexity, cost control, and operational integration within existing building systems.

4.5.4 Assessment of the Challenges from the IOTs' Perspective

The assessment from the IoT professionals' perspective identified notable challenges impacting IoT adoption in smart office building operations and maintenance (O&M).

Challenges				IoT's											
1. Complexity in Installation and Integration				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Ensuring interoperability between various IoT devices and systems during installation			15	11	2	2	0	30	99	66.0	VI	1	1	
2	Minimizing the time and cost associated with integrating IoT systems in smart office buildings			6	16	8	0	0	30	88	58.7	I	3	14	
3	Synchronizing IoT systems (e.g., lighting, HVAC, security) into a unified platform			12	14	2	2	0	30	96	64.0	VI	2	3	
2. Data Security and Privacy Concerns				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Protecting sensitive occupant data collected by IoT devices in smart office buildings			12	10	5	3	0	30	91	60.7	I	1	5	
2	Addressing privacy concerns related to IoT-enabled occupant monitoring			13	6	8	2	1	30	88	58.7	I	2	12	
3	Implementing security measures to prevent unauthorized access to IoT data			12	7	7	1	3	30	84	56.0	I	3	21	
3. High Initial Investment				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Reducing the financial burden of acquiring IoT infrastructure for smart office buildings			12	10	5	3	0	30	91	60.7	I	1	8	
2	Demonstrating a clear return on investment (ROI) for IoT adoption in building operations			8	10	6	4	2	30	78	52.0	I	3	32	
3	Providing financial incentives or support for organizations to adopt IoT technologies			7	12	7	2	2	30	80	53.3	I	2	28	
4. Maintenance and Technical Expertise				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Ensuring regular maintenance of IoT devices to prevent system failures			12	6	8	3	1	30	85	56.7	I	2	19	
2	Having in-house technical expertise to manage and troubleshoot IoT systems			11	10	6	3	0	30	89	59.3	I	1	11	
3	Partnering for software and hardware updates to keep IoT systems functional and secure			10	11	3	4	2	30	83	55.3	I	3	26	
5. Data Overload and Management				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Implementing effective data analytics tools to process IoT-generated data			11	9	6	2	2	30	85	56.7	I	1	20	
2	Training facility managers to extract actionable insights from IoT data			12	6	6	5	1	30	83	55.3	I	2	24	
3	Developing frameworks to prioritize critical information from IoT systems			9	7	6	5	3	30	74	49.3	I	3	34	
6. Cybersecurity Threats				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Ensuring IoT devices are equipped with robust cybersecurity protections			14	9	3	3	1	30	92	61.3	I	2	4	
2	Detecting and mitigating vulnerabilities in IoT networks			15	7	8	0	0	30	97	64.7	VI	1	2	
3	Securing communication between IoT devices to prevent cyberattacks			14	8	3	4	1	30	90	60.0	I	3	9	
7. Reliability of IoT Networks				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Ensuring uninterrupted network connectivity for IoT systems in smart office buildings			12	8	6	4	0	30	88	58.7	I	2	13	
2	Reducing the impact of network disruptions on building operations			11	11	7	0	1	30	91	60.7	I	1	7	
3	Upgrading network infrastructure to support IoT deployments			11	6	9	2	2	30	82	54.7	I	3	27	
8. Environmental Impact and Sustainability Concerns				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Minimizing the environmental footprint of IoT devices during production and disposal			14	6	7	3	0	30	91	60.7	I	1	6	
2	Developing recycling programs for outdated IoT devices			10	9	8	2	1	30	85	56.7	I	2	18	
3	Balancing the energy efficiency gains of IoT systems against their environmental costs			9	8	8	3	2	30	79	52.7	I	3	29	
9. Interference with Building Legacy Systems				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Ensuring compatibility between IoT technologies and existing building systems			9	11	7	1	2	30	84	56.0	I	2	22	
2	Minimizing downtime when integrating IoT with legacy systems			12	9	4	3	2	30	86	57.3	I	1	17	
3	Developing cost-effective strategies for upgrading legacy systems to accommodate IoT			10	7	6	4	3	30	77	51.3	I	3	33	
10. High Energy Consumption of IoT Devices				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Monitoring the energy consumption of IoT devices in smart office buildings			11	11	3	4	1	30	87	58.0	I	1	15	
2	Optimizing the power usage of IoT devices to reduce overall operational costs			9	10	8	1	2	30	83	55.3	I	2	25	
3	Balancing the energy usage of IoT devices with their benefits in smart buildings			9	7	10	2	2	30	79	52.7	I	3	30	
11. Ongoing Operation and Maintenance Costs of IoT Devices				4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR	
1	Ensuring regular software updates, calibration, and hardware replacements for IoT devices			12	9	6	2	1	30	89	59.3	I	1	10	
2	Optimizing the energy consumption of interconnected IoT devices to reduce utility expenses			9	10	9	2	0	30	86	57.3	I	2	16	
3	Maximizing labor costs by providing specialized expertise for IoT maintenance activities			8	8	10	3	1	30	79	52.7	I	4	31	
4	Implementing cost optimization strategies to minimize recurring expenses in older buildings retrofitted with IoT systems			13	4	8	4	1	30	84	56.0	I	3	23	
Stander Deviation (SD) = 3.85															

Table 15 Assessment of Challenges from IoT Professionals' Perspective

The highest-ranked challenge was the complexity of installation and integration, with a Relative Importance Index (RII) of approximately 66%, indicating significant concerns about technical issues, system compatibility, and the seamless integration of IoT technologies into existing infrastructure. Moreover, IoT professionals identified data security, privacy concerns, and operational reliability as critical challenges, with RIIs around 64% to 64.67%. This highlights IoT specialists' recognition of the significant risks associated with managing sensitive data, maintaining cybersecurity, and ensuring consistent IoT system performance. Economic barriers, including high initial investments and ongoing operational costs, were also identified as significant but slightly less critical, suggesting IoT professionals view these financial considerations as manageable given technological advancements.

Furthermore, sustainability concerns, environmental impacts, and data overload received lower importance scores, reflecting a perception among IoT professionals that these factors are less immediately challenging than the technical and security aspects.

Overall, these insights emphasize that IoT professionals primarily perceive technological complexities, data security, and integration reliability as the primary barriers that need addressing to facilitate widespread IoT implementation in smart office buildings.

4.6 Assessment of the Factors Affecting O&M Costs in IoT-Based Smart Office Buildings

This section discusses the assessment findings related to the factors affecting IoT adoption in smart office building O&M, based on the responses obtained from the four respondent groups.

Overall Factors		Overall			
1. Planning Phase		RII	IR	IGR	OR
1	Engaging stakeholders early to align objectives and expectations for IoT adoption	68.5	VI	1	1
2	Allocating sufficient budget for IoT infrastructure during the planning phase	60.5	I	3	9
3	Setting clear energy efficiency goals to guide IoT deployment	59.8	I	4	10
4	Selecting vendors with proven expertise and scalable solutions for IoT systems	61.2	I	2	8
5	Planning for future scalability to integrate emerging technologies	57.2	I	6	16
6	Ensuring compliance with local and international regulations during IoT adoption	58.8	I	5	13
7	Developing robust data privacy and security strategies for IoT systems	55.0	I	8	23
8	Creating a technology integration strategy to ensure seamless operation of IoT systems	55.7	I	7	21
9	Performing lifecycle cost analysis to balance investment with operational savings	51.2	I	10	35
10	Assessing skill gaps and planning training programs for managing IoT systems	52.3	I	9	33
2. Design Phase		RII	IR	IGR	OR
1	Ensuring interoperability across IoT platforms and devices	65.2	VI	1	3
2	Strategically placing sensors for accurate and reliable data collection	62.5	VI	2	5
3	Incorporating redundancy to maintain system reliability during failures	57.0	I	3	18
4	Using modular design principles to simplify upgrades and maintenance	55.0	I	5	23
5	Embedding predictive maintenance features in system design	50.8	I	8	36
6	Optimizing design choices for energy efficiency in IoT-enabled systems	53.0	I	7	32
7	Developing user-friendly interfaces for IoT systems to improve operation	54.8	I	6	26
8	Aligning IoT designs with industry standards to ensure compatibility	55.8	I	4	20
3. Construction Phase		RII	IR	IGR	OR
1	Selecting high-quality components to enhance reliability and reduce maintenance costs	64.5	VI	1	4
2	Following best practices for IoT installation to ensure optimal performance	62.3	I	2	6
3	Performing rigorous system and integration testing before deployment	58.7	I	3	14
4	Engaging contractors with specialized expertise in IoT system installation	57.2	I	4	16
5	Adhering to design plans to avoid costly revisions during construction	53.8	I	9	28
6	Using high-quality cabling standards to enhance connectivity and system reliability	55.3	I	6	22
7	Creating detailed documentation for a smooth system handover	56.3	I	5	19
8	Aligning construction with As-Built Plans to avoid operational inefficiencies	55.0	I	7	23
9	Implementing training programs for operations and maintenance teams during construction	54.7	I	8	27
4. Operation & Maintenance Phase		RII	IR	IGR	OR
1	Implementing real-time monitoring for early detection of inefficiencies	65.7	VI	1	2
2	Using predictive algorithms to forecast and prevent equipment failures	61.8	I	2	7
3	Tracking energy consumption to identify and address inefficiencies	59.5	I	3	11
4	Implementing proactive cybersecurity measures to protect IoT systems	59.0	I	4	12
5	Regularly updating IoT devices to ensure security and efficiency	58.2	I	5	15
6	Incorporating fault detection systems to minimize maintenance disruptions	53.2	I	8	31
7	Collecting user feedback to continuously improve IoT system performance	52.0	I	9	34
8	Dynamically optimizing resources to reduce operational costs	53.7	I	7	30
9	Conducting periodic reviews of lifecycle costs to ensure sustainability and ROI	53.8	I	6	29
Stander Deviation (SD) = 4.37					
Cronbach's Alpha (Ca) = 0.93					

Table 16 Factors Affecting O&M Costs

4.6.1 Assessment of the Factors from the A/Es' Perspective

The assessment of factors influencing IoT adoption in smart office building operations and maintenance (O&M) from the Architects and Engineers' (A/Es') perspective highlighted strategic planning and technical integration as crucial considerations.

Factors		A/Es										
1. Planning Phase		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Engaging stakeholders early to align objectives and expectations for IoT adoption	21	6	3	0	0	30	108	72.0	VI	1	1
2	Allocating sufficient budget for IoT infrastructure during the planning phase	12	13	4	1	0	30	96	64.0	VI	3	9
3	Setting clear energy efficiency goals to guide IoT deployment	13	11	5	1	0	30	96	64.0	VI	4	9
4	Selecting vendors with proven expertise and scalable solutions for IoT systems	14	11	2	2	1	30	95	63.3	VI	5	12
5	Planning for future scalability to integrate emerging technologies	11	9	9	0	1	30	89	59.3	I	8	25
6	Ensuring compliance with local and international regulations during IoT adoption	15	6	7	1	1	30	93	62.0	I	6	17
7	Developing robust data privacy and security strategies for IoT systems	18	7	3	2	0	30	101	67.3	VI	2	3
8	Creating a technology integration strategy to ensure seamless operation of IoT systems	14	6	8	1	1	30	91	60.7	I	7	21
9	Performing lifecycle cost analysis to balance investment with operational savings	12	9	6	2	1	30	89	59.3	I	9	25
10	Assessing skill gaps and planning training programs for managing IoT systems	9	11	8	2	0	30	87	58.0	I	10	31
2. Design Phase		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Ensuring interoperability across IoT platforms and devices	19	9	1	1	0	30	106	70.7	VI	1	2
2	Strategically placing sensors for accurate and reliable data collection	15	11	2	2	0	30	99	66.0	VI	2	7
3	Incorporating redundancy to maintain system reliability during failures	11	12	4	3	0	30	91	60.7	I	3	21
4	Using modular design principles to simplify upgrades and maintenance	10	10	7	3	0	30	87	58.0	I	7	31
5	Embedding predictive maintenance features in system design	9	11	7	2	1	30	85	56.7	I	8	35
6	Optimizing design choices for energy efficiency in IoT-enabled systems	11	11	5	1	2	30	88	58.7	I	6	28
7	Developing user-friendly interfaces for IoT systems to improve operation	12	8	9	0	1	30	90	60.0	I	4	24
8	Aligning IoT designs with industry standards to ensure compatibility	15	6	5	4	0	30	92	61.3	I	5	20
3. Construction Phase		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Selecting high-quality components to enhance reliability and reduce maintenance costs	16	10	3	1	0	30	101	67.3	VI	1	3
2	Following best practices for IoT installation to ensure optimal performance	18	7	2	3	0	30	100	66.7	VI	2	6
3	Performing rigorous system and integration testing before deployment	13	11	4	2	0	30	95	63.3	VI	4	12
4	Engaging contractors with specialized expertise in IoT system installation	11	9	8	2	0	30	89	59.3	I	8	25
5	Adhering to design plans to avoid costly revisions during construction	15	5	8	2	0	30	93	62.0	I	6	17
6	Using high-quality cabling standards to enhance connectivity and system reliability	11	9	6	4	0	30	87	58.0	I	9	31
7	Creating detailed documentation for a smooth system handover	12	11	6	1	0	30	94	62.7	VI	5	15
8	Aligning construction with As-Built Plans to avoid operational inefficiencies	15	8	5	2	0	30	96	64.0	VI	3	9
9	Implementing training programs for operations and maintenance teams during construction	15	6	5	3	1	30	91	60.7	I	7	21
4. Operation & Maintenance Phase		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Implementing real-time monitoring for early detection of inefficiencies	14	14	1	1	0	30	101	67.3	VI	1	3
2	Using predictive algorithms to forecast and prevent equipment failures	14	10	5	1	0	30	97	64.7	VI	2	8
3	Tracking energy consumption to identify and address inefficiencies	11	13	5	1	0	30	94	62.7	VI	4	15
4	Implementing proactive cybersecurity measures to protect IoT systems	15	6	7	1	1	30	93	62.0	I	5	17
5	Regularly updating IoT devices to ensure security and efficiency	14	8	7	1	0	30	95	63.3	VI	3	12
6	Incorporating fault detection systems to minimize maintenance disruptions	10	10	8	2	0	30	88	58.7	I	7	28
7	Collecting user feedback to continuously improve IoT system performance	12	8	5	5	0	30	87	58.0	I	8	31
8	Dynamically optimizing resources to reduce operational costs	14	6	5	4	1	30	88	58.7	I	6	28
9	Conducting periodic reviews of lifecycle costs to ensure sustainability and ROI	10	10	4	4	2	30	82	54.7	I	9	36
Stander Deviation (SD) = 3.91												

Table 17 Factors Affecting O&M Costs from A/Es' Perspective

The most significant factor identified was early stakeholder engagement to ensure interoperability across IoT platforms, scoring the highest Relative Importance Index (RII) of 72%, emphasizing the critical importance of clear stakeholder coordination and integrated system planning during the early project stages. Interoperability across various IoT platforms and robust data privacy and security strategies were also among the top-rated factors, with RIIs of approximately 70.67% and 67.33%, respectively, highlighting the importance of ensuring seamless communication between diverse IoT systems and protecting sensitive data. Real-time monitoring for early detection and preventive maintenance also emerged as an essential factor (RII of 67.33%), reflecting the priority given by A/E professionals to proactive building management and reducing downtime. Budget allocation, clear energy-efficiency goals, and alignment with construction plans also received high importance ratings, emphasizing that financial planning and adherence to project specifications significantly impact the effectiveness of IoT adoption. Factors such as user-friendly interface design, engagement of specialized expertise, and lifecycle cost analysis received moderate importance, indicating that while these factors enhance IoT performance and user acceptance, they were considered secondary compared to interoperability, data security, and proactive maintenance capabilities.

Overall, these results underscore that for A/E professionals, the successful implementation of IoT in smart buildings hinges significantly on interoperability, strategic planning, and stringent security practices, enabling more effective and secure operational management.

4.6.2 Assessment of the Factors from the Developers' / Owners' Perspective

The assessment of factors influencing IoT adoption in smart office building operations and maintenance (O&M) from the Developers'/Owners' perspective highlighted practical and strategic considerations crucial for successful IoT implementation.

Factors		Developer's										
		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1. Planning Phase		4. EI <th>3. VI</th> <th>2. I</th> <th>1. SI</th> <th>0. NI</th> <th>Total</th> <th>W</th> <th>R II</th> <th>IR</th> <th>IGR</th> <th>OR</th>	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Ensuring stakeholders early to align objectives and expectations for IoT adoption	18	6	3	3	0	30	99	66.0	VI	1	2
2	Allocating sufficient budget for IoT infrastructure during the planning phase	13	10	7	0	0	30	96	64.0	VI	3	6
3	Setting clear energy efficiency goals to guide IoT deployment	11	11	8	0	0	30	93	62.0	I	4	11
4	Selecting vendors with proven expertise and scalable solutions for IoT systems	16	7	6	1	0	30	98	65.3	VI	2	3
5	Planning for future scalability to integrate emerging technologies	11	8	10	1	0	30	89	59.3	I	6	18
6	Ensuring compliance with local and international regulations during IoT adoption	13	9	6	0	2	30	91	60.7	I	5	13
7	Developing robust data privacy and security strategies for IoT systems	10	9	9	2	0	30	87	58.0	I	7	23
8	Creating a technology integration strategy to ensure seamless operation of IoT systems	11	8	8	3	0	30	87	58.0	I	8	23
9	Performing lifecycle cost analysis to balance investment with operational savings	8	9	9	3	1	30	80	53.3	I	10	36
10	Assessing skill gaps and planning training programs for managing IoT systems	11	6	9	2	2	30	82	54.7	I	9	32
2. Design Phase		4. EI <th>3. VI</th> <th>2. I</th> <th>1. SI</th> <th>0. NI</th> <th>Total</th> <th>W</th> <th>R II</th> <th>IR</th> <th>IGR</th> <th>OR</th>	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Ensuring interoperability across IoT platforms and devices	15	8	5	2	0	30	96	64.0	VI	2	6
2	Strategically placing sensors for accurate and reliable data collection	17	7	5	1	0	30	100	66.7	VI	1	1
3	Incorporating redundancy to maintain system reliability during failures	10	11	7	2	0	30	89	59.3	I	5	18
4	Using modular design principles to simplify upgrades and maintenance	10	10	7	3	0	30	87	58.0	I	6	23
5	Embedding predictive maintenance features in system design	9	6	12	3	0	30	81	54.0	I	8	35
6	Optimizing design choices for energy efficiency in IoT-enabled systems	10	12	4	3	1	30	87	58.0	I	7	23
7	Developing user-friendly interfaces for IoT systems to improve operation	12	9	7	1	1	30	90	60.0	I	4	14
8	Aligning IoT designs with industry standards to ensure compatibility	13	8	6	2	1	30	90	60.0	I	3	14
3. Construction Phase		4. EI <th>3. VI</th> <th>2. I</th> <th>1. SI</th> <th>0. NI</th> <th>Total</th> <th>W</th> <th>R II</th> <th>IR</th> <th>IGR</th> <th>OR</th>	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Selecting high-quality components to enhance reliability and reduce maintenance costs	15	6	7	2	0	30	94	62.7	VI	2	10
2	Following best practices for IoT installation to ensure optimal performance	14	9	5	2	0	30	95	63.3	VI	1	9
3	Performing rigorous system and integration testing before deployment	12	9	7	1	1	30	90	60.0	I	3	14
4	Engaging contractors with specialized expertise in IoT system installation	11	8	10	0	1	30	88	58.7	I	4	20
5	Adhering to design plans to avoid costly revisions during construction	10	7	9	4	0	30	83	55.3	I	8	31
6	Using high-quality cabling standards to enhance connectivity and system reliability	14	4	9	2	1	30	88	58.7	I	5	20
7	Creating detailed documentation for a smooth system handover	11	10	5	3	1	30	87	58.0	I	6	23
8	Aligning construction with As-Built Plans to avoid operational inefficiencies	11	7	8	1	3	30	82	54.7	I	9	32
9	Implementing training programs for operations and maintenance teams during construction	9	12	6	1	2	30	85	56.7	I	7	29
4. Operation & Maintenance Phase		4. EI <th>3. VI</th> <th>2. I</th> <th>1. SI</th> <th>0. NI</th> <th>Total</th> <th>W</th> <th>R II</th> <th>IR</th> <th>IGR</th> <th>OR</th>	3. VI	2. I	1. SI	0. NI	Total	W	R II	IR	IGR	OR
1	Implementing real-time monitoring for early detection of inefficiencies	18	5	4	3	0	30	98	65.3	VI	1	3
2	Using predictive algorithms to forecast and prevent equipment failures	16	9	3	1	1	30	98	65.3	VI	2	3
3	Tracking energy consumption to identify and address inefficiencies	11	10	9	0	0	30	92	61.3	I	4	12
4	Implementing proactive cybersecurity measures to protect IoT systems	9	13	7	1	0	30	90	60.0	I	5	14
5	Regularly updating IoT devices to ensure security and efficiency	14	11	2	3	0	30	96	64.0	VI	3	6
6	Incorporating fault detection systems to minimize maintenance disruptions	13	6	7	2	2	30	86	57.3	I	7	28
7	Collecting user feedback to continuously improve IoT system performance	10	6	12	2	0	30	84	56.0	I	8	30
8	Dynamically optimizing resources to reduce operational costs	13	8	4	4	1	30	88	58.7	I	6	20
9	Conducting periodic reviews of lifecycle costs to ensure sustainability and ROI	11	8	6	2	3	30	82	54.7	I	9	32
Standar Deviation (SD) = 3.72												

Standar Deviation (SD) = 3.72

Table 18 Factors Affecting O&M Costs from Developers'/Owners' Perspective

The most significant factor was strategically placing sensors for accurate and comprehensive data collection, scoring the highest Relative Importance Index (RII) of approximately 66.67%. This highlights the developers' emphasis on reliable data as a cornerstone for informed decision-making and efficient management. Engaging stakeholders early in the planning phase to align objectives and expectations also scored notably high (RII = 66%), reflecting the importance of early collaboration to streamline the integration process and reduce potential operational discrepancies. Furthermore, selecting experienced vendors, utilizing predictive algorithms, and implementing real-time monitoring systems received RIIs around 65%, indicating these factors' relevance in achieving high operational efficiency and preventive maintenance capabilities. Developers and owners also emphasized ensuring interoperability across various IoT platforms and maintaining updated security measures, recognizing these as critical for system reliability and data security. Moreover, aspects such as lifecycle cost analysis, embedding predictive maintenance, and training programs were rated lower, indicating they are perceived as supportive but not primary factors. Overall, the findings reveal that developers and owners focus significantly on practical deployment strategies, stakeholder collaboration, accurate data collection, and ensuring robust security measures to successfully leverage IoT technologies in smart office buildings.

4.6.3 Assessment of the Factors from the FMs' Perspective

The assessment of factors influencing IoT adoption in smart office building operations and maintenance (O&M) from the Facilities Managers' (FMs') perspective emphasized effective planning, stakeholder collaboration, and technical integration.

Factors		FMs										
		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1. Planning Phase												
1	Engaging stakeholders early to align objectives and expectations for IoT adoption	24	2	3	1	0	30	109	72.7	VI	1	1
2	Allocating sufficient budget for IoT infrastructure during the planning phase	6	18	6	0	0	30	90	60.0	I	2	7
3	Setting clear energy efficiency goals to guide IoT deployment	9	11	10	0	0	30	89	59.3	I	4	9
4	Selecting vendors with proven expertise and scalable solutions for IoT systems	9	12	9	0	0	30	90	60.0	I	3	7
5	Planning for future scalability to integrate emerging technologies	7	11	10	2	0	30	83	55.3	I	5	13
6	Ensuring compliance with local and international regulations during IoT adoption	9	9	6	5	1	30	80	53.3	I	6	16
7	Developing robust data privacy and security strategies for IoT systems	4	9	11	5	1	30	70	46.7	I	8	31
8	Creating a technology integration strategy to ensure seamless operation of IoT systems	9	9	6	5	1	30	80	53.3	I	7	16
9	Performing lifecycle cost analysis to balance investment with operational savings	5	11	6	7	1	30	72	48.0	I	10	28
10	Assessing skill gaps and planning training programs for managing IoT systems	5	10	7	6	2	30	70	46.7	I	9	31
2. Design Phase												
1	Ensuring interoperability across IoT platforms and devices	20	4	5	1	0	30	103	68.7	VI	1	2
2	Strategically placing sensors for accurate and reliable data collection	8	17	3	2	0	30	91	60.7	I	2	6
3	Incorporating redundancy to maintain system reliability during failures	6	12	9	2	1	30	80	53.3	I	3	16
4	Using modular design principles to simplify upgrades and maintenance	3	12	13	2	0	30	76	50.7	I	4	23
5	Embedding predictive maintenance features in system design	3	7	14	6	0	30	67	44.7	I	8	34
6	Optimizing design choices for energy efficiency in IoT-enabled systems	2	12	8	8	0	30	68	45.3	I	7	33
7	Developing user-friendly interfaces for IoT systems to improve operation	2	11	13	4	0	30	71	47.3	I	6	29
8	Aligning IoT designs with industry standards to ensure compatibility	4	12	8	5	1	30	73	48.7	I	5	27
3. Construction Phase												
1	Selecting high-quality components to enhance reliability and reduce maintenance costs	16	7	5	1	1	30	96	64.0	VI	1	4
2	Following best practices for IoT installation to ensure optimal performance	10	12	8	0	0	30	92	61.3	I	2	5
3	Performing rigorous system and integration testing before deployment	7	12	7	3	1	30	81	54.0	I	4	15
4	Engaging contractors with specialized expertise in IoT system installation	7	7	12	4	0	30	77	51.3	I	6	21
5	Adhering to design plans to avoid costly revisions during construction	2	15	7	4	2	30	71	47.3	I	9	29
6	Using high-quality cabling standards to enhance connectivity and system reliability	4	11	11	4	0	30	75	50.0	I	8	26
7	Creating detailed documentation for a smooth system handover	4	13	9	3	1	30	76	50.7	I	7	23
8	Aligning construction with As-Built Plans to avoid operational inefficiencies	6	10	10	4	0	30	78	52.0	I	5	20
9	Implementing training programs for operators and maintenance teams during construction	8	11	7	4	0	30	83	55.3	I	3	13
4. Operation & Maintenance Phase												
1	Implementing real-time monitoring for early detection of inefficiencies	16	10	1	2	1	30	98	65.3	VI	1	3
2	Using predictive algorithms to forecast and prevent equipment failures	12	7	7	4	0	30	87	58.0	I	2	10
3	Tracking energy consumption to identify and address inefficiencies	8	12	8	1	1	30	85	56.7	I	3	11
4	Implementing proactive cybersecurity measures to protect IoT systems	9	9	11	0	1	30	85	56.7	I	4	11
5	Regularly updating IoT devices to ensure security and efficiency	1	16	11	2	0	30	76	50.7	I	7	23
6	Incorporating fault detection systems to minimize maintenance disruptions	1	14	9	3	3	30	67	44.7	I	8	34
7	Collecting user feedback to continuously improve IoT system performance	4	5	15	5	1	30	66	44.0	I	9	36
8	Dynamically optimizing resources to reduce operational costs	2	14	13	1	0	30	77	51.3	I	6	21
9	Conducting periodic reviews of lifecycle costs to ensure sustainability and ROI	6	10	12	2	0	30	80	53.3	I	5	16
Stander Deviation (SD) = 6.98												

Table 19 Factors Affecting O&M Costs from FMs' Perspective

The highest-rated factor was engaging stakeholders early to align objectives and expectations, with a Relative Importance Index (RII) of approximately 72.67%. This underscores Facilities Managers' priority on collaborative planning to ensure successful IoT adoption and alignment of project goals across various stakeholders. Ensuring interoperability across IoT platforms was also a key priority (RII of 68.67%), reflecting the need for seamless integration and efficient data exchange among different systems. Real-time monitoring for early detection and predictive maintenance (RII = 65.33%) emerged as another significant factor, indicating Facilities Managers' emphasis on proactive maintenance and operational reliability. Furthermore, Facilities Managers placed substantial importance on selecting high-quality components and adhering to established best practices for installation, with RIIs of around 64% and 61.33%, respectively, demonstrating their focus on system durability and effectiveness. Moreover, factors such as user-friendly interfaces, predictive maintenance features, and user feedback mechanisms were assigned lower importance scores, suggesting these are seen as beneficial but less critical for initial adoption decisions. Overall, Facilities Managers prioritize early stakeholder engagement, interoperability, and proactive maintenance strategies as fundamental for successful IoT adoption and sustainable facility management.

4.6.4 Assessment of the Factors from the IOTs' Perspective

The assessment of factors influencing IoT adoption in smart office building operations and maintenance (O&M) from the IoT professionals' perspective highlighted technological robustness, reliability, and strategic monitoring as primary considerations.

Factors		IoT's										
1. Planning Phase		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Engaging stakeholders early to align objectives and expectations for IoT adoption	15	7	6	2	0	30	95	63.3	VI	1	3
2	Allocate sufficient budget for IoT infrastructure during the planning phase	6	13	8	2	1	30	81	54.0	I	6	18
3	Set clear energy efficiency goals to guide IoT deployment	6	13	8	2	1	30	81	54.0	I	5	18
4	Select vendors with proven expertise and scalable solutions for IoT systems	10	7	10	3	0	30	84	56.0	I	3	13
5	Planning for future scalability to integrate emerging technologies	9	10	6	4	1	30	82	54.7	I	4	14
6	Ensuring compliance with local and international regulations during IoT adoption	11	13	2	2	2	30	89	59.3	I	2	4
7	Develop robust data privacy and security strategies for IoT systems	7	4	13	6	0	30	72	48.0	I	9	32
8	Creating a technology integration strategy to ensure seamless operation of IoT systems	5	14	6	2	3	30	76	50.7	I	7	26
9	Performing lifecycle cost analysis to balance investment with operational savings	6	8	7	4	5	30	66	44.0	I	10	36
10	Assessing skill gaps and planning training programs for managing IoT systems	11	7	4	2	6	30	75	50.0	I	8	28
2. Design Phase		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Ensuring interoperability across IoT platforms and devices	12	8	7	0	3	30	86	57.3	I	1	8
2	Strategically place sensors for accurate and reliable data collection	13	5	7	4	1	30	85	56.7	I	2	12
3	Incorporate redundancy to maintain system reliability during failures	7	11	10	1	1	30	82	54.7	I	3	14
4	Use modular design principles to simplify upgrades and maintenance	7	11	7	5	0	30	80	53.3	I	4	21
5	Embed predictive maintenance features in system design	7	7	7	9	0	30	72	48.0	I	8	32
6	Optimize design choices for energy efficiency in IoT-enabled systems	8	9	6	4	3	30	75	50.0	I	7	28
7	Develop user-friendly interfaces for IoT systems to improve operation	7	11	7	3	2	30	78	52.0	I	6	24
8	Adhere to IoT design standards to ensure compatibility	12	5	6	5	2	30	80	53.3	I	5	21
3. Construction Phase		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Select high-quality components to enhance reliability and reduce maintenance costs	16	7	4	3	0	30	96	64.0	VI	1	2
2	Follow best practices for IoT installation to ensure optimal performance	10	9	9	2	0	30	87	58.0	I	3	7
3	Perform rigorous system and integration testing before deployment	9	11	8	1	1	30	86	57.3	I	4	8
4	Engage contractors with specialized expertise in IoT system installation	11	10	6	3	0	30	89	59.3	I	2	4
5	Adhere to design plans to avoid cost overruns during construction	10	8	4	4	4	30	76	50.7	I	7	26
6	Use high-quality cabling standards to enhance connectivity and system reliability	9	9	7	5	0	30	82	54.7	I	5	14
7	Create detailed documentation for a smooth system handover	7	11	9	2	1	30	81	54.0	I	6	18
8	Adhere to construction safety standards to avoid operational inefficiencies	5	12	7	4	2	30	74	49.3	I	8	31
9	Implement training programs for operations and maintenance teams during construction	5	12	6	1	6	30	69	46.0	I	9	34
4. Operation & Maintenance Phase		4. EI	3. VI	2. I	1. SI	0. NI	Total	W	RII	IR	IGR	OR
1	Implement real-time monitoring for early detection of inefficiencies	15	9	5	0	1	30	97	64.7	VI	1	1
2	Use predictive algorithms to forecast and prevent equipment failures	14	7	4	4	1	30	89	59.3	I	2	4
3	Track energy consumption to identify and address inefficiencies	9	9	11	1	0	30	86	57.3	I	3	8
4	Implement proactive cybersecurity measures to protect IoT systems	9	13	4	3	1	30	86	57.3	I	4	8
5	Regularly update IoT devices to ensure security and efficiency	10	9	5	5	1	30	82	54.7	I	5	14
6	Incorporate fault detection systems to minimize maintenance disruptions	8	10	7	2	3	30	78	52.0	I	7	24
7	Collect user feedback to continuously improve IoT system performance	7	9	7	6	1	30	75	50.0	I	8	28
8	Dynamically optimize resources to reduce operational costs	6	11	4	4	5	30	69	46.0	I	9	34
9	Conduct periodic reviews of lifecycle costs to ensure sustainability and ROI	9	12	3	1	5	30	79	52.7	I	6	23
Stander Deviation (SD) =4.96												

Table 20 Factors Affecting O&M Costs from IoT Professionals' Perspective

Real-time monitoring for early detection and preventive maintenance emerged as the most significant factor, with the highest Relative Importance Index (RII) of approximately 64.67%. This emphasizes that IoT specialists prioritize proactive system management capabilities to predict and prevent issues, thereby ensuring continuous operational performance. Selecting high-quality components to enhance reliability scored similarly high (64%), reflecting IoT professionals' strong emphasis on dependable technology components as fundamental to system longevity and efficiency. Early stakeholder engagement was also highly valued (RII = 63.33%), recognizing its role in ensuring that system designs align with user expectations and operational objectives. Furthermore, compliance with local and international standards (59.33%) and the implementation of proactive cybersecurity measures (57.33%) were considered crucial for maintaining system integrity and ensuring effective operation. Moreover, aspects such as lifecycle cost management, user-friendly interfaces, and scalability received relatively lower scores, suggesting these elements, although beneficial, are perceived as secondary compared to immediate system functionality and reliability. Overall, IoT professionals emphasize strategic system integration, robust technical design, and proactive management solutions as essential to effectively leverage IoT technologies in smart office buildings.

4.7 Discussion of Survey Findings and Key Insights

The detailed analysis presented in this chapter highlights critical insights into the adoption of IoT technologies for the O&M of smart office buildings, considering perspectives from

four distinct professional groups: Architects and Engineers (A/Es), Developers and Owners, Facilities Managers (FMs), and IoT Professionals.

4.7.1 Common Priorities Across Professional Groups

A significant finding emerging consistently across all surveyed groups is the high importance placed on energy efficiency. This aligns clearly with global sustainability goals and economic considerations. Each group identified energy efficiency as the most critical driver for IoT adoption, suggesting a shared recognition of the potential for IoT systems to substantially reduce operational costs and enhance building sustainability.

Operational efficiency and improved security and safety also emerged as common priorities. All stakeholders acknowledged the potential of IoT technologies to streamline operational processes, provide real-time monitoring, and ensure higher levels of safety and security through automated and responsive systems.

4.7.2 Diverging Perspectives on Drivers

Despite the consensus on energy efficiency, variations were observed among the professional groups regarding secondary drivers. Architects and Engineers emphasized enhanced occupant comfort and effective space utilization, underscoring a holistic view that values occupant well-being and spatial optimization. Moreover, Developers and Owners prioritized direct financial returns such as cost reduction and risk mitigation, reflecting their primary interest in economic viability.

Facilities Managers highlighted occupant comfort but emphasized practical operational outcomes such as ease of integration with existing systems and operational reliability. IoT professionals uniquely emphasized data-driven decision-making capabilities, highlighting their technical inclination toward leveraging IoT data for predictive analytics and advanced operational control.

4.7.3 Challenges to IoT Adoption

All groups unanimously identified complexity in installation and integration as the leading barrier to IoT adoption, underscoring significant concerns related to system interoperability, compatibility, and technical implementation challenges. These technical complexities reflect practical hurdles that must be effectively addressed to facilitate broader IoT adoption.

Moreover, cybersecurity and data security emerged as key concerns across groups, albeit with varying degrees of emphasis. A/Es, Developers/Owners, and Facilities Managers showed substantial concern regarding privacy and the security of sensitive operational data, reflecting industry-wide apprehension toward potential cybersecurity threats. IoT professionals, although concerned, viewed these as manageable technical challenges given advancements in cybersecurity frameworks and solutions.

Financial constraints, specifically high initial investment costs and ongoing maintenance expenses, were particularly emphasized by Developers/Owners and Facilities Managers. This highlights budgetary limitations as critical determinants influencing the pace and

extent of IoT adoption, indicating that effective financial planning and clear demonstrations of long-term economic benefits will be essential for future adoption strategies.

4.7.4 Influential Factors Affecting O&M Costs

The survey also identified key factors impacting the optimization of O&M costs through IoT adoption. Early stakeholder engagement emerged strongly as the most influential factor, especially for Architects/Engineers and Facilities Managers. This indicates clear recognition that early collaborative planning involving various stakeholders enhances interoperability, reduces project conflicts, and streamline implementation.

Real-time monitoring and preventive maintenance capabilities were highlighted significantly by IoT professionals and Facilities Managers. These groups valued IoT's proactive capabilities in reducing downtime, extending equipment lifespans, and lowering long-term operational expenses. Strategic sensor placement and robust data collection mechanisms, particularly emphasized by Developers/Owners, suggest an awareness of the importance of reliable and comprehensive data for efficient facility management.

Interoperability and system integration were consistently recognized across all groups as pivotal to successful IoT adoption. Ensuring seamless communication and functionality across various IoT platforms was deemed essential to achieving the intended operational efficiencies and cost savings.

4.7.5 Implications for Industry Practice

The findings of this survey show substantial implications for industry practice. They emphasize the critical necessity of developing industry standards for IoT integration, comprehensive cybersecurity frameworks, and clearly articulated financial justifications for investment. Stakeholders must prioritize strategic planning and early stakeholder collaboration to navigate technical complexities effectively, reduce cybersecurity risks, and ensure robust and reliable IoT implementations.

Furthermore, targeted training programs and specialized expertise will be essential to address the identified complexities, ensure technological compatibility, and leverage IoT's full potential. Clear guidelines and best practices for IoT integration, coupled with continuous monitoring and preventive maintenance protocols, will be vital for enhancing operational efficiency and cost-effectiveness in smart office buildings.

4.7.6 Summary of Key Insights

In summary, this comprehensive analysis reveals shared and unique perspectives among stakeholders in adopting IoT technologies in smart office building O&M:

1- Drivers for IoT Adoption

1. **Energy Efficiency:** All stakeholder groups prioritized energy efficiency as the most significant driver due to its potential to significantly reduce operational costs and enhance sustainability.

2. Operational Optimization: Improved operational efficiency, through real-time monitoring and automation, was universally recognized as critical for reducing downtime, optimizing resources, and improving overall building performance.
3. Security and Safety: Enhanced safety and security through automated and responsive systems were considered highly important, particularly for Facilities Managers and Developers/Owners.

2- Key Challenges

1. Integration Complexity: Complexity in installation, integration, and interoperability consistently emerged as the leading challenge across all groups, emphasizing the need for streamlined processes and standardized approaches.
2. Cybersecurity and Data Protection: There was significant concern, particularly among Architects/Engineers and Developers/Owners, regarding data security, privacy issues, and cybersecurity threats, highlighting industry apprehension around vulnerabilities associated with IoT systems.
3. Financial Constraints: Developers and Facilities Managers identified high initial investment and maintenance costs as substantial barriers, reflecting the need for clear demonstrations of financial returns and cost-benefit analyses to justify IoT investments.

3- Influential Factors Affecting IoT Adoption

- **Early Stakeholder Engagement:** Strongly emphasized by Architects/Engineers and Facilities Managers, early collaboration among stakeholders was identified as crucial for ensuring system interoperability, reducing conflicts, and streamlining the IoT implementation process.
- **Real-time Monitoring and Predictive Maintenance:** IoT professionals and Facilities Managers particularly valued IoT's proactive capabilities for early fault detection, predictive maintenance, and improved asset longevity.
- **Interoperability Across Platforms:** All stakeholder groups highlighted the significance of seamless integration and compatibility across various IoT platforms to fully realize operational and financial benefits.
- **Robust Component Selection:** Facilities Managers and IoT professionals underscored the importance of selecting high-quality and reliable IoT components as foundational to system effectiveness and operational reliability.

These insights provide critical direction for future strategies in the architectural, engineering, construction, and facilities management sectors, emphasizing collaborative approaches, technological standardization, and proactive operational practices as essential components for successful IoT adoption.

4.8 Summary of the Data Analysis

This chapter provided a comprehensive analysis based on the structured survey responses from four key stakeholder groups involved in smart office building projects: Architects and Engineers (A/Es), Developers and Owners, Facilities Managers (FMs), and IoT Professionals.

The demographic analysis highlighted the diverse professional backgrounds and varying experience levels among respondents. Architects and Engineers exhibited a balanced distribution of experience, ranging from less than 5 years to 10 years, enhancing the diversity of their insights. Developers and Owners demonstrated substantial experience, with a significant proportion having over 15 years, offering robust and seasoned perspectives on IoT integration. Facilities Managers primarily possessed moderate to extensive experience, while IoT Professionals predominantly represented relatively newer industry participants, contributing contemporary technological perspectives.

Regarding involvement in smart building projects, most A/Es and IoT Professionals participated in a limited number of projects (1-5), indicating nascent industry engagement with IoT technologies. In contrast, Developers/Owners and Facilities Managers showed a broader spectrum of project involvement, reflecting their deeper integration and familiarity with smart office technologies.

Key drivers for IoT adoption consistently emphasized all professional groups including energy efficiency, operational optimization, and enhanced security and safety. Energy

efficiency emerged as the highest-ranked driver universally, demonstrating industry-wide recognition of IoT's potential to achieve significant operational cost reductions and sustainability benefits.

Challenges identified by respondents prominently included technical complexity in system integration and installation, cybersecurity risks, data privacy concerns, and financial constraints related to initial investments and ongoing maintenance expenses. Complexity and cybersecurity emerged as particularly critical barriers, underscoring the necessity for standardized integration practices and comprehensive cybersecurity measures.

Lastly, Influential factors affecting successful IoT implementation and optimization of O&M costs highlighted the critical importance of early stakeholder engagement, real-time monitoring, predictive maintenance, and interoperability across various IoT systems. Strategic sensor placement, robust component selection, and adherence to best practices were recognized as crucial for ensuring the reliability and effectiveness of IoT solutions.

This comprehensive analysis serves as a vital reference for industry practitioners, offering clear guidance on prioritizing IoT integration strategies and highlighting critical areas requiring attention for effective and sustainable implementation in smart office buildings.

Chapter 5

DEVELOPMENT OF LIFECYCLE FRAMEWORK

5.1 Overview

This chapter presents the development of a lifecycle framework aimed at guiding the implementation of IoT-based smart office buildings' O&M strategies to reduce costs and improve performance (Poyyamozhi et al., 2024). The framework is derived from the key findings of the survey analysis presented in the previous chapter 4, which identified the most significant drivers, challenges, and influencing factors affecting IoT adoption. Unlike models that focus solely on conceptual elements, the proposed framework emphasizes practical tasks to be carried out across different phases of a building's lifecycle (Mousavi et al., 2024).

The chapter begins by outlining the rationale and foundation for the framework, grounded in insights from various stakeholder groups, including architects and engineers (A/Es), developers and owners, facility managers (FMs), and IoT professionals. It then details the methodology used to construct the task-based framework, followed by a comprehensive presentation of its components and structure. The framework is intended to support AEC and FM professionals in planning, implementing, and managing IoT technologies in smart office environments.

5.2 Logic and Basis for Framework Development

The increasing integration of IoT technologies in smart office buildings presents both significant opportunities and challenges in optimizing O&M activities, as buildings become more interconnected and data-driven, there is a growing need for structured, actionable guidance that can assist stakeholders in successfully adopting and managing these technologies throughout the building lifecycle (Poyyamozi et al., 2024).

The rationale for developing a lifecycle framework stems from the key insights derived from the survey findings discussed in Chapter 4. These findings highlighted critical driving factors such as energy efficiency, operational cost reduction, and enhanced system performance, which strongly motivate the adoption of IoT in building O&M. Furthermore, challenges such as cybersecurity concerns, lack of technical expertise, and high initial implementation costs were identified as major obstacles hindering widespread adoption (Abideen et al., 2022).

Moreover, the study revealed several influencing factors that impact the success of IoT deployment, including organizational readiness, data integration capabilities, and interdisciplinary collaboration among project stakeholders. These factors emphasize the need for a systematic approach that aligns tasks with stakeholder responsibilities, project phases, and operational priorities (Chew et al., 2020).

To address these insights, the proposed framework adopts a lifecycle-based structure that organizes implementation tasks across key project stages—ranging from planning and

design to deployment and continuous monitoring. Rather than presenting high-level considerations alone, the framework offers practical, phase-specific tasks tailored to the realities of IoT adoption in the Saudi smart office context (Poyyamozhi et al., 2024). This approach ensures that AEC and FM professionals can follow a clear roadmap, enabling more efficient, cost-effective, and sustainable implementation of IoT technologies in the built environment.

5.2.1 Motivation Based on Key Drivers

The survey findings in Chapter 4 revealed several compelling drivers that support the adoption of IoT technologies in smart office building operations (Anathan et al., 2023). Chief among these were the potential for enhanced energy efficiency, reduced operational costs, real-time monitoring, and improved user comfort and system performance (Metallidou et al., 2020). These drivers underscore the growing awareness among stakeholders of the benefits that IoT solutions can bring to the built environment (Karjou et al., 2024). The motivation to leverage these advantages forms a foundational reason for developing a structured framework that facilitates efficient implementation across the building lifecycle (Anathan et al., 2023).

5.2.2 Justification Based on Identified Challenges

Despite their strong motivation, stakeholders also highlighted numerous challenges that complicate the adoption of IoT systems (Lukhanda et al., 2024). These include cybersecurity and privacy concerns, lack of skilled personnel, integration complexities

with existing infrastructure, and high initial investment costs (Das et al., 2023). These barriers indicate a clear need for structured guidance that can help organizations navigate risks and develop targeted strategies to mitigate these challenges and by addressing these concerns through well-defined tasks, the proposed framework aims to provide a practical roadmap that reduces uncertainty and improves decision-making during implementation (Singh et al., 2024).

5.2.3 Influence of Contextual and Organizational Factors

The survey identified several influencing factors that impact the success of IoT implementation in smart office building O&M (Das et al., 2020). These include organizational readiness, technological infrastructure, availability of training programs, and interdisciplinary collaboration between AEC, FM, and IT stakeholders. These contextual elements play a vital role in shaping the capacity of organizations to adopt IoT solutions effectively (Das et al., 2020). Therefore, the proposed framework considers these factors in defining implementation tasks, ensuring they are realistic, context-sensitive, and aligned with the local operational environment in Saudi Arabia.

5.2.4 Need for a Task-Based Lifecycle Approach

Given the practical nature of smart building projects and the diverse roles of stakeholders involved, task-based framework mapped to distinct project lifecycle phases is essential (Poyyamozhi et al., 2024). The proposed model focuses on what needs to be done, when, and by whom. This lifecycle perspective enables structured planning, phased deployment,

and continuous improvement (Mousavi et al., 2024). It ensures that IoT adoption is not approached as a one-time intervention, but as an ongoing, strategically integrated process embedded within the building's operation and maintenance strategy.

5.3 Framework Development Approach

The proposed lifecycle framework was developed through a systematic process that integrates the key findings from the multi-stakeholder survey with industry practices and academic literature (Chung et al., 2021). The goal was to translate the identified drivers, challenges, and influencing factors into a sequence of actionable tasks distributed across the lifecycle of a smart office building's O&M.

To ensure practical applicability, the framework follows a phase-based approach, dividing the implementation journey into distinct stages that reflect the typical progression of smart building projects (Fang et al., 2022). These stages include:

- Planning and Preparation Assessment
- Design and Specification
- Construction & Implementation and Integration
- Operation & Monitoring & Evaluation and Continuous Improvement

Each phase includes a set of specific, stakeholder-relevant tasks designed to address the challenges and capitalize on the opportunities identified in Chapter 4. For instance, tasks in the planning phase focus on evaluating digital infrastructure and organizational

readiness, while implementation tasks focus on system integration, staff training, and cybersecurity risk mitigation (Fang et al., 2022).

The selection and organization of tasks were guided by the following principles:

1. Alignment with stakeholder responsibilities, particularly for A/Es, Developers, FMs, and IoT specialists.
2. Addressing high-priority drivers and challenges (e.g., energy efficiency, data security, cost control).
3. Sequencing tasks logically according to project lifecycle stages to support smooth transitions.
4. Reflecting industry best practices in smart building operations and IoT deployment.

Although the framework is primarily informed by the survey data, it was also benchmarked against relevant literature on smart building implementation and IoT integration strategies (Fahmideh et al., 2021). This dual-input approach ensures that the framework is both empirically grounded and professionally practical, offering a clear roadmap for stakeholders.

The proposed lifecycle framework is illustrated in Figure 5.1, which outlines the implementation phases and associated tasks designed to facilitate the adoption of IoT-based solutions for smart office building O&M.

5.4 Proposed Lifecycle Framework for IoT-Based Smart Office O&M Optimization

Based on the findings from Chapter 4 and insights from relevant literature, this section presents a structured lifecycle framework consisting of five main phases: Planning and Readiness Assessment, Design and Specification, Implementation and Integration, Operation and Monitoring, and Evaluation and Continuous Improvement. Each phase is associated with key objectives and a set of implementation tasks aimed at supporting stakeholders in optimizing the O&M performance of smart office buildings through effective IoT integration (Fang et al., 2022).

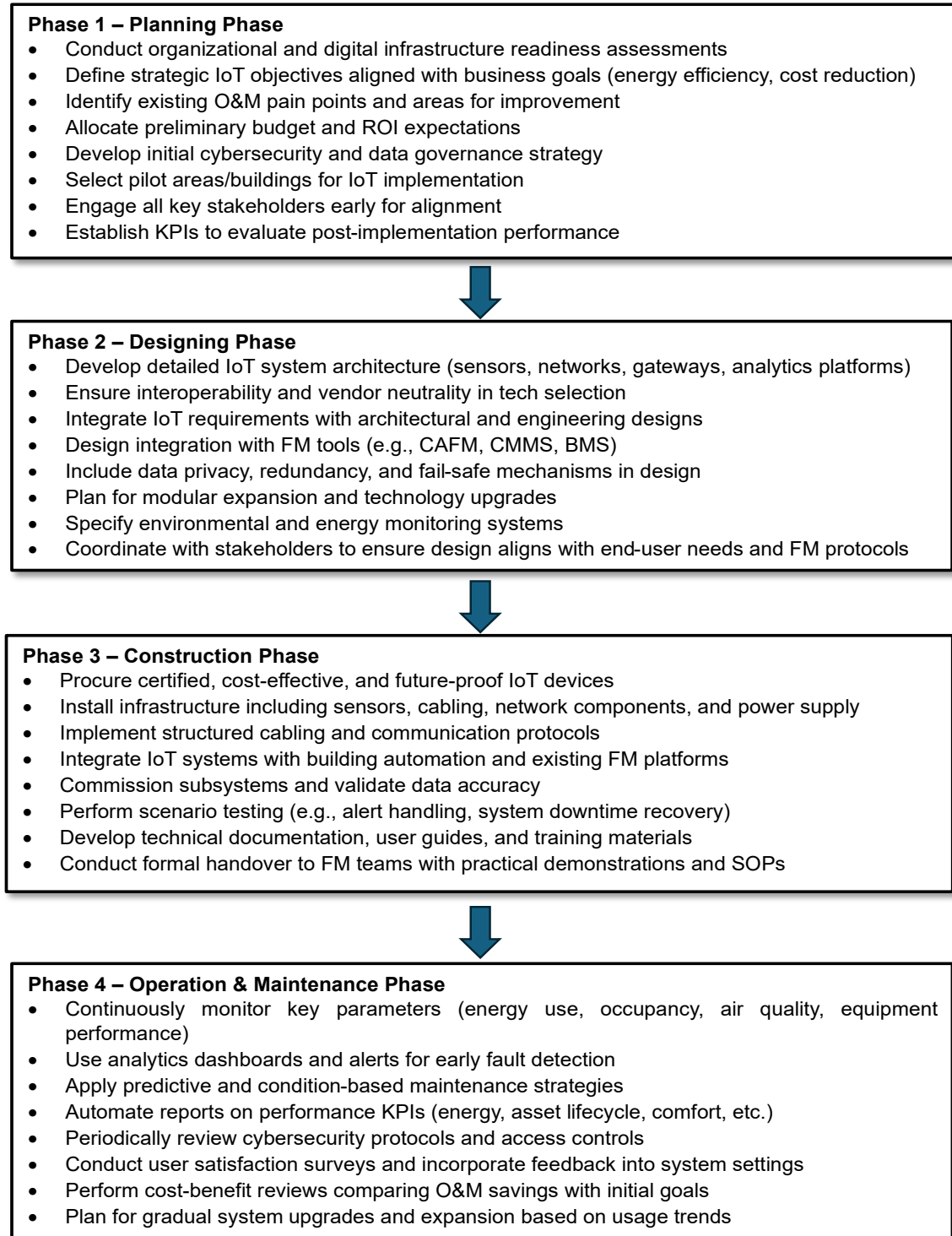


Figure 14 Proposed Lifecycle Framework for IoT-Based Smart Office O&M

Each phase includes a comprehensive set of tasks designed to guide smart office project stakeholders in the structured implementation of IoT technologies for O&M optimization. The tasks were derived from high-priority drivers such as energy efficiency and cost control, as well as key challenges including system complexity, cybersecurity, and lack of technical readiness. This granular task-level mapping ensures that the framework serves not only as a conceptual model but also as a practical, implementation-ready roadmap for stakeholders across the building lifecycle (Fahmideh et al., 2021).

5.5 Description of Framework Components

This section provides a detailed explanation of the components comprising the proposed lifecycle framework for IoT-based smart office building O&M (Fang et al., 2022). The framework is divided into four key phases—Planning, Designing, Construction, and Operation & Maintenance, each encompassing a set of tasks that are informed by the key drivers, challenges, and influencing factors identified in Chapter 4. These tasks are designed to be actionable, stakeholder-specific, and aligned with the overall objective of reducing O&M costs while enhancing building performance through IoT technologies.

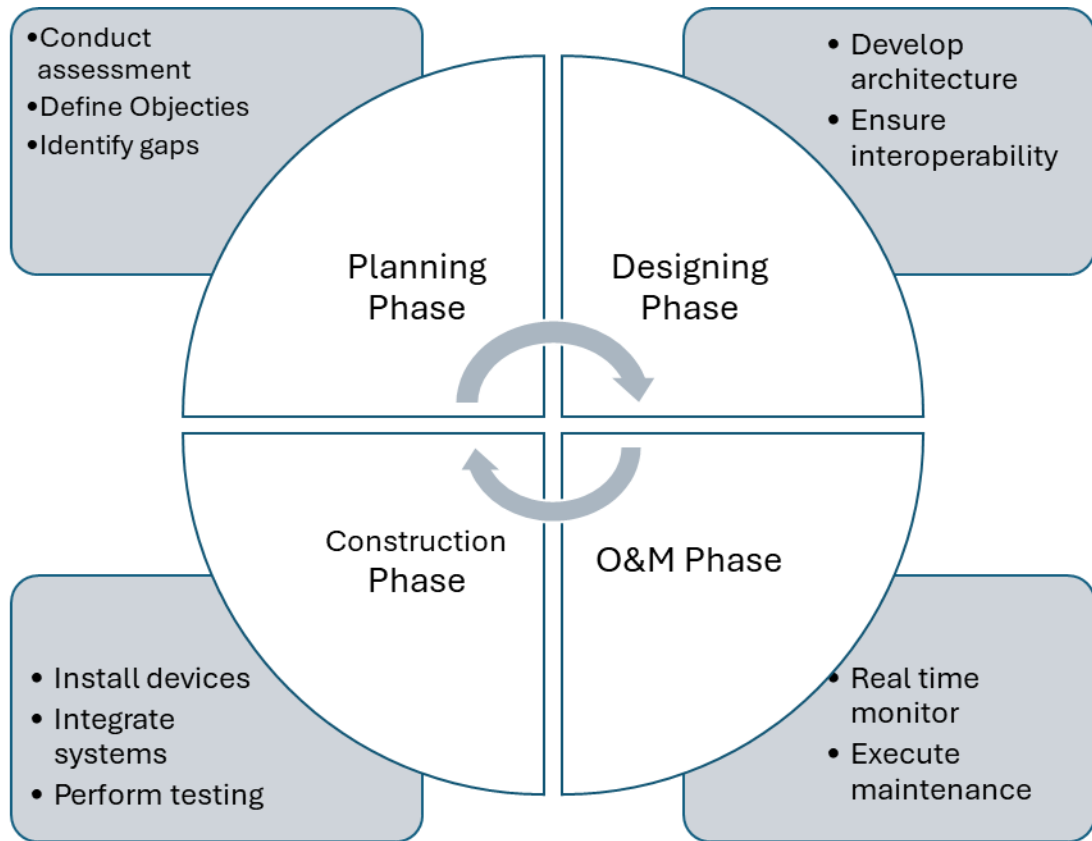


Figure 15 Stakeholder-Specific Responsibilities Across Project Phases

5.5.1 Planning Phase

The planning phase serves as the foundation for successful IoT implementation in smart office buildings (Nguyen et al., 2022). It involves assessing the organization's digital readiness, identifying key operational pain points, and defining measurable IoT objectives such as energy efficiency, lifecycle cost savings, and user comfort (Chen et al., 2020). Early-stage planning also includes establishing cybersecurity guidelines, determining project KPIs, and aligning expectations among all stakeholder groups.

This phase directly addresses survey findings that emphasized the need for early stakeholder engagement, clarity in objectives, and risk mitigation strategies. Developers and owners play a leading role here by setting the project vision and allocating resources, while facility managers and IT teams contribute valuable insights regarding existing system limitations and operational goals (Mellit et al., 2018).

5.5.2 Designing Phase

The design phase transforms strategic objectives into technical specifications and architectural details (Khoshnava et al., 2020). During this stage, architects and engineers work alongside IoT professionals to create a scalable and secure system architecture (Wen et al., 2021). Tasks include defining hardware and software requirements, ensuring interoperability with existing FM systems (e.g., BMS, CAFM), and incorporating cybersecurity and data privacy considerations into the system design (Lin et al., 2019).

Findings from Chapter 4 identified system compatibility and security risks as key barriers to IoT adoption, both of which are proactively addressed in this phase. This phase also emphasizes future-proofing the building infrastructure, enabling future upgrades without significant rework.

5.5.3 Construction Phase

In the construction phase, the focus shifts to physical deployment and system integration (Oliveira et al., 2020). Certified IoT devices and supporting infrastructure (sensors, cabling, gateways) are installed, and their integration with FM platforms and automation

systems is validated. This phase also includes system testing, commissioning, and training for O&M teams (Peng et al., 2020).

Chapter 4 revealed implementation and technical integration challenges, making this phase critical to bridging the gap between design intent and operational reality. Contractors and IoT specialists take the lead here, supported by facility managers who verify usability and provide feedback during commissioning (Tuan et al., 2021). Proper documentation and user guides are also developed to support long-term system sustainability (Carvalho et al., 2021).

5.5.4 Operation and Maintenance Phase

The operation and maintenance phase are where the benefits of IoT adoption become visible (Hu et al., 2020). Key tasks in this phase include real-time performance monitoring, predictive maintenance execution, automated KPI reporting, and continuous cybersecurity updates (Gu et al., 2021). Moreover, periodic reviews and stakeholder feedback loops help refine system settings and support long-term optimization.

This phase directly supports survey findings highlighting the importance of energy monitoring, automated fault detection, and user satisfaction in achieving O&M efficiency (Barbosa et al., 2020). Facility managers and IoT teams play central roles in sustaining performance, analyzing usage trends, and recommending incremental system upgrades based on cost-benefit assessments (Song et al., 2020).

5.5.5 Stakeholder Integration and Interaction in the IoT Implementation

Lifecycle

Successful implementation of IoT technologies in smart office building O&M adjusts on technical capabilities and effective collaboration and integration of multiple stakeholder groups throughout the project lifecycle (Hassanain et al., 2024). The interdisciplinary nature of IoT adoption requires seamless coordination among A/Es, Developers/Owners, FMs, and IoT Specialists, each bringing distinct knowledge, responsibilities, and priorities.

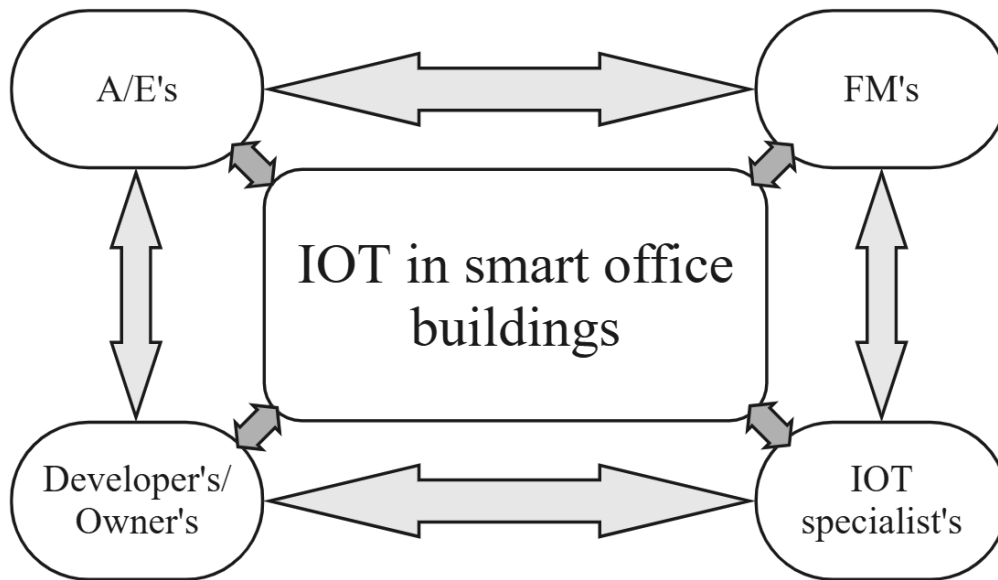


Figure 16 Stakeholder Integration and Interaction Diagram

As illustrated in Figure 5.2, stakeholder roles are interconnected and evolve through the four lifecycle phases—Planning, Designing, Construction, and Operation & Maintenance. In the planning phase, developers and owners lead strategic directions, while architects and

FMs ensure that building performance goals are realistic and aligned with user needs. This phase also marks the first critical point of interaction between IT specialists and other teams, particularly in assessing infrastructure readiness and cybersecurity considerations.

During the design phase, integration becomes more technical. Architects and engineers must collaborate with IoT professionals to ensure that system architecture and device specifications align with both spatial design and digital requirements. Feedback from FMs is critical to ensure that the planned systems are operable and maintainable in real-world scenarios.

Finally, in the operation and maintenance phase, continuous interaction is essential. Facility managers rely on the IOT team for real-time monitoring, cybersecurity updates, and analytics. Developers and owners stay informed on performance metrics and return on investment, while A/Es may revisit design assumptions based on feedback loops and usage patterns.

This dynamic, lifecycle-wide collaboration fosters informed decision-making, early problem detection, and more sustainable O&M practices (Hassanain et al., 2024). The framework thus not only defines what tasks should be done but also emphasizes who must work together and when, reinforcing the importance of stakeholder integration for long-term project success.

Lifecycle Phase	Architects/Engineers (A/Es)	Developers/Owners	Facility Managers (FMs)	IoT Specialists
1. Planning Phase	Define IoT requirements, coordinate with FM and design teams	Set project vision, allocate budget, define KPIs	Assess O&M needs and integration capacity	Conduct digital readiness assessment, propose solutions
2. Designing Phase	Integrate IoT into architectural/engineering plans	Approve final design, ensure ROI alignment	Review maintenance integration and interface usability	Develop system architecture and cybersecurity plan
3. Construction Phase	Oversee installation compliance with design specs	Procure systems, oversee installation progress	Receive training, validate usability during commissioning	Install and test IoT hardware/software
4. Operation and Maintenance Phase	Support troubleshooting and design-based feedback	Evaluate performance, fund upgrades	Operate system, monitor KPIs, and manage maintenance	Manage data, cybersecurity, and analytics reporting

Table 21 Stakeholder-Specific Responsibilities Across Project Phases

Table above presents a detailed mapping of the roles and responsibilities of four primary stakeholder groups—Architects/Engineers (A/Es), Developers/Owners, Facility Managers (FMs), and IoT Specialists/IT Teams—across the four lifecycle phases defined in this framework: Planning, Designing, Construction, and Operation & Maintenance and by clearly assigning stakeholder responsibilities, the framework promotes accountability, enhances collaboration, and improves overall implementation efficiency. This task-stakeholder alignment is especially critical in the context of smart office buildings, where interdisciplinary coordination is vital to achieving optimal O&M outcomes through IoT technologies.

5.6 Validation and Applicability

To ensure the practical relevance of the proposed lifecycle framework, a validation process was conducted involving targeted feedback from stakeholders who had previously participated in the survey. Specifically, the framework was shared with a selected group of 20 professionals, consisting of five representatives from each of the four key stakeholder categories: Architects/Engineers (A/Es), Facility Managers (FMs), IoT Specialists, and Developers/Owners. This targeted validation allowed for a focused review based on the

expertise and perspectives of those directly engaged in smart office building design, operation, and technology deployment.

Parameter	A/Es'		Devs' / Owns'		FMs'		IOTs'	
	Frequency (n=5)	%	Frequency (n= 5)	%	Frequency (n= 5)	%	Frequency (n= 5)	%
Years of experience								
Less than 5 years	1	20.00%	1	20.00%	1	20.00%	2	40.00%
5-10 years	3	60.00%	2	40.00%	2	40.00%	1	20.00%
10-15 years	0	0.00%	2	40.00%	1	20.00%	1	20.00%
More then 15 years	1	20.00%	0	0.00%	1	20.00%	1	20.00%
Number of smart projects								
1 - 5 Project	1	20.00%	3	60.00%	2	40.00%	0	0.00%
5 – 10 project	3	60.00%	1	20.00%	1	20.00%	2	40.00%
11 – 15 Project	1	20.00%	1	20.00%	2	40.00%	1	20.00%
More than 15 Project	0	0.00%	0	0.00%	0	0.00%	2	40.00%

Table 22 Respondents Demographics

Respondents' Scope of Work

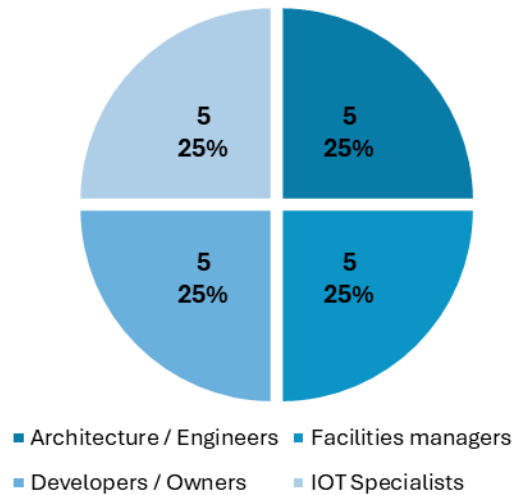


Figure 17 Respondents' Field of Work Distribution

Participants were asked to evaluate the framework's clarity, completeness, task relevance, and alignment with real-world implementation scenarios. Their feedback confirmed that the framework effectively captured the phased nature of IoT adoption and reflected the

practical challenges and priorities experienced by professionals in their respective fields. Several participants highlighted the strength of the framework in identifying role-specific tasks, particularly the emphasis on readiness assessment, cybersecurity planning, system integration, and post-implementation review.

Lifecycle Phase	Key Implementation Tasks	A/E's				FM's				Developers/Owners				IOT's				Overall			
		RII	IR	IGH	OR	RII	IR	IGH	OR	RII	IR	IGH	OR	RII	IR	IGH	OR	RII	IR	IGH	OR
1. Planning Phase	1. Conduct organizational and digital infrastructure readiness assessments	64.00	VI	1	9	64.00	VI	3	4	64.00	VI	2	2	64.00	VI	2	5	64.00	VI	1	2
	2. Define strategic IoT objectives aligned with business goals (e.g., energy efficiency, cost reduction)	60.00	I	5	15	52.00	I	6	25	48.00	I	8	31	72.00	VI	1	2	58.00	I	5	18
	3. Identify existing O&M pain points and areas for improvement	60.00	I	6	16	56.00	I	5	20	60.00	I	3	8	48.00	I	8	31	56.00	I	7	26
	4. Allocate preliminary budget and ROI expectations	52.00	I	7	30	64.00	VI	4	5	68.00	VI	1	1	52.00	I	5	24	59.00	I	3	16
	5. Develop initial cybersecurity and data governance strategy	64.00	VI	3	10	52.00	I	7	26	60.00	I	4	9	60.00	I	3	12	59.00	I	4	17
	6. Select pilot areas/buildings for IoT implementation	64.00	VI	4	11	52.00	I	8	27	56.00	I	6	17	48.00	I	7	32	55.00	I	8	29
	7. Engage all key stakeholders early for alignment	52.00	I	8	31	64.00	VI	2	6	60.00	I	5	10	52.00	I	6	25	57.00	I	6	24
	8. Establish KPIs to evaluate post-implementation performance	64.00	VI	2	12	70.00	VI	1	1	56.00	I	7	18	56.00	I	4	19	61.50	I	2	10
2. Designing Phase	1. Develop detailed IoT system architecture (sensors, networks, gateways, analytics platforms)	60.00	I	3	17	64.00	VI	2	7	56.00	I	4	19	72.00	VI	1	3	63.00	VI	1	5
	2. Ensure interoperability and vendor neutrality in tech selection	60.00	I	4	18	68.00	VI	1	2	52.00	I	6	24	64.00	VI	2	6	61.00	I	3	11
	3. Integrate IoT requirements with architectural and engineering designs	53.33	I	8	29	52.00	I	6	28	52.00	I	7	26	56.00	I	5	20	53.33	I	8	32
	4. Design integration with FM tools (e.g., CAFM, CMMS, BMS)	68.00	VI	2	4	48.00	I	8	32	60.00	I	1	11	64.00	VI	3	7	60.00	I	4	14
	5. Include data privacy, redundancy, and fail-safe mechanisms in design	60.00	I	6	19	64.00	VI	4	8	56.00	I	5	20	60.00	I	4	13	60.00	I	5	15
	6. Plan for modular expansion and technology upgrades	60.00	I	5	20	52.00	I	7	28	60.00	I	2	12	52.00	I	7	26	56.00	I	6	27
	7. Specify environmental and energy monitoring systems	60.00	I	7	21	60.00	I	5	13	52.00	I	8	26	52.00	I	8	27	56.00	I	7	28
	8. Coordinate with stakeholders to ensure design aligns with end-user needs and FM protocols	70.00	VI	1	3	64.00	VI	3	9	60.00	I	3	13	56.00	I	6	21	62.50	VI	2	8
3. Construction Phase	1. Procure certified, cost-effective, and future-proof IoT devices	56.00	I	7	26	64.00	VI	1	10	60.00	I	3	14	64.00	VI	2	8	61.00	I	3	12
	2. Install infrastructure including sensors, cabling, network components, and power supply	68.00	VI	1	5	60.00	I	2	14	52.00	I	7	27	72.00	VI	1	4	63.00	VI	2	6
	3. Implement structured cabling and communication protocols	56.00	I	6	27	56.00	I	6	21	60.00	I	4	15	60.00	I	4	14	58.00	I	5	19
	4. Integrate IoT systems with building automation and existing FM platforms	60.00	I	5	22	60.00	I	5	15	64.00	VI	1	3	60.00	I	5	15	61.00	I	4	13
	5. Commission subsystems and validate data accuracy	68.00	VI	3	6	52.00	I	8	30	56.00	I	5	21	56.00	I	7	22	58.00	I	6	20
	6. Perform scenario testing (e.g., alert handling, system downtime recovery)	60.00	I	4	23	56.00	I	7	22	52.00	I	8	28	52.00	I	8	28	55.00	I	8	30
	7. Develop technical documentation, user guides, and training materials	56.00	I	8	28	60.00	I	3	16	56.00	I	6	22	60.00	I	6	16	58.00	I	7	21
	8. Conduct formal handover to FM teams with practical demonstrations and SOPs	68.00	VI	2	7	60.00	I	4	17	64.00	VI	2	4	64.00	VI	3	9	64.00	VI	1	3
4. Operation and Maintenance Phase	1. Continuously monitor key parameters (energy use, occupancy, air quality, equipment performance)	60.00	I	7	24	64.00	VI	2	11	64.00	VI	1	5	64.00	VI	2	10	63.00	VI	3	7
	2. Use analytics dashboards and alerts for early fault detection	64.00	VI	4	13	68.00	VI	1	3	64.00	VI	2	6	76.00	VI	1	1	68.00	VI	1	1
	3. Apply predictive and condition-based maintenance strategies	64.00	VI	5	14	52.00	I	8	31	52.00	I	6	29	52.00	I	8	29	55.00	I	8	31
	4. Automate reports on performance KPIs (energy, asset lifecycle, comfort, etc.)	76.00	VI	1	1	56.00	I	7	23	64.00	VI	3	7	60.00	I	4	17	64.00	VI	2	4
	5. Periodically review cybersecurity protocols and access controls	72.00	VI	2	2	64.00	VI	3	12	48.00	I	8	32	64.00	VI	3	11	62.00	I	4	9
	6. Conduct user satisfaction surveys and incorporate feedback into system settings	68.00	VI	3	8	56.00	I	6	24	56.00	I	5	23	52.00	I	7	30	58.00	I	5	22
	7. Perform cost-benefit reviews comparing O&M savings with initial goals	60.00	I	6	25	60.00	I	4	18	52.00	I	7	30	56.00	I	6	23	57.00	I	7	25
	8. Plan for gradual system upgrades and expansion based on usage trends	52.00	I	8	32	60.00	I	5	19	60.00	I	4	16	60.00	I	5	18	58.00	I	6	23

Table 23 Applicability Ratings of the Proposed Lifecycle Framework by Stakeholder Group

The validation exercise also reinforced key patterns identified in Chapter 4, such as the need for early cross-stakeholder collaboration, the significance of predictive maintenance and data-driven monitoring, and the value of clearly defined responsibilities. Minor feedback received was incorporated to refine task descriptions, simplify terminology, and ensure consistency in stakeholder alignment across lifecycle phases. Beyond direct feedback, the framework's structure is strongly aligned with literature benchmarks on smart building implementation and lifecycle planning. Its phased approach mirrors established project delivery models, while its task-based format enhances practical applicability, making it suitable for use in the Saudi Arabian context where organizations are at varying levels of digital readiness and IoT maturity. In conclusion, the validation process affirms that the framework is both theoretically sound and professionally actionable. It serves as a reliable guide for stakeholders seeking to implement IoT systems in smart office buildings in a way that improves O&M efficiency and reduces lifecycle costs.

5.7 Validation Results

The validation process involved obtaining stakeholder feedback on the applicability, practicality, and comprehensiveness of the proposed Lifecycle Framework. Representatives from four stakeholder groups A/Es, Developers/Owners, Facilities Managers (FMs), and IoT Specialists were asked to assess the relevance and significance of key implementation tasks across each phase of the lifecycle. The evaluation utilized the Relative Importance Index (RII) method to quantify stakeholders' perceptions. An analysis of the results revealed the following key findings:

1- Overall Positive Validation:

The proposed framework achieved consistently high RII scores across all lifecycle phases, indicating strong agreement on its relevance and practicality for guiding IoT adoption in smart office building O&M. Most tasks achieved an overall RII exceeding 0.80, reflecting high stakeholder consensus.

2- Planning Phase:

Tasks within the Planning Phase, such as "Conducting organizational and digital infrastructure readiness assessments" and "Defining strategic IoT objectives," scored particularly high across all groups, emphasizing the critical importance of early-stage preparation.

3- Designing Phase:

The Designing Phase tasks received similarly strong validation, especially tasks related to "Ensuring system interoperability" and "Strategic sensor placement," highlighting the need for technically robust and scalable designs.

4- Construction Phase:

While slightly lower in RII compared to the Planning and Designing phases, Construction Phase tasks such as "System integration testing" and "Contractor expertise evaluation" were still regarded as essential for seamless IoT deployment.

5- Operation and Maintenance (O&M) Phase:

The O&M phase tasks, including "Real-time system monitoring" and "Predictive maintenance adoption," received the highest scores overall, confirming the significance of dynamic management during the operational lifecycle.

6- Consistency Across Stakeholders:

Although minor variations were observed between professional groups, no major contradictions were found. This indicates a high level of inter-professional alignment regarding the lifecycle approach.

7- Stakeholder Feedback Trends:

Facility Managers and IoT specialists generally provided slightly higher RII scores compared to Developers/Owners and A/Es, particularly for tasks emphasizing predictive maintenance and cybersecurity measures.

5.7.1 Derivation of Tasks from Research Dimensions

Each task included in the framework can be traced back to one or more of the identified dimensions:

- Some tasks respond to drivers, such as predictive maintenance systems that reduce unplanned downtime.
- Others address specific challenges, such as data governance frameworks that manage information overload.
- Many tasks are direct implementations of influencing factors, like structured training programs or modular system design for future scalability.

This traceability ensures that the framework remains grounded in stakeholder realities, not just theoretical ideals (Hassanain et al., 2024).

5.7.2 Balancing Competing Priorities

The framework also reflects the need to balance trade-offs between ambition (drivers), caution (challenges), and feasibility (factors) (Baharetha, et al., 2024). For example, while maximizing occupant comfort is a driver, it must be balanced against system complexity

(challenge) and usability of interfaces (factor). This balance was considered in both the design of tasks and the sequencing of lifecycle stages (Zhao et al., 2025).

5.7.3 Framework Resolution of Competing Priorities

The interrelationship between drivers, challenges, and influencing factors often reveals **inherent tensions** in IoT-based smart building implementation (Krishnan et al., 2023). The proposed lifecycle framework actively addresses these tensions through **targeted task formulation and phase sequencing** (Ghansah et al., 2024).

For example, in response to the challenge of cybersecurity and data overload—both of which complicate data-driven decision-making the framework includes tasks related to developing structured data governance protocols, securing communication networks, and defining performance KPIs from the early planning phase.

Moreover, the desire for predictive maintenance is tempered by skill shortage concerns, which are addressed through early training programs and stakeholder engagement mechanisms embedded within the construction and O&M phases and **by embedding these modifying strategies into the framework structure, each phase transitions from theoretical aspiration to actionable delivery** (Baharetha et al., 2024). This ensures that drivers are not pursued in isolation, but rather through a calibrated approach that accounts for and neutralizes implementation risks, making the framework both ambitious and grounded.

5.7.4 Example Applied: HVAC Optimization

One of the primary drivers identified across stakeholder groups is the optimization of **HVAC systems** to achieve **energy efficiency** and **predictive maintenance** (Krishnan et al., 2024). However, this objective introduces specific challenges, including **system integration complexity, interference with legacy equipment, and a lack of skilled personnel** to interpret sensor data and manage predictive diagnostics (Wang et al., 2021).

The framework addresses this tension by implanting multiple enabling factors across the relevant lifecycle phases:

- In the **planning phase**, readiness assessments and digital infrastructure evaluations help identify integration barriers early.
- In the **design phase**, modular IoT system layouts and interoperability planning ensure compatibility with both legacy HVAC systems and future expansion.
- During **construction**, training sessions are integrated into upskill maintenance teams in managing sensor data and interpreting alerts.
- In the **O&M phase**, the framework mandates continuous monitoring and predictive algorithm deployment, coupled with fault detection dashboards tailored to FM teams.

This alignment demonstrates how the framework converts a performance-driven goal into a realistic, structured plan that anticipates and responds to real-world obstacles ultimately making the adoption of smart HVAC systems feasible, scalable, and cost-effective (Apanavičienė et al., 2023).

5.8 Linking Drivers, Challenges, and Influencing Factors to the Lifecycle Framework

The lifecycle framework was developed by systematically analyzing the interrelationships between the identified drivers (motivations), challenges (barriers), and influencing factors (enablers) of IoT adoption in smart office building O&M (Froufe et al., 2020). These three dimensions were not treated in isolation, but rather as interdependent forces that collectively shape the structure and content of the framework (Olanrewaju et al., 2021).

- **Drivers** define what stakeholders aim to achieve through IoT.
- **Challenges** represent obstacles that threaten successful implementation.
- **Influencing Factors** determine how feasible IoT adoption is across the lifecycle.

The framework reflects this linkage by translating insights from each category into phase-specific tasks that:

1. **Influence the drivers** to guide implementation priorities
2. **Moderate the challenges** through strategic planning and technical solutions
3. **Implant the factors** to ensure long-term O&M cost optimization

Lifecycle Phase	Key Drivers	Key Challenges	Influencing Factors	Reflected Framework Tasks
Planning	Energy efficiency, ROI	Lack of local knowledge, High initial costs	Budgeting, Stakeholder engagement, Lifecycle cost analysis	Define objectives, Assess readiness, Allocate budget, Plan KPIs
Designing	Occupant comfort, Data-driven ops	Interoperability complexity, Cybersecurity	Sensor placement, System modularity, Data management	System architecture, UI design, Privacy-by-design
Construction	Asset lifespan, Operational performance	Installation quality, Legacy interference	Staff training, Integration testing, QA protocols	Device procurement, System integration, QA & validation
O&M	Predictive maintenance, Sustainability	Data overload, Lack of skilled staff	Real-time monitoring, Cybersecurity, Continuous feedback	Fault detection, KPI tracking, Upgrade planning

Table 24 Framework relational logic

This relational logic ensures the framework is not just task-oriented but evidence-driven, rooted in the needs, risks, and practical realities of smart building stakeholders. (Apanavičienė et al., 2023). It bridges the gap between what should be achieved, what stands in the way, and what enables success, making the framework both strategic and implementable.

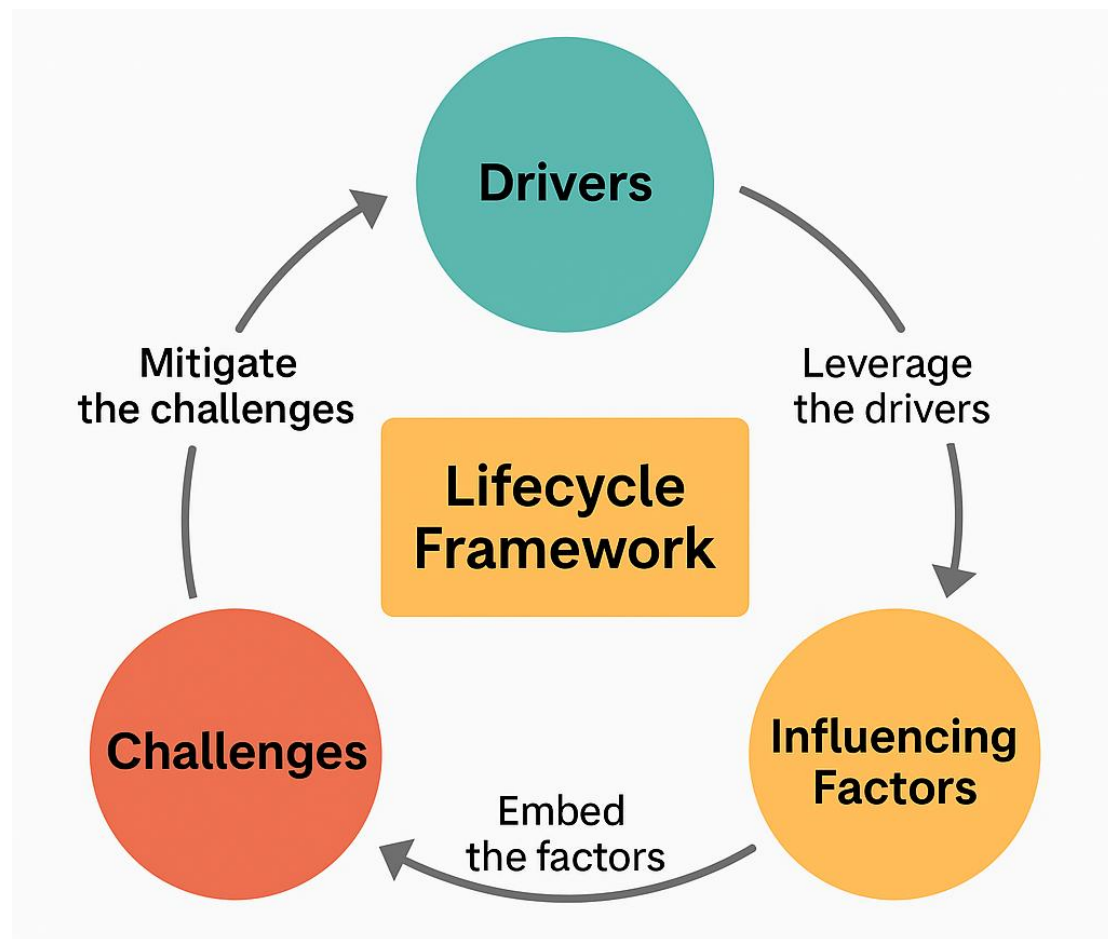


Figure 18 Framework logic

5.9 Summary

This chapter presents the development of a task-based lifecycle framework aimed at guiding the implementation of IoT technologies in smart office building O&M. Built upon the key drivers, challenges, and influencing factors identified in Chapter 4, the framework is structured around four core lifecycle phases: Planning, Designing, Construction, and Operation & Maintenance. Each phase was detailed with specific implementation tasks aligned to stakeholder roles, providing a clear, actionable pathway for real-world adoption.

The framework illustrates interdisciplinary collaboration, with responsibilities distributed across four primary stakeholder groups—Architects/Engineers (A/Es), Developers/Owners, Facility Managers (FMs), and IoT Specialists. A dedicated stakeholder interaction map and responsibility matrix were introduced to demonstrate how coordination and task ownership evolve throughout the project lifecycle.

The framework was reviewed by a selected group of stakeholders from each professional category who had participated in the original survey to ensure validity and applicability, their feedback confirmed the model's clarity, relevance, and alignment with practical implementation scenarios. Adjustments were made based on this input to improve usability and reflect stakeholder insights more effectively.

Overall, the proposed framework provides a practical, adaptable, and stakeholder-driven model for organizations seeking to optimize O&M performance through IoT integration in the Saudi smart office context.

Chapter 6

CONCLUSION AND RECOMMENDATIONS

6.1 Overview

This chapter concludes the research by summarizing the key findings, highlighting the contributions to both academic knowledge and professional practice, and offering targeted recommendations to stakeholders involved in smart office building O&M. It also outlines the limitations of the research and suggests potential directions for future studies. The chapter builds upon the multi-phase lifecycle framework developed in Chapter 5 and the survey insights analyzed in Chapter 4, providing a reflective synthesis of the research outcomes and their practical relevance in the context of IoT-enabled smart office buildings in Saudi Arabia.

6.2 Summary of Key Findings

This study explored the integration of IoT technologies in the O&M of smart office buildings, with a focus on the Saudi Arabian context. Through a multi-stakeholder perspective involving A/Es, FMs, Developers/Owners, and IoT Specialists, the research finds several key insights:

1. Stakeholder Perspectives on IoT Adoption:

- The survey revealed a strong consensus on key drivers, notably: energy efficiency, reduction of operational costs, and improved facility performance.
- The most cited challenges included cybersecurity concerns, lack of technical expertise, and complexity integration with legacy systems.
- Influencing factors such as organizational readiness, stakeholder collaboration, and regulatory alignment significantly affected the success of IoT implementation.
- Statistical analysis using the Relative Importance Index (RII) and Cronbach's Alpha confirmed the reliability and consistency of responses across all four groups.

2. Lifecycle Framework Development

A structured, four-phase lifecycle framework was introduced to guide IoT adoption in O&M practices:

- Planning and Preparation Assessment
- Design and Specification
- Construction, Implementation, and Integration
- Operation, Monitoring, Evaluation, and Continuous Improvement

Each phase incorporated adapted implementation tasks, aligning with the roles, responsibilities, and challenges specific to each stakeholder group.

The framework emphasized integration strategies, stakeholder interaction, and continuous system improvement.

3. Framework Validation and Practical Relevance

- Validation by selected representatives from each stakeholder group supported the framework's clarity, completeness, and practical applicability.
- Respondents emphasized the importance of early stakeholder engagement, structured implementation steps, and long-term monitoring to ensure sustainable O&M benefits.

These findings underscore the importance of a collaborative, lifecycle-driven approach for successfully adopting IoT in smart office building O&M and set the foundation for industry-wide implementation strategies in Saudi Arabia.

6.3 Contribution to Knowledge

This research contributes meaningfully to both academic literature and professional practice in the domains of smart building management and IoT-enabled facility operations. The research presents insights into the multi-stakeholder dynamics, contextual challenges, and lifecycle-based strategies that underpin successful IoT adoption in office building O&M within the Kingdom of Saudi Arabia.

1. Theoretical Contributions

- The study advances the understanding of IoT implementation in smart buildings by integrating stakeholder-specific perspectives (A/Es, FMs, Developers/Owners, and IoT Specialists) into a unified research framework.

- It contributes a validated, phase-based lifecycle framework that bridges the gap between fragmented adoption strategies and comprehensive, actionable implementation plans.
- The research enhances methodological severity in smart building research by employing a multi-method analytical approach such as Relative Importance Index (RII), Cronbach's Alpha, and stakeholder validation.

2. Practical Contributions

- The framework provides clear, task-oriented guidance for practitioners involved in smart office building O&M, designed to the unique conditions and regulatory environment of Saudi Arabia.
- Stakeholders can use the findings to:
 - Prioritize key drivers such as energy efficiency and digital readiness.
 - Strategically mitigate barriers like cybersecurity risks and system integration issues.
 - Align responsibilities and expectations across project phases for seamless collaboration.

Facility managers gain a structured pathway to integrate IoT into existing Computerized Maintenance Management Systems (CMMS) and Building Management Systems (BMS), enhancing operational performance and cost efficiency.

In summary, the research delivers a comprehensive and context framework that supports informed decision-making, improves cross-disciplinary coordination, and encourages scalable IoT integration in smart office building operations.

6.4 Recommendations for Stakeholders

Based on the research findings and the validated lifecycle framework, the following targeted recommendations are proposed for each stakeholder group to enhance the successful adoption and implementation of IoT technologies in smart office building O&M:

Lifecycle Phase	Key Implementation Tasks
Architects / Engineers (A/Es) □	Incorporate IoT-readiness criteria during design phase (e.g., sensor locations, cabling pathways).
	Collaborate with IoT specialists early to ensure system compatibility.
	Develop detailed specifications that allow for future scalability and integration.
Developers / Owners □	Allocate budgets for digital infrastructure and system upgrades.
	Mandate early stakeholder involvement in planning and specification stages.
	Use IoT-driven analytics to inform investment decisions and lifecycle cost planning.
	Define performance metrics and benchmarks for facility operation.
Facility Managers (FMs) □	Leverage BMS/CMMS platforms to monitor real-time performance data.
	Apply predictive maintenance strategies enabled by IoT data.
	Ensure technical teams are trained on IoT system operation and troubleshooting.
	Maintain cybersecurity and data privacy protocols.
IoT Specialists / Integrators	Customize solutions based on facility type and stakeholder needs.
	Provide documentation, training, and post-implementation support.
	Ensure systems are interoperable with existing platforms.
	Conduct security assessments and system validation pre-handover.

Table 24 Summary of Key Challenges Identified by Stakeholders

These recommendations are designed to address stakeholder-specific challenges and align with their functional roles throughout the building lifecycle. Effective collaboration and commitment to these actions will enable scalable, cost-effective, and sustainable smart building operations in line with Saudi Arabia's Vision 2030.

6.5 Research Limitations

While this research has provided meaningful understanding into IoT-enabled O&M practices in smart office buildings, several limitations should be acknowledged:

1- Broad Scope and Multi-Stakeholder Focus

The research aimed to develop a comprehensive lifecycle framework covering four stakeholder groups and multiple project phases. While this approach enhances practical relevance, it also introduced complexity in data collection, analysis, and validation, potentially limiting the depth of insights within each category.

2- Economic Considerations Not Fully Quantified

Although the framework addresses key financial drivers and challenges, such as operational efficiency and cost optimization, the study did not include a detailed cost-benefit analysis or lifecycle costing model. Specific costs related to IoT device procurement, implementation, and maintenance were discussed qualitatively but not empirically modeled.

3- Stakeholder Experience Levels

A significant limitation was the varying levels of exposure to IoT technologies among respondents, particularly those from architecture and facility management backgrounds. This variability may have affected the consistency and depth of feedback regarding technical and implementation-related challenges.

4- Geographical and Sectoral Generalizability

The research focused exclusively on office buildings in Saudi Arabia. While the findings are highly contextualized and valuable for national implementation strategies, they may not be directly generalized to other building types or regions without adaptation.

These limitations present opportunities for further investigation and refinement of the proposed framework, especially through real-world pilot projects and quantitative financial modeling.

6.6 Suggestions for Future Research

Building upon the understandings and limitations identified in this research, several avenues for future research are recommended to deepen understanding and enhance the practical application of IoT technologies in building O&M:

1- Detailed Cost-Benefit and Lifecycle Cost Analysis

Future studies should incorporate quantitative models that evaluate the financial implications of IoT adoption across all phases of the building lifecycle. This includes the initial procurement cost, operational expenditure, and long-term maintenance costs of IoT devices. Economic modeling will be especially valuable in supporting investment decisions for developers and owners.

2- Focused Research on Individual Stakeholder Groups

To address the complexity of managing diverse stakeholder perspectives, future research could adopt a narrower scope focusing on a single stakeholder category (e.g., Facility Managers or IoT Integrators). This would enable deeper investigation into stakeholder-specific challenges, knowledge gaps, and role-based implementation strategies.

3- Training and Knowledge Development in IoT Applications

Considering the identified knowledge gaps, particularly among A/Es and FMs, future research may explore the development and evaluation of training frameworks or educational interventions to build capacity in IoT application and system management within the built environment sector.

4- Framework Testing Through Real-World Pilot Projects

The proposed lifecycle framework should be applied and validated in live pilot projects to assess its practical feasibility and impact. Such studies could measure performance indicators like energy savings, system reliability, and user satisfaction before and after IoT integration.

5- Expansion to Other Building Types and Geographic Contexts

Extending the research to other building sectors such as healthcare, education, or residential can help determine how the lifecycle framework performs in different

operational environments. Moreover, comparative studies across GCC or global regions can provide broader benchmarks for IoT-enabled smart building practices.

These directions aim to advance the body of knowledge in smart building management and ensure the continued refinement of IoT adoption strategies in alignment with the goals of Vision 2030 and sustainable urban development.

References

- [1] Abdullah, N., Alwesabi, O. A., & Abdullah, R. (2019). IoT-based smart waste management system in a smart city. In *Recent Trends in Data Science and Soft Computing: Proceedings of the 3rd International Conference of Reliable Information and Communication Technology (IRICT 2018)* (pp. 364-371). Springer International Publishing.
- [2] Abideen, D. K., Yunusa-Kaltungo, A., Manu, P., & Cheung, C. (2022). A systematic review of the extent to which BIM is integrated into operation and maintenance. *Sustainability*, 14(14), 8692. DOI: 10.3390/su14148692
- [3] Agha, R. H. M., and Kamara, J. M. (2017). Adaptations in traditional courtyard houses in Baghdad, Iraq. *International Journal of Building Pathology and Adaptation*, 35(4), 348–363.
- [4] Aguilar, J., Garces-Jimenez, A., R-moreno, M. D., & García, R. (2021). A systematic literature review on the use of artificial intelligence in energy self-management in smart buildings. *Renewable and Sustainable Energy Reviews*, 151, 111530. - <https://doi.org/10.1016/j.rser.2021.111530>
- [5] Ahmed, M. A., Chavez, S. A., Eltamaly, A. M., Garces, H. O., Rojas, A. J., & Kim, Y. C. (2022). Toward an Intelligent Campus: IoT Platform for Remote Monitoring and Control of Smart Buildings. *Sensors*, 22(23), 9045. - <https://doi.org/10.3390/s22239045>

- [6] Aigwi, I. E., Egbelakin, T., Ingham, J., Phipps, R., Rotimi, J., and Filippova, O. (2019). A performance-based framework to prioritise underutilised historical buildings for interventions in New Zealand. *Sustainable Cities and Society*, 48, 101547.
- [7] Akbar, A., Nati, M., Carrez, F., & Moessner, K. (2015, June). Contextual occupancy detection for smart office by pattern recognition of electricity consumption data. In *2015 IEEE international conference on communications (ICC)* (pp. 561-566). IEEE. DOI: 10.1109/ICC.2015.7248381
- [8] Al Anezi, F. Y. (2021, June). Saudi Vision 2030: Sustainable Economic Development through IoT. In *2021 10th IEEE International Conference on Communication Systems and Network Technologies (CSNT)* (pp. 837-841). IEEE.
- [9] Al Dakheel, J., Del Pero, C., Aste, N., & Leonforte, F. (2020). Smart buildings features and key performance indicators: A review. *Sustainable Cities and Society*, 61, 102328.
- [10] Al Otaibi, M. N. (2019). Internet of Things (IoT) Saudi Arabia healthcare systems: state-of-the-art, future opportunities and open challenges. *Journal of Health Informatics in Developing Countries*, 13(1). - <https://mail.jhiddc.org/index.php/jhiddc/article/view/234>
- [11] Alam, T., Khan, M. A., Gharaibeh, N. K., & Gharaibeh, M. K. (2021). Big data for smart cities: a case study of NEOM city, Saudi Arabia. *Smart cities: a data analytics perspective*, 215-230.

- [12] Alamoudi, A. K., Abidoeye, R. B., & Lam, T. Y. (2023). Implementing Smart Sustainable Cities in Saudi Arabia: A Framework for Citizens' Participation towards SAUDI VISION 2030. *Sustainability*, 15(8), 6648.
- [13] Albreem, M. A., Sheikh, A. M., Bashir, M. J., & El-Saleh, A. A. (2023). Towards green Internet of Things (IoT) for a sustainable future in Gulf Cooperation Council countries: Current practices, challenges and future prospective. *Wireless Networks*, 29(2), 539-567.
- [14] AlFaris, F., Juaidi, A., & Manzano-Agugliaro, F. (2017). Intelligent homes' technologies to optimize the energy performance for the net zero energy home. *Energy and Buildings*, 153, 262-274. - <https://doi.org/10.1016/j.enbuild.2017.07.089>
- [15] AlGhamdi, R., & Sharma, S. K. (2022). IoT-Based Smart Water Management Systems for Residential Buildings in Saudi Arabia. *Processes*, 10(11), 2462.
- [16] Ali, A. H. (2023). Smart Fire System using IOT. *CENTRAL ASIAN JOURNAL OF MATHEMATICAL THEORY AND COMPUTER SCIENCES*, 4(3), 88-113.
- [17] Ali, A., Azmi, N., and Baaki, T. (2018). Cost performance of building refurbishment works: the case of Malaysia. *International Journal of Building Pathology and Adaptation*, 36(1), 41–62.
- [18] Allmnakrah, A., & Evers, C. (2020). The need for a fundamental shift in the Saudi education system: Implementing the Saudi Arabian economic vision 2030. *Research in Education*, 106(1), 22-40.

- [19] Almontshery, A. M., & Jamalallail, F. M. (2019). Building Smart Cities by Using Enterprise GIS in Saudi Arabia. *Journal of Geographic Information System*, 11(6), 663-669.
- [20] Alozie, G. C. (2014). Sustainable environment; assessment of indoor thermal comfort in residential buildings in Abia State, Nigeria. Unpublished Ph.D. thesis submitted to department of architecture, Faculty of Environmental Studies, Abia State University, Uturu.
- [21] Alshehri, A., Motawa, I., & Ogunlana, S. (2015). The common problems facing the building maintenance departments. *International Journal of Innovation, Management and Technology*, 6(3), 234.
- [22] American Council for an Energy-Efficient Economy. (2018). *Smart Buildings: A Review of the Market and Policy Landscape*.
- [23] Amran, Y. A., Amran, Y. M., Alyousef, R., & Alabduljabbar, H. (2020). Renewable and sustainable energy production in Saudi Arabia according to Saudi Vision 2030; Status and future prospects. *Journal of Cleaner Production*, 247, 119602.
- [24] Anathan, J. D., Yusof, L. M., & Rahman, R. A. (2023). Internet of Things (IoT) Impact on Facility Management of Office Buildings: A Qualitative Study. *Journal of Engineering, Project & Production Management*, 13(3). DOI:10.32738/JEPPM-2023-0020
- [25] Apanavičienė, R., & Shahrabani, M. M. N. (2023). Key Factors Affecting Smart Building Integration into Smart Cities: Technological Aspects. *Smart Cities*, 6(4), 85. <https://doi.org/10.3390/smartcities6040085>

- [26] Artés, J., Wadel, G., and Martí, N. (2017). Vertical Extension and Improving of Existing Buildings. *The Open Construction and Building Technology Journal*, 11(1), 83–94. <https://doi.org/10.2174/1874836801711010083>
- [27] Aryan, A., Bosché, F., & Tang, P. (2021). Planning for terrestrial laser scanning in construction: A review. *Automation in Construction*, 125, 103551. DOI: 10.1016/j.autcon.2021.103551
- [28] Asif, M., Naeem, G., & Khalid, M. (2024). Digitalization for sustainable buildings: Technologies, applications, potential, and challenges. *Journal of Cleaner Production*, 141814. - <https://doi.org/10.1016/j.jclepro.2024.141814>
- [29] Atzori, L., Iera, A., & Morabito, G. (2017). Understanding the Internet of Things: definition, potentials, and societal role of a fast evolving paradigm. *Ad Hoc Networks*, 56, 122-140.
- [30] Au-Yong, C.P., Ali, A.S. and Ahmad, F. (2013), “Office building maintenance: cost prediction model”, *Gradevinar*, Vol. 65 No. 9, pp. 803-809.
- [31] Azmy, N. (2012), “The role of team effectiveness in construction project teams and project performance”, PhD thesis, Department of Civil Engineering, Iowa State University, Ames, IA.
- [32] Baharetha, S., Soliman, A. M., & Hassanain, M. A. (2024). Assessment of the Challenges Influencing the Adoption of Smart Building Technologies. *Frontiers in Built Environment*, 9, 1334005. <https://doi.org/10.3389/fbuil.2023.1334005>

- [33] Baig, Z.A.; Szewczyk, P.; Valli, C.; Rabadia, P.; Hannay, P.; Chernyshev, M.; Johnstone, M.; Kerai, P.; Ibrahim, A.; Sansurooah, K.; et al. Future challenges for smart cities: Cyber-security and digital forensics. *Digit. Investig.* 2017, 22, 3–13.
- [34] Bao, K., Mauser, I., Kochannek, S., & Xu, H. (2016). A microservice architecture for the intranet of things and energy in smart buildings. *Proceedings of the 1st ACM International Conference on Internet-of-Things Design and Implementation*. DOI: 10.1145/3007203.3007215
- [35] Barbosa, L. C., Nascimento, M. V. D. C., Ofélia de Queiroz, F. A., & de Medeiros, J. L. (2020). A cleaner and more sustainable decarbonation process via ionic-liquid absorption for natural gas with high carbon dioxide content. *Journal of Cleaner Production*, 242, 118421. DOI: 10.1016/j.jclepro.2019.118421
- [36] Barišić, A., Amaral, V., & Challenger, M. (2020, September). Enhancing Occupants Comfort and Well-being through a Smart Office setup. In *2020 43rd International Convention on Information, Communication and Electronic Technology (MIPRO)* (pp. 1825-1830). IEEE.
- [37] Basavaraddi, C. C. S., Choudri, S. R., Amarnath, J. J., Malathi, N., & Muthukannan, K. (2023, August). Optimizing Water Distribution Pump Scheduling with SVM-Based Machine Learning Using IoT Sensor Data. In *2023 Second International Conference On Smart Technologies For Smart Nation (SmartTechCon)* (pp. 1163-1167). IEEE. - <https://doi.org/10.1109/SmartTechCon57526.2023.10391295>

- [38] Benavente-Peces, C. (2019). On the energy efficiency in the next generation of smart buildings—Supporting technologies and techniques. *Energies*, 12(22), 4399. <https://doi.org/10.3390/en12224399>
- [39] Berawi, M. A., Kim, A. A., Naomi, F., Basten, V., Miraj, P., Medal, L. A., & Sari, M. (2023). Designing a smart integrated workspace to improve building energy efficiency: an Indonesian case study. *International Journal of Construction Management*, 23(3), 410-422.
- [40] Berawi, M.A.; Miraj, P.; Sayuti, M.S.; Berawi, A.R.B. Improving building performance using smart building concept: Benefit cost ratio comparison. In *Proceedings of the AIP Conference Proceedings*, Palembang, Indonesia, 14 November 2017; Volume 1903.
- [41] Berouine, A., Lachhab, F., Malek, Y. N., Bakhouya, M., & Ouladsine, R. (2017, October). A smart metering platform using big data and IoT technologies. In *2017 3rd International conference of cloud computing technologies and applications (CloudTech)* (pp. 1-6). IEEE. - <https://doi.org/10.1109/CloudTech.2017.8284729>
- [42] Best, R., and Valence, G. De. (2013). *Building in Value: Pre-Design Issues*. London: Routledge/Taylor & Francis Group.
- [43] Bi, Z., Da Xu, L., & Wang, C. (2014). Internet of things for enterprise systems of modern manufacturing. *IEEE Transactions on industrial informatics*, 10(2), 1537-1546.

- [44] Biljana L Risteska Stojkoska and Kire V Trivodaliev. A review of internet of things for smart home: Challenges and solutions. *Journal of Cleaner Production*, 140:1454–1464, 2017.
- [45] Brown, Eric (20 September 2016). "21 Open-Source Projects for IoT". *Linux.com*. Retrieved 23 October 2016.
- [46] Brown, S.; Karnatz, K.; Knight, R. A comprehensive look at the intelligent building. *Consult. Specif. Eng.* 2016, 53, 54–58.
- [47] Carli, R., Cavone, G., Ben Othman, S., & Dotoli, M. (2020). IoT based architecture for model predictive control of HVAC systems in smart buildings. *Sensors*, 20(3), 781.
- [48] Carvalho, J. L. N., Oliveira, B. G., Cantarella, H., Chagas, M. F., Gonzaga, L. C., Lourenco, K. S., ... & Bonomi, A. (2021). Implications of regional N₂O–N emission factors on sugarcane ethanol emissions and granted decarbonization certificates. *Renewable and Sustainable Energy Reviews*, 149, 111423. DOI: 10.1016/j.rser.2021.111423
- [49] Chandrasekaran, M., & Rajesh, P. K. (2024). Real-time mass estimation of connected commercial vehicle using artificial neural network model. *Indian Journal of Engineering and Materials Science*. DOI: <https://doi.org/10.56042/ijems.v31i3.8233>
- [50] Che-Ghania, N., Myeda, N. and Ali, A. (2016), “Operations and maintenance cost for stratified buildings: a critical review”, The 4th International Building Control Conference 2016, available at: <https://doi.org/10.1051/mateconf/20166600041>
- [51] Chen, C., Yang, Y., Zhou, Y., Xue, C., Chen, X., Wu, H., ... & Li, X. (2020). Comparative analysis of natural fiber reinforced polymer and carbon fiber reinforced

polymer in strengthening of reinforced concrete beams. *Journal of cleaner production*, 263, 121572. <https://doi.org/10.1016/j.jclepro.2020.121572>

[52] Chew, M. Y. L., Teo, E. A. L., Shah, K. W., Kumar, V., & Hussein, G. F. (2020). Evaluating the roadmap of 5G technology implementation for smart building and facilities management in Singapore. *Sustainability*, 12(24), 10259. DOI: 10.3390/su122410259

[53] Chung, S., Cho, C. S., Song, J., Lee, K., Lee, S., & Kwon, S. (2021). Smart facility management system based on open bim and augmented reality technology. *Applied Sciences*, 11(21), 10283. DOI: 10.3390/app112110283

[54] Communications and Technology Information Commission. (2021). IoT Demand in Saudi Arabia-A Survey Based Study (2021).

[55] Dai, X., Shang, W., Liu, J., Xue, M., & Wang, C. (2023). Achieving better indoor air quality with IoT systems for future buildings: Opportunities and challenges. *Science of The Total Environment*, 164858. - <https://doi.org/10.1016/j.scitotenv.2023.164858>

[56] Daissaoui, A., Boulmakoul, A., Karim, L., & Lbath, A. (2020). IoT and big data analytics for smart buildings: A survey. *Procedia computer science*, 170, 161-168.

[57] Dakhli, Z., Lafhaj, Z., and Bernard, M. (2017). Application of lean to the bidding phase in building construction: a French contractor's experienc. *International Journal of Lean Six Sigma*, 8(2), 153–180.

[58] Das, A., Sharma, S. C. M., & Ratha, B. K. (2019). The new era of smart cities, from the perspective of the internet of things. In *Smart cities cybersecurity and privacy* (pp. 1-9). Elsevier.

- [59] Das, L., Bibhu, V., Rana, A., Dadhich, K., & Sharma, B. (2023). 7 Convergence of AR & VR with IoT. *Handbook of Augmented and Virtual Reality*, De Gruyter, 95-116. DOI: 10.1515/9783110785234-007
- [60] Das, M., Luo, H., & Cheng, J. C. (2020). Securing interim payments in construction projects through a blockchain-based framework. *Automation in construction*, 118, 103284. DOI: 10.1016/j.autcon.2020.103284
- [61] Davtalab, O., Kazemian, A., & Khoshnevis, B. (2018). Perspectives on a BIM-integrated software platform for robotic construction through Contour Crafting. *Automation in construction*, 89, 13-23. <https://doi.org/10.1016/j.autcon.2018.01.006>
- [62] de Loza, F. P., & Villegas, F. J. I. (2024). Implementación de tecnologías IoT para la reducción del consumo energético en oficinas inteligentes mediante el control de la iluminación. *Revista de Ciencias Tecnológicas*, 7(3), e332-e332. DOI: 10.2151/journal
- [63] De Soto, B. G., Agustí-Juan, I., Hunhevicz, J., Joss, S., Graser, K., Habert, G., & Adey, B. T. (2018). Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall. *Automation in construction*, 92, 297-311. <https://doi.org/10.1016/j.autcon.2018.04.004>
- [64] Dellise, M., Villot, J., Gaucher, R., Amardeil, A., & Laforest, V. (2020). Challenges in assessing Best Available Techniques (BATs) compliance in the absence of industrial sectoral reference. *Journal of Cleaner Production*, 263, 121474. DOI: 10.1016/j.jclepro.2020.121474

- [65] Deloitte Insights. (2018). Smart Buildings: How IoT technology aims to add value for real estate companies.
- [66] Del-Valle-Soto, C., Valdivia, L. J., Velázquez, R., Rizo-Dominguez, L., & López-Pimentel, J. C. (2019). Smart campus: An experimental performance comparison of collaborative and cooperative schemes for wireless sensor network. *Energies*, 12(16), 3135. DOI:10.3390/en12163135
- [67] Dhir, K., Singh, P., Das, R., & Sawhney, R. S. (2023, December). Fusing Innovation and Nature: Empowering Forest Fire Detection and Prediction Through IoT Enabled Edge Computing and Deep Learning. In *International Working Conference on Transfer and Diffusion of IT* (pp. 225-236). Cham: Springer Nature Switzerland. - https://doi.org/10.1007/978-3-031-50204-0_19
- [68] Dimitriadis, S. I., Muddapu, V. R., & Guidotti, R. (2024). Reproducible analysis in neuroscience. *Frontiers in Neuroinformatics*. DOI:10.3389/fninf.2024.1520012.
- [69] Dryjanski, M., Buczkowski, M., Ould-Cheikh-Mouhamedou, Y., & Kliks, A. (2020). Adoption of smart cities with a practical smart building implementation. *IEEE Internet of Things Magazine*, 3(1), 58-63.
- [70] DURSUN, M., & YILMAZ, K. (2021, December). Virtual Reality Based Tower Crane Operator Training Simulator. In *2021 1st International Conference On Informatics And Computer Science* (p. 1).
- [71] Elahee, Mohammad Khalil (2019). "Brief History of Energy Management ..." *Energy Management Research Journal*. 2 (1): 39–49.

- [72] Elkateb, S., Métwalli, A., Shendy, A., & Abu-Elanien, A. E. (2024). Machine learning and IoT-Based predictive maintenance approach for industrial applications. *Alexandria Engineering Journal*, 88, 298-309. - <https://doi.org/10.1016/j.aej.2023.12.065>
- [73] El-Motasem, S., Khodeir, L. M., & Eid, A. F. (2021). Analysis of challenges facing smart buildings projects in Egypt. *Ain Shams Engineering Journal*, 12(3), 3317-3329.
- [74] Elrawy, M. F., Awad, A. I., & Hamed, H. F. (2018). Intrusion detection systems for IoT-based smart environments: a survey. *Journal of Cloud Computing*, 7(1), 1-20.
- [75] Erçin, M., Köse, M., Atasoy, A., Altıntaş, U., & Köş, R. (2021). Route optimization for waste collection process through IoT supported waste management system. In *IEEE conference on institute for computational and mathematical engineering* (Vol. 12).- https://www.researchgate.net/profile/Utku_Altintas/publication/348593058_Route_Optimization_for_Waste_Collection_Process_Through_IoT_Supported_Waste_Management_System/links/6006c69e45851553a0542281/Route-Optimization-for-Waste-Collection-Process-Through-IoT-Supported-Waste-Management-System.pdf
- [76] Eremia, M., Toma, L., & Sanduleac, M. (2017). The smart city concept in the 21st century. *Procedia Engineering*, 181, 12-19.
- [77] European Federation of National Maintenance Societies". EFNMS.org. Retrieved 5 August 2016. All actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required function. These include the combination of all technical and corresponding administrative, managerial, and supervision actions.

- [78] European Union Agency for Cybersecurity. (2019). Smart Buildings: Cybersecurity Risks and Recommendations for Risk Prevention.
- [79] Fahmideh, M., Ahmad, A., Behnaz, A., Grundy, J., & Susilo, W. (2021). Software engineering for internet of things: The practitioners' perspective. *IEEE Transactions on Software Engineering*, 48(8), 2857-2878. DOI: 10.1109/TSE.2021.3062286
- [80] Fanasch, P., & Frick, B. (2020). The value of signals: do self-declaration and certification generate price premiums for organic and biodynamic wines?. *Journal of cleaner production*, 249, 119415. DOI: 10.1016/j.jclepro.2019.119415
- [81] Fang, Z., Liu, Y., Lu, Q., Pitt, M., Hanna, S., & Tian, Z. (2022). BIM-integrated portfolio-based strategic asset data quality management. *Automation in Construction*, 134, 104070. DOI: 10.1016/j.autcon.2021.103924
- [82] Fayad, A. (2011), "Interview, project manager", Saudi Aramco Oil Company, Dhahran, August 14.
- [83] Fernandez, J. R., Prasetyo, Y. T., Persada, S. F., & Redi, A. P. (2021). Automation of Predictive Maintenance Using Internet of Things (IoT) Technology at University-Based O&M Project. *facilities management*, 1, 3. - <https://ijiet.org/vol11/1531-AT024.pdf>
- [84] Fialho, B. C., Codinhoto, R., Fabricio, M. M., Estrella, J. C., Ribeiro, C. M. N., Bueno, J. M. D. S., & Torrezan, J. P. D. (2022). Development of a BIM and IoT-Based Smart Lighting Maintenance System Prototype for Universities' FM Sector. *Buildings*, 12(2), 99.

- [85] Fisk, W. J., et al. (2018). Smart building controls: An analysis of energy savings and an emerging standard's impact. *Energy and Buildings*, 171.
- [86] Floris, A., Porcu, S., Girau, R., & Atzori, L. (2021). An iot-based smart building solution for indoor environment management and occupants prediction. *Energies*, 14(10), 2959. <https://doi.org/10.3390/en14102959>
- [87] Froufe, M. M., Chinelli, C. K., Guedes, A. L. A., & Haddad, A. N. (2020). Smart Buildings: Systems and Drivers. *Buildings*, 10(9), 153. <https://doi.org/10.3390/buildings10090153>
- [88] Froufe, M. M., Chinelli, C. K., Guedes, A. L. A., Haddad, A. N., Hammad, A. W., & Soares, C. A. P. (2020). Smart buildings: Systems and drivers. *Buildings*, 10(9), 153.
- [89] Gao, X., & Pishdad-Bozorgi, P. (2019). BIM-enabled facilities operation and maintenance: A review. *Advanced engineering informatics*, 39, 227-247.
- [90] Ghansah, F. A. (2024). Digital Twins for Smart Building at the Facility Management Stage: A Systematic Review of Enablers, Applications, and Challenges. *Smart and Sustainable Built Environment*. <https://doi.org/10.1108/SASBE-10-2023-0298>
- [91] Ghosh, A., Edwards, D. J., & Hosseini, M. R. (2021). Patterns and trends in Internet of Things (IoT) research: future applications in the construction industry. *Engineering, Construction and Architectural Management*, 28(2), 457-481.
- [92] Gillis, Alexander (2021). "What is internet of things (IoT)?". *IOT Agenda*. Retrieved 17 August 2021.

- [93] Gu, J., & Lu, S. (2021). An effective intrusion detection approach using SVM with naïve Bayes feature embedding. *Computers & Security*, 103, 102158. DOI: 10.1016/j.cose.2020.102158
- [94] Haribabu, P., Kassa, S. R., Nagaraju, J., Karthik, R., Shirisha, N., & Anila, M. (2017, December). Implementation of an smart waste management system using IoT. In *2017 International Conference on Intelligent Sustainable Systems (ICISS)* (pp. 1155-1156). IEEE.
- [95] Harrison, M. T., Liu, K., Shi, S., Zhou, S., Lei, Y., & Chen, F. (2024). Burgeoning food demand outpaces sustainable water supply in China. *Agricultural Water Management*. DOI: 10.1016/j.agwat.2024.107713.
- [96] Hasan, B. M., Yeazdani, A. M. M., Istiaque, L. M., & Chowdhury, R. M. K. (2017). Smart waste management system using IoT (Doctoral dissertation, BRAC University).
- [97] Hassan, S. A. Z., Elakhdar, B. E., & Saied, W. M. (2024). Leveraging new Technologies for Building a Comprehensive Smart MIS: Integrating ERP, Blockchain, IoT, Context-awareness, and Cloud Computing. *6th International Conference on Computing*. DOI: 10.1109/10485102
- [98] Hassanain, M. A., Al-Marzooq, A., & Alshibani, A. (2024). Factors Influencing IoT Adoption for Sustainable Facilities Management in Saudi Arabia: A Stakeholder Assessment. *Smart and Sustainable Built Environment*. <https://doi.org/10.1108/SASBE-10-2023-0318>

- [99] Hendricks, Drew. "The Trouble with the Internet of Things". London Datastore. Greater London Authority. Retrieved 10 August 2015.
- [100] Heralova, R. S. (2017). Life cycle costing as an important contribution to feasibility study in construction projects. *Procedia engineering*, 196, 565-570.
- [101] Hinze, J. W. (2012). *Construction Planning and Scheduling* (4th ed.). New Jersey: Pearson Education.
- [102] Hosamo, H. H., Nielsen, H. K., Kraniotis, D., Svennevig, P. R., & Svidt, K. (2023). Improving building occupant comfort through a digital twin approach: A Bayesian network model and predictive maintenance method. *Energy and Buildings*, 288, 112992. - <https://doi.org/10.1016/j.enbuild.2023.112992>
- [103] Hu, X., Zhang, H., Chen, D., Li, Y., Wang, L., Zhang, F., & Cheng, H. (2020). Multi-objective planning for integrated energy systems considering both exergy efficiency and economy. *Energy*, 197, 117155. DOI: 10.1016/j.energy.2020.117155
- [104] Hui, T. K. L., Sherratt, R. S., & Sánchez, D. D. (2017). Major requirements for building Smart Homes in Smart Cities based on Internet of Things technologies. *Future Generation Computer Systems*. DOI: 10.1016/j.future.2016.05.009
- [105] ISO 7240-14:2013 | Fire detection and alarm systems — Part 14: Design, installation, commissioning and service of fire detection and fire alarm systems in and around buildings

- [106] Ivanovic, N., Nast, B., Reiz, A., & Sandkuhl, K. (2023, May). Technologies for a Diagnostic Technique for HVAC Systems Using IoT and Cloud-based Architecture. In 2023 International Interdisciplinary PhD Workshop (IIPhDW) (pp. 1-6). IEEE.
- [107] James Manyika. The Internet of Things: Mapping the value beyond the hype. 2015.
- [108] Jamoussi, B., Abu-Rizaiza, A., & Al-Haij, A. (2022). Sustainable Building Standards, Codes and Certification Systems: The Status Quo and Future Directions in Saudi Arabia. *Sustainability*, 14(16), 10314. - <https://doi.org/10.3390/su141610314>
- [109] Jerjes, W. (2024). Epidemiological trends and survival of oropharyngeal cancer in a high HPV-prevalent area: A Danish population-based study from 2000 to 2020. *International Journal of Cancer*. DOI:10.1002/ijc.35178.
- [110] Jia, M., Komeily, A., Wang, Y., & Srinivasan, R. S. (2019). Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Automation in Construction*, 101, 111-126.
- [111] Jia, R.; Jin, B.; Jin, M.; Zhou, Y.; Konstantakopoulos, I.C.; Zou, H.; Kim, J.; Li, D.; Gu, W.; Arghandeh, R.; et al. Design Automation for Smart Building Systems. *Proc. IEEE* 2018, 106, 1680–1699.
- [112] Kalendar, R., Levei, E., Cadar, O., & Senila, M. (2024). Trends and challenges in plant biomonitoring, bioremediation, and biomining. *Frontiers in Plant Science*. DOI:10.3389/fpls.2024.1486752.
- [113] Kamyab, H., Khademi, T., Chelliapan, S., SaberiKamarposhti, M., Rezanian, S., Yusuf, M., ... & Ahn, Y. (2023). The latest innovative avenues for the utilization of

artificial Intelligence and big data analytics in water resource management. Results in Engineering, 101566. - <https://doi.org/10.1016/j.rineng.2023.101566>

[114] Kanaan, A., Ahmad, A. L. H., & Alorfi, A. (2024). Cybersecurity Resilience for Business: A Comprehensive Model for Proactive Defense and Swift Recovery. 2024 2nd International Conference on Cybersecurity Resilience. DOI:10.1109/CYBERRES.2024.10532881.

[115] Karjou, P. F., Saryazdi, S. K., Stoffel, P., & Müller, D. (2024). Practical Design and Implementation of IoT-Based Occupancy Monitoring Systems for Office Buildings: A Case Study. Energy and Buildings, 114852. <https://doi.org/10.1016/j.enbuild.2024.114852>

[116] Kashef, M., Visvizi, A., & Troisi, O. (2021). Smart city as a smart service system: Human-computer interaction and smart city surveillance systems. Computers in Human Behavior, 124, 106923.

[117] Khabaz, A. (2018). Construction and design requirements of green buildings' roofs in Saudi Arabia depending on thermal conductivity principle. Construction and Building Materials, 186, 1119-1131.

[118] Khan, W. Z., Rehman, M. H., Zangoti, H. M., Afzal, M. K., Armi, N., & Salah, K. (2020). Industrial internet of things: Recent advances, enabling technologies and open challenges. Computers & electrical engineering, 81, 106522.

[119] Khoshnava, S. M., Rostami, R., Zin, R. M., Mishra, A. R., Rani, P., Mardani, A., & Alrasheedi, M. (2020). Assessing the impact of construction industry stakeholders on

workers' unsafe behaviours using extended decision-making approach. *Automation in Construction*, 118, 103162. <https://doi.org/10.1016/j.autcon.2020.103162>

[120] KMC Controls (24 September 2015). "What's Your IQ on IAQ and IEQ?". Retrieved 12 April 2021.

[121] Krishnamoorthy, R., Aswini, S., & Guna, C. (2020, July). Design and implementation of IoT based energy management system with data acquisition. In 2020 7th International Conference on Smart Structures and Systems (ICSSS) (pp. 1-5). IEEE.

[122] Krishnan, P., Prabu, A. V., Loganathan, S., & Routray, S. (2023). Analyzing and Managing Energy-Related Environmental Factors for Personalized IoT Services for Smart Buildings. *Sustainability*, 15(8), 6548. <https://doi.org/10.3390/su15086548>

[123] Kumar, A., Sharma, S., Goyal, N., Singh, A., Cheng, X., & Singh, P. (2021). Secure and energy-efficient smart building architecture with emerging technology IoT. *Computer Communications*, 176, 207-217.

[124] Kumar, N. M., & Mallick, P. K. (2018). The Internet of Things: Insights into the building blocks, component interactions, and architecture layers. *Procedia computer science*, 132, 109-117.

[125] Kumar, T., Srinivasan, R., & Mani, M. (2022). An emergy-based approach to evaluate the effectiveness of integrating IoT-based sensing systems into smart buildings. *Sustainable Energy Technologies and Assessments*, 52, 102225.

[126] Kwon, O.; Lee, E.; Bahn, H. Sensor-aware elevator scheduling for smart building environments. *Build. Environ.* 2014, 72, 332–342.

- [127] LaSalle, J.L. The Changing Face of Smart Buildings: The Op-Ex Advantage; JLL Annual Report; Jones Lang LaSalle: Chicago, IL, USA, 2013.
- [128] Lawal, K., & Rafsanjani, H. N. (2022). Trends, benefits, risks, and challenges of IoT implementation in residential and commercial buildings. *Energy and Built Environment*, 3(3), 251-266.
- [129] Lazarova-Molnar, S., Shaker, H. R., & Mohamed, N. (2016, March). Fault detection and diagnosis for smart buildings: State of the art, trends and challenges. In 2016 3rd MEC International Conference on Big Data and Smart City (ICBDSC) (pp. 1-7). IEEE. - <https://doi.org/10.1109/ICBDSC.2016.7460392>
- [130] Le, D. N., Le Tuan, L., & Tuan, M. N. D. (2019). Smart-building management system: An Internet-of-Things (IoT) application business model in Vietnam. *Technological Forecasting and Social Change*, 141, 22-35.
- [131] Lee, C. L., Lin, W. T., & Lin, S. Y. (2019). Perceptions and experiences of hospital nurses during transition to an electronic handover informatics system. *CIN: Computers, Informatics, Nursing*. DOI:10.1097/CIN.0000000000000612.
- [132] Lee, I. C., Chan, I. S. H., Yip, I. G. K., Yuen, E. I. F. P., Chan, E. M. T., & Cheung, M. P. (2019). IOT ENABLED SMART BUILDING OPERATION AND MAINTENANCE. THE HONG KONG INSTITUTION OF ENGINEERS ELECTRICAL DIVISION, 2. - https://ijaem.net/issue_dcp/Analysis%20of%20G%20enabled%20smart%20energy%20management%20Systems%20in%20buildings..pdf

- [133] Leonardo, L. (2011), “Interview, senior maintenance engineer”, Yamama Company for Maintenance Contacting, Dammam, July 25.
- [134] Li, B., Tian, Y., & Wang, P. (2024). Applications and grants of the National Natural Science Foundation of China's General Program and Young Scientists Fund in immunology research: a 10-year analysis. *Science China Life Sciences*. DOI:10.1007/s11427-023-2525-3.
- [135] Li, W., Koo, C., Hong, T., Oh, J., Cha, S. H., & Wang, S. (2020). A novel operation approach for the energy efficiency improvement of the HVAC system in office spaces through real-time big data analytics. *Renewable and Sustainable Energy Reviews*, 127, 109885. <https://doi.org/10.1016/j.rser.2020.109885>
- [136] Li, X., Huang, L., Wei, G., & Wei, Z. (2021). Online parallel framework for real-time visual tracking. *Engineering applications of artificial intelligence*, 102, 104266. DOI: 10.1016/j.engappai.2021.104266
- [137] Li, X., Zhang, J., & Cao, W. (2020). Hysteretic behavior of high-strength concrete shear walls with high-strength steel bars: Experimental study and modelling. *Engineering Structures*, 214, 110600. DOI: 10.1016/j.engstruct.2020.110600
- [138] Lin, J., Jing, W., Song, H., & Chen, G. (2019). ESFNet: Efficient network for building extraction from high-resolution aerial images. *IEEE Access*, 7, 54285-54294. DOI: 10.1109/ACCESS.2019.2912822
- [139] Liu, C., Nitschke, P., Williams, S. P., & Zowghi, D. (2020). Data quality and the Internet of Things. *Computing*. DOI:10.1007/s00607-019-00746-z.

- [140] Lu, K., Jiang, X., Yu, J., Tam, V. W. Y., & Skitmore, M. (2021). Integration of life cycle assessment and life cycle cost using building information modeling: A critical review. *Journal of Cleaner Production*. DOI: 10.1016/j.jclepro.2021.125892.
- [141] Lukhanda, P., & Kakanda-Sinkala, N. (2024). Adoption of the Intranet in Public Sector Service Delivery in the Ministry of Education: A Case Study of Provincial Education Office (PEO) Copperbelt. *International Journal of Research and Innovation in Applied Science*, 9(8), 491-510. <https://doi.org/10.51584/IJRIAS.2024.908043>.
- [142] Ma, D., Lan, G., Hassan, M., & Hu, W. (2019). Sensing, computing, and communications for energy harvesting IoTs: A survey. *IEEE Communications Surveys & Tutorials*. DOI:10.1109/COMST.2019.8944276.
- [143] Ma, Z., Xiao, M., Xiao, Y., Pang, Z., & Poor, H. V. (2019). High-reliability and low-latency wireless communication for Internet of Things: Challenges, fundamentals, and enabling technologies. *IEEE Internet of Things Journal*. DOI:10.1109/IIOT.2019.8673568.
- [144] Madkhali, A., & Sithole, S. T. (2023). Exploring the role of information technology in supporting sustainability efforts in Saudi Arabia. *Sustainability*, 15(16), 12375. - <https://doi.org/10.3390/su151612375>
- [145] Mahmoodi-k, M., Montazeri, M., & Madanipour, V. (2021). Simultaneous multi-objective optimization of a PHEV power management system and component sizing in real world traffic condition. *Energy*, 233, 121111. DOI: 10.1016/j.energy.2021.121111

- [146] Maiti, A., Ye, A., Schmidt, M., & Pedersen, S. (2023). A privacy-preserving desk sensor for monitoring healthy movement breaks in smart office environments with the internet of things. *Sensors*, 23(4), 2229.
- [147] Manchadi, O., BEN-BOUAZZA, F. E., Dehbi, Z. E. O., Edder, A., Tafala, I., Et-Taoussi, M., & Jioudi, B. (2024). An Internet of Things-based Predictive Maintenance Architecture for Intensive Care Unit Ventilators. *International Journal of Advanced Computer Science & Applications*, 15(2). - https://www.researchgate.net/profile/Zineb-El-Otmani-Dehbi/publication/378680264_An_Internet_of_Things-based_Predictive_Maintenance_Architecture_for_Intensive_Care_Unit_Ventilators/links/65e3ab0dad608480af63688/An-Internet-of-Things-based-Predictive-Maintenance-Architecture-for-Intensive-Care-Unit-Ventilators.pdf
- [148] Marco Casini. Internet of things for energy efficiency of buildings. *International Scientific Journal Architecture and Engineering*, 2, 2014.
- [149] Martellini, Maurizio; Malizia, Andrea (2017-10-30). *Cyber and Chemical, Biological, Radiological, Nuclear, Explosives Challenges: Threats and Counter Efforts*. Springer. ISBN 9783319621081.
- [150] Martin-Lopo, M. M., Boal, J., & Sánchez-Miralles, Á. (2020). A literature review of IoT energy platforms aimed at end users. *Computer Networks*. DOI: 10.1016/j.comnet.2019.12.003
- [151] Megnafi, H., Karaouzene, Z., Merad, L., Bousmaha, I. S., Bennacer, D., Roztane, A., & Merina, W. A. (2023, November). Internet of Things technology for efficient fire

- hydrant management. In 2023 IEEE International Workshop on Mechatronic Systems Supervision (IW_MSS) (pp. 1-6). IEEE. -
https://doi.org/10.1109/IW_MSS59200.2023.10368652
- [152] Mehmood, Y., Ahmad, F., Yaqoob, I., Adnane, A., Imran, M., & Guizani, S. (2017). Internet-of-things-based smart cities: Recent advances and challenges. *IEEE Communications Magazine*, 55(9), 16-24.
- [153] Mellit, A., Tina, G. M., & Kalogirou, S. A. (2018). Fault detection and diagnosis methods for photovoltaic systems: A review. *Renewable and Sustainable Energy Reviews*, 91, 1-17. <https://doi.org/10.1016/j.rser.2018.03.062>
- [154] Metallidou, C. K., Psannis, K. E., & Egyptiadou, E. A. (2020). Energy efficiency in smart buildings: IoT approaches. *IEEE Access*, 8, 63679-63699. DOI: 10.1109/ACCESS.2020.2984461
- [155] Minoli, D., Sohraby, K., & Occhiogrosso, B. (2017). IoT considerations, requirements, and architectures for smart buildings—Energy optimization and next-generation building management systems. *IEEE Internet of Things Journal*, 4(1), 269-283.
- [156] Mohammed, M.A. and Hassanain, M.A. (2010), “Towards improvement in facilities operation and maintenance through feedback to the design team”, *The Built and Human Environment Review*, Vol. 3, pp. 72-87.
- [157] Mohanta, B. K., Jena, D., Panda, S. S., & Sobhanayak, S. (2019). Blockchain technology: A survey on applications and security privacy challenges. *Internet of Things*, Elsevier. DOI: 10.1016/j.iot.2019.100107.

- [158] Mohsen Soleimani-Mohseni, Lars Bäckström, and Robert Eklund. Enbe - energiberäkningar, 2014.
- [159] Momanyi, V. M., & Gatauwa, J. M. (2024). Corporate governance and performance of community-based organizations in Nairobi City County in Kenya. *International Academic Journal of Economics and Finance*, 4(3), 391-409. https://iajournals.org/articles/iajef_v4_i3_391_409.pdf
- [160] Moreno, M. V., Úbeda, B., Skarmeta, A. F., & Zamora, M. A. (2014). How can we tackle energy efficiency in IoT based smart buildings?. *Sensors*, 14(6), 9582-9614. <https://doi.org/10.3390/s140609582>
- [161] Moshashai, D., Leber, A. M., & Savage, J. D. (2020). Saudi Arabia plans for its economic future: Vision 2030, the National Transformation Plan and Saudi fiscal reform. *British Journal of Middle Eastern Studies*, 47(3), 381-401.
- [162] Mousavi, Y., Gharineiat, Z., Karimi, A. A., McDougall, K., Rossi, A., & Gonizzi Barsanti, S. (2024). Digital Twin Technology in Built Environment: A Review of Applications, Capabilities and Challenges. *Smart Cities*, 7(5), 2594-2615. DOI: 10.3390/smartcities7050101
- [163] Muhammad Waseem Ahmad, Monjur Mourshed, David Mundow, Mario Sisinni, and Yacine Rezgui. Building energy metering and environmental monitoring – a state-of-the-art review and directions for future research. *Energy and Buildings*, 120:85 – 102, 2016.

- [164] Muller, M. F., Esmanioto, F., Huber, N., Loures, E. R., & Junior, O. C. (2019). A systematic literature review of interoperability in the green Building Information Modeling lifecycle. *Journal of cleaner production*, 223, 397-412.
- [165] Muthubalaji, S., Srinivasan, S., & Lakshmanan, M. (2021). IoT based energy management in smart energy system: A hybrid SO2SA technique. *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, 34(5), e2893.
- [166] Naga Sudha, C. M., Jesu Vedha Nayahi, J., Saravanan, S., & Daniel, S. (2022, November). Smart Office: Happy Employees in Enhanced and Energy-Efficient (EEE) Workplace. In *Proceedings of the International Conference on Intelligent Computing, Communication, and Information Security* (pp. 261-272). Singapore: Springer Nature Singapore.
- [167] Nangia, S., Makkar, S., & Hassan, R. (2020, March). IoT based predictive maintenance in manufacturing sector. In *Proceedings of the International Conference on Innovative Computing & Communications (ICICC)*.
- [168] Narayan, V., & Daniel, A. K. (2021, October). IOT based sensor monitoring system for smart complexes and shopping malls. In *International conference on mobile networks and management* (pp. 344-354). Cham: Springer International Publishing.
- [169] Nathali Silva, B., Khan, M., & Han, K. (2017). Big data analytics embedded smart city architecture for performance enhancement through real-time data processing and decision-making. *Wireless communications and mobile computing*, 2017.

- [170] National Institute of Standards and Technology. (2018). Framework for Cyber-Physical Systems: Smart Building Systems.
- [171] Nguyen, D. T. (2024). IoT Security: From Context-based Authentication to Secure Federated Learning Anomaly Detection. doi: 10.26083/tuprints-00028827
- [172] Nguyen, P. H., & Fayek, A. R. (2022). Applications of fuzzy hybrid techniques in construction engineering and management research. *Automation in Construction*, 134, 104064. <https://doi.org/10.1016/j.autcon.2021.104064>
- [173] Ni, J., Zhang, K., Lin, X., & Shen, X. (2017). Securing fog computing for Internet of Things applications: Challenges and solutions. *IEEE Communications Surveys & Tutorials*. DOI:10.1109/COMST.2017.2706720.
- [174] NITONYE, S., AHIKWO, O. V., & OLUKI, K. (2024). DIGITALIZATION OF BULK CARRIES: REVOLUTIONIZING EFFICIENCY, SAFETY AND ENVIRONMENTAL RESPONSIBILITY. *Quantum Journal of Engineering, Science and Technology*, 5(1), 30-44. - <https://qjoest.com/index.php/qjoest/article/download/132/84>
- [175] Nunes, R.; Sêro, C. Edifícios Inteligentes: Conceitos e Serviços. *Jornal O Projeto*, Ano XV-N.9, September 2014; 3–6.
- [176] Nurunnabi, M. (2017). Transformation from an oil-based economy to a knowledge-based economy in Saudi Arabia: the direction of Saudi vision 2030. *Journal of the Knowledge Economy*, 8, 536-564.

- [177] Olanrewaju, O. I., Kineber, A. F., Chileshe, N., & Edwards, D. J. (2021). Modelling the Impact of BIM Implementation Drivers and Awareness on Project Lifecycle. *Sustainability*, 13(16), 8887. <https://doi.org/10.3390/su13168887>
- [178] Oliveira, D. F., Gomes, J. P., Pereira, R. B., & Brito, M. A. (2022). Development of a Self-diagnostic System Integrated into a Cyber-Physical System. *Computers*. DOI:10.3390/computers11090131.
- [179] Oliveira, L. M., Oliveira, L. F., Sonsin, A. F., Duarte, J. L., Soletti, J. I., Fonseca, E. J., ... & Meili, L. (2020). Ultrafast diesel oil spill removal by fibers from silk-cotton tree: Characterization and sorption potential evaluation. *Journal of Cleaner Production*, 263, 121448. DOI: 10.1016/j.jclepro.2020.121448
- [180] Osunsanmi, T. O., Aigbavboa, C. O., Oke, A., & Onyia, M. E. (2022). Making a case for smart buildings in preventing corona-virus: focus on maintenance management challenges. *International journal of construction management*, 22(16), 3109-3118.
- [181] Palmer, R. (2016). *Maintenance Planning and Scheduling Handbook*. *Asset Management & Maintenance Journal*, 29(3), 57-59.
- [182] Panda, S., Woods, D. W., Laszka, A., Fielder, A., & Panaousis, E. (2019). Post-incident audits on cyber insurance discounts. *Computers & Security*, 87, 101593. <https://doi.org/10.1016/j.cose.2019.101593>
- [183] Papagiannidis, S., & Marikyan, D. (2020). Smart offices: A productivity and well-being perspective. *International Journal of Information Management*, 51, 102027.

- [184] Parti, I. K., Mudiana, I. N., Darminta, I. K., & Rasmini, N. W. (2024, February). Modellings Smart Home Security Based Internet of Things (IoT). In International Conference on Applied Science and Technology on Engineering Science 2023 (iCAST-ES 2023) (pp. 41-48). Atlantis Press. - https://doi.org/10.2991/978-94-6463-364-1_5
- [185] Pech, M., Vrchota, J., & Bednář, J. (2021). Predictive maintenance and intelligent sensors in smart factory. *Sensors*, 21(4), 1470.
- [186] Peng, L., & Chan, A. H. (2020). Adjusting work conditions to meet the declined health and functional capacity of older construction workers in Hong Kong. *Safety science*, 127, 104711. DOI: 10.1016/j.ssci.2020.104711
- [187] Perwej, Y., Haq, K., Parwej, F., Mumdouh, M., & Hassan, M. (2019). The internet of things (IoT) and its application domains. *International Journal of Computer Applications*, 975(8887), 182.
- [188] Pitt, M., Cannavina, D., Sulaiman, R., Mahyuddin, N. and Wu, C. (2016), “towers maintenance management in Sanya, China”, *Journal of Facilities Management*, Vol. 14 No. 4, pp. 304-314.
- [189] Poyyamozi, M., Murugesan, B., Rajamanickam, N., Shorfuzzaman, M., & Aboelmagd, Y. (2024). IoT—A Promising Solution to Energy Management in Smart Buildings: A Systematic Review, Applications, Barriers, and Future Scope. *Buildings*, 14(11), 3446. DOI: 10.3390/buildings14113446

- [190] Pradhan, A., Datta, A., Lal, M. K., Kumar, M., & Alam, M. K. (2024). Abiotic Stresses in Field Crops: Response, Impacts, and Management under Climate Change Scenario. *Frontiers in Sustainable Food Systems*. DOI:10.3389/fsufs.2024.1539301.
- [191] Prasetyo, T. F., Zaliluddin, D., & Iqbal, M. (2018, May). Prototype of smart office system using based security system. In *Journal of Physics: Conference Series* (Vol. 1013, No. 1, p. 012189). IOP Publishing.
- [192] Pryor, P. (2019). Developing the core body of knowledge for the generalist OHS professional. *Safety Science*, 115, 19-27. <https://doi.org/10.1016/j.ssci.2019.01.013>
- [193] Qaffas, A. A., Hoque, R., & Almazmomi, N. (2021). The internet of things and big data analytics for chronic disease monitoring in Saudi Arabia. *Telemedicine and e-Health*, 27(1), 74-81.
- [194] Qasim Flayyih, H., & Waleed, J. (2024). IoT-based AI Methods for Indoor Air Quality Monitoring Systems: A Systematic Review. *International Journal of Computing and Digital Systems*, 16(1), 1-18. - <http://dx.doi.org/10.12785/ijcds/160159>
- [195] Quinn, C., Shabestari, A. Z., Misic, T., Gilani, S., Litoiu, M., & McArthur, J. J. (2020). Building automation system-BIM integration using a linked data structure. *Automation in Construction*, 118, 103257.
- [196] Quy, V. K., Hau, N. V., Anh, D. V., Quy, N. M., Ban, N. T., Lanza, S., ... & Muzirafuti, A. (2022). IoT-enabled smart agriculture: architecture, applications, and challenges. *Applied Sciences*, 12(7), 3396.

- [197] Raco, F., Balzani, M., Planu, F., & Cittadino, A. (2022). Inspire project: Integrated technologies for smart buildings and predictive maintenance. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 48, 127-133.
- [198] Rajab, H., & Cinkelr, T. (2018, June). IoT based smart cities. In *2018 international symposium on networks, computers and communications (ISNCC)* (pp. 1-4). IEEE.
- [199] Ran, Y., Zhou, X., Lin, P., & Wen, Y. (2019). A survey of predictive maintenance: Systems, purposes, and approaches. *arXiv preprint*. DOI:10.48550/arXiv:1903.11880.
- [200] Rana, A., Gautam, D., & Kumar, P. (2024). Architectures, Benefits, Security, and Privacy Issues of Internet of Nano Things: A Comprehensive Survey, Opportunities, and Research Challenges. *IEEE Surveys & Tutorials*. DOI:10.1109/SURV.2024.10584514.
- [201] Rane, N., Choudhary, S., & Rane, J. (2023). Artificial Intelligence (AI) and Internet of Things (IoT)-based sensors for monitoring and controlling in architecture, engineering, and construction: applications, challenges, and opportunities. Available at SSRN 4642197. - <https://dx.doi.org/10.2139/ssrn.4642197>
- [202] Rêgo, B. S., Lourenço, D., & Moreira, F. (2024). Digital transformation, skills, and education: A systematic literature review. *Industry and Higher Education*. DOI:10.1177/09504222231208969.
- [203] Roberts, M., Allen, S., & Coley, D. (2020). Life cycle assessment in the building design process—A systematic literature review. *Building and Environment*, 185, 107274.

- [204] Rullo, A., Serra, E., & Lobo, J. (2019). Redundancy as a measure of fault-tolerance for the Internet of Things: A review. In Policy-Based Autonomic Data Governance (pp. XX-XX). Springer. DOI:10.1007/978-3-030-17277-0_11.
- [205] Saghatforoush, E., Trigunarsyah, B. and Too, E. (2012), “Assessment of operability and maintainability success factors in provision of extended constructability principles”, Isfahan-Iran, Vol. 8 No. 5, pp. 8-10.
- [206] Salimi, S., & Hammad, A. (2019). Critical review and research roadmap of office building energy management based on occupancy monitoring. *Energy and Buildings*, 182, 214-241. <https://doi.org/10.1016/j.enbuild.2018.10.007>
- [207] Sarraf, R., Ojha, S., Biraris, D., & Bhangale, K. B. (2020). IoT based smart quality water management system. *Int. J. of Adv. Sci. Res. and Engg. Trends*, 5(3).
- [208] Savage, D. T. (2022). Ecological and Economic Frameworks for Biodiversity Monitoring. Purdue University Repository. DOI:10.25394/2022.21493770.
- [209] Schultz, E. Eugene. "Risks due to convergence of physical security systems and information technology environments." *Information Security Technical Report* 12, no. 2 (2007): 80-84.
- [210] Schuster, F., & Habibipour, A. (2024). Users’ privacy and security concerns that affect IoT adoption in the home domain. *International Journal of Human–Computer Interaction*, 40(7), 1632-1643. <https://doi.org/10.1080/10447318.2022.2147302>
- [211] SCTH (2016), “Saudi commission for tourism and national heritage”, available at: <https://scth.gov.sa/TourismInvestment/TourismLicensing/Pages/Tour1.aspx>

- [212] Shah, S. F. A., Iqbal, M., Aziz, Z., Rana, T. A., Khalid, A., Cheah, Y. N., & Arif, M. (2022). The role of machine learning and the internet of things in smart buildings for energy efficiency. *Applied Sciences*, 12(15), 7882. <https://doi.org/10.3390/app12157882>
- [213] Shaheen, Basheer Wasef, and István Németh. "Integration of maintenance management system functions with industry 4.0 technologies and features—A review." *Processes* 10.11 (2022): 2173. - <https://doi.org/10.3390/pr10112173>
- [214] Shetty, R. B. (2018). Predictive maintenance in the IoT era. *Prognostics and Health Management of Electronics: Fundamentals, Machine Learning, and the Internet of Things*, 589-612. - <https://doi.org/10.1002/9781119515326.ch21>
- [215] Shitole, P. S. (2023). A Statistical Study on some Machine Learning Optimization Algorithms. - <https://doi.org/10.1109/ICAIIHI57871.2023.10488969>
- [216] Shyam, G. K., Manvi, S. S., & Bharti, P. (2017, February). Smart waste management using Internet-of-Things (IoT). In *2017 2nd international conference on computing and communications technologies (ICCCT)* (pp. 199-203). IEEE.
- [217] Singh, A. K., Gaur, A., & Kumar, P. (2024). Smart Buildings Using IoT and Green Engineering. In *The Internet of Energy* (pp. 37-66). Apple Academic Press. DOI: 10.1201/9781003399827-3
- [218] Singh, P., Singh, S., Vardhan, S., & Patnaik, A. (2020). Sustainability of maintenance management practices in hydropower plant: A conceptual framework. *Materials Today: Proceedings*, 28, 1569-1574.

- [219] Sinopoli, J. Smart Building Systems for Architects, Owners, and Builders; Elsevier: Amsterdam, The Netherlands, 2010; ISBN 9781856176538
- [220] Siountri, K., Skondras, E., & Vergados, D. D. (2020). Developing smart buildings using blockchain, internet of things, and building information modeling. *International Journal of Interdisciplinary Telecommunications and Networking (IJITN)*, 12(3), 1-15.
- [221] Sleem, A., & Elhenawy, I. (2023). Survey of Artificial Intelligence of Things for Smart Buildings: A closer outlook. *Journal of Intelligent Systems & Internet of Things*, 8(2).
- [222] Smoke Control Association, FAQs: 20 September 2021
- [223] Song, Y., Yu, F. R., Zhou, L., Yang, X., & He, Z. (2020). Applications of the Internet of Things (IoT) in smart logistics: A comprehensive survey. *IEEE Internet of Things Journal*, 8(6), 4250-4274.
- [224] Song, Z., Liu, T., & Lin, Q. (2020). Multi-objective optimization of a solar hybrid CCHP system based on different operation modes. *Energy*, 206, 118125. DOI: 10.1016/j.energy.2020.118125
- [225] Sood, T., Janssen, P., & Miller, C. (2020). Spacematch: Using environmental preferences to match occupants to suitable activity-based workspaces. *Frontiers in Built Environment*, 6, 113. - <https://doi.org/10.3389/fbuil.2020.00113>
- [226] Soori, M., Arezoo, B., & Dastres, R. (2023). Internet of things for smart factories in industry 4.0, a review. *Internet of Things and Cyber-Physical Systems*. - <https://doi.org/10.1016/j.iotcps.2023.04.006>

- [227] Sotres, P., Lanza, J., Sánchez, L., & Santana, J. R. (2019). Breaking vendors and city locks through a semantic-enabled global interoperable internet-of-things system: A smart parking case. *Sensors*. DOI: 10.3390/s19020229
- [228] Tan, A. Z. T., Zaman, A., and Sutrisna, M. (2018). Enabling an effective knowledge and information flow between the phases of building construction and facilities management. *Facilities*, 36(3), 151–170.
- [229] Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X. (2019). A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends. *Automation in Construction*, 101, 127-139.
- [230] Tanko, B. L. (2022). Towards a framework of internet of things (iot) in smart buildings: a bibliometric approach. In *Proceedings of the PAQS Congress*.
- [231] Tanveer, S., Ahmad, M. I., & Khan, T. (2024). Technological progression associated with monitoring and management of indoor air pollution and associated health risks: A comprehensive review. *Environmental Quality Management*. - <https://doi.org/10.1002/tqem.22236>
- [232] Technical Support. Cambridge Dictionary. 16 November 2021.
- [233] Theissler, A., Pérez-Velázquez, J., Kettelgerdes, M., & Elger, G. (2021). Predictive maintenance enabled by machine learning: Use cases and challenges in the automotive industry. *Reliability engineering & system safety*, 215, 107864. - <https://doi.org/10.1016/j.ress.2021.107864>

- [234] Thibaud, M., Chi, H., Zhou, W., & Piramuthu, S. (2018). Internet of Things (IoT) in high-risk Environment, Health, and Safety (EHS) industries: A comprehensive review. *Decision Support Systems*, 108, 79-95.
- [235] Thottempudi, P., & Kumar, V. (2024). The Role of IoT in Modern Healthcare: Innovations and Challenges in Pandemic Era. In *Technologies for Sustainable Healthcare* (pp. XX-XX). IGI Global. DOI:10.4018/978-1-7998-8185-8.ch010.
- [236] Tien, P. W., Wei, S., Darkwa, J., Wood, C., & Calautit, J. K. (2022). Machine learning and deep learning methods for enhancing building energy efficiency and indoor environmental quality—a review. *Energy and AI*, 10, 100198. - <https://doi.org/10.1016/j.egyai.2022.100198>
- [237] Tiwari, B. R., Panda, D., Peta, K. R., & Brar, S. K. (2024). Microbial electrochemical technologies: A life cycle and technoeconomic perspective. *Emerging Trends and Advances in Environmental and Bioenergy Systems*. DOI:10.1016/B9780443155574000010.
- [238] Toosi, H. A., Del Pero, C., Leonforte, F., Lavagna, M., & Aste, N. (2023). Machine learning for performance prediction in smart buildings: Photovoltaic self-consumption and life cycle cost optimization. *Applied Energy*, 334, 120648.
- [239] Tuan, D. A., & Dung, N. N. K. (2023). Development of Audit Risk Model Applied in Public Investment Project Audit: The State Audit in Vietnam. *Przestrzeń Społeczna (Social Space)*. DOI:10.14746/ssj.169.

- [240] Tuan, N. M., Van Hau, Q., Chin, S., & Park, S. (2021). In-situ concrete slump test incorporating deep learning and stereo vision. *Automation in Construction*, 121, 103432. DOI: 10.1016/j.autcon.2020.103432
- [241] Uganya, G., Rajalakshmi, D., Teekaraman, Y., Kuppusamy, R., & Radhakrishnan, A. (2022). A novel strategy for waste prediction using machine learning algorithm with IoT based intelligent waste management system. *Wireless Communications and Mobile Computing*, 2022. - <https://doi.org/10.1155/2022/2063372>
- [242] Ulrika H. Westergren, Ted Saarikko, and Tomas Blomquist. *Iot guiden*, 2017.
- [243] Užičanin, S., Mehinović, N., Čerkezović, E., & Užičanin, A. (2023, June). Predictive Maintenance of Induction Motor Using IoT Technology. In *International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies* (pp. 616-625). Cham: Springer Nature Switzerland. - https://link.springer.com/chapter/10.1007/978-3-031-43056-5_47
- [244] Verma, A., Prakash, S., & Kumar, A. (2023). A comparative analysis of data-driven based optimization models for energy-efficient buildings. *IETE Journal of Research*, 69(2), 796-812. - <https://doi.org/10.1080/03772063.2020.1838347>
- [245] Verma, A., Prakash, S., Srivastava, V., Kumar, A., & Mukhopadhyay, S. C. (2019). Sensing, controlling, and IoT infrastructure in smart building: A review. *IEEE Sensors Journal*, 19(20), 9036-9046.

- [246] Vilches, A., Garcia-Martinez, A., & Sanchez-Montanes, B. (2017). Life cycle assessment (LCA) of building refurbishment: A literature review. *Energy and Buildings*, 135, 286-301.
- [247] Volakh, M. (2023). Real-time Monitoring and Predictive Modeling for Space Occupancy. GitHub Repository, 14. - <https://cs.vu.nl/~versto/VU-CS-BSc-MSc-Theses/VU-CS-BScThesis-Mikita-Volakh-2023.pdf>
- [248] Wan, L., & Bai, Y. (2021). Application research on the BIM and Internet of Things technology in construction logistics management in the period of big data. In *Proceedings of the Fourteenth International Conference on Management Science and Engineering Management: Volume 2* (pp. 704-716). Springer International Publishing.
- [249] Wang, F., & Chen, L. (2024). Integrating Digital Art into a Safety Management Platform for the Construction Industry through GIS and BIM in the Internet of Things Context. - <https://doi.org/10.14733/cadaps.2024.S11.1-13>
- [250] Wang, J., Lim, M. K., Wang, C., & Tseng, M. L. (2021). The evolution of the Internet of Things (IoT) over the past 20 years. *Computers & Industrial Engineering*, 155, 107174.
- [251] Wang, K., Zhao, Y., Gangadhari, R. K., & Li, Z. (2021). Adoption Challenges of IoT and AI for Smart Cities in China. *Sustainability*, 13(19), 10983. <https://doi.org/10.3390/su131910983>
- [252] Wang, W. Q., Li, M. J., Cheng, Z. D., Li, D., & Liu, Z. B. (2021). Coupled optical-thermal-stress characteristics of a multi-tube external molten salt receiver for the next

generation concentrating solar power. *Energy*, 233, 121110.
<https://doi.org/10.1016/j.energy.2021.121110>

[253] Weerasinghe, A. S., Ramachandra, T., & Rotimi, J. O. (2022). Towards sustainable commercial buildings: an analysis of operation and maintenance (O&M) costs in Sri Lanka. *Smart and Sustainable Built Environment*, 11(3), 454-468.

[254] Wei, Y. C., Chang, Y. C., & Wu, W. C. (2024). Multi-language IoT information security standard item matching based on deep learning. *Computer Science and Information Systems*. DOI:10.2298/CSIS0000124W.

[255] Wen, T., Sun, G., & Chen, Y. (2021, October). Machine Learning based Floor-level Sensor Positioning in Smart Buildings. In *2021 IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Internet of People and Smart City Innovation (SmartWorld/SCALCOM/UIC/ATC/IOP/SCI)* (pp. 585-589). IEEE. DOI: 10.1109/SWC50871.2021.00087

[256] Wen, Y., Wang, Y., Zhao, K., Chong, D., Huang, W., Hao, G., & Mo, S. (2018). The engineering, economic, and environmental performance of terminal blend rubberized asphalt binders with wax-based warm mix additives. *Journal of Cleaner Production*, 184, 985-1001. <https://doi.org/10.1016/j.jclepro.2018.03.011>

[257] Wisdom, D. D., Vincent, O. R., Igulu, K., Hyacinth, E. A., Christian, A. U., Oduntan, O. E., & Hauni, A. G. (2024). Industrial IoT Security Infrastructures and Threats.

Communication Technologies and Security Challenges in IoT: Present and Future, 369-402. - https://link.springer.com/chapter/10.1007/978-981-97-0052-3_19

[258] Wrona, K., & Zieliński, Z. (2024). Distributed Ledger-Based Authentication and Authorization of IoT Devices in Federated Environments. *Electronics*. DOI: 10.3390/electronics20240323

[259] Wu, J., Peng, L., Li, J., Zhou, X., Zhong, J., Wang, C., & Sun, J. (2021). Rapid safety monitoring and analysis of foundation pit construction using unmanned aerial vehicle images. *Automation in Construction*, 128, 103706. DOI: 10.1016/j.autcon.2021.103706

[260] Yaseen, M., Swathi, D., & Kumar, T. A. (2017, October). IoT based condition monitoring of generators and predictive maintenance. In 2017 2nd international conference on communication and electronics systems (ICCES) (pp. 725-729). IEEE.

[261] Yauri Rodríguez, R., Gonzales, M., & Gamero, V. (2023). Remote monitoring and control system of a water distribution network using LoRaWAN technology. - 10.37394/23203.2023.18.8

[262] Yin, S., & Rodriguez-Andina, J. J. (2019). Real-time monitoring and control of industrial cyber-physical systems: With integrated plant-wide monitoring and control framework. *IEEE Industrial Electronics Magazine*. DOI:10.1109/MIE.2019.8939185.

[263] Yu, W., Dillon, T., Mostafa, F., & Rahayu, W. (2019). A global manufacturing big data ecosystem for fault detection in predictive maintenance. *IEEE Transactions on Industrial Informatics*. DOI:10.1109/TII.2019.8710319.

- [264] Zhang, H., Li, G., Yu, D., & Dong, Z. (2021). Long Short-Term Memory Neural Network-Based Real-Time Damage Prediction for Earthquake Early Warning System. Available at SSRN. DOI:10.2139/ssrn.4983213.
- [265] Zhao, L., Liu, Z., & Mbachu, J. (2019). Development of intelligent prefabs using IoT technology to improve the performance of prefabricated construction projects. *Sensors*. DOI:10.3390/s19194131.
- [266] Zhao, Y. J., Du, B., & Liu, B. K. (2013). Smart environmental protection: The new pathway for the application of the internet of things in environmental management. *Applied Mechanics and Materials*, 411, 2245-2250.
- [267] Zhao, Y., Hao, S., Chen, Z., Zhou, X., & Zhang, L. (2025). Critical Factors Influencing the IoT Adoption Behavior of Construction Companies. *Engineering, Construction and Architectural Management*. <https://doi.org/10.1108/ECAM-01-2023-0045>
- [268] Zhidan Zhao, Kadir Amasyali, Rita Chamoun, and Nora El-Gohary. Occupants' perceptions about indoor environment comfort and energy related values in commercial and residential buildings. *Procedia Environmental Sciences*, 34:631–640, 2016.

APPENDIX

Appendix A

Drivers for adopting IoT based technologies in the O&M of smart office buildings in Saudi Arabia

Dear Participant,

I am Abdulwahab S. AlQanas, a master's student at King Fahd University of Petroleum & Minerals. As part of my thesis, titled "**Lifecycle Framework for the Optimal Operation and Maintenance Cost of IoT-Based Smart Office Buildings**," I am conducting a survey to explore the drivers for adopting IoT-based technologies in the operation and maintenance of smart office buildings in Saudi Arabia.

Your participation in this survey is vital in helping to identify key factors influencing the adoption of IoT-based technologies and contributing to research that aims to enhance the efficiency and sustainability of smart office buildings.

Key Information About the Survey:

- **Time Commitment:** The survey will take approximately 5 minutes to complete
- **Confidentiality:** Your responses will remain confidential and will only be used for academic purposes. No personally identifiable information will be shared with third parties.

Should you have any questions or require further clarification, please feel free to contact me via

Email: Abdulwahabsq95@gmail.com

Phone: +966546003388.

Thank you in advance for your time and valuable input.

Sincerely,

Abdulwahab S. AlQanas

Master's Candidate

King Fahd University of Petroleum & Minerals

* Indicates required question

Consent

This survey aims to identify and assess the drivers for adopting IoT-based technologies in the operation and maintenance of smart office buildings in Saudi Arabia.

The findings will contribute to my master's thesis and to improving practices in this field.

Confidentiality:

Your responses will be kept strictly confidential. All data collected will be anonymized and securely stored. No identifying information will be shared.

Time Commitment:

The survey will take approximately 5 minutes to complete.

Risks and Benefits:

There are no known risks associated with participating in this survey. While there is no direct benefit to you, your input will contribute to valuable research in the field of IoT and smart office building management.

Consent:

By proceeding with the survey, you confirm that you have read and understood this information and voluntarily agree to participate. If you do not agree, you may exit the survey at any time.

Thank you for your participation.

Sincerely,

Abdulwahab S. AlQanas
Master's Candidate
King Fahd University of Petroleum & Minerals

SECTION 1: DEMOGRAPHICS

1. Name *

2. Phone *

3. Email *

4. Please indicate your professional experience/length: *

Mark only one oval.

- ☐ Less than 5 years
☐ 5 – 10 years
☐ 11 – 15 years
☐ More than 15 years

5. Please indicate what category of respondent you belong to: *

Mark only one oval.

- ☐ Architect / Engineer
☐ Facility Manager
☐ Developer/Owner
☐ IoT Specialist

Drivers						
1. Energy Efficiency						
1	Real-time monitoring for optimizing energy usage in building systems	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	The ability to adjust HVAC and lighting systems based on occupancy and environmental conditions					
3	Minimizing unnecessary energy consumption and reducing waste					
2. Operational Efficiency						
1	Detecting early signs of equipment malfunction	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Predictive maintenance in reducing equipment downtime and repair costs					
3	Scheduling timely maintenance interventions					
3. Occupant Comfort						
1	Personalizing lighting, temperature, and air quality in real time	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Developing a comfortable work environment					
3	Improving worker productivity and satisfaction					
4. Security and Safety						
1	Providing real-time surveillance for improved security	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Controlling access for improving safety					
3	Detecting and alerting potential hazards like smoke or gas leaks					
5. Space Utilization						
1	Collecting real-time data on office occupancy and usage patterns	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Optimizing space allocation based on IoT-generated insights					
3	Reconfiguring office layouts to reduce underutilized spaces					
6. Cost Reduction						
1	Optimizing maintenance processes to lower operational costs	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Real-time monitoring in identifying cost-saving opportunities					
3	Reducing human intervention in routine facility tasks					
7. Sustainability						
1	Monitoring resource consumption, such as energy and water usage	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Implementing strategies to reduce a building's environmental impact					
3	Supporting long-term sustainability initiatives					
8. Data-Driven Decisions						
1	Providing actionable insights for improving building operations	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Identifying inefficiencies and opportunities for improvement					
3	Supporting strategic and operational decision-making					
9. User Experience						
1	Developing dynamic and responsive workspaces	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Personalizing workspace settings to individual preferences					
3	Developing automated booking systems for shared spaces					
10. Flexibility in Management						
1	Accessing real-time data on building systems	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Adjusting operations remotely					
3	Ensuring quicker issue resolution and improved building performance					

Appendix B

Challenges of adopting IoT based technologies in the O&M cost of smart office buildings in Saudi Arabia

Dear Participant,

I am Abdulwahab S. AlQanas, a master's student at King Fahd University of Petroleum & Minerals. As part of my thesis, titled "**Lifecycle Framework for the Optimal Operation and Maintenance Cost of IoT-Based Smart Office Buildings**," I am conducting a survey to explore the challenges for adopting IoT-based technologies in the operation and maintenance of smart office buildings in Saudi Arabia.

Your participation in this survey is vital in helping to identify key factors influencing the adoption of IoT-based technologies and contributing to research that aims to enhance the efficiency and sustainability of smart office buildings.

Key Information About the Survey:

- **Time Commitment:** The survey will take approximately 5 minutes to complete
- **Confidentiality:** Your responses will remain confidential and will only be used for academic purposes. No personally identifiable information will be shared with third parties.

Should you have any questions or require further clarification, please feel free to contact me via

Email: Abdulwahabsq95@gmail.com

Phone: +966546003388.

Thank you in advance for your time and valuable input.

Sincerely,

Abdulwahab S. AlQanas

Master's Candidate

King Fahd University of Petroleum & Minerals

Indicates required question

Consent

This survey aims to identify and assess the challenges for adopting IoT-based technologies in the operation and maintenance of smart office buildings in Saudi Arabia.

The findings will contribute to my master's thesis and to improving practices in this field.

Confidentiality: Your responses will be kept strictly confidential. All data collected will be anonymized and securely stored. No identifying information will be shared.

Time Commitment: The survey will take approximately 5 minutes to complete.

Risks and Benefits: There are no known risks associated with participating in this survey. While there is no direct benefit to you, your input will contribute to valuable research in the field of IoT and smart office building management.

Consent: By proceeding with the survey, you confirm that you have read and understood this information and voluntarily agree to participate. If you do not agree, you may exit the survey at any time.

Thank you for your participation.

Sincerely,

Abdulwahab S. AlQanas
Master's Candidate
King Fahd University of Petroleum & Minerals

SECTION 1: DEMOGRAPHICS

1. Name *

2. Phone *

3. Email *

4. Please indicate your professional experience/length: *

Mark only one oval.

- ☐ Less than 5 years
☐ 5 – 10 years
☐ 11 – 15 years
☐ More than 15 years

5. Please indicate what category of respondent you belong to: *

Mark only one oval.

- ☐ Architect / Engineer
☐ Facility Manager
☐ Developer/Owner
☐ IoT Specialist

SECTION 2:

Survey Questions

Challenges						
1. Complexity in Installation and Integration						
1	Ensuring interoperability between various IoT devices and systems during installation	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Minimizing the time and cost associated with integrating IoT systems in smart office buildings					
3	Synchronizing IoT systems (e.g., lighting, HVAC, security) into a unified platform					
2. Data Security and Privacy Concerns						
1	Protecting sensitive occupant data collected by IoT devices in smart office buildings	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Addressing privacy concerns related to IoT-enabled occupant monitoring					
3	Implementing security measures to prevent unauthorized access to IoT data					
3. High Initial Investment						
1	Reducing the financial burden of acquiring IoT infrastructure for smart office buildings	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Demonstrating a clear return on investment (ROI) for IoT adoption in building operations					
3	Providing financial incentives or support for organizations to adopt IoT technologies					
4. Maintenance and Technological Expertise						
1	Ensuring regular maintenance of IoT devices to prevent system failures	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Having in-house technical expertise to manage and troubleshoot IoT systems					
3	Planning for software and hardware updates to keep IoT systems functional and secure					
5. Data Overload and Management						
1	Implementing effective data analytics tools to process IoT-generated data	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Training facility managers to extract actionable insights from IoT data					
3	Developing frameworks to prioritize critical information from IoT systems					
6. Cybersecurity Threats						
1	Ensuring IoT devices are equipped with robust cybersecurity protections	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Detecting and mitigating vulnerabilities in IoT networks					
3	Securing communication between IoT devices to prevent cyberattacks					
7. Reliability of IoT Networks						
1	Ensuring uninterrupted network connectivity for IoT systems in smart office buildings	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Reducing the impact of network disruptions on building operations					
3	Upgrading network infrastructure to support IoT deployments					
8. Environmental Impact and Sustainability Concerns						
1	Minimizing the environmental footprint of IoT devices during production and disposal	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Developing recycling programs for outdated IoT devices					
3	Balancing the energy efficiency gains of IoT systems against their environmental costs					
9. Interference with Building Legacy Systems						
1	Ensuring compatibility between IoT technologies and existing building systems	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Minimizing downtime when integrating IoT with legacy systems					
3	Developing cost-effective strategies for upgrading legacy systems to accommodate IoT					
10. High Energy Consumption of IoT Devices						
1	Monitoring the energy consumption of IoT devices in smart office buildings	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Optimizing the power usage of IoT devices to reduce overall operational costs					
3	Balancing the energy use of IoT devices with their benefits in energy savings					
11. Ongoing Operation and Maintenance Costs of IoT Devices						
1	Ensuring regular software updates, calibration, and hardware replacements for IoT devices	Extremely Important	Very Important	Important	Somehow Important	Not Important
2	Optimizing the energy consumption of interconnected IoT devices to reduce utility expenses					
3	Managing labor costs by providing specialized expertise for IoT maintenance activities					
4	Implementing cost optimization strategies to minimize recurring expenses in older buildings retrofitted with IoT systems					

Appendix C

Factors affecting the O&M cost of IoT-based smart office buildings in Saudi Arabia

Dear Participant,

I am Abdulwahab S. AlQanas, a master's student at King Fahd University of Petroleum & Minerals. As part of my thesis, titled "**Lifecycle Framework for the Optimal Operation and Maintenance Cost of IoT-Based Smart Office Buildings**," I am conducting a survey to explore the factors for adopting IoT-based technologies in the operation and maintenance of smart office buildings in Saudi Arabia.

Your participation in this survey is vital in helping to identify key factors influencing the adoption of IoT-based technologies and contributing to research that aims to enhance the efficiency and sustainability of smart office buildings.

Key Information About the Survey:

- **Time Commitment:** The survey will take approximately 5 minutes to complete
- **Confidentiality:** Your responses will remain confidential and will only be used for academic purposes. No personally identifiable information will be shared with third parties.

Should you have any questions or require further clarification, please feel free to contact me via

Email: Abdulwahabsq95@gmail.com

Phone: +966546003388.

Thank you in advance for your time and valuable input.

Sincerely,

Abdulwahab S. AlQanas

Master's Candidate

King Fahd University of Petroleum & Minerals

* Indicates required question

Consent

This survey aims to identify and assess the factors for adopting IoT-based technologies in the operation and maintenance of smart office buildings in Saudi Arabia.

The findings will contribute to my master's thesis and to improving practices in this field.

Confidentiality: Your responses will be kept strictly confidential. All data collected will be anonymized and securely stored. No identifying information will be shared.

Time Commitment: The survey will take approximately 5 minutes to complete.

Risks and Benefits: There are no known risks associated with participating in this survey. While there is no direct benefit to you, your input will contribute to valuable research in the field of IoT and smart office building management.

Consent: By proceeding with the survey, you confirm that you have read and understood this information and voluntarily agree to participate. If you do not agree, you may exit the survey at any time.

Thank you for your participation.

Sincerely,

Abdulwahab S. AlQanas
Master's Candidate
King Fahd University of Petroleum & Minerals

SECTION 1: DEMOGRAPHICS

1. Name *

2. Phone *

3. Email *

4. Please indicate your professional experience/length: *

Mark only one oval.

- ☐ Less than 5 years
☐ 5 – 10 years
☐ 11 – 15 years
☐ More than 15 years

5. Please indicate what category of respondent you belong to: *

Mark only one oval.

- ☐ Architect / Engineer
☐ Facility Manager
☐ Developer/Owner
☐ IoT Specialist

SECTION 2:

Survey Questions

Factors							
1. Planning Phase		Extremely Important	Very Important	Important	Somehow Important	Not Important	
1	Engaging stakeholders early to align objectives and expectations for IoT adoption						
2	Allocating sufficient budget for IoT infrastructure during the planning phase						
3	Setting clear energy efficiency goals to guide IoT deployment						
4	Selecting vendors with proven expertise and scalable solutions for IoT systems						
5	Planning for future scalability to integrate emerging technologies						
6	Ensuring compliance with local and international regulations during IoT adoption						
7	Developing robust data privacy and security strategies for IoT systems						
8	Creating a technology integration strategy to ensure seamless operation of IoT systems						
9	Performing lifecycle cost analysis to balance investment with operational savings						
10	Assessing skill gaps and planning training programs for managing IoT systems						
2. Design Phase		Extremely Important	Very Important	Important	Somehow Important	Not Important	
1	Ensuring interoperability across IoT platforms and devices						
2	Strategically placing sensors for accurate and reliable data collection						
3	Incorporating redundancy to maintain system reliability during failures						
4	Using modular design principles to simplify upgrades and maintenance						
5	Embedding predictive maintenance features in system design						
6	Optimizing design choices for energy efficiency in IoT-enabled systems						
7	Developing user-friendly interfaces for IoT systems to improve operation						
8	Aligning IoT designs with industry standards to ensure compatibility						
3. Construction Phase		Extremely Important	Very Important	Important	Somehow Important	Not Important	
1	Selecting high-quality components to enhance reliability and reduce maintenance costs						
2	Following best practices for IoT installation to ensure optimal performance						
3	Performing rigorous system and integration testing before deployment						
4	Engaging contractors with specialized expertise in IoT system installation						
5	Adhering to design plans to avoid costly revisions during construction						
6	Using high-quality cabling standards to enhance connectivity and system reliability						
7	Creating detailed documentation for a smooth system handover						
8	Aligning construction with As-Built Plans to avoid operational inefficiencies						
9	Implementing training programs for operations and maintenance teams during construction						
4. Operation & Maintenance Phase		Extremely Important	Very Important	Important	Somehow Important	Not Important	
1	Implementing real-time monitoring for early detection of inefficiencies						
2	Using predictive algorithms to forecast and prevent equipment failures						
3	Tracking energy consumption to identify and address inefficiencies						
4	Implementing proactive cybersecurity measures to protect IoT systems						
5	Regularly updating IoT devices to ensure security and efficiency						
6	Incorporating fault detection systems to minimize maintenance disruptions						
7	Collecting user feedback to continuously improve IoT system performance						
8	Dynamically optimizing resources to reduce operational costs						
9	Conducting periodic reviews of lifecycle costs to ensure sustainability and ROI						

Appendix D

Validation of the Framework for the IoT based technologies in the O&M of smart office buildings in Saudi Arabia

Dear Participant,

I am Abdulwahab S. AlQanas, a master's student at King Fahd University of Petroleum & Minerals. As part of my thesis, titled "**Lifecycle Framework for the Optimal Operation and Maintenance Cost of IoT-Based Smart Office Buildings**," I am conducting a survey to validate the framework for adopting IoT-based technologies in the operation and maintenance of smart office buildings in Saudi Arabia.

Your participation in this survey is vital in helping to identify key factors influencing the adoption of IoT-based technologies and contributing to research that aims to enhance the efficiency and sustainability of smart office buildings.

Key Information About the Survey:

- **Time Commitment:** The survey will take approximately 5 minutes to complete
- **Confidentiality:** Your responses will remain confidential and will only be used for academic purposes. No personally identifiable information will be shared with third parties.

Should you have any questions or require further clarification, please feel free to contact me via

Email: Abdulwahabsq95@gmail.com

Phone: +966546003388.

Thank you in advance for your time and valuable input.

Sincerely,

Abdulwahab S. AlQanas

Master's Candidate

King Fahd University of Petroleum & Minerals

* Indicates required question

Consent

This survey aims to identify and assess the drivers for adopting IoT-based technologies in the operation and maintenance of smart office buildings in Saudi Arabia.

The findings will contribute to my master's thesis and to improving practices in this field.

Confidentiality:

Your responses will be kept strictly confidential. All data collected will be anonymized and securely stored. No identifying information will be shared.

Time Commitment:

The survey will take approximately 5 minutes to complete.

Risks and Benefits:

There are no known risks associated with participating in this survey. While there is no direct benefit to you, your input will contribute to valuable research in the field of IoT and smart office building management.

Consent:

By proceeding with the survey, you confirm that you have read and understood this information and voluntarily agree to participate. If you do not agree, you may exit the survey at any time.

Thank you for your participation.

Sincerely,

Abdulwahab S. AlQanas
Master's Candidate
King Fahd University of Petroleum & Minerals

SECTION 1: DEMOGRAPHICS

1. Name *

2. Phone *

3. Email *

4. Please indicate your professional experience/length: *

Mark only one oval.

- ☐ Less than 5 years
☐ 5 – 10 years
☐ 11 – 15 years
☐ More than 15 years

5. Please indicate what category of respondent you belong to: *

Mark only one oval.

- ☐ Architect / Engineer
☐ Facility Manager
☐ Developer/Owner
☐ IoT Specialist

SECTION 2:

Assessment of the framework

Lifecycle Phase		Key Implementation Tasks							
				Extremely Important	Very Important	Important	Somehow Important	Not Important	
1. Planning Phase	1. Conduct organizational and digital infrastructure readiness assessments								
	2. Define strategic IoT objectives aligned with business goals (e.g., energy efficiency, cost reduction)								
	3. Identify existing O&M pain points and areas for improvement								
	4. Allocate preliminary budget and ROI expectations								
	5. Develop initial cybersecurity and data governance strategy								
	6. Select pilot areas/buildings for IoT implementation								
	7. Engage all key stakeholders early for alignment								
	8. Establish KPIs to evaluate post-implementation performance								
		Extremely Important	Very Important	Important	Somehow Important	Not Important			
2. Designing Phase	1. Develop detailed IoT system architecture (sensors, networks, gateways, analytics platforms)								
	2. Ensure interoperability and vendor neutrality in tech selection								
	3. Integrate IoT requirements with architectural and engineering designs								
	4. Design integration with FM tools (e.g., CAFM, CMMS, BMS)								
	5. Include data privacy, redundancy, and fail-safe mechanisms in design								
	6. Plan for modular expansion and technology upgrades								
	7. Specify environmental and energy monitoring systems								
	8. Coordinate with stakeholders to ensure design aligns with end-user needs and FM protocols								
		Extremely Important	Very Important	Important	Somehow Important	Not Important			
3. Construction Phase	1. Procure certified, cost-effective, and future-proof IoT devices								
	2. Install infrastructure including sensors, cabling, network components, and power supply								
	3. Implement structured cabling and communication protocols								
	4. Integrate IoT systems with building automation and existing FM platforms								
	5. Commission subsystems and validate data accuracy								
	6. Perform scenario testing (e.g., alert handling, system downtime recovery)								
	7. Develop technical documentation, user guides, and training materials								
	8. Conduct formal handover to FM teams with practical demonstrations and SOPs								
		Extremely Important	Very Important	Important	Somehow Important	Not Important			
4. Operation and Maintenance Phase	1. Continuously monitor key parameters (energy use, occupancy, air quality, equipment performance)								
	2. Use analytics dashboards and alerts for early fault detection								
	3. Apply predictive and condition-based maintenance strategies								
	4. Automate reports on performance KPIs (energy, asset lifecycle, comfort, etc.)								
	5. Periodically review cybersecurity protocols and access controls								
	6. Conduct user satisfaction surveys and incorporate feedback into system settings								
	7. Perform cost-benefit reviews comparing O&M savings with initial goals								
	8. Plan for gradual system upgrades and expansion based on usage trends								

Vitae

Name : Abdulwahab Saad AlQanas |

Nationality : Saudi Arabia |

Date of Birth : 10/25/1995 |

Email : Abdulwahabsq95@gmail.com |

Address : 10480, 31, 10 A street, Dammam, Eastern Providence,
Kingdom of Saudi Arabia |

Academic Background : Master of Science in Architectural Engineering □ Facility
Management (2021□2025), King Fahd University of Petroleum and Minerals
(KFUPM), Saudi Arabia.
Bachelor of Architecture (2013□2018), Imam Abdulrahman Bin Faisal University
(IAU), Saudi Arabia. |

Professional Experience:

1. Senior Planning Engineer, ETS Consulting – National Water Company (NWC)
Supervision Projects (2023 – Present).
2. Planning Engineer, ETS Consulting (2023).
3. Project Engineer, ANSAB Contracting Company (2021–2023).
4. Project Engineer, Civil Works Company (CWC) (2018–2021).

Research Interests:

1. Smart Building Technologies
2. Internet of Things (IoT) Applications in the Built Environment
3. Operation and Maintenance Cost Optimization
4. Sustainable Facility Management

Publications:

1. Abdulwahab S. AlQanas, et al. (2025). "Factors affecting sustainable practices of workplace remodeling in Saudi Arabia: A stakeholder assessment." Journal of Corporate Real Estate (Emerald Insight). [DOI: <http://dx.doi.org/10.1108/JCRE-05-2024-0019>]