A Multi-Stakeholder Information Model to Drive Process Connectivity In Smart Buildings

Miftah Abdulmajeed Ghneim

PhD

May 2023

A Multi-Stakeholder Information Model to Drive Process Connectivity In Smart Buildings

Miftah Abdulmajeed Ghneim

Faculty of Computing, Engineering, and Built Environment (CEBE)

A thesis submitted to the school of Computing, Engineering, and Built Environment in partial fulfilment for the degree of Doctor of Philosophy

May 2023

Thanks be to Allah for the strength and willpower.

This thesis is dedicated to my family for words of encouragement, support, and prayers, which were the fuel that kept me going. I will always appreciate what you have done, especially my Father, **Abdulmajeed Ghneim.** <3 for his love and support throughout the entire journey.

ABSTRACT

Smart buildings utilise IoT technology to provide stakeholders with efficient, comfortable, and secure experiences. However, previous studies have primarily focused on the technical aspects of it and how it can address specific stakeholder requirements. This study adopts socio-technical theory principles to propose a model that addresses stakeholders' needs by considering the interrelationship between social and technical subsystems. A systematic literature review and thematic analysis of 43 IoT conceptual frameworks for smart building studies informed the design of a comprehensive conceptual model and IoT framework for smart buildings.

The study's findings suggest that addressing stakeholder requirements is essential for developing an information model in smart buildings. A multi-stakeholder information model integrating multiple stakeholders' perspectives enhances information sharing and improves process connectivity between various systems and subsystems. The socio-technical systems framework emphasises the importance of considering technical and social aspects while integrating smart building systems for seamless operation and effectiveness.

The study's findings have significant implications for enhancing stakeholders' experience and improving operational efficiency in commercial buildings. The insights from the study can inform smart building systems design to consider all stakeholder requirements holistically, promoting process connectivity in smart buildings. The literature analysis contributed to developing a comprehensive IoT framework, addressing the need for holistic thinking when proposing IoT frameworks for smart buildings by considering different stakeholders in the building.

ACKNOWLEDGEMENTS

First and foremost, I am grateful to Allah, whose mercy and blessing have supported me through my PhD journey. Followed by that, there are a number of people without whom this thesis might not have been possible and to whom I am greatly indebted.

I would like to express my deepest appreciation and gratitude to my valued director of studies (DoS), **Dr. Gerald Feldman**, for his exceptional supervision and constant support throughout my entire PhD journey. Dr. Feldman's professional and excellent guidance has played a fundamental role in shaping my research and academic development, and I am truly fortunate to have had him as my mentor. Furthermore, I cannot emphasise enough the tremendous support I have received from Dr. Feldman. His availability and willingness to provide guidance, even during his busiest times, have been invaluable. Whether it was discussing research or offering advice on academic, career opportunities and personal matters, he has consistently shown a genuine commitment to my success. I honestly could not have done this or reached this level without him. "*Thank you*".

I also greatly appreciate my second supervisors, Prof. **Sharon Cox** and **Dr. Mohammad Mayouf,** for their valuable inputs, suggestions, and guidance throughout my PhD journey. Their expertise, support, and willingness to invest their time and effort in my academic growth have been invaluable. I am grateful for their contributions and their positive impact on my research and personal development. Their mentorship has enhanced the quality of my work and inspired me to strive for excellence in my future endeavours. Thank you, Prof. Cox and Dr. Mayouf, for your invaluable contributions to my academic journey.

I would also like to extend my sincere appreciation to my colleagues and friends, Dr Haitham Mahmoud, Ensi Smajli, Nour Albaarini, Dr Nassir Ibrahim, Sohaib Misurati, and Dr Anastasios Christodoulides. Their support, motivation, and fruitful discussions have significantly contributed to the success of my research work, and I am truly grateful for their presence in my academic journey. A special thank you to Dr Haitham and Ensi Smajli, who have been exceptional colleagues and friends, always ready to lend a helping hand and provide valuable insights. Our discussions and brainstorming sessions have been stimulating, pushing the boundaries of our research and fostering innovative ideas. Their positive energy and unwavering support have been a constant inspiration and encouragement.

Lastly, I would like to express my deep gratitude to my family for their continuous support and encouragement throughout my entire PhD journey. Their presence and belief in me have been the foundation of my success, and I am truly blessed to have them by my side.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

IoT Internet of Things

BMS Building Management Systems

BAS Building Automation Systems

FBS Functional Building Systems

CBS Component Building Systems

BIM Building Information Modelling

HVAC Heating, Ventilation, and Air Conditioning

IT Information Technology

OSI Open Systems Interconnection

UIDs Unique Identifications

MSIM Multi-Stakeholder Information Model

SBs Smart Buildings

VLM Viable System Model

1 INTRODUCTION

This chapter begins by introducing Smart Buildings as the research domain. It provides an overview of the challenges this study intends to address, followed by the problem statement, research aims and objectives. Furthermore, the chapter provides an overview of the thesis structure and explains the importance of each section in achieving the research objectives and goals. The research background outlines buildings and their evolution with the advancement of building system technologies.

1.1 Background

Throughout history, buildings have undergone significant transformations in design and construction, from primitive caves to modern architectural marvels. Today, buildings serve as essential spaces where people spend a significant portion of their lives (Hu et al., 2018). Technological advancements have played a pivotal role in shaping the evolution of buildings, particularly in the realm of smart buildings (Kejriwal and Mahajan, 2016; Palattella et al., 2016; Casado-Mansilla et al., 2018; Wirtz, Weyerer, and Schichtel, 2019).

Smart buildings encompass a wide range of systems, including structural, mechanical, electrical, and plumbing systems, with each system comprising multiple subsystems (Minoli, Sohraby, and Occhiogrosso, 2017). These systems are equipped with sensors that collect information and facilitate environmental management, ultimately transforming buildings into intelligent entities (Pasini et al., 2016). Key among the technologies employed in smart buildings is the Internet of Things (IoT), which enables the sharing of data and integration of systems to meet specific user requirements within a building (Mammeri and Younus, 2020a).

By integrating IoT into buildings, traditional approaches to energy consumption reduction and other functionalities shift from disparate systems to an extensive and interconnected sensing and control network (Ma et al., 2018). The IoT network serves as a platform for information and data exchange between building systems and the individuals who interact with them on a daily basis (Koh et al., 2018). However, IoT is focused on connecting and integrating devices, sensors, and systems while overlooking the importance of facilitating seamless information sharing and collaboration between different stakeholders (Kim and Lee, 2014; Koh *et al.*, 2018; Al-Ali *et al.*, 2020). In order to gain an understanding of the flow of information in smart buildings, it is necessary to break down the IoT processes and recognise the role that IoT plays within them. In the smart building context, various stakeholders design, manage, control, and utilise buildings, including architects, building facility managers, owners, and occupants (Nuutinen et al., 2022a). These stakeholders, collectively referred to as building stakeholders, have distinct requirements for smart buildings, encompassing factors such as comfort improvement, enhanced productivity, optimised system performance, and energy and cost savings (Jia et al., 2018). IoT frameworks in smart buildings often fall short of addressing the diverse needs of building stakeholders due to design limitations, customisation challenges, usability issues, security concerns, and more (Fok et al., 2011; Panteli, Kylili, and Fokaides, 2020; Qolomany *et al.*, 2019). This consequently limits the exposure of IoT to meet stakeholders' requirements (e.g. occupants' needs or operational issues for facility managers). In addition, in smart buildings, IoT is often tailored to produce certain outputs, which imposes another complexity in terms of looking into different information flows to meet stakeholders' needs and requirements (Ramprasad et al., 2018). Achieving a well-connected and interoperable system in smart buildings requires a comprehensive understanding of the information flow between stakeholders and building systems (Le, Le Tuan, and Dang Tuan, 2019). Thus, within the context of IoT frameworks for smart buildings, a socio-technical approach entails addressing technical requirements for data exchange between building systems and stakeholders and acknowledging different stakeholders' social needs and preferences (Sony and Naik, 2020a). To address this limitation, a socio-technical approach, informed by the socio-technical systems theory, can be employed to incorporate both social and technical factors when designing and implementing IoT systems (Shin, 2014). The diverse applications of IoT across industries demonstrate its potential to improve efficiency, provide data-driven insights, and enhance user experiences. On the one hand, it is important to indicate that the use of IoT, in most sectors, is often tailored/predetermined, which target a particular need/requirement (e.g. energy efficiency) to meet an objective. On the other hand, in some sectors, the receiving beneficiaries of IoT systems can be diverse, which is recognised in smart buildings for some sectors such as the Education sector that involves a wide variety of stakeholders. Hence, for the scope of this research, the education sector was chosen as a case study due to its readiness for technology integration, diverse stakeholder needs, and the opportunity to leverage IoT to create more effective and innovative learning environments. A smart building can be defined as an intelligently designed and interconnected structure that leverages IoT technologies to facilitate data exchange and integration among various systems while also considering the diverse requirements and preferences of building stakeholders. In smart buildings, it is the expectation that smart systems such as IoT can support meeting the building’s needs and requirements, however, as stated earlier, most IoT systems in smart buildings often fall short of addressing the diverse needs of building stakeholders. This was attributed to certain complexities such as design limitations, customisation challenges, usability issues, security concerns, and many instances, the tailored/predetermined nature of IoT systems in a smart building. Therefore it is essential to provide a holistic view of IoT systems in order to gain richer understanding on their role in meeting diverse stakeholder needs and requirements.

In information systems, soft systems are recognised as an effective mechanism to tackle complex system issues while incorporating different perspectives of stakeholders in a chosen context (Sony and Naik, 2020b). As one of the soft systems techniques, socio-technical systems are recognised as an effective mechanism that provides a holistic view of situation perceiving from people, technology and processes. Therefore, for the purpose of this research, a socio-technical approach is suggested to bridge the gap in addressing users' needs when implementing IoT frameworks in smart buildings. By recognizing the intricate interplay between social and technical factors, this approach ensures that technology solutions align with the diverse requirements of stakeholders while considering the broader social context in which these solutions operate. As a result, this study adopts a socio-technical approach to explore the requirements of all stakeholders, leading to an information model that supports a process connected to smart building.

1.2 Problem Statement

IoT has emerged as a transformative technology in the context of smart buildings, enabling connectivity and data exchange between various sensors and devices to optimise building operations. However, a critical issue needs to be addressed regarding the processes of IoT in smart buildings. Specifically, the current approach to IoT processes does not adequately take into consideration the diverse requirements and needs of different stakeholders involved in these buildings (Fok *et al.*, 2011; Jansson, Schade and Olofsson, 2013; Ramprasad *et al.*, 2018; Panteli, Kylili and Fokaides, 2020).

The stakeholders in smart buildings (building managers, facilities managers, maintenance staff, and building occupants such as building occupants and administrative staff) share information with building systems to ensure the functioning of the building and its systems. Each stakeholder has distinct responsibilities and objectives that must be considered when making

IoT-enabled buildings. However, the existing IoT frameworks and solutions primarily focus on technical aspects and fail to address the specific requirements of these stakeholders.

For instance, building managers are responsible for overseeing the overall operation of the building, including energy efficiency and cost reduction. Facilities managers and maintenance staff are concerned with maintenance and upkeep activities, ensuring the proper functioning of the building's infrastructure. On the other hand, building occupants utilise the different spaces within the building, requiring a comfortable and conducive environment for effective teaching and learning. Administrative staff handle various administrative functions related to the educational institution. Each stakeholder has unique priorities, challenges, and expectations that must be acknowledged to ensure a successful means of an IoT-enabled building. The lack of a holistic approach to IoT-enabled buildings can lead to several issues. Firstly, it may result in a disconnect between the technology and the actual requirements of the stakeholders, leading to a significant lack of utilisation of IoT capabilities. For example, IoT systems may generate vast amounts of data, but if the data is not coded, they do not provide actionable insights relevant to the stakeholders, which leads to the potential benefits of IoT are not fully realised. Also, a lack of consideration of stakeholder requirements can promote user acceptance and adoption of IoT technologies (Shin. 2019). If the implemented IoT systems do not align with the stakeholders' goals and preferences, they may be unwilling to engage with the technology, limiting its effectiveness and hindering the realisation of desired outcomes (Alaloul et al., 2020).

Furthermore, neglecting stakeholder requirements may result in an increased workload for the stakeholders or create new challenges that inhibit their ability to perform their roles effectively. For instance, if IoT systems generate excessive notifications or data streams that are not relevant or actionable for specific stakeholders, it can lead to information overload and hamper decisions for operational processes. Therefore, these challenges need to be addressed to unlock the full potential of IoT in smart buildings, and it is imperative to develop a multi-stakeholder approach to IoT processes in smart buildings. Such approaches should take into account the unique requirements, objectives, and constraints of each stakeholder group, ensuring that the IoT systems are tailored to their specific requirements (Batool and Niazi, 2017; Minoli, Sohraby and Occhiogrosso, 2017; Al-Ali *et al.*, 2020). By doing so, the benefits of IoT technologies, such as energy optimisation, cost reduction, and improved building performance, can be effectively enhanced while simultaneously addressing the concerns and objectives of the diverse stakeholders involved (Wirtz *et al.*, 2019).

1.3 Research Question

How to improve the connectivity of IoT processes between systems and subsystems to satisfy different stakeholders' requirements within a smart building?

1.4 Research Aim and Objectives

This research aims to develop a multi-stakeholder information model to drive process connectivity within smart buildings. In order to achieve this aim, this research proposes the following objectives:

(1) Explore IoT frameworks and their application in smart buildings, emphasising their role in satisfying stakeholders' requirements.

(2) Identify the key stakeholders' requirements within the IoT processes in smart buildings to propose a conceptual framework capturing stakeholders' requirements.

(3) To develop an information model to improve the connectivity between processes in smart buildings.

(4) To evaluate and validate the developed model to identify its usefulness in supporting process connectivity.

1.5 Research Scope

This research focuses on six smart buildings located in a city campus in the United Kingdom that serve as learning spaces and public educational buildings. These buildings have Building Management Systems (BMS) installed, which are used to control various aspects of the building, such as heating, ventilation, and air conditioning. The BMS systems in these buildings are of particular interest as they provide a wealth of data that can be used to optimise energy efficiency, reduce costs, and improve building performance. These systems are connected to a gateway, which is connected to an application where data can be visualised, controlled, and monitored from any place, at any time, and through any network. This creates an IoT system that collects data from various sensors and devices within the building, enabling a smart building to operate efficiently and effectively. The different stakeholders each have an essential role in the effective functioning of the BMS systems. The stakeholders include building managers, facilities managers, maintenance staff, and building occupants (teachers, students, and other administrative staff). For example, the behaviour of building occupants affects the management of the building's environment; building managers are responsible for overseeing the building's overall operation, while facilities managers are responsible for ensuring the building's maintenance and upkeep.

This research uses a socio-technical approach to improve smart building connectivity by integrating IoT processes and stakeholders' requirements. The study will investigate how each stakeholder interacts with the BMS systems and the data they provide. The research will also examine each stakeholder's challenges in using and interpreting BMS data and how these challenges can be overcome. The study will focus on IoT processes in these buildings, which are demonstrated in IoT frameworks in smart buildings, starting from the point of collecting data at the physical and devices layer up to the application and service layer. The research will investigate how IoT technology is used in public buildings, the types of data it collects, and how this data is used to optimise building performance. One of the reasons for choosing these public buildings is the ease of accessing BMS systems and data from stakeholders compared to the private sector. The study will explore the challenges associated with incorporating multiple stakeholders within IoT processes in smart buildings and the potential benefits of integration.

1.6 Overview of The Thesis Structure

This research aims to develop a multi-stakeholder information model to drive process connectivity within smart buildings. An overview of the thesis structure is provided in the first chapter. This includes background information, the problem statement, the research question, the aims and objectives of the study, and a discussion of the scope of the study. The second chapter is a literature review, which discusses the concepts of smart buildings, IoT, systems of smart buildings, stakeholders, processes, stages, process connectivity, and socio-technical systems. The third chapter focuses on the methodology of the research, including research philosophy, approaches, strategy, design implementation, qualitative data analysis, and ethical considerations. The fourth chapter is dedicated to IoT frameworks in smart buildings. It discusses the importance of IoT frameworks, reviews existing literature on IoT frameworks, presents the developed IoT framework, and provides a discussion of the limitations and capabilities of IoT frameworks. The fifth chapter presents case studies and results, including a university campus case study, research participants, data collection scope, roles and duties in the building, definitions and concepts of smart buildings, technology, data, space, and the results and findings. The sixth chapter provides an analysis based on Soft-Systems Methodology SSM to structure the views of different stakeholders and help develop the information model for this study. In the seventh chapter, the researcher examines in detail how the multi-stakeholder information model was developed and outlines the study's primary contribution. In addition, it presents the results of the validation and experimentation of the model in order to demonstrate its validity and reliability. Chapter Eight summarises the study's overall contributions and future research directions.

2 LITERATURE REVIEW

The literature review chapter provides a detailed understanding of smart buildings and their various components. Smart buildings are becoming increasingly popular due to their ability to integrate various technologies, processes, and systems to optimize building performance and improve the overall occupant experience. This chapter will explore the literature on smart buildings, including the technologies used in smart buildings, the processes and systems that contribute to their functionality, and the various stakeholders involved in the development and operation of smart buildings. Additionally, this chapter will examine the concept of process connectivity and how it is related to a socio-technical systems approach in the context of smart buildings. Understanding these various components is essential for designing and implementing effective smart buildings that meet the needs of all stakeholders and contribute to a sustainable built environment.

2.1 Smart Buildings

There has been an increased interest in constructing smart buildings as they are seen as a solution to minimising many environmental factors caused by buildings, i.e. reducing energy waste, leading to numerous studies on smart buildings. For example, Bashir and Gill, (2017) looked into real-time data in smart buildings; Kim *et al.*, (2022) investigated automation in smart buildings. Panteli, Kylili and Fokaides, (2020) investigate the use of IoT in Building Information Modelling (BIM) in smart buildings. Furthermore, a comprehensive review of the literature reveals three broad aspects of smart buildings: one, understanding and formulating concepts (Sinopoli, 2010; Buckman, Mayfield and Beck, 2014a; Ma, Badi and Jørgensen, 2016); a second, technology and automation (Darby, 2018; Jia *et al.*, 2019a); and a third, identifying and understanding the drivers that can enhance a building's intelligence (Buckman, Mayfield and Beck, 2014b; Froufe *et al.*, 2020).

In these studies, there have been various definitions of 'Smart Buildings' proposed, but these definitions differ based on the concept investigated (Kaklauskas *et al.*, 2010; McGlinn *et al.*, 2010; Wang *et al.*, 2012; Bashir and Gill, 2017; Manogaran *et al.*, 2018; Saidi *et al.*, 2018a). The definition either addresses intelligence and sustainability (Wang *et al.*, 2012), smart environment (McGlinn *et al.*, 2010), integrated systems (Saidi *et al.*, 2018a), or Internet of Things implementation within a building (Bashir and Gill, 2017). In addition, Table 2-1 summarises the current smart building definitions:

Table 2-1: Current concepts and definitions of Smart Buildings.

Author	Definition	Themes
(Bashir and Gill, 2017, pp. 153)	*"Smart buildings are buildings equipped and deployed with a lot of IoT sensors which continuously monitor the environment inside the smart building and keep storing this valuable information on a server."*	Internet of Things IoT. Information. Automated monitoring.
(Wang et al., 2012, pp.249)	*"Address both intelligence and sustainability issues by utilising computer and intelligent technologies to achieve the optimal combination of overall comfort level and energy consumption."*	Sustainability. Computer technology. The comfort level and energy consumption.
(McGlinn et al., 2010, pp.15)	*"a subset of smart environments" where smart environments are "able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment."*	Smart environment. Knowledge. Occupant Experience.
(Sinopoli, 2010, pp. 88)	*"Allow information and data about the building's operation to be used by multiple individuals occupying and managing the building".*	Data-sharing. Multi-stakeholders' interaction.

(Buckman, Mayfield and Beck, 2014a, pp.102)	*"Smart Buildings are buildings which integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at the core, in order to meet the drivers for building progression: energy and efficiency, longevity, and comfort and satisfaction. The increased amount of information available from this wider range of sources will allow these systems to become adaptable and enable a Smart Building to prepare itself for context and change overall timescales."*	Integration. Adaptability. Comfort and Satisfaction.
(Marikyan, Papagiannidis and Alamanos, 2019, pp.142)	*"a residence that is equipped with computing and information technology, which responds to the needs of the occupants and provides comfort, convenience, security and entertainment."*	Computer powered. Information Technology. Comfort and convenience.
(Lawrenz et al., 2018, pp.109)	*"for a building to be smart, it needs to be adapted, which refers to a process where the behaviour of an interactive system can be adapted to different users according to the information needed about its users and its environment."*	Adaptability. Interactive systems.

According to a study conducted by (Arditi, Mangano and De Marco, 2015), a smart building is defined as a building that uses advanced automation and integration to monitor, control, and optimize building systems and performance, including heating, ventilation, and air conditioning (HVAC), lighting, security, and other systems. Similarly, in a study by Al Dakheel *et al.*, (2020), a smart building is defined as a building that uses sensors, networks, and automation to optimise building performance, reduce energy consumption, and enhance user comfort.

In addition to the use of sensors, data sharing and integration are also important aspects of a Smart Building, as noted by (Ateeq *et al.*, 2019), who defined a Smart Building as a building that integrates various systems and technologies to enable real-time data exchange and information sharing, leading to enhanced building performance, user comfort, and sustainability.

Furthermore, the definition of a Smart Building also emphasises the importance of creating an environment that is responsive to the changing requirements of occupants, organisations, and society. This idea is consistent with the idea that a Smart Building as a building that uses advanced technologies to adapt to the needs of occupants and stakeholders, improve sustainability, and enhance the building's value (Sinopoli, 2010; Louis and Rashid, 2018; Mammeri and Younus, 2020).

Therefore, in this research, a Smart Building is defined as:

> "a building that is equipped with smart systems which are connected through an information network to create an adapted, integrated environment that is responsive to the changing requirements of occupants, organization, and society."

This definition incorporates the key characteristics of a Smart Building as identified by various researchers and emphasizes the importance of the integration of technologies. The use of technology, such as sensors and automation, allows for the collection and analysis of data that can be used to optimise building performance and enhance user comfort.

However, technology alone is insufficient to create a truly smart building (Pašek and Sojková, 2019), as the involvement of building managers, occupants, and other stakeholders is critical to creating a connected environment (Leonidou *et al.*, 2020). Fan and Xiao (2017) noted that the successful implementation of a smart building requires the engagement and participation of all stakeholders, including building managers, occupants, and other stakeholders.

A study by Ma *et al.*, (2018) found that user acceptance is a critical factor in the success of smart building technologies and that users focused design can help ensure that technology is used to meet the needs and preferences of occupants.

Therefore, to create a truly smart building, it is important to balance the use of technology and data with the occupants' requirements and preferences and to engage all stakeholders in the process. As Fântână and Oae, (2021) noted, "the most successful smart buildings are designed with people in mind and that use technology to create an environment that enhances the well-being of occupants and stakeholders." Therefore, integrating data, technology, and people is crucial to optimising a successful smart building for building performance, user comfort, and sustainability.

2.1.1 Technology in Smart buildings

Smart buildings could be developed and evolved by including and depending on network and sensor technology as an essential part of the building. Bashir and Gill (2017) and Chang et al.(2020) support this view by highlighting the importance of network and sensor technology in developing and evolving smart buildings. Network and sensor technology plays a crucial role in the functionality and efficiency of smart buildings (Louis and Rashid, 2018). This particular part can work as a network to allow information sharing between systems and subsystems of a smart building and its stakeholders (Lawrenz et al., 2018). The network is to meet the drivers for building progression: energy and efficiency, longevity, comfort and satisfaction. Smart buildings integrate and account for intelligence, enterprise, control, materials, and construction as an entire building system based on adaptability rather than reactivity (Wilson, Hargreaves and Hauxwell-Baldwin, 2015). One of the most currently used technologies for data-sharing in buildings is the Internet of Things (IoT) (Mammeri and Younus, 2020). Smart buildings use IoT devices to monitor building characteristics, analyse the data, and generate insights about usage patterns and trends to optimise their environment and operations (Anjana *et al.*, 2019). Connectivity via a network, sensors, and software are all part of these devices. The use of technology can allow users to have greater control over their buildings (Samuel, 2016). IoT systems can connect different components of a building, such as lighting, heating, ventilation, and security, and enable them to communicate with each other. This allows building managers to monitor and control building systems remotely, making optimising energy consumption and improving occupant comfort easier (Akhtar *et al.*, 2018). IoT sensors can also collect data on building performance, providing valuable insights that can be used to identify areas for improvement and optimise maintenance schedules. Overall, IoT systems are increasingly important in constructing, managing, and maintaining modern buildings.

Bashir and Gill (2017) systematically review the literature on IoT-enabled smart buildings. The authors review a total of 63 papers to identify the state-of-the-art and research gaps in this field. The study finds that IoT-enabled smart buildings are gaining popularity due to their ability to improve energy efficiency, reduce costs, and enhance user comfort. Some of the key findings in their study identify the key technology components of IoT-enabled smart buildings, including sensors, actuators, communication protocols, and cloud computing. The authors note that while there are many studies on the technical aspects of smart buildings, there is a need for research on these technologies' social and economic impacts. Other studies comprehensively review the literature on IoT-enabled smart buildings or smart homes, identifying the key components of these technologies, examining their benefits and challenges, and emphasising the need for user participation in the design and implementation (Minoli, Sohraby and Occhiogrosso, 2017; Jia *et al.*, 2019a; Verma *et al.*, 2019).

These studies (Burhan *et al.*, 2018; Jha *et al.*, 2019; Krishnamurthy, Singh and Sriraman, 2019) also identify several challenges and limitations of IoT-enabled smart buildings, including the lack of standards and protocols, data privacy and security concerns, and the need for user education and acceptance**.** Samuel, (2016) and Verma *et al.* (2019) suggest that future research should focus on addressing these challenges to ensure the successful implementation of IoT-enabled smart buildings.

2.1.1.1 Internet of Things (IoT)

Its origins can be traced back to the internet's development and the development of technology over several decades. Connecting devices and enabling them to communicate and share data dates back to the early 1980s when vending machines and Coke machines became the first internet-connected appliances. However, the term "Internet of Things" wasn't coined until the 1990s by British technology pioneer Kevin Ashton (Kramp, van Kranenburg and Lange, 2013). IoT continued to evolve over the following years through advancements in wireless technologies, sensors, and embedded systems. During the 2000s, smartphones and high-speed internet enabled the IoT to gain significant traction, allowing the integration of healthcare, transportation, agriculture, and smart homes. With its vast network of interconnected devices, data analytics, and automation capabilities, the Internet of Things is poised to revolutionise industries, improve efficiency, and enhance our daily lives. Recently, IoT has been one of the critical disruptive technological developments. It is seen as the next era in the Information Technology (IT) sector, which would dominate the field of technology and take it to new heights (Santhi Sri *et al.*, 2016). IoT consists of a wide range of interconnected devices, digital and mechanical machines, and things with unique identifiers (UIDs). These connected things can transfer and share data over a network without demanding human-to-human or human-to-computer communication (Burhan *et al.*, 2018).

2.1.1.1.1 Concepts and Definitions

IoT is defined as the connectivity between the digital and the physical world (Ray, 2018), which explains IoT from a network point of view. Other studies (Liau, Shen and Su, 2006; Perera *et al.*, 2013; Kim and Lee, 2014; Lee and Lee, 2015; Ullah *et al.*, 2017; Hakim, 2018; Tortonesi *et al.*, 2019) viewed IoT as a developing technology that offers a connected network that enables things to share information between each other at any time, ideally by using any connection, any path, and any service. Sniderman *et al.* (2016) defined IoT from a system point of view as a technology that has led to an era of connectivity that assists systems to function in novel, extended ways.

IoT, in turn, opened an opportunity for connected things that can improve serving customers' individual needs (Conti *et al.*, 2018) and collect information to drive the development of more interconnected systems and subsystems (Ng *et al.*, 2015; Maatoug, Belalem and Mahmoudi, 2019). Hence, many things surrounding us today will be connected and a part of the IoT network. With the expansion of this network, which is expected to reach 50 billion connected devices by 2020 through collecting and sharing information (Shih *et al.*, 2016; Burhan *et al.*, 2018). The numerous and diverse potential applications of IoT are introduced into all areas of the daily life of individuals, organisations, and society.

Furthermore, IoT systems are embedded in a building to interconnect the end-users with the conceptual point of collecting, integrating, and acting on data (Tan and Wang, 2010; Casado-Mansilla *et al.*, 2018; Soultatos *et al.*, 2018). Employing IoT as a subsystem in smart buildings allows data-sharing and information flow between building management systems BMS and building stakeholders (Ahvar *et al.*, 2017; Krishnamurthy, Singh and Sriraman, 2019). However, understanding how information flows within an IoT system in a building requires understanding the role of IoT in smart buildings (Jha *et al.*, 2019). This will allow understanding of processes, methods used, stakeholders involved, and components' structures within an IoT framework deployed in Smart Buildings (Sony and Naik, 2020a).

2.1.1.1.2 The role of IoT within smart buildings

Since IoT aims to connect the building components online, it contributes to the system being managed and controlled (Irshad *et al.*, 2020). The deployment of IoT technologies significantly transforms how buildings are managed, controlled and maintained, as well as interactions between different stakeholders, affecting many processes of the building systems. The potential benefits of deploying IoT in such applications are obtained when several challenges regarding the modelling and implementation of such processes are solved to see broader deployments of IoT (Haller and Magerkurth, 2011). IoT allows several components to be connected to form a smart building, such as sensors, actuators, networking, communication, software platforms, HVAC systems, and smart control devices, as shown in Figure 2-1.

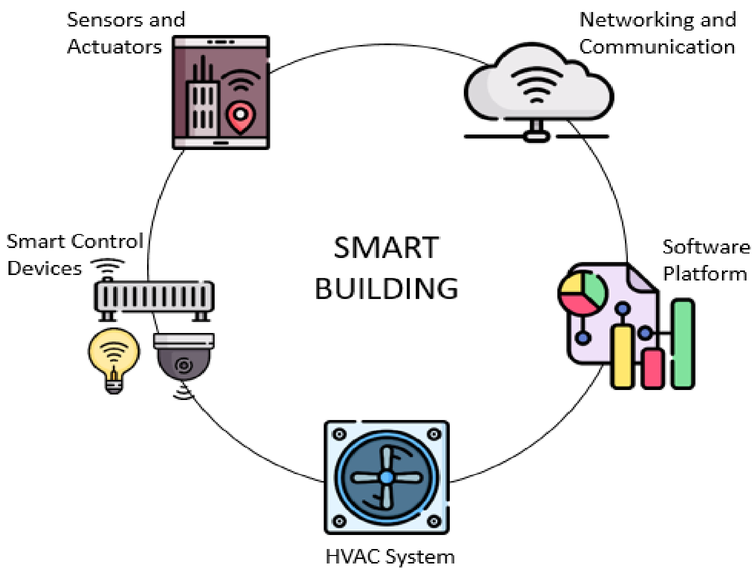


Figure 2-1: The Components of IoT in Smart Buildings.

The IoT processes within a smart building depend on the interconnectivity between the systems and subsystems of the building (Apanaviciene, Vanagas and Fokaides, 2020; Arasteh, Hosseinnezhad and Concepts, 2016). However, interconnected implies that the building systems are functionally or physically integrated (Saidi *et al.*, 2018a). Functional integration refers to the building systems connected to operate in a way that data goes into several processes and sub-processes to achieve a certain objective, which also satisfies the different users' needs (Graven, 2015). On the other hand, physical interconnection refers to the actual physical connections between different building systems, devices, and components that enable them to communicate and exchange information with each other (Uviase and Kotonya, 2018). This includes the wiring, cabling, and networking infrastructure that is used to connect sensors, actuators, controllers, and other devices in a building (Clements-Croome, 2013). One of the primary motivations for the present research is to gain a deeper understanding of the processes and mechanisms by which IoT systems are functionally integrated within building systems and subsystems (Kim *et al.*, 2022). The investigation seeks to identify and analyse the various components and elements of these systems, their interdependencies, and how they interact and interoperate to achieve specific objectives (Prokhorov, Pronchakov and Fedorovich, 2020). However, most of the research is more concerned about how these systems are physically interconnected rather than looking into the processes of how a system can work, which does not support the means for providing a smart building system that includes all the different people and components needed for the view (Garzone, Guermouche and Monteil, 2018).

As noted by Minoli, Sohraby and Occhiogrosso, (2017), the integration of IoT technology as a subsystem in smart buildings enables the sharing of data and information flow between building management systems (BMS) and stakeholders. However, comprehending the intricacies of information flow within an IoT system in a building necessitates a thorough understanding of the IoT frameworks applied in smart buildings. Such an understanding is crucial for identifying the processes and mechanisms involved in functional integration, data sharing, and stakeholder engagement within IoT systems in smart buildings (Minoli, Sohraby and Occhiogrosso, 2017). Also, understand processes, methods used, stakeholders involved and the structure of components within an IoT framework (Panteli, Kylili and Fokaides, 2020), which are explained in Chapter 4. Some studies have attempted to use the Open Systems Interconnection (OSI) model to understand the frameworks' components, establish the framework's layout, and implement the layout of their proposed IoT frameworks (Simoneau, 2006; Bora *et al.*, 2014). These studies leveraged the layered structure of the OSI model to model their IoT framework. Based on a number of authors who suggested the approach, such as (Saxena, 2013; Bora *et al.*, 2014; Mensa, 2014), IoT could have been applied without any further architectural modelling based on the OSI model. Adapting a similar approach, the OSI model was used to review IoT frameworks to again insights about the components, layout, and processes. Appendix 1, 10.1 shows how the OSI model supports networks and how hardware and software components work together, separating networks into small pieces that can assist in troubleshooting, and gives a better definition for the terms that networking professionals use by comparing the basic functional relationships or different network, aids users to understand new trends of technology as they develop, and helps in interpreting vendors explanations of product functionality.

However, several limitations when using OSI to analyse IoT frameworks were observed, as the OSI model does not consider the specific requirements and constraints of IoT frameworks in smart buildings. IoT frameworks in smart buildings require specific protocols and standards that are tailored to the unique features and characteristics of these environments, such as the types of sensors and devices used, the communication channels available, and the data processing and analysis requirements (Fayyaz, Rehman and Abbas, 2019). Therefore, there was a need to find another method that could be used to understand the information sharing and component that makes up an IoT framework in smart buildings. Weyrich and Ebert (2016) say that the OSI model gives a detailed view of the IoT's information technology aspects (Appendix 1, 10.1).

2.1.1.1.3 IoT Frameworks within Smart Buildings

IoT framework offers a structured approach to embedding IoT elements within Smart Building (Ammar, Russello and Crispo, 2018a). The structure consists of rules, protocols, and regulations that systemise data processing and exchange information between involved parties, such as smart devices and stakeholders (Ramprasad *et al.*, 2018). Frameworks are used to support the high-level implementation of IoT applications. Several studies proposed IoT frameworks for smart buildings, as shown in Table 2. These IoT frameworks discussed the data infrastructure of IoT and the benefits of IoT (Drummond and Alves, 2013; Zhu *et al.*, 2017; Ramprasad *et al.*, 2018; Sava *et al.*, 2018; Le, Le Tuan and Dang Tuan, 2019) energy systems, for example (Carrillo *et al.*, 2015; Hu *et al.*, 2018; Liu *et al.*, 2019) and security systems, for example, (Ahvar *et al.*, 2017).

Table 2-2 summarises the focus of most of the included studies and what they proposed:

Table 2-2 Current Studies of IoT Frameworks Within Smart Buildings.

Author	Study focus	Limitations
(Rehman, Ullah and Kim, 2019)	The study proposes a framework for controlling different peripherals in smart buildings and providing real-time feedback to end users in order to address the lack of communication between devices and end users.	There is a lack of details on the specific technology or framework proposed for controlling peripherals in smart buildings. It may not address the interoperability and data security challenges that can arise in IoT-based smart buildings.
(Zhang, Wei and Cheng, 2020)	In this study, a WiFi-based activity recognition framework was proposed in order to provide accurate activity recognition services that are timely and energy efficient.	Limited information on the actual accuracy and energy efficiency achieved by the proposed WiFi-based activity recognition framework. The study may not account for real-world challenges, such as signal interference and device compatibility issues with WiFi.
(Clements-Croome *et al.*, 2018)	Based on IoT, a plug-and-play building thermal learning framework was developed. By using historical operating data, this framework was able to learn the properties of a building directly without human intervention.	The study mentions learning the properties of buildings from historical data, but it may not discuss the potential limitations of this approach, such as the need for diverse data sources and the accuracy of predictions.
(Le, Le Tuan and Dang Tuan, 2019)	This study was conducted to investigate whether IoT-enabled management is lacking within an IoT system, as well as the involvement of various parties within the system. As a possible solution to the problem, the author proposed a conceptual model to enhance the joint operation of the entire IoT ecosystem.	The description doesn't provide details on the specific IoT-enabled management issues or the conceptual model proposed. It may not offer a comprehensive analysis of the involvement of various parties in IoT systems.
(Liu *et al.*, 2019)	The study examined the problem of a lack of integration between smart electric grids, heat and gas supply grids,	Lack of information on the specific challenges faced in integrating smart electric grids, heat, and gas supply grids.

	and network traffic in order to provide unified energy management for smart buildings. In this study, a software model of an IoT-based energy management system was developed using intelligent edge computing.	The study may not thoroughly address the practicality of implementing an IoT-based energy management system with intelligent edge computing.
(Kim *et al.*, 2019)	Spinal Codes (Perry et al., 2012) was used to develop a new compiler-runtime framework for near-user computation that automatically partitions an original cloud-centric program into distributed sub-programs.	It's unclear how Spinal Codes were used to develop the compiler-runtime framework, and the description lacks details on the effectiveness of this approach. The scalability and applicability of the framework to different cloud-centric programs may not be discussed.
(Ateeq *et al.*, 2019)	According to this study, a solution was proposed for improving reliability in IoT and WSN applications as well as reducing energy consumption.	The description doesn't provide specific details on the proposed solution for improving reliability in IoT and WSN applications. It may not address the trade-offs between reliability and energy consumption in IoT systems.
(Fayyaz, Rehman and Abbas, 2019)	A framework for smart building was proposed in this study that integrates cloud infrastructure with a middle layer of fog infrastructure.	Limited information on how cloud and fog infrastructure integration was achieved in the proposed smart building framework. The study may not thoroughly discuss the challenges and trade-offs associated with cloud-fog integration.
(Krishnamurthy, Singh and Sriraman, 2019)	This study explains how optimising BMS configurations offers an additional 10% energy savings opportunity via a hybrid cloud on-premises model.	It mentions the potential for energy savings but lacks specifics on how BMS configurations are optimised. The study may not explore potential obstacles to implementing a hybrid cloud on-premises model.
(Raghavan *et al.*, 2020)	This study suggests using an API-based cloud architecture. It developed a data sharing and integration model to overcome technical limitations in the cross-domain integration of smart building data.	While it proposes an API-based cloud architecture, the description doesn't provide details on the model for data sharing and integration. It may not discuss the practical challenges of implementing cross-domain integration of smart building data.

(Drummond and Alves, 2013)	The study investigates building systems and the lack of inter-system connectivity to the larger networks of IoT devices. The study proposed a framework in order to enable the utilisation of the data processed in separate building systems for new IoT use cases. This framework's main concern is integrating IoT and BIM data standards together.	The study focuses on proposing a framework for integrating IoT and BIM data standards, but it may not delve into the practical challenges and complexities of implementing such integration. It may not provide specific examples or use cases where the proposed framework has been applied successfully.
(Benson *et al.*, 2018)	The study investigates the importance of real-time event detection in case of fire incidents within a smart environment. The paper proposed an integration middleware which combines smart space IoT data and infrastructure with programmable network infrastructure and specific applications.	While it emphasizes the importance of real-time event detection in fire incidents, it might not discuss the challenges and limitations of implementing real-time monitoring systems in smart environments. The paper may not provide a detailed evaluation of the proposed integration middleware.
(Garzone, Guermouche and Monteil, 2018)	The study claims that it is challenging to create and manage a dynamic, diverse IoT infrastructure that consists of a number of mobile and resource-limited devices. Therefore, an automatic management approach based on semantics was proposed as a solution for service-oriented IoT systems.	The study suggests an automatic management approach based on semantics for service-oriented IoT systems, but it may not thoroughly discuss the practicality and scalability of implementing such a system. The effectiveness of the proposed approach in managing diverse IoT infrastructure may not be fully explored.
(Sava *et al.*, 2018)	This study aimed to investigate the lack of real-time data and the connection between real-time and virtual building problems. IoT and BIM can be incorporated into the design phase with easy access to information through IoT devices and protocols, enabling building operations to use efficient energy modes or avoid inefficient energy modes.	While the study addresses the integration of IoT and BIM for efficient building operations, it may not discuss potential challenges or obstacles faced during the integration process. The study may not provide concrete examples of how the integration of IoT and BIM has been applied in real-world scenarios.

(Koh *et al.*, 2018)	In the study, it is concluded that buildings' legacy systems lack a common information model that enables different systems to integrate the data of each other. A long-term goal of the paper was to combine and navigate diverse sensory data.	The study highlights the lack of a common information model in legacy building systems, but it may not offer specific solutions for overcoming this challenge. The long-term goal of combining and navigating diverse sensory data may not include practical implementation strategies.
(Khalil, Esseghir and Merghem-Boulahia, 2020)	An IoT-based system utilising machine learning was introduced in the study in order to predict the thermal comfort inside buildings. A low-cost analysis is implemented in the proposed system in order to determine the parameters that should be fed into the proposed model.	While it introduces an IoT-based system for predicting thermal comfort, it might not thoroughly discuss the accuracy and reliability of the machine learning model used. The study may not provide detailed insights into the low-cost analysis and the parameters considered for thermal comfort prediction.
(Soultatos *et al.*, 2018)	A framework for securing, protecting, relying on, and interoperating with the Internet of Things (IoT) was proposed in this study. Through the use of the underlying IoT infrastructure, the proposed framework can provide smart functionality requirements and modelling and administration capabilities that can guarantee the SPDI properties.	Although it proposes a framework for securing and protecting IoT, it may not address specific challenges related to real-world security threats and attacks. The study might not provide practical implementation guidelines for guaranteeing SPDI (Security, Privacy, Data Integrity) properties.
(Pacheco and Hariri, 2016)	This paper proposes a framework for developing a general threat model that detects and minimises cyber-attacks on the Internet of Things.	While it proposes a framework for detecting and minimizing cyber-attacks on IoT, it may not explore the evolving nature of cyber threats and challenges in keeping up with new attack vectors. The study may not discuss the potential resource requirements for implementing the proposed threat model.

(Carrillo *et al.*, 2015)	This study addresses the problem of the lack of use of computational power in smart buildings. The paper proposes a cloud computing framework to provide computational power for interconnected automotive technology within and between smart buildings.	The study addresses the lack of computational power in smart buildings but may not provide specific details on the feasibility and scalability of implementing a cloud computing framework for this purpose. It may not discuss potential challenges in adopting cloud computing in smart building environments.
(Bellagente *et al.*, 2015)	This study finds that there is a lack of information management based on the behaviour of customers of smart buildings to monitor and supervise energy management systems distribution.	While it identifies a lack of information management based on customer behaviour, it may not provide concrete strategies for implementing behaviour-based monitoring and supervision of energy management systems. The study might not discuss the practicality and challenges of obtaining and utilizing customer behaviour data in smart buildings.
(Hernández-Ramos *et al*,. 2015)	This study investigated the problem of privacy and security concerns, which are not properly addressed within an IoT ecosystem. He proposed a framework to address privacy and security concerns that threaten an IoT ecosystem.	The study proposes a framework for addressing privacy and security concerns in IoT ecosystems but may not provide specific solutions for mitigating these concerns. It may not thoroughly analyze IoT privacy and security's legal and regulatory aspects.

Despite these studies proposing IoT frameworks, their focus has been on understanding the technical aspects that can be utilised to facilitate information sharing. Although technology plays a critical role in enabling communication and information sharing within smart buildings, it is important to take into account human and organizational factors as these influence the adoption and implementation of these frameworks (Li *et al.*, 2021). Hence, focusing on the processes, stakeholders' engagement, and information sharing would provide more context on the application of these frameworks within the Smart Buildings (Watson *et al.*, 2018; Leonidou *et al.*, 2020). A detailed understanding of how IoT frameworks work would improve information sharing and communication among systems and stakeholders to achieve smart buildings' goals (Omar, 2018). It will also provide a mechanism to assess the framework's effectiveness, identify potential barriers to adoption and implementation, and develop strategies to overcome them.

Chapter 4 offers the outcome of the systematic literature analysis evaluating IoT frameworks within smart buildings, resulting in identifying gaps in currently used IoT frameworks, such as interoperability, incorporating different stakeholders, and standardisation of a general framework structure of IoT. Additionally, the analysis explores the complexities and values of studies of IoT frameworks within smart buildings, which was important to establish the current issues with exiting IoT frameworks with the specific application to smart buildings. As explained in Chapter 4, understanding how information is shared within smart buildings can help identify potential blocks or barriers to effective communication and collaboration among stakeholders. Furthermore, information sharing can be used to develop strategies and models to improve and promote more effective information sharing within smart buildings. Smart buildings rely on a range of interconnected systems to efficiently and effectively manage the building's operations.

2.1.2 Systems and Processes of Smart Buildings

In the modern era, buildings contain a number of complex systems (electrical systems, plumbing systems, mechanical systems, and structural systems) and subsystems, such as cooling and heating systems, lighting and control systems, and ventilation systems (Capozzoli, Lauro and Khan, 2015). These systems are embedded in the building environment as the driving force to reach different objectives, such as energy efficiency and user experience. The integration of these systems and their processes is key to the functioning of smart buildings (Saidi *et al.*, 2018b). This section aims to explore the various systems and processes that make up smart buildings, their roles in achieving sustainability, and their impact on stakeholders.

According to (Le, Le Tuan and Dang Tuan, 2019), Smart building systems work together to enhance building performance and efficiency while providing occupants with a comfortable and safe environment. For example, the HVAC system is an essential component of smart buildings, as it plays a crucial role in regulating indoor air quality and temperature (Zhang *et al.*, 2020). HVAC systems in smart buildings are designed to optimise energy consumption and reduce carbon emissions by incorporating features such as occupancy sensors and temperature control systems (Fazenda *et al.*, 2014; Fan *et al.*, 2020).

Lighting systems in smart buildings are also designed to be energy-efficient and promote occupant well-being. Smart lighting systems use sensors to detect occupancy, natural light levels, and other environmental factors to adjust the lighting accordingly (Whitmore, Agarwal and Da Xu, 2015). This not only reduces energy consumption but also promotes occupant comfort and productivity. Smart buildings' security and fire safety systems also incorporate technology to enhance safety and security while minimising false alarms. Hence, smart buildings also rely on various processes to optimise their performance and sustainability. The automation of those processes enables the integration and automation of various systems within the building. Building automation systems use sensors, controllers, and software to control and monitor building operations, including HVAC, lighting, security, and other systems. This allows for real-time monitoring and control of building operations, reducing energy consumption and improving building performance (Bonetto Jr, 2018).

Another critical key element in smart buildings is data analytics, which involves collecting and analysing data from various building systems and processes to identify patterns and optimise building performance. Data analytics can be used to identify areas of high energy consumption, detect equipment malfunctions, and predict equipment failures, allowing for proactive maintenance and repair (Berat Sezer *et al.*, 2016; Bashir and Gill, 2017). This improves building performance and reduces operational costs and downtime (Jia *et al.*, 2018, 2019a).

Smart building systems and processes significantly impact building sustainability and stakeholders' well-being. For example, smart buildings contribute to global sustainability goals by optimising energy consumption and reducing carbon emissions. Additionally, smart buildings improve occupant well-being by providing a comfortable and safe environment, promoting productivity, and reducing stress and health risks associated with poor indoor air quality (Hietaharju, Ruusunen and Leivisk, 2018; Liu, Zhang and Wang, 2020). In addition, the integration of various systems by identifying streamlined processes is key to the functioning of smart buildings, optimising energy consumption and reducing carbon emissions while promoting occupant comfort and safety (Shen *et al.*, 2010; Uviase and Kotonya, 2018; Apanaviciene, Vanagas and Fokaides, 2020). As the demand for sustainable building design continues to grow, the systems and processes of smart buildings will play an increasingly critical role in achieving these goals (Akadiri, Chinyio and Olomolaiye, 2012; Herazo and Lizarralde, 2016).

The development of information and communication technology systems aids users with possibilities to create new smart services to assist them in the user-driven innovation process and, more importantly, introduce adaptive, integrated systems to the building industry. Nowadays, buildings consist of several systems, such as structural, mechanical, electrical, and plumbing systems. Each system consists of several subsystems, such as a lighting control system and a security and alarm system, which fall under the electrical systems (Panteli, Kylili and Fokaides, 2020).

2.1.2.1 Buildings As Systems

It is important to understand what a system means to be able to look at a building from a system point of view. Nowadays, buildings are becoming more complex as they consist of a number of systems and sub-systems, such as cooling and heating systems, lighting and control systems, and ventilation systems (Zhang *et al.*, 2020). The term system was initially explained and proposed by Von Bertalaffy (1956) as "a complex of interacting elements", which does not vary from the definitions given by researchers nowadays. From the literature, the distinctive perspectives on systems can be incorporated within a building as an example of an environment that consists of interacting elements working together to achieve a particular objective, which, to a certain extent, transforms it into a system (Christiansson *et al.*, 2011; Buckman, Mayfield and Beck, 2014a; Clements-Croome *et al.*, 2018). These systems are embedded in the building environment as the driving force to reach different objectives. These objectives can be understood by breaking the building into systems and subsystems to satisfy the altering needs of building stakeholders who have distinctive requirements for building systems. Based on a report by (Menassa and Baer, 2014; Kejriwal and Mahajan, 2016), a building is broken down into three main categories of building systems according to their functional plan (Operational efficiency, Occupant experience, Security and safety). However, each category is a mixed output containing information data and processes within systems and subsystems. Christiansson *et al.*, (2011) gave a more comprehensive example for viewing a building as a system, which can be seen from two perspectives (Functional Building Systems, FBS, and Component Building Systems, CBS). Functional building systems refer to building management systems (BMS) or building automation systems (BAS). These systems are computer-based systems installed in a building to control and monitor the mechanical, electrical and plumbing, such as lighting, power system, ventilation, fire system, and security systems (Ettler *et al.*, 2015). On the other hand, CBS refer to the design aspect of the building that consists of the structural building components. Structural building products are usually designed, engineered and manufactured under measured settings for a specific application and are incorporated into the structural building system by the designer (Žigart *et al.*, 2018).

Furthermore, Krishnamurthy, Singh and Sriraman, (2019) claim that smart BMS can identify, describe, decide or assist in making decisions based on available information and, by that, carrying out smart actions through highly developed interfaces between subsystems and end-users. Smart devices and sensors thus provide solutions to help gain the immediate benefits of integrating technologies and systems for a more connected environment. As a result, they are providing both challenges and opportunities to the smart building and facility management industry (Bombieri *et al.*, 2015).

Recently, there has been rapid development within the hardware standards (Ammar, Russello and Crispo, 2018a). Every developed technology has evolved to include software that enables interactivity with other hardware or software (Marinakis and Doukas, 2018). It has been revealed that this technology improves building systems' value (Eckelman *et al.*, 2018). Also, people are now beginning to deploy this technology for a wide variety of systems, for example, through monitoring older people or people with disabilities using this technology to stay in their own homes and ensure their safety (Vijayan *et al.*, 2020). Smart buildings tend not to be deployed as finished products because they are self-learning technology that can be retrofitted into different facility systems as new innovations are released (Lowe, Chiu and Oreszczyn, 2018; Al Dakheel *et al.*, 2020). There are several drivers for such behaviour, including technology, integration, and flexibility, among others, and it is always accompanied by the word "smart", which encompasses a set of factors that explain and justify the performance of buildings' systems (Buckman, Mayfield and Beck, 2014a). Drivers such as sustainability, energy, security, health and technology (Lima *et al.*, 2020) are also present in smart buildings, addressing common features and specific attributes. Examples of particular drivers are those that emphasize longevity, energy and efficiency (Darby, 2018; Omar, 2018; Zhang, Wei and Cheng, 2020); system integration regarding the improvement of building's operational performance and collaborative work (Baghchesaraei and Baghchesaraei, 2016; Shih *et al.*, 2016; Clements-Croome *et al.*, 2018); interaction and flexibility; security, comfort and health (Balta-Ozkan, Boteler and Amerighi, 2014); and the use of advanced systems of building technology (Sinopoli, 2010). The use of these systems requires a number of processes to deal with data within the building environment.

Smart buildings incorporate various features that promote occupant well-being and comfort, such as adjustable lighting, temperature, and air quality control (Obrecht *et al.*, 2019). Additionally, occupants can engage with building systems and processes through interfaces such as mobile apps, touchscreens, and voice assistants, allowing for real-time feedback and control. This enhances occupant comfort and promotes energy conservation by encouraging occupants to adjust their behaviours and habits (Kim, Schiavon and Brager, 2018). Stakeholders' engagement is also a critical process in smart buildings (Ståhlbröst, Bergvall-Kåreborn and Eriksson, 2015). Therefore, in order to ensure the successful implementation and operation of smart buildings, it is important to identify and engage with the various stakeholders involved in the process, as explained in Section 2.1.3.

2.1.3 Stakeholders of Smart Buildings

According to Menassa and Baer, (2014), stakeholders in smart buildings are more complex compared to those in most other industries due to the complexity of smart building systems and technologies. The long lifespan of smart buildings and their impact on the environment and economy also make it relevant to a wide range of stakeholders. Furthermore, a recent study by Herazo and Lizarralde, (2016) highlights the importance of stakeholder engagement in achieving sustainable practices in smart buildings. The study emphasises the need for collaboration among stakeholders to adopt smart building standards and promote sustainable supply chain practices. Ahmed, Alnaaj and Saboor, (2020) and Fok *et al.*, (2011) argue that engaging stakeholders is crucial in the smart building industry to achieve sustainability goals, and recent research highlights the importance of collaborative efforts among stakeholders to achieve sustainable practices. Feige, Wallbaum and Krank, (2011) provide valuable insights into the challenges and opportunities in promoting smart building practices and highlight stakeholder motivation's importance in achieving sustainability goals in the building sector.

Based on the literature review, the stakeholders of a smart building are the individuals, groups, or organisations interested in the building's design, construction, operation, or outcomes (Shabha, 2006). The stakeholders of a smart building can be categorised into three main groups: owners and investors, building occupants, and the wider community.

2.1.3.1 Owners and Investors

Owners and investors are the primary stakeholders in any building project, and smart buildings are no exception (Haddadi *et al.*, 2016). Owners and investors are responsible for funding the smart building project and ensuring that it is completed on time and within budget (Greenwood and Kassem, 2016). They are interested in smart building technology because it can improve the building's overall value, reduce operational costs, and increase energy efficiency, which can lead to higher rental and resale values (Zhang *et al.*, 2018).

Smart building technology can also enhance the building's safety and security (Liu, Zhang and Wang, 2020), which is another key concern for owners and investors. Smart building technology can monitor access points, detect potential hazards, and provide real-time alerts in the event of an emergency. This can reduce liability risk and enhance the building's reputation, making it a more attractive investment opportunity.

Generally, the term "Building Owner" refers to the board of managers, board of directors, homeowners' association, or other representative body of a jointly owned building with authority to make decisions regarding building assessments and alterations (Greenwood and Kassem, 2016). Moreover, owners of non-residential buildings or agents authorized to act on behalf of owners of non-residential buildings are considered building owners (Froufe *et al.*, 2020). The term building owner may also be used to refer to the registered owner of a multi-unit residential building or to the owner's designate (e.g., the property manager) in charge of a multi-unit building. According to Sinopoli (2010), several building owners find the concept of smart buildings to be both persuasive and intuitive. There is, however, a struggle with moving from the concept to actual implementation. The persuasive nature of smart buildings can be attributed to their ability to improve energy efficiency, reduce operational costs, and improve occupant comfort and safety (Yun and Won, 2012). Building owners see the value of providing their tenants with a seamless experience by creating a connected and responsive environment. However, despite smart buildings' persuasive nature and intuitive appeal, there are challenges in moving from the concept to actual implementation. A significant obstacle is the difficulty of integrating diverse systems and technologies into existing buildings (Pacheco *et al.*, 2018).

Incorporating smart features into traditional buildings can be challenging, requiring careful planning, coordination, and substantial investments.

Furthermore, different systems, protocols, and devices from different manufacturers may present technical barriers and compatibility issues (Balta-Ozkan, Boteler and Amerighi, 2014). Also, when implementing different components, ensuring interoperability and seamless communication can be challenging (Robert *et al.*, 2017). Additionally, building owners may encounter resistance or hesitancy from occupants and stakeholders who are unfamiliar with or resistant to change (Li *et al.*, 2021). To gain support for smart building initiatives, addressing privacy and security concerns and potential impacts on occupant comfort and control is critical. It is also important to consider financial considerations when implementing IoT-enabled buildings. Smart building technologies and infrastructure retrofit can have substantial upfront costs (Al Dakheel *et al.*, 2020). Building owners must carefully evaluate the return on investment and the long-term benefits to justify the initial expenses.

2.1.3.2 Building Occupants

The term "Occupant of the Building" refers to any tenant or affiliate of such tenant occupying any portion of the premises within the building and a subtenant of such tenant or affiliate (Omar, 2018). The large interest of building occupants in smart buildings is due to their ability to meet their expectations and needs in terms of comfort, health, safety, and satisfaction (Baghchesaraei and Baghchesaraei, 2016; Ghaffarianhoseini *et al.*, 2016) in both their workplaces and in their homes.

Another study by Jia *et al.*, (2018) highlights that building occupants are another important group of stakeholders in smart buildings. They are the people who will be living or working in the building and have a vested interest in the building's design, functionality, and overall environment. Smart building technology can improve the quality of life for building occupants by creating a more comfortable and efficient living or working environment (Nuutinen *et al.*, 2022).

For example, smart building technology can adjust the lighting, heating, and cooling systems in response to occupancy levels, weather conditions, and other factors, creating a more comfortable and energy-efficient space. Smart building technology can also provide building occupants with real-time feedback on their energy usage, allowing them to make informed decisions about reducing their energy consumption and saving money on utility bills.

Building occupants are also interested in smart building technology because it can improve their safety and security (Alam, Chowdhury and Noll, 2011). Smart building technology can provide access control systems that use biometric data or smart cards to ensure that only authorised individuals can enter the building or certain areas within it (Soultatos *et al.*, 2018). Smart building technology can also provide emergency notification systems that can alert building occupants in the event of a fire, natural disaster, or another emergency.

2.1.3.3 Facility manager and estate department team

Facility managers are responsible for the daily operation and maintenance of the building, including ensuring that all systems are functioning properly and responding to any issues or emergencies that arise (Pašek and Sojková, 2019). Smart building technology can help facility managers manage building operations, reduce downtime, and increase productivity (Greenwood and Kassem, 2016) more efficiently. For example, smart building technology can provide real-time data on energy consumption, HVAC system performance, and occupancy levels, allowing facility managers to identify and address issues more quickly (Wang, Ali and Au-Yong, 2022). Smart building technology can also automate routine tasks, such as lighting and HVAC system adjustments, freeing up facility managers to focus on more strategic initiatives. Barret and Baldry (2003) described the role of facility management as an integrated approach to operating, adopting, maintaining, and enhancing the performance of buildings and infrastructure facilities. FM is considered a multi-skilled profession that optimises the built environment's performance and supports the building's core activities (Haddadi *et al.*, 2016). FM has operational functions, as well as real-estate, finance, management contract and procurement, and health and safety functions.

On the other hand, the estate department team is responsible for managing the physical assets of the building, including its design, construction, and ongoing maintenance (Kassem *et al.*, 2015). Smart building technology can help the estate department team to design and construct more efficient and sustainable buildings, reducing the overall cost of ownership and improving the building's long-term value. For example, smart building technology can provide data on building performance, allowing the estate department team to identify areas where improvements can be made to reduce energy consumption and optimise operations (Al Dakheel *et al.*, 2020). Smart buildings can also provide real-time data on building occupancy and usage patterns, allowing the estate department team to make informed decisions about building design and layout. In addition, according to (Greenwood and Kassem, 2016), facility managers and the estate department team are critical stakeholders in smart buildings. Smart building technology can help these teams more efficiently manage building operations, reduce downtime, and increase productivity while enabling the estate department team to design and construct more efficient and sustainable buildings.

In conclusion, the building's impact on the environment, local economy, and community health and well-being are all also important considerations for the wider community, and the building-keeping and security teams are two groups that should be considered in smart buildings.

All stakeholders play an important role in the design, construction, and management of smart buildings, with their decisions and actions having a significant impact on the performance of the building and the utilisation of the building. As such, it is important for stakeholders to work together to ensure that smart building projects are designed, implemented, and operated in a way that benefits everyone involved. In addition, the ability to share information between different systems and devices is one of the key features of smart buildings (Hernández-Ramos *et al.*, 2015; Chinchero, Alonso and Ortiz T, 2020; Panteli, Kylili and Fokaides, 2020).

2.1.4 Contextualizing the Process Connectivity in Smart Buildings

Smart buildings employ technologies, open communication standards, and data analytics to improve building performance, reduce energy consumption, and improve occupant comfort. Various building systems, as well as long-term analysis and planning, are monitored and controlled in real-time.

The technology of smart buildings is continuously evolving, with new sensors, devices, and communication protocols being developed to improve efficiency and functionality. The data of smart buildings provides insights into building performance and stakeholders' requirements. Figure 2-2 highlights the complexity of smart buildings (Jha *et al.*, 2019) and their technology, people, processes, and data components. This sophisticated connection between all these components in a smart building requires carefully considering how all the parts communicate. Also, any attempts at integration should focus on all parts of the system, as there is limited knowledge regarding the consideration of both elements (technical and social) in the system's processes (Kassem *et al.*, 2015). Therefore, by adopting a social-technical systems lens to explore the complex dynamics of a smart building, both technical and social aspects are taken into account (Lowe, Chiu and Oreszczyn, 2018).

2.2 Socio-Technical Systems

In 1960, Emery and Trist proposed that socio-technical systems are composed of human, machine, organizational structure, and work system interactions (Baxter 2011). In the late

1950s, despite the advent of new technology and increased mechanization during the post-war reconstruction, an STS was identified in which productivity did not increase, and the organisation's performance did not improve (Avis, 2018). Since the acceptance of STS has been increasing, the theory and philosophy behind it have been proven practical and relevant, contributing to the evolution of STS thinking and practice (Davis *et al.*, 2014).

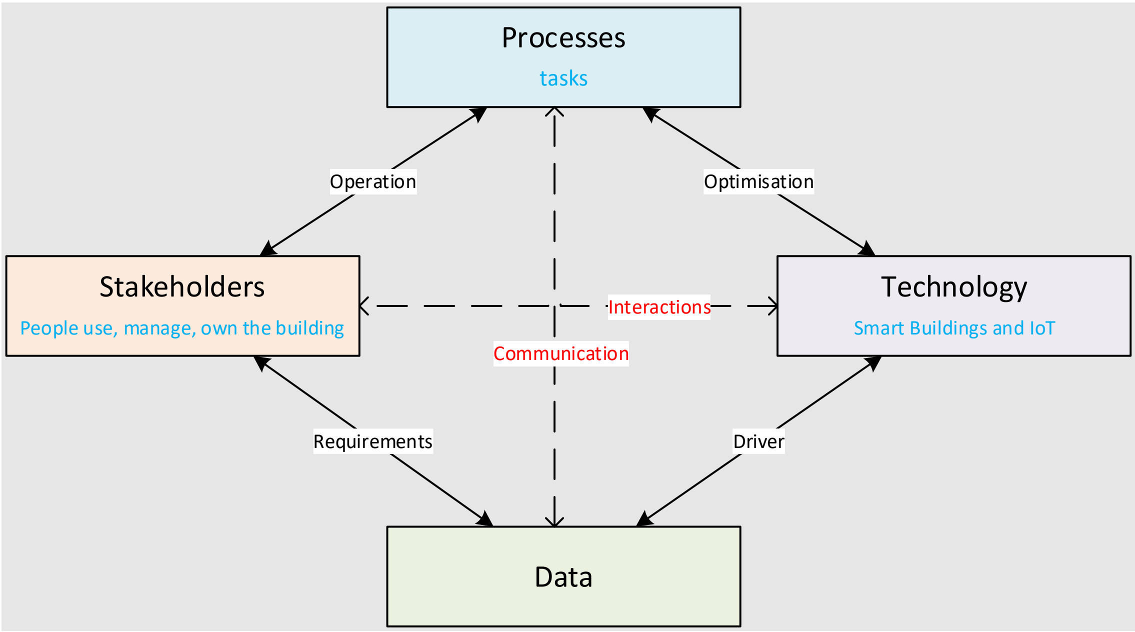


Figure 2-2: Summary Framework for Smart Buildings and Its Interactions

Socio-technical systems (STS) consist of complex interactions between social humans, technical systems, and the environment of a working system (Baxter and Sommerville, 2011). STS guided system designers regarding the potential roles of users in creating new systems. It developed a deeper understanding of how new technologies can be incorporated into existing social systems (Baxter and Sommerville, 2011). The socio-technical framework is useful for understanding the complex interplay between technology and social factors in the design and implementation of smart buildings. According to Avis, (2018), the socio-technical system perspective suggests that changes in organisational structure, roles and responsibilities, and work practices should accompany technological changes. This means that it is important to consider not only the technical aspects of the system but also the social, organisational, and cultural factors that influence its use and adoption to realise the full potential of smart building. A key element of the socio-technical systems is the concept of "joint optimisation" (Malatji, Von Solms and Marnewick, 2019). This refers to the idea that a system's technical and social aspects should be designed and implemented together rather than separately. In the context of smart buildings, this means that the design of the building's physical infrastructure should be integrated with the design of the building's digital systems and the social practices of its users. Another important aspect of the socio-technical systems is the idea of "boundary spanning" (Aldrich and Herker, 1977), which refers to the ability of individuals and groups to bridge the gaps between different parts of the system. In the context of smart buildings, it is important to have individuals or groups responsible for facilitating communication and collaboration between the building's technical and non-technical stakeholders.

Therefore, the socio-technical framework provides a useful lens to understand the complex and multifaceted nature of smart buildings and identify strategies for designing and implementing these systems to maximise their benefits for both stakeholders and organisations (Sony and Naik, 2020a).

2.2.1 Existing work of STS in Smart Buildings

It is generally acknowledged that in order for smart buildings to share information between stakeholders, the social and technical elements must be considered in tandem. Sony and Naik, (2020) propose an architecture for vertical, horizontal, and end-to-end integration that is informed by socio-technical systems theory. Additionally, the meta-integration should revolve around this framework, allowing individual management and decision-making issues to be addressed within vertical, horizontal, and end-to-end integration. It is important to note that Sony and Naik, (2020) have developed a generic framework that may be applied to any industry or organization in their study. Tangible, sustainable benefits could be attained by incorporating the principles of socio-technical systems theory while designing the integration architecture. As a result of the guiding framework proposed by Sony and Naik, (2020), it will be possible to design integration strategies and implement smart buildings. One of the major limitations of their study is that they are focused on the theoretical approach rather than intended and unintended interactions between the elements of their frameworks. As a result, a better design of interactions of those elements in the framework anticipates that smart buildings will contribute to increased integrations between systems within their environment (Buer *et al.*, 2018). Buer et al (2018) proposed a multi-sectoral study and comparison, which was conducted to categorise the relationships between the elements of STS. Therefore, investigating whether existing socio-technical design principles can be applied to smart buildings is beneficial to link all parts of the system together. Hence, from a social perspective, sharing data and information is crucial to smart building, which supports long-term analysis and planning, facilitates real-time monitoring and control, and facilitates interoperability between different systems. As a result, all parts of the system and concerns must be addressed at all levels of stakeholders and for everyone involved.

2.2.2 Information Sharing in Smart Buildings

Technology advancements and the need for energy-efficient buildings have contributed to the popularity of smart buildings. A smart building uses sensors, devices, and systems to monitor and control various aspects of the building, such as lighting, temperature, security, and energy usage (Khalil, Esseghir and Merghem-Boulahia, 2020). Building performance can be optimized, energy consumption can be reduced, and occupant comfort can be enhanced with the data collected from these systems (Alrashed, 2020). By combining data from various sources, a complete picture of a building's operations can be provided. For example, occupancy sensors can be used to optimize HVAC and lighting systems, while energy meters can be used to optimize energy consumption (Pourzolfaghar, Mcdonnell and Helfert, 2017; Drisko, 2020). From a technical point of view, various communication protocols, such as Wi-Fi, Bluetooth, and ZigBee, facilitate the sharing of information in smart buildings (Palattella *et al.*, 2016; Jha *et al.*, 2019). Using these protocols, devices and systems can communicate wirelessly, enabling real-time monitoring and control. Interoperability between systems, devices, and manufacturers is also enhanced through the use of open communication standards, which facilitates a seamless, integrated approach to building management (Verma *et al.*, 2019).

Data collected from smart building systems can be used for long-term analysis and planning as well as real-time monitoring and control (Pacheco, Benitez and Pan, 2019; Vijayan *et al.*, 2020). For example, by analysing energy usage data, it is possible to identify trends and patterns that can be used to develop strategies for reducing energy consumption and improving efficiency (Al-Shammari *et al.*, 2020). However, with the sharing of information comes concerns about data privacy and security (Verma *et al.*, 2019). As more devices and systems are connected in smart buildings, the risk of cyber-attacks and data breaches increases (Pacheco and Hariri, 2016; Conti *et al.*, 2018).

2.3 Process Connectivity

Process connectivity refers to the degree to which different processes within a system or organisation are connected and integrated with each other. In other words, it refers to the extent to which different parts of a system or organisation work together seamlessly to achieve common goals. Gagnaire (2020) claims that process connectivity is important because it can impact the efficiency, effectiveness, and overall performance of the system or organisation. When processes are well-connected, information and resources can be shared easily and quickly, tasks can be coordinated more effectively, and decisions can be made in a timely and informed manner. However, there are three different components of connectivity: structural, functional, and process connectivity (Larsen *et al.*, 2012; Bracken *et al.*, 2013). Connectivity at the structural and functional levels refers to the physical links between locations and the processes that govern the magnitude and direction of fluxes (Lexartza-Artza and Wainwright, 2009; Gagnaire, 2020). In a system, process connectivity refers to the flow of information from system drivers to sinks and is determined by the structural and functional connectivity of the system (Larsen *et al.*, 2012; Wang *et al.*, 2012). It is possible to visualise process connections as a process network in which variables act as nodes and couplings serve as links that illustrate significant information flows (Ruddell and Kumar, 2009).

Process connectivity can be enhanced through a variety of means, such as by implementing information systems that enable real-time data sharing (Ciribini *et al.*, 2017), standardising processes across different departments or teams (Haller and Magerkurth, 2011), and fostering a culture of collaboration and communication within the organisation (Basri *et al.*, 2015). However, achieving high levels of process connectivity can also require significant effort and resources, particularly in large and complex organisations.

2.4 Stages of a Smart Building

The development of buildings has evolved over the years, and the concept of smart buildings has emerged in recent times. The stages and phases of building development include planning, design, construction, and operation. Panteli, Kylili and Fokaides (2020) examined the trends identified as being the most important stages of a smart building. The authors present the three main phases of a building's life cycle: the pre-construction phase, the construction phase, the operation phase, and the post-construction phase, as highlighted in Figure 2-3.

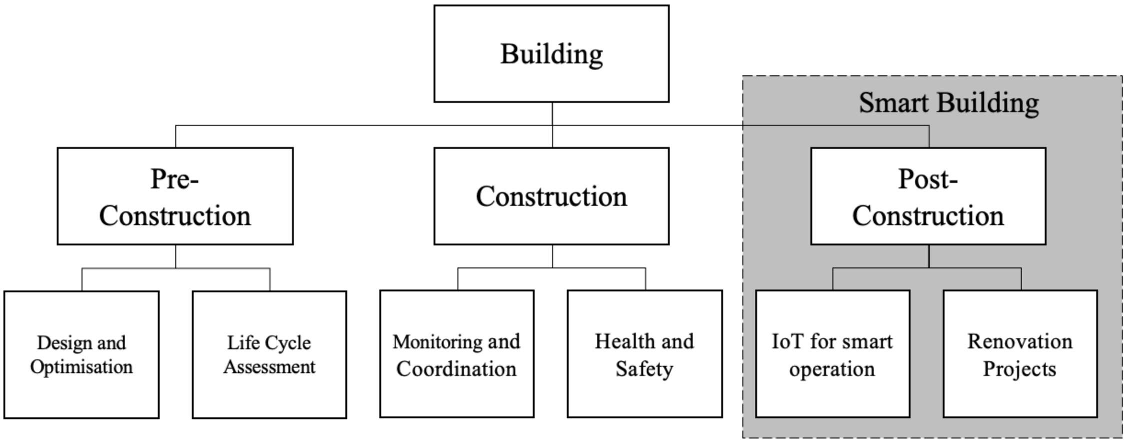


Figure 2-3: Use of BIM in Buildings Pre-, During and Post-Construction Phases Adopted From (Panteli et al., 2020).

According to Panteli, Kylili and Fokaides (2020), given the emergence of the smart building industry, which embeds smart devices in many spaces to enhance building comfort conditions. The data extracted from BIM is used to assess the feasibility of implementing smart IoT devices in smart buildings. Ghaffarian *et al.*, (2017) say in the lifecycle of a building, the development of the smart building begins in the post-construction phase. Ghosal and Halder (2018) claim that integrating smart systems within a building is the first step in creating a smart environment. Similarly, according to a study by Mishra, Gupta and Shree (2020), the planning stage involves identifying the purpose and scope of the building, assessing the feasibility of the project, and developing a project plan. The design stage involves creating a detailed blueprint of the building, including its layout, structure, and systems. Additionally, during construction, the building is physically constructed according to the design specifications, while in the operation stage, the building is maintained and managed.

Smart buildings, on the other hand, are designed to optimise energy efficiency, comfort, and security using advanced technologies such as Internet of Things (IoT), Artificial Intelligence

(AI), and Building Information Modelling (BIM). According to Li et al. (2020), the development of smart buildings involves four phases: sensing and data collection, data analysis and decision-making, control and optimisation, and feedback and continuous improvement. The sensing and data collection phase involves the installation of sensors to collect data on various aspects of the building's environment, such as temperature, humidity, and occupancy. The data analysis and decision-making phase involves using AI and machine learning algorithms to analyse the data and make informed decisions on optimising the building's performance. In the control and optimisation phase, the building's systems are adjusted to achieve optimum performance, such as heating and cooling, lighting, and ventilation.

Finally, the feedback and continuous improvement phase involves monitoring and analysing the building's performance over time and making adjustments as needed to improve efficiency and performance. In conclusion, the development of buildings and smart buildings involves multiple stages and phases, each with its unique set of challenges and opportunities (Panteli, Kylili and Fokaides, 2020).

2.5 Chapter Summary

Chapter 2 provides a literature review of smart buildings, socio-technical systems, and process connectivity. The chapter starts with an overview of smart buildings, their technology, systems, and stakeholders. It explores the concept of the Internet of Things (IoT) and its role within smart buildings. IoT frameworks within smart buildings are also discussed in this section.

The chapter highlights the systems and processes that make up smart buildings, including their information-sharing and data-analysis capabilities. The stakeholders of smart buildings are identified and discussed, including owners, investors, building occupants, facility managers, estate department teams, and other stakeholders. Next, the chapter delves into socio-technical systems (STS) and how they relate to smart buildings. The existing work of STS in smart buildings is explored in detail, highlighting the need for effective collaboration between stakeholders and the role of technology in facilitating such collaboration.

Finally, the chapter focuses on process connectivity and its importance in smart buildings. Process connectivity refers to the ability of different systems and processes within smart buildings to communicate seamlessly. The chapter emphasizes the need for process connectivity to enable effective data sharing and analysis, which is essential for achieving the goals of smart buildings. The chapter presented an all-encompassing perspective on the fundamental notions and structures that lay out smart buildings, along with their respective beneficiaries and how significant it is for them to cooperate effectively. The comprehension of these details is necessary not just for scholars but also for professionals partaking in smart building construction endeavours and those who create policies related to this field.

3 METHODOLOGY

This chapter outlines the methodology, whereby the research was conducted in two phases: data collection and data analysis. The data collection phase involved the use of literature and primary data sources, while the data analysis phase involved thematic analysis. This chapter describes the research design, data collection procedures, and data analysis methods used in this study.

3.1 Research Onion

The Saunders research onion is a model that comprises different layers of techniques (Figure 3-1) that provide a systematic approach to designing and conducting research studies (Saunders, 2012). The research strategy layer is crucial as it determines the approach and methods used to answer the research questions.

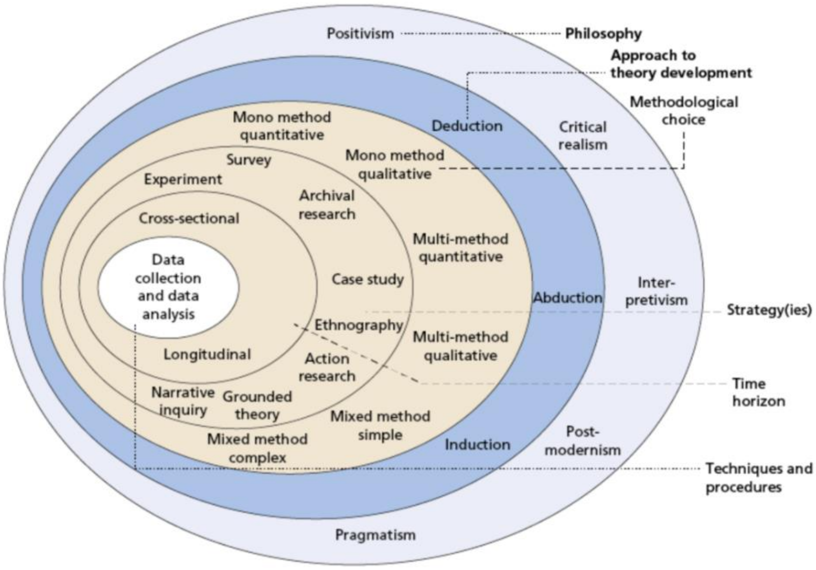


Figure 3-1: Research Onion (Saunders, 2012).

One example of a research strategy is case study research. According to Yin (2014), case study research is a qualitative research strategy involving an in-depth exploration of a particular phenomenon or case. This research strategy is particularly useful when the research questions are focused on understanding a particular situation, event, or process within a specific context. Case study research often involves multiple data sources, such as interviews, observations, and document analysis, and it allows for a comprehensive understanding of the phenomenon under investigation. Moreover, case study research provides insights into the complexity and nuances of the studied phenomenon, which may not be captured by other research strategies such as surveys or experiments (Yin, 2014). Overall, the Saunders research onion provides a useful framework for researchers to navigate the complex research process.

3.2 Research Philosophy

According to Brayman (2004), a research philosophy is a set of beliefs about the phenomenon or nature of reality being investigated, and according to Saunders et al, (2007), it reflects how the researcher regards the development of knowledge and how the research should proceed. Thus, it is important to identify the way in which knowledge is perceived, as this influences research design. As Flick, (2015) explains, the assumptions derived from a research philosophy provide the basis for how the research will be conducted. Goddard and Melville (2004) argue that research philosophies can differ in terms of the research objectives and the best strategy to achieve these objectives. This is because it sets out the basic set of beliefs that influence an action, a paradigm or epistemology and ontology - which in turn sets the course for the investigation. Therefore, understanding the research philosophy can assist in elucidating how assumptions are built into the research process and how they align with the methodology employed (May, 2011). However, it is necessary to consider both society and science's nature when developing core ontological and epistemological assumptions when deciding on the research philosophy (Burke, 2007).

3.2.1 Ontology

It is a branch of metaphysics or philosophy of mind that refers to the study of the nature of things or beings that exist in reality. According to Effingham (2013), ontologists are not concerned with the existence of old things but rather with the question of what things exist. It is possible to categorise objects as abstractions or concrete objects. Abstract objects, such as numbers, properties, possibilities, facts, and propositions, cannot be perceived by the senses, whereas concrete objects can be experienced.

On the other hand, interpretivist ontology focuses on the subjective nature of reality and the importance of understanding people's interpretations and meanings in their social context (Silva, 2007). This study views reality as being socially constructed and shaped by human interpretations and experiences. Hence, an interpretive ontology would influence this research methodology by emphasising the importance of collecting rich data on building stakeholders' experiences and interpretations.

3.2.2 Epistemology

A concept, theory, or problem that is central to understanding knowledge is treated as epistemology. In epistemology, justification is as important as knowledge. Alternatively, epistemology can be defined as a subdivision of philosophy concerned with investigating human knowledge's nature, origin, methods, and limitations (Silva, 2007).

The philosophers often extend their attention to the nature of perception and the sources of knowledge that can be determined through perception or other sources of knowledge such as memory, consciousness, reflection, or testimony. An epistemology is based on sensory experience and describes the experience based on the beliefs represented by the sensory experience. People believe things based on their experience, which is rational. It is expected that justified beliefs are desirable and reasonable and that they are also reliable.

It is explained by Jones, Hayward, and Cardinal (2004) that justification can be divided into belief justification, situation justification, and propositional justification. Actual beliefs constitute belief-justification. Situational justification is when facts are used to justify a decision, and that means perceptions, beliefs, and background knowledge are included. A propositional justification refers to a justification based on the facts at hand. Sosa (2008) points out that justified belief is essential to understanding knowledge as many believed things are also justified, and many justified things are also known. Despite the close association between knowledge and justified belief, the major difference is whether they are true or false. Regarding epistemology, Audi (2011) highlights that perceptual, memorial, introspective, a priori, inductive, and testimony-based beliefs are distinct.

3.2.3 Research Philosophical Paradigms

Researchers define a paradigm or worldview as "a set of beliefs that provide a framework for action" (Creswell, 2014). Paradigms determine perspectives, including how we understand and relate to things. For Information Systems (IS) research, Orlikowski & Baroudi (1991) and Myers and Avison (2002) suggest philosophical perspectives: positivism, interpretivism, and critical realism for information systems research (Figure 3-2).

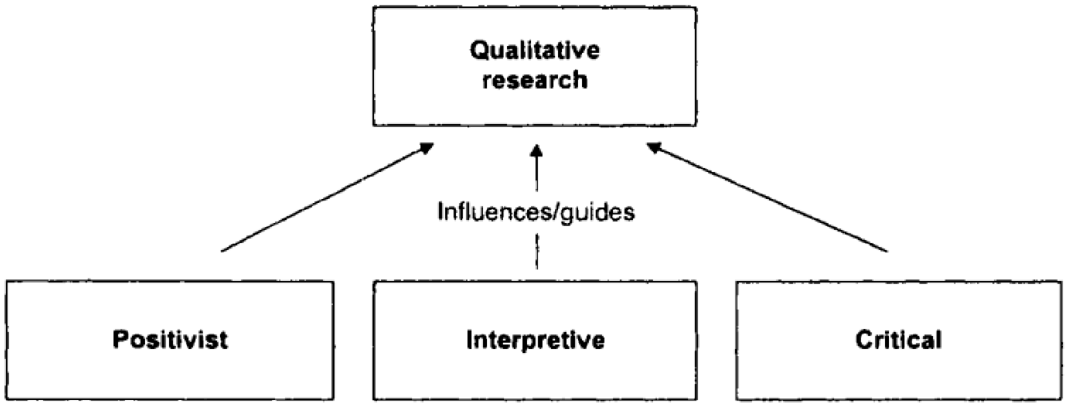


Figure 3-2 Philosophical Paradigms in Information Systems.

3.2.3.1 Positivist research

Philosophically, positivism holds that only knowledge derived through observation (the senses), including measurement, can be trusted. Studies of positivism limit the researcher's role to the collection and interpretation of data in an objective manner. In other words, the researcher conducts the research objectively and distances her/himself from various personal values in conducting the study. Research findings in these types of studies are usually observable and quantifiable (Kaboub, 2008).

Positivism relies on quantitative observations, resulting in statistical analyses. It has been a dominant research method in business and management disciplines for decades. In its philosophy, positivism agrees with the empiricist view that knowledge is derived from human experience. Its view of the world is atomistic and ontological, considering discrete, observable elements and events that interact in an observable, determined, and regular manner.

3.2.3.2 Interpretive research

According to Denzin and Lincoln (2006), interpretivist research is shaped by the researcher's beliefs and feelings about how the world should be understood and studied. Benoliel (1996) explains that knowledge varies according to particular historical, temporal, cultural, and subjective circumstances and consists of multiple representations of reality (individual interpretations of reality). Interpretivism acknowledges multiple meanings and ways of knowing and acknowledges that objective reality cannot be captured (Denzin and Lincoln, 2006). Generally, the interpretive paradigm recognises and interprets the meaning of human experiences and actions (Fossey et al., 2002).

An interpretive epistemology would imply seeing the reality of smart buildings and their connectivity as being shaped by the interpretations and experiences of building stakeholders. This makes it interesting to understand how different stakeholders perceive and make sense of smart building connectivity and how their interpretations and experiences shape the reality of smart buildings. It also aligns with constructivism, as it recognises that reality is subjective and that knowledge is constructed through the interaction of individuals with their environment.

3.2.3.3 Critical research

Zachariadis et al. (2010) state that critical realism permits the adoption of different types of research methods, depending on the scope of the study. Possibly, this can be explained by one of the main characteristics of critical realism, namely its strong emphasis on ontology (Bhaskar, 1998), which allows for both quantitative and qualitative approaches to be used together.

According to Wainwright (1997) and Scotland (2012), a paradigm's ontology is about what is, which includes what exists (Wainwright, 1997). Fraley and Pearce (2007) state that ontological questions identify the entities and structures that form the domain into which one is enquiring. One can determine the possibilities and limits of knowledge by examining the ontological principles of any philosophical framework (Brown, 2009).

A critical realist's primary concern is an ontology which asks what exists (Bergin et al., 2008; Frauley & Pearce, 2007). It distinguishes between three layers of knowledge, the 'real', the 'actual' and the 'empirical', using a unique stratified ontology.

3.2.3.4 Adopted Research Philosophy

This research focuses on the diverse requirements of building stakeholders and the use of a socio-technical approach to address these requirements. The study requires understanding the complex social and technical factors that influence connectivity in smart buildings and the subjective human experiences in a smart building to derive the needs and improve the connectivity of smart buildings. Therefore, this study adopts interpretivism as the philosophical stance to guide the research design to understand stakeholders' meanings and interpretations of smart building connectivity.

An interpretive perspective is aligned with the study's approach because it seeks to understand the viewpoints and experiences of smart building stakeholders. According to interpretivism, social phenomena are understood through the interpretations and meanings attributed by individuals. This approach would involve exploring and analysing perspectives and experiences of stakeholders involved, such as building owners, occupants, and facility managers, in smart buildings. The study seeks to go beyond quantitative data and objective measurements, instead concentrating on the stakeholders' subjective viewpoints, attitudes, and behaviours by taking an interpretive approach. It acknowledges that individuals' perceptions and interpretations influence their understanding of smart buildings and their interactions.

3.3 Approach To Theory Development

According to Saunders et al. (2015), there are two broad approaches to theory development: deductive and inductive. Deductive theory development involves starting with a theoretical framework and testing specific hypotheses derived from that framework. In contrast, inductive theory development involves generating a theory based on observations and data collected from the research participants (Gregory *et al.*, 2011). According to Gregory *et al.*, (2011), inductive research is a type of research that involves collecting data and analysing it to develop theories, concepts, and models. It is a bottom-up approach that emphasizes the collection and analysis of data to generate new insights and knowledge. In the case of the multi-stakeholder information model for smart buildings, inductive research would involve collecting data from various stakeholders, such as building owners, occupants, designers, and technology providers, to understand their perspectives and needs. Therefore, inductive research is an appropriate choice for developing the multi-stakeholder information model for smart buildings because it allows for a bottom-up approach to understanding the complex interactions and relationships between stakeholders in the design, construction, and operation of smart buildings. The data collected could include interviews, surveys, focus groups, and observation of smart buildings in operation. Once the data is collected, the researcher can analyse it to identify patterns, themes, and relationships that emerge from the data. This analysis can then be used to develop a model that captures the different perspectives and needs of the various stakeholders involved in the design, construction, and operation of smart buildings.

3.4 Methodological Choice

Research methodologies are usually classified as quantitative or qualitative, though other classifications exist (Figure 3-3). The information systems research approach methods have been the subject of a longstanding debate regarding adequacy for decades. Particular attention has been directed to the selection of research methodology for effective alternatives to methods derived from natural sciences in social research.

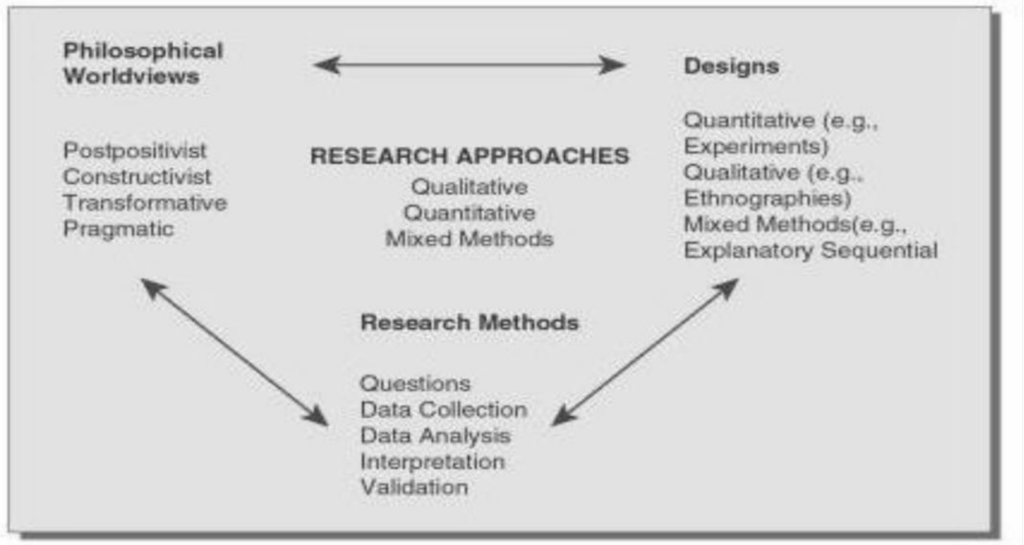


Figure 3-3: Research Framework (Creswell, 2014).

3.4.1 Quantitative Research

In quantitative research, the researcher can examine the relationship among variables by measuring them using instruments and analysing them using statistical methods. In this method, deductive tests are conducted, bias is minimized, alternative explanations are controlled, and results are generalised to the general population. In addition, quantitative research involves examining the relationship between variables to test hypotheses. Variables are measured using tools so that a set of statistical procedures may be applied to the numbered data (Creswell, 2009). A quantitative study uses a variety of numerical measures to represent different levels and magnitudes of theoretical constructs. The methods of quantitative research described by Myers and Avison (2002) include survey methods, laboratory experiments, and numerical methods.

3.4.2 Qualitative Research

Qualitative research has several definitions. Creswell (2013) defines it as; “an approach to inquiry that begins with the assumption, an interpretive/theoretical lens, and the study of research problems exploring the meaning individuals or groups ascribe to a social or human problem.” (Creswell, 2013, p. 64). This approach involves developing questions about the phenomenon, collecting data from respondents within the respondents' setting, and analysing the data inductively from particular to specific themes related to the subject under investigation. This method focuses on understanding the phenomenon from an individual perspective and the importance of presenting the complexity of the process within smart buildings.

According to Creswell (2013), A qualitative research study is normally conducted within its natural setting, which enables researchers to collect and analyse data inductively and/or deductively to form themes or patterns. Because qualitative research has a subjective nature, it allows the researcher to see events from an insider's point of view. By exploring events from the past in relation to future events, this approach shows an understanding of the context and importance of past events.

3.4.3 Mixed Research

Using mixed methods research, a researcher collects quantitative and qualitative data, integrating the two types of evidence, which permits the researcher to design research approaches that incorporate philosophical assumptions and theoretical frameworks. It has been demonstrated that the combination of qualitative and quantitative approaches will provide a more comprehensive understanding of the research problem than either technique alone.

3.4.4 Selected Methodological Choice

According to Creswell (2013), quantitative research can be used to: "study a research problem when the problem needs to be explored; when a complex, detailed understanding is needed; when the researcher wants to write in a literary, flexible style; and when the researcher seeks to understand the context or settings od participants." (Creswell, 2013, p. 65).

As the research objective is to obtain a deeper understanding of the process within Smart Buildings, the qualitative approach is appropriate to explore, understand, and explain the phenomenon of IoT processes within smart buildings. The failure to design research using a robust approach can adversely affect the collection and analysis of data (Bryman and Burgess, 2002). As such, this study adopts a qualitative research methodology to collect data from building stakeholders and analyse it thematically.

3.5 Research Strategy

The research strategy layer is particularly important as it determines the overall approach and methods used to answer research questions. This research strategy is particularly useful when the research questions are focused on understanding a particular situation, event, or process within a specific context. Case studies, interviews, focus groups, and qualitative surveys are examples of methods commonly used in qualitative research to explore a particular phenomenon in depth.

3.5.1 Case Study Method

Researchers use case studies to answer either descriptive or explanatory questions. A descriptive question asks, “What has happened?” or “What is happening?” While an explanatory question asks, “How did something happen?” or "Why did something happen?" (Shavelson and Towne, 2002). According to Yin (2014), the case study research method involves an in-depth exploration of a particular phenomenon or case to explain how and why a social phenomenon makes sense based on the research questions. Case studies often involve multiple data sources, such as interviews, observations, and document analysis, allowing for a comprehensive understanding of the phenomenon under investigation. Moreover, case studies provide insights into the complexity and nuances of the studied phenomenon, which may not be captured by other research strategies such as surveys or experiments (Yin, 2014).

Myer (1997, p.7) explains, "The term "case study" has multiple meanings. It can refer to a unit of analysis (e.g., a case study of a certain organization), or it can refer to a research method. As for case study, Yin (2014, p.16) defines it as an "empirical inquiry". It examines a contemporary phenomenon in its actual context. He notes this situation when the boundaries between phenomenon and context are unclear.

A case study can be holistic or sub-case embedded within a holistic case study (Figure 3-4). A case study emphasises the importance of collecting data in its natural setting as opposed to relying on derived data. Therefore, it is more appropriate to address a phenomenon within the context of its real-world context (Yin, 2013). However, Yin (2014) suggests that case studies could also be used in evaluations as a research method. The research strategy chosen for this study is an interpretive case study that allows extensive and in-depth examination of smart buildings within a higher educational institute.

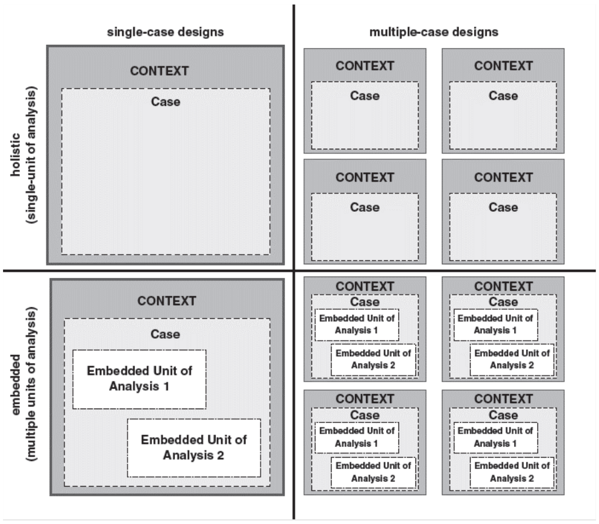


Figure 3-4: Basic Types of Case Studies Design (adapted from Yin, 2014, pp. 50).

This method allows the review of qualitative data into different novel concepts, resulting in an enhanced understanding of the usage, impact, benefits, obstacles, quality and challenges of a building in smart building contexts. The use of a case study in this research will provide insights into smart buildings by examining definitions of smart buildings and the process of creating a smart building from the stakeholders' perspective. This inquiry also examines the Internet of Things (IoT) to find out what value it provides to building performance and what barriers need to be overcome to achieve smart buildings. However, valid conclusions must be drawn to develop valid implications from the case study strategy (Larsen *et al.*, 2012). Therefore, using case studies will offer an in-depth analysis of a social phenomenon in the stakeholders' perceptions and requirements within a smart building.

3.6 Techniques and Procedures

Saunders (2012) presents several techniques and procedures that can be used in research methodology. These techniques and procedures can be categorised into two main areas: data collection and data analysis.

3.6.1 Data Collection

The data collection process involved two main sources of data: literature and primary data. The literature review provided a broad overview of the research topic and informed the development of the interview questions. The primary data was collected through semi-structured interviews with participants. The interviews were conducted in person, over the phone or via video conferencing, depending on the preference of the participant.

3.6.1.1 Stage one: Literature Analysis Data Collection

According to Kiduk and Meho (2006), the literature review involves an extensive search of academic databases, including Scopus, Web of Science, and Google Scholar. The search terms included phrases such as "data collection methods," "qualitative research methods," "thematic analysis," and "interviews." The articles that were selected for review were based on their relevance to the research question and their potential to contribute to the study.

The literature review provided a broad understanding of the research topic, including the methods that have been used in similar studies. It also informed the development of the interview questions and helped identify areas requiring further exploration. The literature review also highlighted the importance of ensuring the validity and reliability of the data collected, which was addressed using multiple data sources and the careful selection of participants.

An analysis based on IoT frameworks within smart buildings was conducted in this stage. This study carried out a qualitative literature synthesis of the currently used literature of IoT frameworks within the application of smart buildings in response to different stakeholders' needs and requirements. A qualitative literature synthesis applies a massive array of data collection and analysis methods conducted in a wide-ranging format (Drisko, 2020). A systematised literature analysis was conducted as part of this thesis's first objective. A qualitative approach is taken because it provides a deeper level of understanding and analysis of the collected data (Cruzes and Dybå, 2011). It used Scopus to select the most relevant papers from the literature that address this topic. Scopus provides access to extensive scholarly literature across various disciplines through its abstract and citation databases. There are several reasons why researchers and academics value Scopus: (1) Comprehensive coverage, (2) Comprehensive search functionality, (3) Citation analysis, (4) Author and affiliation profiles, (5) Research evaluation and benchmarking, (6) International coverage.

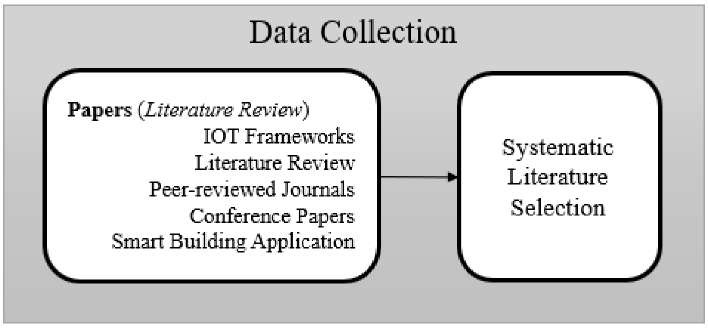


Figure 3-5: Data collection for stage one (SLR).

Articles were selected by using a systematic approach with the most relevant keywords to the scope of this research (Castleberry and Nolen, 2018). The study focused on generating themes from the literature to be used as criteria to analyse the selected frameworks.

The systematic literature review used the following keywords (Smart buildings, Internet of Things, IoT, Model, Framework) to construct the search query: "Smart Buildings" AND IoT OR "Internet of Things" AND Framework OR Model. As can be seen from Figure 3-5, the inclusion criteria included available English-written articles and conference papers on different Scopus databases. It included papers that presented an IoT framework or a conceptual model within a smart building between 2015 and 2020. Moreover, this study excluded non-English written papers and any paper unrelated to IoT within Smart buildings. After further analysis, the papers that presented the architecture of IoT instead of a framework or a conceptual model were excluded, as this study is looking at the holistic conceptual structure of IoT within smart buildings. Lastly, the study excluded papers that introduced a framework for smart buildings; however, the frameworks were not based on IoT systems.

3.6.1.2 Stage two: Case Study

The chosen case study, City Centre Campus, is a multi-million-pound centre of excellence in the heart of Birmingham's East-side development. The campus consists of several buildings (Curzon Building, Millennium Point, Parkside Building, Joseph Priestley Building, The STEAM house building, and the Conservator). These buildings were built to accommodate different faculties within the university (e.g., the Parkside building is home to both the Birmingham Institute of Art and Design and the Faculty of Performance, Media and English). Using university buildings and spaces is one approach to having a successful case study for creating a smart environment (Monti *et al.*, 2022). Alrashed (2020) argue that university campuses provide a unique opportunity for creating smart environments due to their complex and diverse buildings and spaces. They state that "universities offer a complex environment in which to design, test, and deploy a range of smart technologies due to the diversity of building types, user groups, and activities on campus. Villegas-Ch, Palacios-Pacheco and Luján-Mora (2019) suggest that universities can serve as ideal testbeds for smart city technologies and solutions, with potential benefits including improved energy efficiency, enhanced safety and security, and increased user satisfaction. Therefore, using university buildings and spaces as a case study for creating a smart environment can provide valuable insights into the challenges and opportunities associated with implementing smart technologies in complex and dynamic settings. Furthermore, universities are often at the forefront of innovation and research, making them an ideal setting for testing and developing smart building solutions. The primary data collection involved the use of semi-structured interviews with participants. The interview questions were developed based on the research questions and the themes that emerged from the literature review. The questions were designed to be open-ended, allowing participants to provide detailed responses in their own words. The interviews were audio recorded with the consent of the participants and transcribed verbatim for analysis within the case study.

3.6.1.2.1 Participants

The participants were selected based on their relevance to the research question and their ability to provide insights into the topic. The inclusion criteria (Figure 3-6) were individuals who had experience within the buildings and were familiar with the space they use.

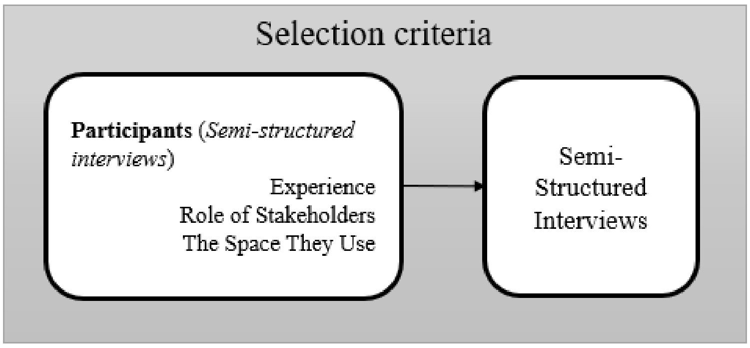


Figure 3-6: Selection Criteria for Semi-Structured Interviews.

Participants were recruited through convenience and purposive sampling, which involved reaching out to individuals who met the inclusion criteria and were willing to participate in the study. The role of each stakeholder was a key element in selecting the participants who were interviewed, with a mix of genders, ages and diverse professional backgrounds.

This case study targeted stakeholders of the different buildings within the city centre campus. The first group is represented by the facilities management team and estate departments team as these are two entities working together to operate and maintain the building daily. The second group is the building management team, and these stakeholders (e.g., BMS managers and energy managers) hold managerial positions where they can control and act on data gathered from the different systems in the building. Finally, the third group is grouped as occupants representing the stakeholders using the building, such as students and staff members. It is important to note that the selection of the stakeholders was mainly based on their roles and the stage of the building. The stage of the building is the operational stage, as it is important to the scope of research to collect data from a building in use to assure the quality of the gathered information. Additionally, the interview questions were designed to explore misunderstandings regarding the nature of the research and what could be defined as a smart building from multiple perspectives because it is important to have a clear and shared understanding of what is being studied in order to ensure that the research is valid, and the results are meaningful.

Misunderstandings can lead to incorrect assumptions and misinterpretation of data, ultimately compromising the research quality. By exploring these misunderstandings through interview questions, researchers can identify potential areas of confusion or disagreement and address them, thereby increasing the accuracy and reliability of the research results. Additionally, considering multiple perspectives can help ensure that the definition of a smart building is comprehensive and inclusive, considering a range of different viewpoints and opinions.

3.6.1.2.2 Interviews

According to Oates, Griffiths and McLean (2022), interviews are usually used in case studies and can be used in other strategies as well. It is believed that using this technique can assist researchers in gathering valid and reliable information relevant to their research questions (Saunders et al, 2007; Yin, 2014). In general, in-depth interviews may be both structured and semi-structured. Structured interviews are conducted according to a predetermined and standardised set of questions that cannot be diverted (Koparan and Yilmaz, 2015). The semi-structured interviews allow the researcher to be more flexible in asking follow-up questions and allow participants to present their own ideas. It is particularly useful in that it provides in-depth information and an opportunity for the researcher to uncover the participant's experience and thoughts in their own words, and to express their opinions freely to formulate a larger or other enquiry. As Oates, Griffiths and McLean (2022) highlighted, semi-structured and unstructured interviews are used primarily for 'discovery' purposes and to explore beliefs.

In order to explore the different requirements of different stakeholders within the chosen buildings, six main questions were asked in a face-to-face semi-structured interview. In all interviews, the main purpose was to gather sufficient information to meet the purpose and objectives of the present study. In order to design interviews for this study, the researcher reviewed best practices in interview design, such as collecting informed consent, creating open-ended questions, and starting with the basics, which resulted in developing precise interview questions.

The researcher had two options for conducting interviews: face-to-face and online. Online interviews are easier to schedule, there is no travel requirement, and there are numerous opportunities to ask follow-up questions. However, the scope of this research seeks the views and perspectives of different stakeholders of a building in use. Ensuring that the participants are interviewed in the same space they use will enhance the quality of the answers, as face-to-face interviews are very effective as the surroundings will influence the participants. Also, the interviewer can use the space as an example to explain questions to the interviewees to help put them at ease and engage them in more detailed conversations, which is sometimes difficult to establish in online interviews. Face-to-face interviews were appropriate for this research since the participants were comfortable holding face-to-face meetings. Furthermore, the researcher prepared for situations such as a conversation going awry by using a standard interview protocol (Islam and Omasreiter, 2005).

3.6.2 Data Analysis

A data analysis purpose is to draw conclusions and/or inferences based on the findings of a study. Drawing meaningful conclusions from the data can be difficult without careful analysis. Therefore, data analysis is necessary to properly examine and understand the data to reach valid and reliable conclusions (Lawal and Rafsanjani, 2022).

Data analysis involves various techniques and methods, including statistical analysis, to identify patterns and relationships in the data. By carefully examining the data and applying appropriate analytical techniques, researchers can gain insights and make informed decisions based on the data. Without proper data analysis, drawing reliable and valid conclusions from the data can be challenging. The majority of data in quantitative data analysis is displayed graphically (i.e., as percentiles or charts indicating changes over time) or numerically (i.e., as the "P" value or confidence interval). As in both cases, the overall amount of data has been reduced to a simple chart or statistic, summarising the data using generally accepted analytical methods. This summary allows valid conclusions to be drawn regarding the data. Due to the extensive nature of qualitative data, qualitative data analysis aims to make a large amount of data more manageable and provide a valid representation of the entire data set. In general, researchers using qualitative research methods typically collect data until they reach a point of saturation, when there is no further input of information. Unlike quantitative research, which typically analyses data at the end of data collection, qualitative research typically starts to analyse data at the beginning of the research process. Qualitative data analysis is a reflexive process that begins as soon as the researcher begins collecting data and not after it has been completely gathered (Stake, 1995). A thematic analysis approach was used to identify patterns and themes within the data (Braun *et al.*, 2008). The analysis was conducted in several stages, including data familiarization, coding, theme generation, and theme refinement.

3.6.2.1 Data Familiarisation

Data familiarization is the process of becoming acquainted with the data that will be used in a research study. This involves understanding the characteristics of the data, such as its structure, format, and content. According to Clarke *et al.*, (2013), data familiarization is an important step in the research process because it helps researchers " appreciate the range of variation, patterns, and other features of the data that might not have been apparent before."

Data familiarization involved reading through the transcripts of the interviews multiple times to gain a thorough understanding of the data. The transcripts of the interviews were subjected to a thorough and iterative analysis to identify patterns and themes within the data. In the subsequent stage of data collection, the researcher transcribed the discussions from the recorded interviews and meticulously examined the transcribed text for relevant information.

3.6.2.2 Coding

The second stage of the data analysis involved the coding of the data. The transcripts were thematically coded using an inductive approach, where the codes were generated from the data rather than from a pre-existing theoretical framework. The codes were then grouped into categories based on their similarity, which helped to identify themes within the data. The coding process involves the transformation of raw data into conceptual meaning, usually themes and sub-themes. In essence, each code represents a theme and sub-themes that enable data to be pinpointed. As Miles and Huberman (1994) note: “Codes are tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study. Codes are usually attached to ‘chunks’ of varying size – words, phrases, sentences or whole paragraphs.” (Miles and Huberman, 1994, p. 56).

These standards say good codes should be valid, mutually exclusive, and exhaustive. This means that they should accurately represent the research topic. Miles and Huberman (1994) recommend that codes be distinct and do not overlap with each other. Through the coding process, data is being reduced.

3.6.2.3 Theme Generation

The third stage of the data analysis involved the generation of themes. The sub-themes that were identified through coding were further refined and organised into themes. The themes were identified based on their relevance to the research question and their ability to provide insight into the experiences and perspectives of the participants. In this study, the transcripts in both stages were analysed thematically, putting the main ideas, supporting ideas, and examples of the text into paragraphs that were in accordance with the research questions and the subject matter of the study. This led to the establishment of an overall mind map for the coding process. According to an analysis of extracts from the interview transcript, a detailed description of the critical events was created.

3.6.2.4 Theme Refinement

The final stage of the data analysis involved the refinement of the themes. This involved reviewing the themes to ensure that they accurately reflected the data and that they were meaningful in relation to the research question. The themes were refined and organised into a coherent narrative that provided insight into the research question.

3.6.2.5 Data visualisation

In stage one of the study, the results were displayed in a comprehensive table featuring all the themes identified during the thematic analysis. Subsequently, an elaborate account was provided elucidating the table's contents, specifically IoT frameworks in the context of smart buildings. However, in stage two, the findings are presented in tables where each table represents the parties mentioned above: the building management team, the facility management team and the building occupants. Each table consists of the focus of the questions and the participants involved with their responses. In order to clarify the responses, Table 3-1 has been used to categorise them.

Table 3-1 The coding used to present the responses in the interviews.

Text	Explanation
Italic, Blue	Participants respond to the questions asked during the interviews.
Italic, **Bold,** Black	Interviewee questions and follow-up questions.

3.6.2.6 Data Validity and Reliability

The validity and reliability of the data were addressed through the use of multiple data sources and the careful selection of participants. The use of multiple data sources, including literature and primary data, helped to ensure the validity of the data by providing a broad understanding of the research topic. The careful selection of participants, based on their relevance to the research question and their ability to provide insights into the topic, helped to ensure the reliability of the data by ensuring that the participants were knowledgeable and experienced in the field of data collection.

3.6.2.6.1 Use Case Scenarios

When it comes to assessing the validity and reliability of data, use-case scenarios can be a helpful tool. Validity refers to the accuracy of the measurement and whether it is measuring what it intends to measure (Pourzolfaghar, Mcdonnell and Helfert, 2017). Use-case scenarios can be used to test whether the measurement accurately reflects real-world scenarios and situations (Davis and Dawe, 2001). For example, if a study is measuring job satisfaction, use-case scenarios could involve presenting hypothetical work situations and asking participants to rate their satisfaction with each scenario. This can help ensure that the measurement is accurately capturing participants' experiences and perceptions of job satisfaction. Reliability, on the other hand, refers to the consistency of the measurement. In other words, if the same measurement were taken multiple times, would it produce consistent results (Garzone, Guermouche and Monteil, 2018)? Use-case scenarios can also help assess reliability by presenting participants with multiple scenarios that are similar in nature, and researchers can determine whether the measurement produces consistent results across different situations (Davis and Dawe, 2001). For instance, if a study measures customer satisfaction with a product, use-case scenarios could involve presenting different scenarios in which customers use the product and measuring their satisfaction levels in each scenario. This can help ensure that the measurement is reliable and produces consistent results across different situations.

3.6.2.7 Soft-Systems Analysis

A Soft Systems Analysis methodology is a structured approach used for analysing complex situations and identifying solutions that are suited to the specific context in which they are applied. Checkland and Scholes (1999) describe Soft Systems Analysis as a process that involves defining the problem situation, creating models of the current system, identifying the relevant stakeholders, exploring alternative solutions, and implementing and monitoring any changes made. According to Checkland and Scholes (1990), Soft Systems Analysis involves the following steps: (1) Understanding and defining the problem situation, (2) creating descriptive models of the situation, (3) comparing the situation with other, presumably better situations, (4) defining feasible and desirable changes that can be made to the situation, (5) identifying and agreeing upon changes that should be made, and (6) implementing and monitoring changes. Therefore, in Chapter 7, soft systems will serve as an analytical tool to investigate divergent views on the case study. By utilising soft systems, the distinct findings of this chapter will represent varied perspectives. The application of soft systems is expected to aid in the exploration of methods to connect data, technology, and space, thus comprehending the distinct needs of stakeholders for smart buildings and bridging any existing gaps.

3.7 Research Design

According to Gorard (2013), research design provides a foundation for convincing an audience who might be sceptical about the research findings and the morality of the decisions underlying them. A rigorous approach to design addresses issues such as safety, efficiency, and equality. A number of factors should be considered when choosing the research design. As Yin (2013) suggested, avoiding problems that hinder evidence-gathering is essential. Many factors can affect this measurement, including, but not limited to, the nature of the study and the type of question it is seeking to answer. Additionally, Saunders et al. (2011) claimed that research questions and objects, philosophical positioning, the extent of existing knowledge, and various other factors determine research design.

This study was designed as a qualitative research project that aimed to explore the experiences and perspectives of participants in relation to the research question. The qualitative approach was chosen as it allowed for an in-depth exploration of the research topic, with a focus on the meaning and interpretation of the data. The research design was also guided by the principles of phenomenology, which seeks to understand the essence of human experiences and how individuals make sense of the world around them (Moustakas, 2011). However, the researcher also aimed to make the findings useful to a wider community, including professional practices to enable information sharing between systems and various stakeholders within smart buildings. The research function is to investigate and find answers to a set of questions, which is accomplished by gathering information and analysing it. The study is systematically and methodically conducted, demonstrating that the study is well-organised and involves a series of stages intended to expand knowledge of processes within smart buildings. Berman et al,.

(2000) research design that used nine stages to answer a research question related to obtaining specific knowledge about processes within smart buildings in higher educational institutes using action research. Bell (2006) suggests that methods of gathering information can help understand what is possible or practical given the circumstances. This research involves studying various stakeholders' different views, roles, and needs and conducting interviews to explore their key requirements, which will inform the process model. This research aims to develop a multi-stakeholder information model that will drive process connectivity within IoT in smart buildings.

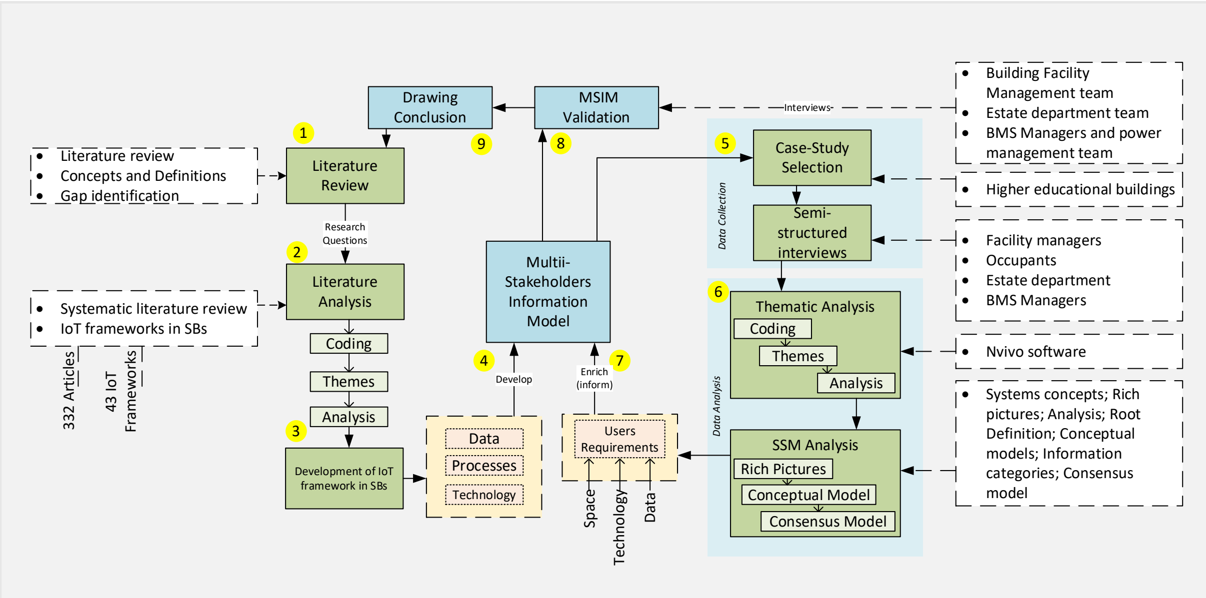


Figure 3-7: Research Design.

The first stage of this research involved examining extensive literature to analyse the existing IoT frameworks within smart buildings. The findings led to the development of a framework that includes the core features of an IoT framework with a smart building. This framework was used to develop a process model for building systems that was supplemented with requirements gathered from semi-structured interviews.

The research focused on the technological aspects of smart buildings and IoT applications, limitations, and frameworks. The review of various studies and IoT frameworks within smart buildings led to the identification of core features of an IoT framework within a smart building that was used to develop the information process model. One of the main limitations identified was the lack of stakeholder involvement in sharing information, resulting in limited identification of their smart building needs. The research used a case study approach to obtain additional primary data by engaging with stakeholders to collect more information about their requirements to address this limitation.

3.8 Ethical Considerations

Regarding ethical considerations, the application form was filled out and submitted for approval before primary data was collected. All stakeholders (supervisory team, departments, etc.) were made aware of the research's aim and objectives. In addition, the supervisory team and those involved in data collection (interviewees) were briefed on the research project and its purpose. As data was collected through interviews, obtaining informed consent from individuals involved was also necessary. In the final thesis or the work derived from the research, quotations are not attributed to any respondents by name. The researcher is aware of any refusal to give data to any of the stakeholders involved in the research. Changes within the organization will directly impact the individuals within it, and thus, another company will be selected for the research. All interviewees were anonymous. After the research was completed, all collected data was kept in a safe place (the University's network and an encrypted hard drive that is password protected) and destroyed when it was no longer necessary. The data will be kept for future publication and practice development purposes.

3.9 Chapter Summary

This chapter has provided a detailed description of the methodology used to conduct this PhD study. The research design was guided by the principles of phenomenology and involved a qualitative approach that aimed to explore the experiences and perspectives of participants in relation to the research question. The data collection process involved the use of literature and primary data sources, including semi-structured interviews with participants. The data analysis involved a thematic analysis approach that involved the identification of patterns and themes within the data. The validity and reliability of the data were addressed through the use of multiple data sources and the careful selection of participants. Ethical considerations were also addressed to ensure that the research was conducted in an ethical and responsible manner. Overall, the methodology used in this study was designed to provide a comprehensive understanding of the research question and to ensure that the findings were reliable and valid.

4 IOT FRAMEWORKS IN SMART BUILDINGS

An analysis of the current IoT frameworks used in smart buildings is presented in this chapter. Throughout the analysis, the study highlights how IoT can be used to meet the requirements of various stakeholders in smart buildings. Following a systematic selection of current studies on smart buildings and IoT, a thematic analysis of the current IoT frameworks was conducted. Furthermore, this chapter presents a novel holistic IoT conceptual framework for smart buildings that considers the various components, data-sharing methods, and applications of IoT.

4.1 Background

Researchers frequently focus on the IoT's communication components, assuming that this is the only factor that users need to consider when sharing information (Batool and Niazi, 2017). However, that method is problematic since it does not consider the numerous components involved in the information exchange process (Panteli, Kylili and Fokaides, 2020). First, focusing entirely on the device's communication capabilities while ignoring the reality that it is a part of humans' daily lives can lead to several problems. Furthermore, one of the major challenges in modelling the IoT using existing methodologies and tools (Hu *et al.*, 2018; Marinakis and Doukas, 2018; Liu, Zhang and Wang, 2020) is that the number of devices in the real world significantly outnumbers the one utilised as a proof-of-concept in traditional simulation tool research publications. The key obstacles to research and development include a lack of real-time models and design approaches that describe the dependable interworking of heterogeneous systems: the interconnections between technological, economic, social, and environmental systems (Batool and Niazi, 2017). In this chapter, a literature synthesis is used to inform the development of an information model that ensures consistent data sharing between all these subsystems to prevent overlapping and give the term "Smart building" its true meaning. However, the developed models must correspond to reality and be comprehensible to all users (stakeholders) interested in the systems' information. Moreover, it shows a need for a detailed and comprehensive generic model based on IoT and integrating these systems within a smart building.

4.2 The Importance of an IoT Framework within Smart Buildings

Many modern challenges increasingly challenge information systems projects in government and academic institutions. Factors such as environmental complexity, dynamism, new technologies, and competition may exploit the weaknesses in a paradigm that is already in place. According to (Einstein, 1946): "A new type of thinking is essential if mankind is to survive and move toward higher levels." Critical thinking is required to analyse the relationships between the current IoT frameworks within a smart building when it comes to implementing and developing building projects. According to Richmond (1994, p. 139), who first coined the term "System Thinking" in 1986, it can be defined as follows: *"Systems Thinking is the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure."*. This part analyses the various IoT frameworks to break out of the old thinking patterns and ultimately reach the higher level necessary to resolve any problem. For this reason, it is becoming increasingly important to develop a deeper understanding of the underlying structure of buildings to make sense of complex and uncertain phenomena systematically (Wirtz, Weyerer and Schichtel, 2019). As interest in IoT-enabled smart buildings continues to grow, there are still a number of challenges to overcome. With the use of ubiquitous computing and communication technologies, smart devices can be seamlessly integrated into the Internet infrastructure, resulting in a new generation of innovative and valuable services. Nonetheless, if all issues do not receive proper attention, then the potential of this ecosystem may be compromised. Building spaces are subject to a wide range of requirements related to comfort, usability, security, and energy efficiency. IoT-enabled systems can provide an integrated response to these requirements. However, it does not consider multiple stakeholders' different perspectives and requirements.

4.3 SL Review for IoT Frameworks in Smart Buildings

In this section, the study followed the PRISMA systematic literature review methodology. Following Page *et al.*, (2020), the PRISMA approach facilitates transparent reporting of why a systematic review was conducted, what the authors did, and what they found.

Systematic reviews serve many critical functions. Future research priorities can be identified based on the current state of knowledge; they are able to answer questions that could otherwise not be addressed by individual studies; they can identify limitations in primary research that should be addressed in future research; as well as generating or evaluating theories concerning the causes and effects of phenomena (Gough, Thomas and Oliver, 2019). As a result, systematic reviews generate a variety of types of knowledge for different types of users (e.g., patients, healthcare providers, researchers, and policymakers).

4.3.1 Study Research Design

This section provides a review based on the SLR method as a research study assessment for classifying IoT frameworks within smart buildings. As mentioned in Chapter 3 in Section 3.4.4, this study carried out a qualitative literature synthesis of the currently used IoT frameworks within the application of smart buildings in response to different stakeholders' needs and requirements. A qualitative literature synthesis applies a massive array of data collection and analysis methods conducted in a wide-ranging format (Drisko, 2020). This systematic literature review section presents inclusive answers to the following question: What are the current issues of IoT frameworks within smart buildings?

This section takes a qualitative approach because it gives a unique depth of understanding and analysis of the collected data (Cruzes and Dybå, 2011). This study used Scopus to select the most relevant papers from the literature that address this topic. Articles were selected by using a systematic approach with the most relevant keywords to the scope of this research (Castleberry and Nolen, 2018). The study focused on generating themes from the literature to be used as criteria to analyse the selected frameworks.

4.3.2 Data Collection

The data was collected using Scopus as it can narrow down the research keywords to fit within the research scope and filter the research according to the document type and time of publication.

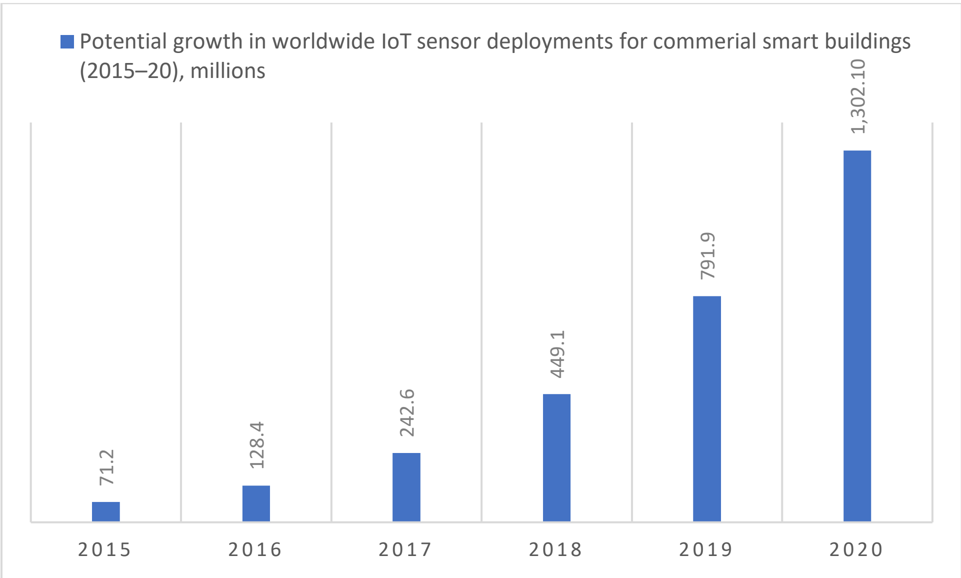


Figure 4-1: Potential growth in worldwide IoT sensor deployment for smart commercial buildings (Battezzati, 2016).

It is an accurate tool as developers claim 99% of citing references used by Scopus matched exactly (Burnham, 2006). Based on a systematic approach, the study selected research papers on IoT frameworks within smart buildings between 2015 and 2020. Figure 4-1, the literature analysis, relied on the publishers' papers from 2015, as the implementation of IoT within smart buildings reached a peak and experienced significant growth afterwards (Kejriwal and Mahajan, 2016). Qolomany *et al.*, (2019) claim that the emergence, development, and initial deployment of IoT technologies and solutions mark the period between 2015 and 2020. It was a time of exploration, learning, and setting the foundation for IoT's subsequent growth and integration into various industries.

4.3.3 Data Analysis

The study adopts Braun and Clarke's (2006) framework for qualitative data analysis as it provides a structured approach and methods of analysis that should be applied rigorously to the data. A key structure for organising data in qualitative research is coding. Coding is a key in thematic analysis to enable the researcher to test and report on coding reliability – indeed, it is considered essential for quality (Terry *et al.*, 2017). As can be seen from Figure 4-2, 332 records were identified through the database search, and 294 records were screened (see studies in Appendix 2, 10.2).

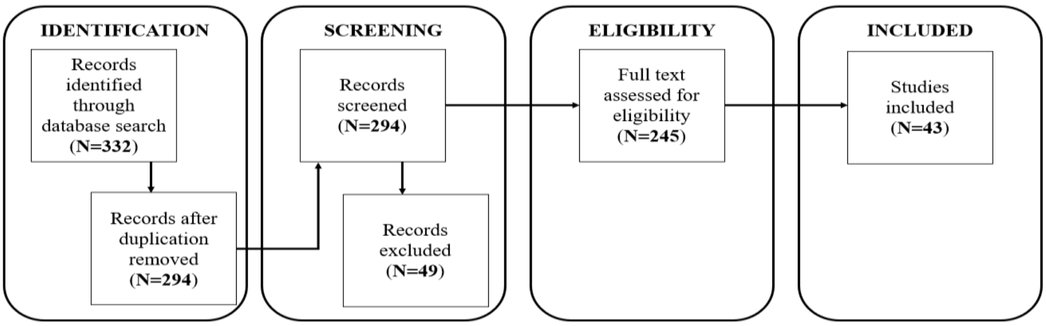


Figure 4-2: Data collection of Systematic literature review.

Qualitative data coding methods fall into two categories: automated coding and manual coding. Coding provides researchers with nuanced access to study informants' thoughts, perspectives, and reactions to study topics. Open coding allows the researcher to select and integrate data organised from the text encoding into coherent and meaningful expressions formed as subthemes (Cruzes and Dybå, 2011). This study uses manual-open coding for collecting data related to each code. The researchers use their data to develop and assign codes and themes manually. Although manual coding is time-consuming, it can streamline the overall analysis process (Williams and Moser, 2019).

4.4 Results

As listed in the findings in Table 4-1, Through the process of coding, the identification and labelling of patterns within data has resulted in the formation of sub-themes. These sub-themes are then analysed and grouped together to form overarching main themes. This process is an essential step in qualitative research, particularly in the analysis of complex and heterogeneous data. Moreover, this process helps to uncover the underlying structures, relationships, and themes that may not have been immediately apparent in the raw data. As a result, coding is an indispensable tool for researchers seeking to analyse qualitative data in a rigorous and systematic way.

Table 4-1: List of codes, sub-themes, and themes.

Codes	Sub-Themes	Themes
Sensors, Actuators, Smart Appliances, IoT objects, Smart Meters, Elements, Components, Entities, Smart Installations, Server, Parameters, Controller, Detectors, monitoring and management of engineering subsystems, access control, video content analysis, resource analytics, things (Sensors), the gateway, and the cloud (networks), motion detectors, sound detectors, light detectors, smoke detectors, alarms, and gate controllers.	Components	**Structure**

System Layers, Physical Infrastructure, Physical Layer, Medium Access Control (MAC) Layer, Application Layer, IoT sensors Layer, Data Management Layer, Analytics Layer, Level, Distribution Layer, Network Layer, and Sensor layer.	Layers	
Smart Energy and Information Networks, WSNs, Statistical Techniques, Energy Consumption Based Networks, Relationships, Communications, Software, Network Technologies [Z-wave and Ethernet], and SDN-enabled edge infrastructure. Edge-Computing, Software-Defined Network [SDN].	Methods	**Methods of data-sharing**
Deep learning, Periodically Transition, Top to Bottom, Real-time Data Analytics.	Data-sharing, Data-flow	
Smart Building Management Systems, Smart Security Management Systems, Facility and Building automation Systems, Small-to-medium Scale Smart Buildings, API-enabled devices in smart buildings, Energy Management Systems, Emergency Management Systems, and Fire Emergency Systems.	Service	**Application**
Smart Facilities, Access Control within Smart Buildings, Increasing reliability of Energy Consumption, Data Generation, Data Extraction, Data Ingestion, Data Analytics, Real-time Control, and Event Prioritisation.	Scope	
Facility Manager, The Customers of Smart Buildings, Fire Fighters, and Residents.		**Stakeholders**

Therefore, as highlighted in Figure 4-3, the analysis has led to focus on four main themes in order to form a clear, structured IoT framework within smart buildings: 1) The structure of the framework, 2) The methods of data sharing, 3) The application area, and 4) The stakeholders involved.

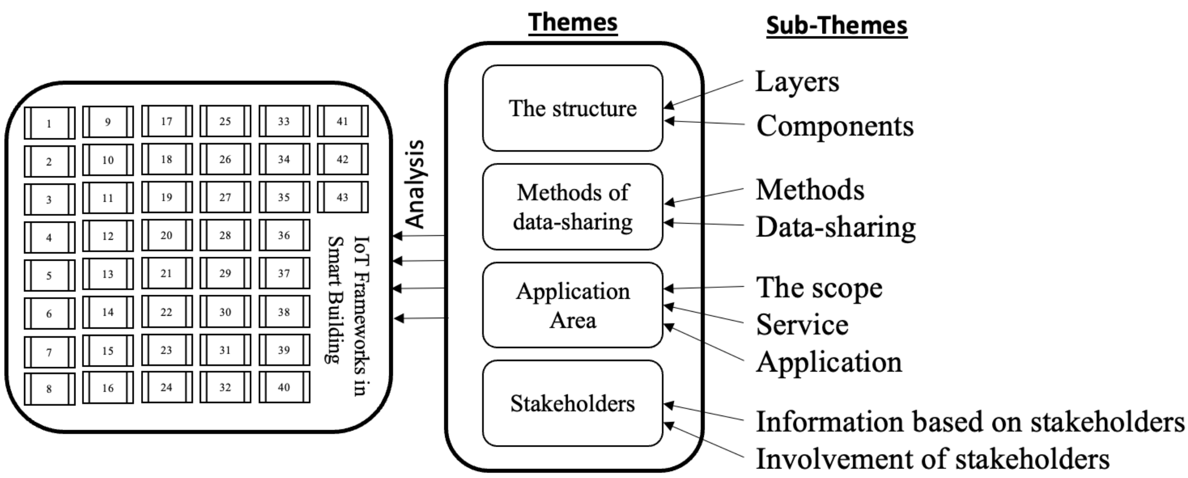


Figure 4-3: Themes map.

In accordance with Al-Fuqaha *et al* (2015), IoT frameworks have four primary objectives: (1) shorten development times and accelerate the delivery of IoT solutions; (2) reduce the apparent complexity associated with deploying and operating an IoT network; (3) enhance application portability and interoperability; and (4) optimise serviceability and reliability. The findings have been classified based on Table 4-2 in order to discuss the importance of considering the different layers, methods of data-sharing, application areas, and stakeholders when formulating a generic IoT framework for smart buildings.

4.4.1 Structure of IoT Frameworks

The structure of the IoT framework refers to the layout of different layers and components used to illustrate the data flow within the framework. Each layer represents a set of elements or components with a unique purpose to help data-sharing between all the layers. Usually, it is presented in a bottom-to-top approach (Raghavan *et al.*, 2020). However, there are many frameworks that do not have a specific structure.

When it comes to analysing the structure of the frameworks, Rehman, Ullah and Kim (2019) used the structure of an IoT framework, which is formed of three layers: sensing layer, network

Layer, end-users, and devices layer. Le, Le Tuan and Dang Tuan, (2019) proposed a framework consisting of three layers: the sensing, delivery and management layer, the data processing and modelling layer, and the smart building services layer. In the same way, Benson *et al.*, (2018) presented a middleware consisting of three main layers: network Infrastructure Layer, data exchange middleware Layer, and Application Layer. Despite the fact that the number of layers is the same, the names and functions of the proposed layers may vary from study to study. Other studies, such as (Liu *et al.*, 2019), proposed a framework consisting of four main layers: The sensing layer, network Layer, cognition Layer, and application layer. Similarly, Sava *et al.*, (2018) proposed a framework structure consisting of four layers: sensor layer, network and communication layer, service and management layer, and Interface and Application layer. In contrast, other studies failed to introduce a structure of the proposed framework, such as Kim *et al.*, (2019), who illustrated the framework's structure by listing the different components, the method used and the explanation of information flow between the components. Likewise, Ateeq *et al.* (2019) and Garzone, Guermouche and Monteil (2018) proposed a framework without layers.

4.4.2 Methods of Data-Sharing

Data can be collected from a workspace in a variety of ways, whether it is user behaviour or work patterns. There are, however, some important rules that must be followed prior to taking advantage of this feature. Moreover, a key part of the structure of frameworks is the data-sharing method used to connect components within the system. As shown in Table 4-2, the data-sharing method can be different from one study to another according to the focus of the study and the problem they are tackling. Studies that are trying to solve the problem of connectivity tend to look at the network methods used to connect the system components. However, studies such as (Koh *et al.*, 2018) used data mapping to transfer between building systems. Other studies, such as (Soultatos *et al.*, 2018), had limitations in demonstrating how data is shared and how components are connected to the IoT framework proposed in their study. Hernández-Ramos *et al.*, (2015) proposed a framework that lacks detail in how decisions are taken, particularly in forecasting (e.g. Looks for space capacity in a building, but it is unclear if it considers future anticipated need).

Also, from the analysis, it appears that the systems in both buildings are built together, so process connectivity is built in. Bellagente *et al.*, (2015) did not demonstrate how the information is being collected and shared with a different user, as the study did not show what each user requires from such a system. Also, what information could be gathered from or shared with each stakeholder? The framework proposed by Hernández-Ramos et al,. (2015) delays response between automated systems and actions performed. Therefore, the framework does not meet the requirements of different stakeholders, which causes a delay in the response time. The findings have been classified based on the following criteria (as highlighted in Table 4-2) in order to discuss the importance of considering the different layers, components, and end users when formulating a generic IoT framework for smart buildings.

Table 4-2: Thematic analysis for currently used IoT frameworks within smart buildings.

Author	Layered Structure	Method of Data-sharing	Application area	Stakeholders
(Jha *et al.*, 2019)	Five Layers	Edge computing	Smart healthcare, smart building, smart transportation and smart manufacturing	Users
(Irshad *et al.*, 2020)	Three Layers	Cloud computing	Smart home	User / Admin
(Al-Shammari *et al.*, 2020)	Five Layers		Smart building applications	
(Prokhorov, Pronchakov and Fedorovich, 2020)		Cloud	Smart buildings	Residents / Tenants

(Liu, Zhang and Wang, 2020)	Four Layers	LoRa technology	Indoor safety management system	
(Zhang *et al.*, 2020)	Three Layers	Edge computing	Building energy management systems	
(Zhang, Wei and Cheng, 2020)	Four Layers	Edge computing	Energy consumption systems within smart buildings	
(Khalil, Esseghir and Merghem-Boulahia, 2020)	Three Layers	Control mechanisms and cloud	Building management systems in smart buildings	End-users
(Anjana *et al.*, 2019)	Eight Layers	IoT gateway	Connected buildings	Consumers, utility companies, building owners, and community managers
(Rehman, Ullah and Kim, 2019)	Three Layers	Named-Data Networking	Smart buildings	Facility and building managers
(Le, Le Tuan and Dang Tuan, 2019)	Three Layers	Cloud computing	Smart buildings' management systems	Property Managers, Apartment Owners, Residents and Third-party service providers
(Liu *et al.*, 2019)	Four Layers	Cloud computing	Energy management systems within a smart building	End-users of people control and manage the building, such as Facility managers
(Zhang, Li and Deng, 2020)		Cloud server	Smart buildings	
(Fayyaz, Rehman and Abbas, 2019)	Three Layers	Fog computing	Fire systems within smart buildings	Building Facility Manager
(Bagaa *et al.*, 2020)	Two Layers	Different clouds and edges and physical network functions	Smart environment	End-users
(Raghavan *et al.*, 2020)	Four Layers	API-based cloud architecture / Top-down standard-based approaches	Smart buildings within smart cities	
(Kim *et al.*, 2019)		Computing from cloud-centric programs.	IoT frameworks within smart infrastructures	Near-users for the system

(Ateeq *et al.*, 2019)		Statistical Techniques and deep learning methods	Small-to-medium scale buildings	Clients
(Pacheco, Benitez and Pan, 2019)	Four Layers	IoT fog and cloud services	Smart buildings application	Users
(Krishnamurthy, Singh and Sriraman, 2019)	Three Layers	Cloud-based	Smart buildings	Building owner Building operator
(Maatoug, Belalem and Mahmoudi, 2019)		Fog computing platform Fog computing	Smart buildings	Consumers of Services IoT applications
(Drummond and Alves, 2015)		By integrating the IoT and BIM data standards	Smart building management systems	IoT stakeholders
(Garzone, Guermouche and Monteil, 2018)		Software services deployed on the cloud	Smart cities, smart buildings, smart vehicles.	System-users and smart city citizens
(Koh *et al.*, 2018)			Information systems within smart buildings	Developers and vendors who navigate building information
(Soultatos *et al.*, 2018)	Four Layers	Cloud computing	Smart buildings	Stakeholders of a smart building
(Sava *et al.*, 2018)	Four Layers	Systems integration between IoT and BIM. Using Network communication, cloud, and data sharing	Building automation and control systems. Smart buildings. BIM models.	Designers
(Hu *et al.*, 2018)	Three Layers	Wireless Sensor Network WSN	Energy management systems	Building occupants
(Ramprasad *et al.*, 2018)	Three Layers	Edge computing, cloud, Bluetooth.	Building management systems	Building facility managers
(Ma *et al.*, 2018)	Four Layers		Smart appliances within a smart building	
(Zikria *et al.*, 2018)	Four Layers	Cloud and/or fog services	Smart water systems	
(Park and Rhee, 2018)	Three Layers	Internet-connected gateway and a dedicated big data cloud	IoT-based smart building	Building occupants

(Zhu *et al.*, 2017)		Cloud services	Building management systems within a smart building	Building occupants
(Pappachan *et al.*, 2017)	Three Layers		Building management systems within a smart building	Smart building users
(Ahvar *et al.*, 2017)	Four Layers	Smart energy and information networks	Smart Security Management System (SSMS) within a smart building	Not mentioned, however, it targets Building Facilities manager.
(Bashir and Gill, 2017)			Building management systems within a smart building	
(Saralegui, Antón and Ordieres-Meré, 2017)	Four Layers	Cloud computing	HVAC systems within a smart room environment.	Residents, building facility managers, doctors and nurses
(Pacheco and Hariri, 2016)	Four Layers	Cloud and Fog computing	Smart infrastructure, such as Smart Homes and Smart Buildings.	
(Bandara *et al.*, 2016)			API-enabled devices in smart buildings	
(Conti *et al.*, 2016)	Two layers		Smart offices, Smart buildings	Office employees and some intruders in the building.
(Krishna and Verma, 2016)		Scheduling and synchronisation methods	Smart home and smart building.	Smart homeowner.
(Carrillo *et al.*, 2015)	Four Layers	Cloud computing and resource sharing. Bluetooth, USB, internet network.	Emergency, resource management (water, energy).	End-users and Administrators
(Bellagente *et al.*, 2015)		network technologies [Z-wave and Ethernet]	Energy management systems within smart buildings.	Customers of the smart building
(Hernández-Ramos *et al.*, 2015)	Three Layers	Cloud computing	Smart buildings' management and control systems.	Property managers, apartment owners, residents, and third-party service providers

4.4.3 Application Areas

The application area in this study is smart buildings. However, some studies focus on developing a framework for a specific system or several systems within the smart building. Generally, most of the analysed frameworks focus on smart buildings. The application area for the framework proposed by Pacheco and Hariri (2016) is the smart infrastructure, such as smart homes and smart buildings. Similarly, Rehman et al., (2019) proposed a framework for smart buildings, and the stakeholder targeted was the facility building manager. A study proposed by Le, Le Tuan and Dang Tuan (2019) addresses a number of stakeholders involved in the process of collecting and acting on data collected and mainly focuses on smart building management and control systems. However, it failed to explain how the different parties are involved in the process of the flow of information. Similarly, Liu *et al.*, (2019) framework targets building Facility Managers who take control of energy management systems within a smart building as the main application service for their framework. On the other hand, Kim *et al.*, (2019) proposed a framework to be used on IoT frameworks within smart infrastructures as the main application, considering end-users as the stakeholders.

4.4.4 Stakeholders of IoT Frameworks

It is important to analyse and manage data that will be included in the final estimation of the day-to-day use of certain systems in the building. Therefore, there is a variety of sensors around the building to extract data collected from the occupants' behavioural patterns (Fabi, Spigliantini and Corgnati, 2017). The managers have to access data to implement better performance and define maintenance plans and custom services; the owners can promote a service of the assets to promote extended uses to increase income, and the users can enrich their experience by the reaction to their behaviour of the built environment (Ciribini *et al.*, 2017).

A key finding is that most research papers reviewed focus on the benefits of implementing IoT technology for better building management performance, not for a better experience for building occupants. However, the literature focused on experience is looked into the health aspect because the majority of health aspects are slightly related to technology (Park and Rhee, 2018; Kim *et al.*, 2019; Khalil, Esseghir and Merghem-Boulahia, 2020). For instance, the use of IoT systems within elderly houses enhances their experience within the building (Saralegui, Antón and Ordieres-Meré, 2017).

4.5 Discussion

Based on the thematic analysis from the frameworks analysed, the themes identified were in relation to structure, methods of sharing data, application, and stakeholders. In relation to structure, papers discussed many different IoT framework structures (See Table 4-2) for different systems within a smart building. Each framework focuses on addressing a specific issue, and there is a limited focus on creating a structure that could be used on multiple systems within a smart building. In some cases, IoT frameworks focus on explaining the function of a particular layer of the framework rather than considering the different parts within that layer. IoT frameworks within smart buildings need a clearer layered structure and research direction, mainly taking the form of what is relevant to the study to which they are being applied (Burhan *et al.*, 2018). However, no single study agreed that the IoT framework within smart buildings could be applied to multiple systems within a smart building (Pacheco, Benitez and Pan, 2019). Smart buildings vary in complexity, and the number of framework layers depends on the requirements of the specific building and system for which the framework was designed. The methods of data sharing between systems in a smart building can be a potential cause of added complexity with regard to IoT frameworks (Benson *et al.*, 2018).

In relation to data-sharing methods, it is important to consider the type of technologies, theories, and communication methods used to transmit data from one layer to another. Data sharing provides information flow within applications. Ammar, Russello and Crispo (2018b) advise choosing the most appropriate data-sharing method that can be used to support information flow between components within an IoT structure. Information flow between different components within the system should be clearly identified as it shows how the different layers are interconnected and complement each other (Kanter, Rahmani and Mahmud, 2014).

According to Perumal, Sulaiman and Leong (2013), IoT frameworks offer significant value for enabling interoperable IoT applications by hiding much of the complexity of multiple information flows and messaging solutions that incorporate hundreds or thousands of components. In addition, data schemas present consistent, declarative, and vendor-neutral expressions of IoT objects. Due to the differing nature of systems within smart buildings, careful consideration of the individual differences between systems is required. As a result, IoT frameworks that support the extensive range of systems that are present within smart buildings can be developed.

With relation to stakeholders, this paper has highlighted that despite the extensive work done on IoT frameworks, incorporating multiple requirements of different stakeholders seems to be a continuous challenge (Woo and Menassa, 2014; Ståhlbröst, Bergvall-Kåreborn and Eriksson, 2015; Robert *et al.*, 2017; Ahmed, Alnaaj and Saboor, 2020). The majority of developed IoT frameworks are primarily designed for one stakeholder (While, Krasniewicz and Cox, 2018; Pašek and Sojková, 2019). However, due to the significant expansion of systems and subsystems within a smart building, additional stakeholders, such as building facility managers and energy advisors, who are usually manually assigned access as needed, are included in the process of sharing information. Also, the number of stakeholders has grown significantly to include, among others, occupants, managers, and staff members of those smart buildings due to the implementation of many sensors in the building environment. Occupants can, for example, personalise their own experience, while managers of smart buildings can now enforce policies for the use of buildings for better energy cost as part of increasingly tight operation budgets (Menassa and Baer, 2014). Multiple stakeholders can provide different perspectives on the demands, requirements, and conflict resolution between smart building systems. However, most of the frameworks analysed in this study have shown multiple smart building stakeholders' lack of involvement in data sharing. Domestic smart systems, such as smart thermostats, lighting control systems, and security systems, are increasing the expectations of building users in several ways: (1) These systems provide increased convenience and control for the users, allowing them to easily adjust various aspects of their home environment through a smartphone or other device. This can include things like controlling the temperature, lighting, and even the security of their home remotely. (2) Smart systems often provide increased energy efficiency, which can lead to cost savings for the building users. For example, smart thermostats can learn a user's schedule and adjust the temperature accordingly to reduce energy consumption, and smart lighting systems can be programmed to turn off lights when a room is not in use. (3) Smart systems often provide increased safety and security features, such as remote monitoring and alerts for intrusion, fire, and other hazards. This can give building users peace of mind, knowing that their home is being monitored and protected even when they are not there. Overall, domestic smart systems are raising the bar for building users' expectations regarding convenience, energy efficiency, and safety.

Continuous research on IoT frameworks is required to successfully implement smart buildings in the future using IoT to connect any individual, system, and the entire environment from any location and at any time. In an advanced smart building, artificial intelligence and machine learning are used to analyse the data collected, which increases the demand for integrated heterogeneous data. As a result, the building industry-standard technical requirements for IoT and its integration needs were identified (Jia *et al.*, 2019a).

4.6 Developed IoT Framework within Smart Buildings

This study started with a review of different studies of IoT and smart buildings and selected the main studies with IoT frameworks within a smart building. It extracted all the core features of the analysed frameworks to form a four-layered framework for IoT. The work explains various functionalities of the IoT and how functionalities are integrated into the system to develop smart buildings. The presented framework solved the limitation of a clear structure of a layered framework and looked into the different methods used for data sharing within IoT frameworks. In this study, one of the key points was that the framework presented provided a means for addressing the limitation of involving different stakeholders in sharing information with one another. In spite of this, the framework presented by the author was unable to solve this problem, so this will have to be addressed in the future.

It was taking into account the applications that have already been presented in previous studies, which have mainly been related to smart buildings. It is also important to consider the different IoT structures and methods of data sharing proposed in the studies that have been analysed. An IoT framework is presented within the context of a smart building in order to provide a detailed understanding of the main features. The following are different layers of the framework that can be explained as follows:

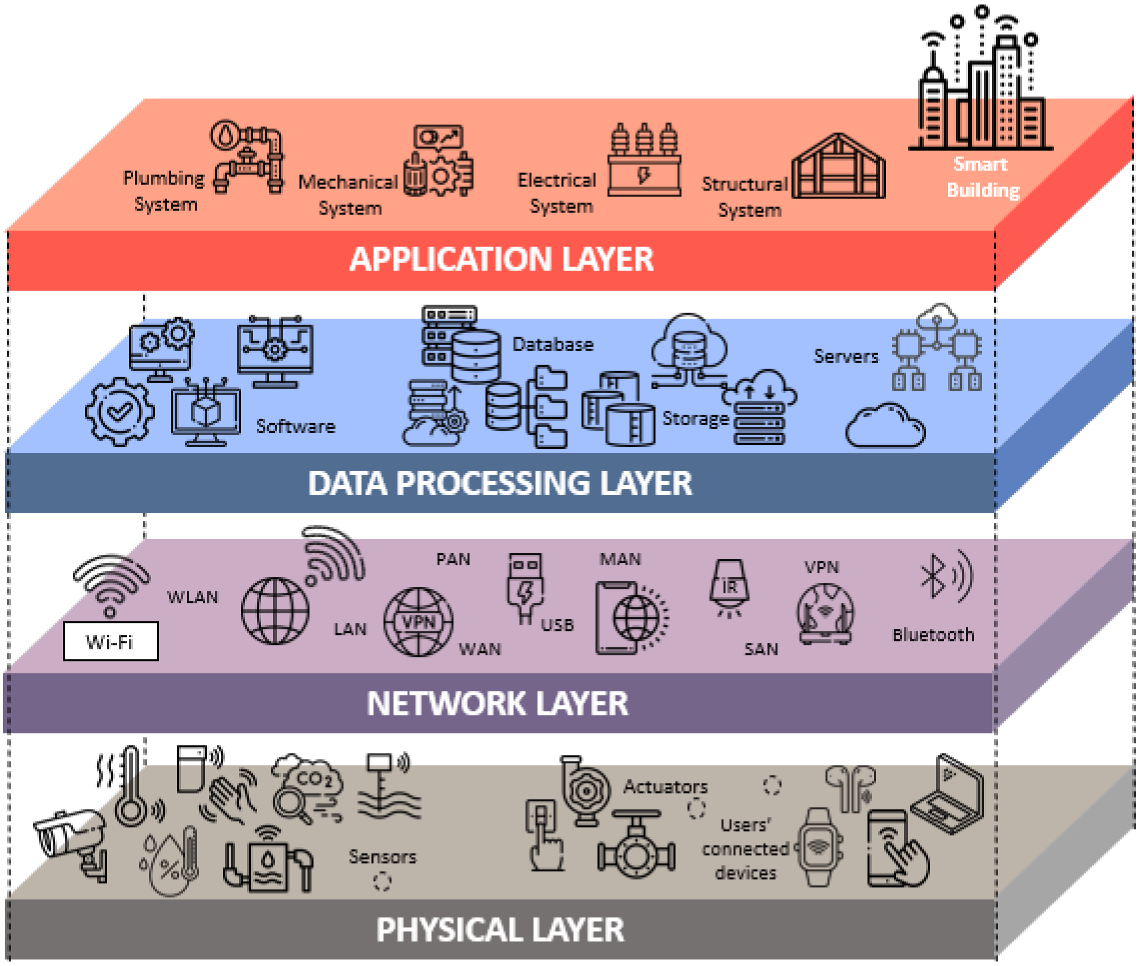


Figure 4-4 IoT conceptual framework in smart buildings.

4.6.1 Physical Layer

Smart buildings collect large amounts of data from as many different sources as possible. The building systems and sensors are capable of huge volumes of operational data regarding conditions, levels, maintenance needs and more. Data capture provides a fundamental smart building layer and a layer that should fully provide a complete ecosystem of trackers and sensors, producing real-time data to be stored in storage data for processing and analysis in the data processing.

4.6.2 Network Layer

There are several ways to connect components, and networking plays an important role in this regard. For example, wireless sensor networks play a key role in continuously detecting and monitoring building energy, the environment and the behaviour and interactions of different users and stakeholders.

4.6.3 Data processing Layer

IoT systems are designed to capture, process, and store data for additional requirements in this layer. Each device sends millions of data streams to the IoT network. Here, the data comes in different shapes, speeds, and sizes. Separating essential data from these voluminous flows is a major concern. Unstructured data in raw forms, such as photos and video streams, can be quite huge and needs to be done efficiently to collect factors for the business. Understanding the procedures to identify data needs and obtain future benefits helps enhance data-sharing within the IoT system. In addition, interoperability between systems and sub-systems of smart buildings plays a role in the data processing layer.

4.6.4 Application Layer

The application layer is the systems and services with which stakeholders of different building systems interact. The responsibility of this layer is to deliver application-specific services, which are smart buildings in this case, to the different stakeholders—for example, adjusting the optimum temperature for a building space where the IoT system collects data from the surrounding environment and sets the temperature in the space.

4.7 Limitation and Conclusion

A key limitation of IoT frameworks within smart buildings is the lack of the different building stakeholders' involvement. The majority of IoT frameworks are developed primarily for one stakeholder. However, due to the significant expansion of systems and sub-systems within a smart building, additional stakeholders, such as building facility managers and energy advisors, are usually manually assigned access as needed. Also, the number of stakeholders now significantly grows to include, among others, occupants, managers, and staff members of smart buildings. Occupants can, for example, personalise their own experience, while managers of smart buildings can now enforce policies for the use of buildings for better energy cost as part of increasingly tight operation budgets. Multiple stakeholders also create potential between their different demands, requirements, and conflict resolution. However, most of the frameworks analysed in this study have shown a lack of involvement of multiple smart building stakeholders in data sharing. It reviewed 332 studies between 2015 and 2020 regarding IoT frameworks within smart buildings by examining the application of IoT frameworks, their structure, and how data is presented within the proposed structure. The review has investigated the benefits of smart buildings, current research limitations, and existing frameworks' core components of an IoT framework in smart buildings.

In conclusion, based on the findings, a number of issues have been identified with the IoT frameworks currently being used in smart buildings. For example, some of the key issues reported include structure (Maatoug, Belalem and Mahmoudi, 2019), data sharing (Al-Shammari *et al.*, 2020), and application implementation (Bashir and Gill, 2017), a holistic framework is formulated to emphasise the importance of an integrated system between various layers. The available evidence indicates that many IoT frameworks in existing studies are developed to overcome a specific problem. The researchers involved in the analysis provided their perspectives on the development of IoT frameworks for smart buildings. In addition, the estimates of the use of IoT frameworks in smart buildings vary considerably from study to study due to the fact that different frameworks are employed in the same application. There are several conceptual IoT frameworks that have been proposed for smart buildings, each with its own set of key concepts, components, and relationships. It is evident that an integrated system framework is lacking.

One of the primary issues remains the lack of incorporating multiple users' perspectives within the process of sharing information, which will be investigated in future research. As only one stakeholder has typically been considered in the existing studies, the role of several stakeholders within a smart building has been highlighted. A limitation of this study is the lack of consideration of multiple stakeholders at the end of the construction process. As all functions are interconnected, the inclusion of multiple stakeholders can have a significant impact. Future work will address to what extent the results from research and technological development work in the IoT frameworks in smart buildings match the identified stakeholder requirements developed.

4.8 Chapter Summary

According to the contemporary literature, this chapter discussed the relationship between stakeholder information flow and building management systems. Furthermore, the correlation between the stakeholders and buildings' systems was evaluated to identify users' different needs related to the buildings' systems and subsystems. As a final step, an explanation of the information process connectivity within the IoT and the building's stakeholders and systems is presented to better understand the alignment between the stakeholders and the systems of the building. Buildings will be viewed as a system consisting of several systems and subsystems for this study.

This chapter discusses the values and complexities of IoT frameworks within the context of smart buildings based on a literature review. By examining the application, structure, and presentation of data within the proposed IoT frameworks, this study reviewed 332 studies conducted between 2015 and 2020 regarding IoT frameworks within smart buildings. An examination of the benefits of smart buildings, the limitations of current research, and the enhancement of the capabilities of existing frameworks have been conducted in this review. Based on the review, a holistic framework is developed to emphasize the importance of an integrated system at different levels.

5 Case Study and Results

5.1 Introduction

The purpose of this chapter is to present the results of a case study on a Higher Educational Building. The previous chapter explained that the case study was chosen to investigate the stakeholders' requirements for a smart building in use. This chapter shows how the results of one interview influenced the direction of the next step. The focus of the case study was on stakeholders within a building currently in use, which included the Facility management team, the Estates department, and the building occupants (students and staff).

5.2 Background

The purpose of the chosen case study was to obtain insights into the perspectives on smart buildings by examining the definitions of smart buildings and the operational process from the perspectives of the different stakeholders. In the literature, smart buildings are defined as buildings that use technology and rely on it to operate effectively. However, the incorporated users of the building are seen as an essential part that needs to determine the means and challenges to be addressed to ensure that it succeeds in reaching their perspectives. It is anticipated that the range of meanings may result from various experiences and different roles within a building. The results of this study suggest that there is a need to determine what constitutes a smart building, as well as the factors that affect delivering a more enjoyable experience for people using the building. So, 'Use of space' is chosen as the concept to be examined to develop an understanding of smart buildings. This is because space provides the medium through which different perspectives can be positioned.

As the purpose of this chapter is to address the requirements of various stakeholders within the building, people with different roles within the building are involved in perceiving their work environments in different ways. This is done by looking into the daily activities performed by each stakeholder, and each can identify ways in which they can enhance the process. The findings of this case study show that smart buildings have a multitude of meanings and that a wide range of factors affect them. The case study also revealed that different people have different views of buildings and definitions of smart buildings.

5.3 University Campus Case Study

The chosen case study, City Centre Campus, is a multi-million-pound centre of excellence in the heart of Birmingham's East-side development. The campus consists of several buildings (Curzon Building, Millennium Point, Parkside Building, Joseph Priestley Building, The STEAM house building, and the Conservator). These buildings were built to accommodate different faculties within the university (e.g., the Parkside building is home to both the Birmingham Institute of Art and Design and the Faculty of Performance, Media, and English). Below is a detailed description of the buildings selected:

- **Millennium Point**

Millennium Point is a versatile complex in Birmingham, UK, serving multiple functions. It acts as a meeting and conference venue a public building, and is managed as a charitable trust. Inside, you'll find various event spaces, including a 354-seat auditorium that once housed a giant-screen IMAX cinema. Additionally, it houses the Birmingham Science Museum. It serves as the home for the School of Acting within the Royal Birmingham Conservatoire and Birmingham City University's Faculty of Computing, Engineering, and The Built Environment.

- **Parkside Building**

The Parkside Building is a key component of Birmingham City University's City Centre Campus. It caters to several functions and is home to multiple academic schools. Specifically, it hosts the Birmingham School of Architecture and Design, the School of Fashion and Textiles, and the School of Visual Communication. The building is designed to provide modern and collaborative learning environments, featuring studios and social spaces conducive to creative endeavours.

- **Curzon Building**

The Curzon Building holds a prominent place within Birmingham City University. It has evolved over the years, originally from the Department of English & Secretarial Studies in the 1950s. Since then, it has transformed into a hub of education and creativity. The building houses various faculties and departments, making it a centre for academic pursuits. It has been crucial in supporting students across disciplines, including arts, design, and media. In addition, the library of Birmingham City University Library city centre campus is located within this building.

- **STEAMhouse Building**

The STEAMhouse Building is a cutting-edge facility dedicated to innovation and entrepreneurship in Birmingham. It boasts extensive space spread across five floors, providing state-of-the-art office facilities and support for businesses. What sets STEAMhouse apart is its focus on fostering collaboration among a diverse community, accommodating small to mid-sized enterprises as well as larger organizations. The building serves as a catalyst for creative ideas and business development within the Birmingham community. It currently houses the Faculty of Computing, Engineering, and The Built Environment in Birmingham City University.

- **Joseph Priestley Building**

The Joseph Priestley Building is an essential component of Birmingham City University. It was constructed to house key departments, including Estates Management, HR, IT, and

Finance. The building underwent meticulous fit-out work to meet high specifications, featuring meeting rooms, server rooms, collaborative "huddle" spaces, and well-equipped kitchens and coffee areas. It also received comprehensive interior upgrades, including new flooring, decorations, and an extensive furniture and equipment package. The building's infrastructure was enhanced to include a new Cat 6 data network, a controlled access system with CCTV monitoring, fire alarm improvements, and power and lighting installations adaptations.

- **Conservatoire Building**

The Conservatoire Building, also known as the Royal Birmingham Conservatoire, is a prestigious institution in Birmingham, offering education in music, acting, and related disciplines up to postgraduate levels. It is a unique conservatoire as it is affiliated with a university, specifically the Arts, Design, and Media faculty at Birmingham City University. The building houses a 500-seat concert hall and various performance spaces, including a recital hall and a dedicated jazz club. Founded in 1886, it holds historical significance as the first music school to be established in England outside London. Today, it continues to be a prominent centre for music and drama education and performance in the region.

5.3.1 A Rationale For the Selection

It is argued that using university buildings and spaces is one approach for having a successful case study for creating a smart environment (Villegas-Ch, Palacios-Pacheco and Luján-Mora, 2019b; Ahmed, Alnaaj and Saboor, 2020; Alrashed, 2020). The city centre campus of Birmingham City University is a small town with over 2,500 users, 10 Buildings, and over a hundred teaching spaces with implemented smart technologies within them. According to the facility management team, it was argued that the use of this technology would enable a smart building to be achieved for the complete life of the building and potentially provide a solution to support better management throughout its operation. Using the campus as a living workspace is a tool for smart building development. Some of the space projects may lead to behaviour change by individuals and institutions; these projects allow students to act in support of developing a smart building.

5.3.2 Research Participants

This case study targeted stakeholders of the different buildings within the city centre campus. The first group is represented by the facilities management team and estate departments team, as these are two entities working together to operate and maintain the building daily. The second group is the building management team, and these stakeholders (e.g., BMS managers and energy managers) hold managerial positions where they can control and act on data gathered from the different systems in the building. Finally, the third group is grouped as occupants representing the stakeholders using the building, such as students and staff members. It is important to note that the selection of the stakeholders was mainly based on their roles and the stage of the building. The stage of the building is the operational stage, as it is important to the scope of research to collect data from a building in use to assure the quality of the gathered information. Additionally, the interview questions were designed to explore misunderstandings regarding the nature of the research and what could be defined as a smart building from multiple perspectives because it is important to have a clear and shared understanding of what is being studied in order to ensure that the research is valid, and the results are meaningful.

Misunderstandings can lead to incorrect assumptions and misinterpretation of data, ultimately compromising the research quality. By exploring these misunderstandings through interview questions, researchers can identify potential areas of confusion or disagreement and address them, thereby increasing the accuracy and reliability of the research results. Additionally, considering multiple perspectives can help ensure that the definition of a smart building is comprehensive and inclusive, considering a range of different viewpoints and opinions.

5.3.3 Data Collection Scope

Semi-structured interviews were conducted with the parties mentioned above in order to collect the data. There were some differences between the interview questions used by each party. This is because the data was collected from stakeholders based on their roles and daily interaction with the building and its systems. The data was collected by forming the questions in the interviews as the researcher refers to certain systems by their actual name. However, in certain situations where the participant is unaware of what a term or phrase is used for a specific system, the researcher explains the term, e.g., the Internet of Things will be referred to as sharing information using sensors to some participants.

As mentioned before, a study objective is to inquire into smart buildings and how information is shared within the concept of smart buildings. Therefore, the interview questions focused on exploring definitions of smart buildings and the processes conducted to achieve the concept of a smart building. The case study examines the role that *technology* (IoT) plays in smart buildings as part of the overall research goal in order to determine the value it brings to smart buildings and the limitations it can overcome.

5.4 Results and Findings

The findings are presented in tables where each represents the parties mentioned above: the building management team, the facility management team and the building occupants. Each table consists of the focus of the questions and the participants involved with their responses. In order to clarify the responses, Table 5-1 has been used to categorise them.

Table 5-1: Participants' table

P	Role	Min-biography for the participants
P1	User / Occupant	As an Admin Manager Staff member, P1 possesses extensive experience in organizational administration and management. Their role involves overseeing the administrative aspects of smart building projects, making them well-suited to provide insights into the operational and administrative challenges faced in implementing smart technologies within buildings.
P2	User / Occupant	P2 is a versatile participant, serving as both a Research Assistant and a PhD Researcher. With a strong academic background and a focus on smart building technologies, they contribute valuable research skills to the study. P2's dual role allows them to bridge the gap between theory and practical application in the context of smart buildings.
P3	User / Occupant	P3, a Fellow Academic Tutor, brings an academic perspective to the study. Their expertise lies in pedagogy and curriculum development, making them well-placed to discuss how smart building concepts are taught and integrated into academic programs, offering valuable insights into the educational aspect of the study.
P4	User / Occupant	P4 serves as a Lecture Assistant, actively supporting academic activities related to smart buildings. Their role involves assisting in lectures and workshops, and providing hands-on support to both students and lecturers. P4's engagement in academic interactions enhances their understanding of practical challenges and student perspectives.
P5	User / Occupant	P5 holds a dual role as a PhD Candidate and Visiting Lecturer. Their academic journey as a candidate contributes research insights, while their experience as a visiting lecturer offers practical knowledge on how smart building concepts are taught in different institutions.
P6	Facility Manager	P6 is a Facility Manager with expertise in the day-to-day management of buildings. Their practical experience in facility operations and maintenance provides a valuable perspective on the challenges and benefits of implementing smart building technologies.
P7	User / Occupant	P7, as a student, represents the end-users and beneficiaries of smart building technologies. Their experiences and expectations as building occupants offer an essential user perspective, shedding light on the impact of smart technologies on daily life within buildings.
P8	User / Occupant	P8 is a dedicated Ph.D. student with a focus on smart building technologies. Their academic pursuits contribute to the study's research component, enriching the examination of smart building trends and advancements.

P9	Estate department / BMS Manager	P9 holds a dual role in the Estate Department and as a Building Management System (BMS) Manager. Their expertise in real estate management and building systems management positions them to discuss integrating smart technologies into property management.
P10	Estate department / BMS	P10 complements P9's role in the Estate Department and BMS. Together, they offer a holistic perspective on property and systems management in the context of smart buildings.
P11	User / Occupant	P11, as an Associate Staff member, plays a vital role in day-to-day building operations. Their insights into practical challenges and operational needs contribute to the study's understanding of facility management.
P12	User / Occupant	P12 is a Lecturer and Workshop Manager, providing academic guidance and practical workshop experiences. Their role bridges the academic and hands-on aspects of smart building education.
P13	IT Manager	P13 serves as the IT Manager, responsible for technology infrastructure within buildings. Their expertise in IT systems and cybersecurity offers insights into the integration and security of smart technologies.
P14	IT Assistant	P14 supports P13 in managing IT systems. Their role involves troubleshooting and ensuring the smooth operation of technology within smart buildings.
P15	Estate department /Power Manager	P15's dual role in the Estate Department and as a Power Manager allows them to provide insights into power management within smart buildings, addressing energy efficiency and reliability.
P16	Estate department	As a key figure in the Estate Department, Participant 16 brings a wealth of experience in managing and overseeing the physical assets and properties of the organisation. Their expertise lies in real estate management, property valuation, and strategic planning to optimise the organization's estate resources. P16 contributes to the Estate Department's perspective on property management. Their role adds depth to the examination of real estate-related challenges and opportunities.
P17	Facility Manager	P17 is another Facility Manager, offering a distinct viewpoint on facility management practices and challenges within the context of smart buildings. Participant 17 is a Facility Manager with a strong background in maintaining and optimising facility operations. Their expertise spans maintenance, space planning, safety regulations, and budget management, making them a vital part of the study.

5.4.1 Roles and Duties in the Building

It is important to define roles and responsibilities in order to provide clarity, alignment, and expectations to those responsible for executing the work and maintaining the building. Identifying roles and responsibilities facilitates effective communication between the various stakeholders teams and the integration of the departments and systems in the building. The following quotations show some of the roles of the participants:

"*I am an assistant lecturer in computer science. I am mostly working in Millennium Point, and I work from my office here. I use the labs and the classrooms for teaching purposes. This is me in a nutshell and what I do in this building*." (P4, MPB)

Defining the role of occupants in a building is essential to understanding how they interact with the spaces and systems. The above quotation illustrates the participants' most important spaces in (P4, MPB) daily activities. On the other hand (P6, PSB) explains his role as:

> *"I work for facilities. We are basically old-fashioned caretakers."*

This role is mainly responsible for maintaining the facilities as (P6, PSB) explains in the following quotation:

"We try and maintain the systems the best we can with our limited knowledge because we are not (do not know) of what goes on in the buildings. We do need professional contractors to comment, finalise, issues, faults, but anything facilities can do themselves, we will do it." (P6, PSB)

It is important to note that most building stakeholders are not limited to the space in which they are located, but they can also use multiple interactive spaces, such as the library or other open areas of the building.

"*Sometimes, I go and use other areas to motivate myself in doing work. So I've tried the library in the Curzon building, computer facilities (on the bridge between MP and Parkside),* *Starbucks coffee shop in the Parkside building, and the different pods across the building*." (P2, MPB)

Knowing the roles and the daily responsibilities determine how different stakeholders from the different departments work together to achieve certain objectives. The following quotations give an example of how people work together and share information to achieve organisational objectives:

"*I'm one of the senior learning developers working in the Centre for Academic Success, which is part of EDS, which is the Education Development Service. So, what we do is we support students and colleagues or academics in helping them to improve student retention, to improve student attainment gap."* (P3, CBB)

"*My daily bases tasks is providing a first line support for staff and students who are on site as well as looking after the hardware and software that is deployed in the various rooms across the site."* (P14, PSB)

The quotation above illustrates the interaction and support that multi-stakeholders with different roles in the building provide each other daily. As can also be seen, technical support is provided by the IT team and other skills support is provided by academics and staff. Roles play a significant role in influencing stakeholders' perspectives when trying to understand what a smart building is. In addition, a stakeholder's level of role provides an understanding of their involvement in a building as (P9, JPB) explains:

"*I'm the BMS manager. It's a fairly new role, actually, because I'm the first person to hold it. I've been here about two and a half years. I also sort of manage the contractors who come in and service the plans and the BMS systems*." (P9, JPB)

The above quotation illustrates some of the duties of a stakeholder in a managerial position and how they utilize both technical and human resources. This will help define how utilizing both resources in the building can facilitate the completion of tasks. According to the job description, (P9, JPB) is also responsible for integrating the different building management systems into a single system so that all buildings can communicate with one another using only one interface.

"*One of the things in my job description was to get them amalgamated into just the one*." (P9, JPB)

In the quotation above, the participant means by "*them*" the different BMS systems within the buildings in the university. In the following quotations, other different stakeholders illustrate their roles within the different buildings in the university:

"*I am a support technician and I work for IT at Birmingham City University*." (P14, PSB)

"*I'm a fashion design student, and in my final year, I'm in about three days a week, but I'd like to come in mainly every day so I can use the facilities on all the sewing machines and the print rooms and knitting and all of those kinds of things*." (P7, PSB)

"*My primary role is a researcher, a PhD student. I use the Millennium Point building largely to do my research work, and I also use the Curzon building. I use the Parkside just to walk through as a bridge. Also, I am a staff, and I teach in my lecturing role. So that is what I do in the buildings*." (P5, MPB)

5.4.2 Definitions and Concepts of a Smart Building

In the absence of a standard explanation for what a smart building is, the concept and view of a smart building may differ from stakeholder to stakeholder. Based on their respective roles within the building, each stakeholder will define what is smart according to their own perception and understanding. An example of this might be a facility manager who examines a smart building from the perspective of maintaining it most efficiently. It is important to note that the implementation of smart technologies has generated considerable interest among most stakeholders in utilizing smart technologies in their buildings. However, poorly implemented technologies may disempower occupants, taking control away from them regarding the environment, and insufficient instruction or training can lead to incorrect implementation of technology, resulting in inefficient operation of buildings.

A smart building is associated with technology, which is seen as an important aspect that makes a smart building based on the responses of the IT team. However, they have pointed out that sharing information with different stakeholders through the embedded network in the building will ease the process of getting the daily work done. For instance, looking at two responses received from the IT team regarding the meaning of a smart building:

> "*A smart building is just simply making it work better for you in terms of providing the access and providing security, providing a comfortable environment in terms of and it can include things like energy efficiency, for example, as well as security. So yeah, that's what comes to mind."* (P13, PSB)

The above-mentioned quotation defines a smart building from the needed requirements point of view. These requirements are summarised as security and a comfortable space supporting energy efficiency. However, efficiency might not be a concern of the participant according to his role in the building. Yet, he has mentioned that it is a key aspect that a smart building must include. However, when looking at efficiency based on an occupant view, it is realised that a more structured response was provided with how efficiency could be perceived within a space in a building (in addition to those mentioned by the other stakeholder group). How efficiency is seen is as follows:

> *"I think if there's no one in the room, I do think for the environment, it's good that they should be turned off, not just to help the environment, but it also helps their*

organization as well reduce their costs in terms of the electricity bill, Even the heating bill as well." (P3, CBB)

On the other hand, the next quotation mainly highlights that a smart building is defined by sensors that gather data to set the most suitable environment for users.

"A smart building incorporates a multitude of sensors which gather different aspects of the building such as lighting, motion, it can even detect weight and temperature and humidity as well and automates some tasks, simple tasks such as the lighting switching on when you enter the room or heating adjusted depending on the temperature of the inside and outside." (P14, PSB).

The above quotation explains the aspect of data collection through various sensors to automate simple tasks within the building, such as controlling the light and the temperature of the building. According to the results of this study, stakeholders view smart buildings from a variety of perspectives. Smart buildings are defined differently by different people based on different requirements and drivers. However, some users do not feel comfortable with the idea of smart buildings and the benefits they may provide.

"I think that is one of the problems with the smart buildings as well. It might suit some people, but not everyone." (P6, PSB)

The above quotation confirms that some users might accept a smart building, but it does not interest other users, as they can explain how they would like the most suitable environment for them to be, and then building managers see how smart buildings can achieve this. Hence, a smart building or space can be viewed from three different drivers, as seen in Figure 5-1.

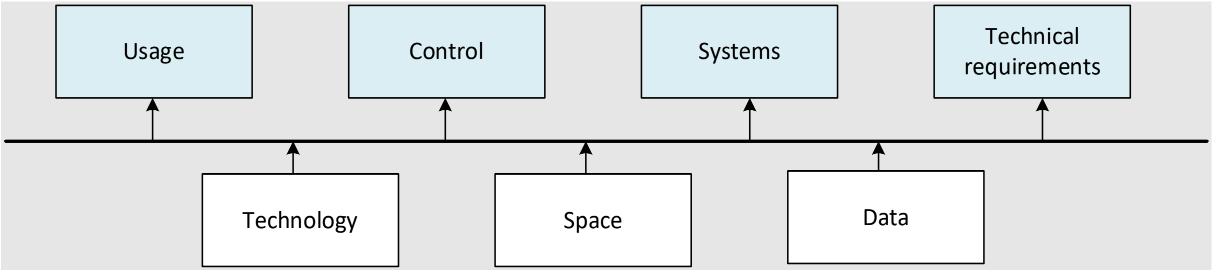


Figure 5-1: Stakeholders' perspectives in Smart Building.

The concept of a smart building derives from consolidating several factors, including technology, space, and data. These drivers were identified through a comprehensive analysis of responses obtained from interviews conducted with building occupants, managers, and estate department personnel, as highlighted in Figure 5-2.

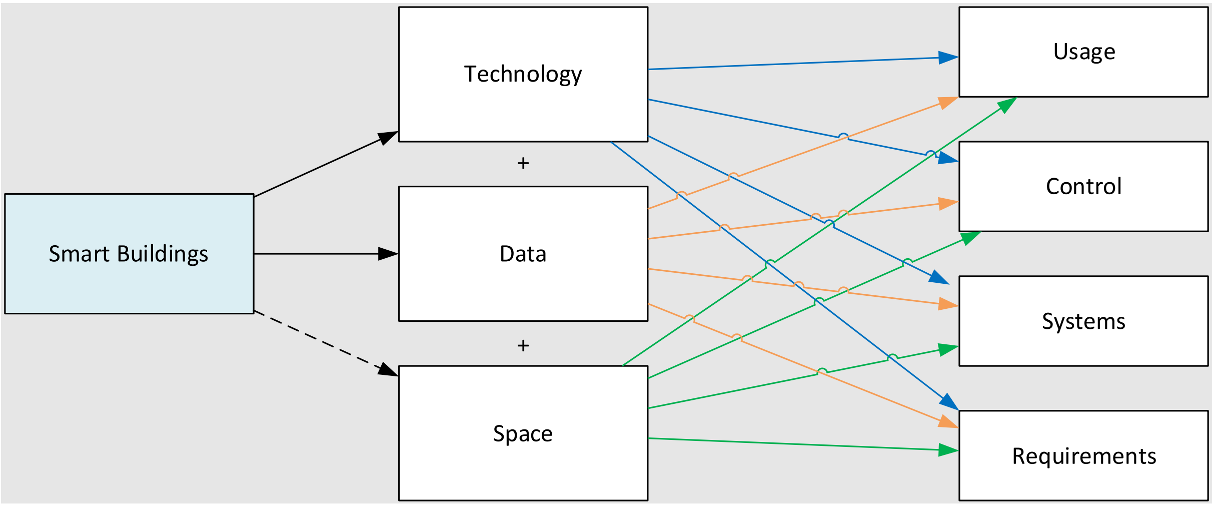


Figure 5-2: Stakeholders' drivers to view smart buildings.

The participants' responses showed that smart buildings are characterised by their ability to utilise technology to enhance the overall services and occupant experience. In addition to technology, smart buildings are also designed to maximize the use of available space. This can be achieved through the integration of flexible workspaces that can be easily reconfigured to meet changing occupancy needs. Data is also a critical component of smart buildings, as it allows building managers to make informed decisions about building operations and maintenance.

5.4.3 Technology

Smart building technology refers to the tools that stakeholders are able to use for monitoring, analysing, and optimizing how their buildings operate. They can benefit from these systems by increasing energy efficiency, improving indoor air quality, and making their workplace healthier, happier, and more productive. Users are able to gain greater insight into the objects in their workplace that they use every day, from pipes to furniture, from heating systems to windows and doors, by using Internet of Things technologies. Smart buildings can be transformed from conventionally inert items into connected devices by incorporating sensors. As a result, smart buildings are equipped with sensors that provide real-time updates on the use of the building, energy consumption, maintenance, cleanliness, air quality, viral risk, and many other factors. Many stakeholders view a smart building from a technological perspective. It is their belief that smart buildings can only be created by integrating and implementing technology, as illustrated by the quote below.

> *"I think, for me, a smart building is all about technology."* (P6, PSB)

The above-mentioned quotation explains that smart buildings are associated with technology. On the other hand, other people believe that even with technology implementation, it fails to deliver what it is expected to deliver. The following quotation illustrates how people are carried away with the idea of automating processes within a building without considering that it may not be suitable for the majority of users. In addition, some stakeholders continue to worry about integrating and finding the most suitable methods to connect all the implanted technologies.

> *"To my mind, I haven't found anything yet that looks like a shining example. There are always sorts of gaps in the thinking and this Internet of Things idea. I think a lot of*

people get carried away with the idea of just automating everything and everything being smart and intelligent without thinking about the unintended consequences and some of the barriers that there may be to doing that and some of the technological barriers to doing it in terms of the openness of the protocols that are used between the different types of sensors and controllers that you might want to be using." (P15, JPB)

The interviews with different stakeholders revealed that technology is understood from various perspectives. While some participants are interested in the use of technology, others are primarily concerned with the technology implemented in the building, some with the degree of control they have over these systems, and finally, with the requirements needed to implement these technologies.

5.4.3.1 Use of technology

The use of technology within the building depends on some drivers. In other words, how technology is used to satisfy some stakeholders' requirements in their workspace. (P4, MPB) has explained the importance of technology within the workspace environment when defining a smart building. The following quotation by (P4, MPB) shows what requirements technology could fulfil for different stakeholders in the building. As seen in the following quote, the participant was mainly concerned about the safety that the implemented IoT technologies could bring to the environment.

> *"A smart building has to use these IoT devices for safety-critical functionalities"* (P4, MPB)

Along with the technology being used to meet the requirements of stakeholders, others view the use of technology as a method to create an automated environment. The following quote shows how automation is perceived as an important element in smart buildings.

"This is the way things are going. Smart buildings, you can walk in an area one person, and that room will adjust itself to accommodate the needs of that person." (P6, PSB)

The question remains, however, whether it is necessary to be something meaningful for some stakeholders, as they do not see the value of automating the control process for the building's systems. The

*"**Does technology add any value to you within your workspace?** At the current time, not really, from my point of view, as most of it can be done manually. You can adjust the heating yourself."* (P14, PSB)

In summary, the use of technology for (P14, PSB) is primarily aimed at automating the process of switching on and off systems within an environment. Regarding technology being viewed to automate processes in the system, the participant does not agree that it could add any value. This may be a result of unclear information about how and what technology can deliver in a building.

5.4.3.2 Technology Systems

In buildings, technology systems may be understood as a collection of innovative tools, machinery, modifications, software, etc., that enable advancements in the field of construction, including semi-automated and automated equipment. A key system in buildings is the BMS system and the systems connected.

"Each building has a building management system that has controllers and sensors that control what happens in the building. So it's mainly controlling the HVAC, lighting, that sort of stuff. So, at the moment, each building is on a different system. So, they have different types of controllers, and the software itself that manages those controllers is

different. So the project is to bring all of the different buildings onto a common shared platform." (P15, JPB)

The previous quotation shows the systems implemented in the building, and technology is used to connect and integrate all these systems. (P15, JPB) explained that a key element for using technology is to make sure all those systems equipped in the building are working under one controlled platform. However, (P3, CBB) argues that integrating systems using technology is not easy.

"We have some great technology out there, but it's getting them to talk to each other and integrate them and getting them to work." (P3, CBB)

"What I would consider a smart building is an interconnection of a mixture between IT and building." (P5, MPB)

5.4.3.3 Technology Control

Taking control of the technology within a space is an unsolved issue in smart buildings; there are a few problems associated with who could control certain systems in certain spaces. This could happen through a strategy set between teams in the building. However, the following quotation indicates how complex different teams make the situation and how it can create problems.

"The problem is, the more complex that strategy is, it's good for making a building smart in the long run, but in the short term, you've only got to have a few lines or something in that strategy that's been altered or maybe corrupted or whatever. All of a sudden, it can cause all sorts of problems. It takes people a long time to find that problem." (P10, JPB)

Another problem could be that users would like to control their systems within their space environment. The reason is that they do not trust technology to take over their simple way of communicating with the environment, which they were used to before.

> *"It takes time to learn technology. Technology fails you. Technology frustrates people, and it can cause surprises every now and then. If you are teaching and technology fails, then you are like, There, I can not do the class that I have just planned."* (P12, PSB)

The following quotation by the same participant highlights that there are requirements from users to have control of the technology instead of relying completely on it to change the environment around them.

> *"I like to know that the lights are going to work. I like to know that I can control the temperature. I would like to know that the electricity will work, just about it."* (P12, PS)

5.4.3.4 Technology requirements

A technology requirement refers to the need for such systems in the space environment. The following quotation explains that users are interested and excited about implementing technology in buildings rather than looking at the requirements for implementing them. Technology requires integration and the ability to be used correctly by the many stakeholders in the building to deliver the desired output. In addition, there is the concern of privacy where many users won't be happy with using technology for privacy issues and concerns.

> *"People get very excited about this connectivity idea, but without thinking about what you're actually going to use it for, I think there are so many stakeholders involved, and there are also all the Privacy issues involved."*

Most of the users of the building are interested in the technology and smart devices installed in the building rather than in understanding why and when they should be utilised. The requirements for these devices differ from one space to another. According to (P2, MPB) data is an essential requirement for technology, and it should only be accessed by the users related to it.

> *"The people related to this development should only be the ones that can access the data to ensure that the autonomous systems work properly (assuming it will be implemented)."* (P2, MPB)

The above-mentioned quotation illustrates that data is a key driver for technology. However, the technology requirements are viewed differently from the point of view of other stakeholders.

5.4.4 Data

In computing, the term 'data' refers to discrete facts, such as numbers. It is possible to structure data to obtain information, organise data to create knowledge, and apply that knowledge to provide wisdom, for instance, to make decisions. However, data in this context is mainly referring to the data collected from users, spaces, and smart devices in the buildings. Users are concerned about sharing data about the spaces they use. An example would be the temperature of the space and why there is no clear indication of what the temperature is inside the space. The following quotation shows that the participant needs to access the temperature data and assumes that there is no indicator within the space showing that information. The participant may be seeking data on where users can find this information in the space, so the question is where such information may be located.

> *"I wanted to check the temperature. I cannot figure out what the temperature is here; there is no indicator, and even if there is, it is not anywhere which I am aware of."* (P4, MPB)

On the other hand, building managers and the estate department would like users to share their requirements through a platform (e.g., Outlook) to help monitor the space they are using.

> *"So, If people use Outlook or whatever to actually put in their diary requirements. And yes, that could be integrated into a BMS. Sure. It could be."*

The above response shows that data collected from many users could be beneficial factors. However, such a response provides awareness of who would and would not share their information, as many users are mainly concerned about the privacy of the data they share.

> *"Sometimes it goes back to privacy, and data collection is what you would want to do with that data."*

5.4.4.1 Use of Data

(P2, MPB) stated that the use of data is one of the main considerations to achieve a smart building. Moreover, and from a broader perspective, the participant mentions the need to share data with other stakeholders to develop different solutions for smart buildings.

> *"Keeping this data with the related people and sharing it with other academics for research projects will keep developing innovative solutions to the building." (*P2, MPB)

In addition, the data could be used to notify users of the building when certain situations occur within their workspace. In clarifying that, the (P2, MPB) stated:

> *"Send you an email or a message notification once you are running low or running out of a certain product."* (P2, MPB)

It could also be used to make certain processes automated and cut down the number of processes stakeholders usually go through. (P4, MPB) suggests that:

"The cards that we used to enter the building and the data that are collected from this system can be easily used to spare the students from the not very productive process for us sending and queueing for the checks to be done." (P4, MPB)

According to the above-quoted quotation, occupants could be tracked using the access control systems to enrol for a monthly visa check without queueing and signing for attendance. However, the integration between the two systems is missing in the suggested process. Also, a key fundamental point by (P5, MPB) is that sharing the data of the space and how it can assist the building facility manager in tracking the issues raised by building occupants who reported a fault within the space, followed by a contact from the facility team for those who are using the space to inform them that the issue has been resolved. (P5, MPB) discussed the importance of the previously mentioned process of data shared between the stakeholders:

"The data I am interested in, as I said earlier, would be about what is the space capacity of each room and where I am likely to find space quickly without wasting time and, what the temperature is like in those rooms and what is the air circulation. For a building manager or worker, he might want to know where there are any building issues that have been reported and how I can use the data about faults that have been logged or complaints that have been logged and use this to make my job easier." (P5, MPB)

On the same level, the building manager agrees that it is beneficial to understand the information about the place stakeholders are using.

"I think knowing the usage of the area that you are using is an advantage. If it started to rain the windows would close." (P6, PSB)

It is essential to understand and know the usage of the space in order to ensure that the space can be used effectively. As evidenced by the previous quotation, the facility management team would benefit from having other users or systems respond to the environment around them. According to the study, how the data is used in the building is a crucial issue that is of interest to all stakeholders. Each stakeholder, however, views the situation from a different perspective. For example, a staff member may be concerned about the data for security reasons, while a building manager may be interested in improving the building's performance.

5.4.4.2 Data Systems

In the building, several systems rely heavily on data to function. As an example, the access control system collects and stores information concerning the number and time of stakeholders entering and leaving the building. The following quotation emphasises the importance of integrating the systems that collect the data to achieve the desired outcome.

> *"I believe the integration of some smart sensors and mechanical systems can help in getting input to the system and contribute to adjusting the output of the system."* (P2, MPB).

From the quotation by (P2, MPB), it appears that building systems can be integrated if they can understand the data that is shared between them.

5.4.4.3 Data Control

Most stakeholders find this section to be one of the most concerning. Throughout history, there has been and will always be an argument as to who has access and who does not have access to the data. It is more important to determine which of the stakeholders has control over the data rather than relying on machine learning and sensors to do that.

"The people related to this development should only be the ones that can access and control the data to ensure that the autonomous systems work properly (assuming it will be implemented)." (P2, MPB)

According to the previous quotation, it is important to ensure that only the people who are using the premises have access to this information. In reasoning why such a statement is true, every stakeholder will look at it from their own point of view. For example, a member of the facility management team may understand that the rest of the users may not be able to interpret the data coming from the systems. On the other hand, a staff member or student will primarily be concerned with the privacy of the information they share with systems and other stakeholders and who has access to and control over it. The following quotation discusses how it is difficult to please everyone in terms of how other users understand that there are certain regulations regarding the use of data. For example:

"Now the problem for us is we cannot please everybody, and you have to explain to the users that each room has got the temperature, it sets at 21 degrees" (P6, PSB)

Moreover, only those who are responsible for the management of the building would understand why other users should not be able to access and control the data. Based on the following quotation, certain building systems are made to work in a particular manner as a result of data.

"is controlling the time schedules and sensors and set points and all the rest of it." (P10, JPB)

Nevertheless, there are several stakeholders who have control over the shared data from their personal devices and how it might be accessed (e.g., location services). Each stakeholder does not necessarily need to be able to control the thermostat in a specific space.

"It's not plugged into the BMS. But if you had talked about if it detects people's devices, you could switch on ventilation or lighting, and then you certainly save energy. You don't want stuff running when you don't need it" (P9, JPB)

As discussed in the previous quotation, the control of data within specific systems within the building by different stakeholders may result in an environment that is inefficient.

5.4.4.4 Data requirements

In the building, certain systems and devices require some aspect to function. Data requires sensors and other smart devices to collect. There is then a system for cleaning and interpreting it to be used, and most importantly, a network for transferring it through the correct path to the target system.

"I would expect Wi-Fi or any communication signal to be easily accessible. I would say in these new buildings, especially in CAS, there have been numerous issues with Wi-Fi. Actually, if I get Wi-Fi or even getting reception on your phone, I wouldn't even say Wi-Fi, I would say reception. I mean, now, sometimes I have to go outside in the open in that garden space on level one just to get reception, just to get a phone call or to get a text message. So I would say in that sense, I would put it down as below average."

In the previous quotation, a number of those data requirements are outlined that are necessary in order to create a data-connected environment.

5.4.5 Space (Environment)

One of the most important aspects of a building is the amount of space that can be used to meet the requirements of different stakeholders. This quotation explains the importance of the environment in a building when it comes to delivering the correct and desired experience for stakeholders.

> *"The office environment is the key thing for us to be comfortable and has the right temperature and these sort of things; otherwise staff won't be happy and won't do a good job."* (P11, CB)

Space within a building is often associated with a building's comfort and suitability for use.

> *"The key thing when using a building is the use of comfort."* (P4, MPB)

In order to understand how space is viewed from different perspectives when considering a smart building, the following sections explain how space is viewed from different perspectives.

5.4.5.1 Use of Space

Space refers to how a certain stakeholder prefers to use a space or has the required knowledge of how a space should be used. The use of space is a key element of how people perceive a smart building. The use of space was appointed as one of the key components that define a smart building by a number of stakeholders.

> *"It will be the usage of the building, which is obviously really useful, comfortability of the building if the things we talked about are fine and clear, that would be a big thing for the university and for the Millennium Point."* (P1, MPB)

It is evident from the above quotation that the participant highlights the benefits of knowing what the purpose of the space is to help users feel comfortable.

> *"For teaching, we use a lot of computer labs for a large group of students, and I prefer the rooms in Curzon."* (P1, MPB)
>
> *"I suppose good examples are we quite often walk around the estate, and at some point, a space has been chopped up and used. Someone said, oh, here's a lovely old storage*

cupboard. It's quite a good space. It's got a window; let's turn it into an office. But because it's been designed as a storage cupboard and not as an office, it hasn't got any mechanical ventilation delivered to it. And then people wonder why they're getting headaches, and they wonder why it's a horrible space to work in." (P1, MPB)

A functional and ready-to-use space is always required. The users, however, misunderstand that the space will be effective for the purpose for which it was designed. In light of the previous quotation by (P1, MPB), several spaces in the building could be repurposed to perform functions for which they were not intended during the design phase. Following is a discussion of how different stakeholders interpret their requirements based on the space systems.

5.4.5.2 Space Systems

It is important to note that stakeholders have a variety of expectations regarding what system requirements should be implemented in each area. However, it appears that the majority of stakeholders agree on the importance of a good lighting system, a good energy transfer system where I do my gadgets, and then a good temperature in the building in addition to a good environment (As it can be seen from the following quotation).

"There should be a space where you can come, study, good lighting system, good energy transfer system where I do my gadgets and then a good temperature in the building plus a good environment." (P8, CBB, JPB)

A building's space system should be able to deliver what a smart building promises on the inside and its equipment. According to the following quotation, certain systems have been unable to achieve what they are expected to due to problems in the design of the space zoning. As a result of the design of the space, there are systems implemented in the building that do not work because the level of accuracy required of them cannot be met.

"There's also the ability of the kit itself, the equipment that we've got in buildings, to be able to actually deliver what the inside of things smart building is promising. There's a lot of talk about doing all this fancy zoning and having more personalized HVAC delivery. Well, a lot of our buildings couldn't deliver that. You couldn't zone it to that level of accuracy. It just wouldn't work." (P15, JPB)

The user's role determines the level of controlling space in the building and what the space is used for. In a classroom, for example, students and teachers will have control over the layout of the room, but not on most of the systems.

5.4.5.3 Space Control

Mainly, controlling the space environment depends on the systems implemented within the space and the user who controls them. There are regulations governing who has control over spaces within the building, and all stakeholders should be aware of these regulations.

"Estates have the policies on heating and what the procedures are if it is too hot, too cold, whether it is in summer or winter and what the temperature should be." (P6, PSB)

According to the previous quotation, Estates have policies regarding heating and what the procedures are in the event that it is too hot or too cold, whether it is summer or winter, as well as the appropriate temperature.

5.4.5.4 Space requirements

A stakeholder's space requirements may differ from another's, which mainly depends on the space used.

"The lights of the library are not beneficial for me because we don't have the big wood tables that we can use to cut fabrics and stuff" (P7, PSB)

This quotation examines the buildings in the case study as a whole by identifying what type of space (P7, PSB) is required and where to locate it. Conversely, (P10., JPB) considers the space requirement from a health and safety perspective. Based on the following quotation, it is evident that a space must be able to control things better in terms of safety and behaviour towards its systems.

> *"What we've got to deliver to allow that to happen. Things like the CO2 sensors we need a lot more CO2 sensors and smarter systems in some of our other buildings to be able to control things better, and two, the data collection over a period of a week or month or whatever it might be because that tells us how something is behaving could be used usually ventilation or water"* (P10, JPB)

When considering the different perspectives of different stakeholders in a smart building, there are three main drivers to consider. The following section explains the findings and results of the collected data using semi-structured interviews.

5.5 Data Analysis

The social and technical systems approach is used to analyse the key elements of the interview findings. The reason for choosing SSM comes from the literature related to IoT and smart buildings. IoT is considered as the technical part of the system, while stakeholders of the building are seen as the social part of the system. As established in Chapter 2 Section 2.2, smart buildings include technology, people, processes and data, which has led this study to use SSM systems as a lens to contextualise the data obtained from different perspectives and how the stakeholders' requirements are perceived in the context of smart building. This has shaped the findings to focus on three aspects of a building (Data, Technology, and space) to understand how each stakeholder perceives a smart building. As discussed before, each stakeholder has a different view of smart buildings, and the collected data showed the drivers that led to different stakeholders' creation of that view. In this section, the socio-technical system approach is used to see where and how those drivers would fit in STS systems.

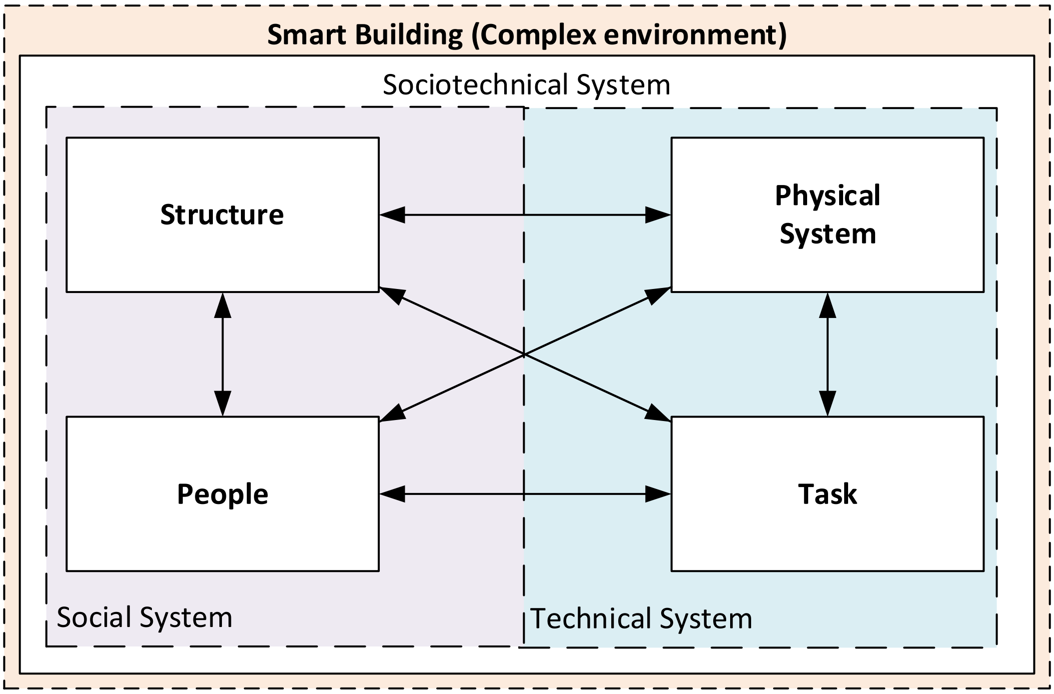


Figure 5-3: Socio-technical Approaches in Looking at the Complex System of a Smart Building.

The socio-technical element will engage in goal-directed behaviour to achieve the integration of sub-systems within smart buildings. The interaction of social-technical systems will create a joint optimisation within various subsystems within the building, as opposed to either technical or social elements. Therefore, while trying to understand the meaning of a smart building for each stakeholder, social principles such as the impact on people, infrastructure, technology, processes, culture and data must be considered. The vertical integration will usually have a set of goals and metrics within the building. The stakeholders within the building with varying attitudes and skills interact with technical systems within the organisation. The technological components include IoT, customisation within a physical infrastructure, operating with different views, and using sets of processes and working practices. These five factors are interdependent and interact with each other within the building. Special care must be taken while considering the vertical integration to consider the interaction factors. The vertical integration system should also be considered within a wider context, incorporating a regulatory framework, sets of stakeholders, and an interactive environment (Space). A self-regulating component of vertical integration within the building should further track the evolving nature of the needs of the subsystems. Such a mechanism will bring balance within the technical and social subsystems to maintain a steady state condition within the vertical integration. The design of both the social and technical system for horizontal configuration must be done simultaneously within the value of all stakeholders in the building. Therefore, understanding the means of stakeholders' different requirements for horizontal integration should be considered in the entire building system. There should be cooperation and coordination between the participating stakeholders to achieve a common goal through horizontal integration (Satisfy the stakeholders' requirements to solve the intended problems raised in the environment).

5.6 Chapter Summary

This chapter documents the data and findings from the case study undertaken in this research. There were different targeted stakeholders, and the findings reveal different views of smart buildings (Space, Technology, data). It also showed that stakeholders have different views of buildings and building operations. Also, it showed that inquiring into different experiences of using space supported encapsulating different factors influencing the use of a smart building. Finally, it showed that representations of space, technology and data need to be information-rich to capture the different requirements of smart buildings.

Therefore, for the next chapter, soft systems will be applied as an analytical tool to explore the divergent views of the case study. Therefore, using soft systems, each of the findings of this chapter will be used to represent the different views. It is anticipated that the use of soft systems will help explore how to bridge the gap between data, technology and space to understand the different stakeholders' different requirements for smart buildings.

6 Soft Systems Analysis

6.1 Introduction

This thesis explores the problem of connectivity and sharing information within the smart building. Soft Systems Analysis is a human-centric approach, emphasising stakeholder engagement and problem structuring capabilities, making it a strong choice for addressing stakeholders' diverse needs in smart buildings in IoT frameworks. While the Viable System Model (VSM) is valuable for analysing organisational viability, its focus on internal structures might be less suited for addressing the specific challenges of smart building IoT frameworks. Based on the results, it appears that the problem can be divided into two fundamental domains. Specifically, these domains are concerned with how people perceive and act in the world. First is the technical domain, which consists of the different technologies implemented in the building. Within the technical side, information and data are key elements to running and controlling the technical systems embedded in the building. Second is the social domain, which mostly consists of people’s views, perspectives, behaviours, requirements, and experiences. As explained in the literature, the problem is that the technical part does not take into consideration the different requirements of the other part. These two parts of the system are currently working independently of each other, even though there are various ways to establish their connection. In the world of Information Technologies (IT), this fundamental problem is not novel but is often overlooked since new applications and models are marketed to provide companies with a new capability to act in the world. This chapter uses the empirical findings to inform the research model. First, the criteria for discussion involve dividing stakeholders' requirements based on technology, data, and space. The Soft Systems Analysis (SSA) is used as a tool to understand the requirements related to the different requirements that make smart buildings presented (As highlighted in Figure 6-1).

According to Checkland (2000), SSM analysis offers a means of ‘‘*intervening in the complex, ongoing flux of interacting events and ideas which unfolds through time, to bring about improvements through an organised process of learning which can absorb and deal with the multiple worldviews which will always be present*’’ and thus, plays an important role in understanding complexity associated with emerging technology. The outcome of an SSM analysis is a set of capabilities and high-level specifications of an organisation's capabilities. This includes models of purposeful human activity that embody the capability of transforming inputs into outputs (Watson *et al.*, 2018). This study uses SSM analysis to explore the complex situation of incorporating the different stakeholders’ requirements in a smart building aligned to the themes, as shown in Figure 6-1.

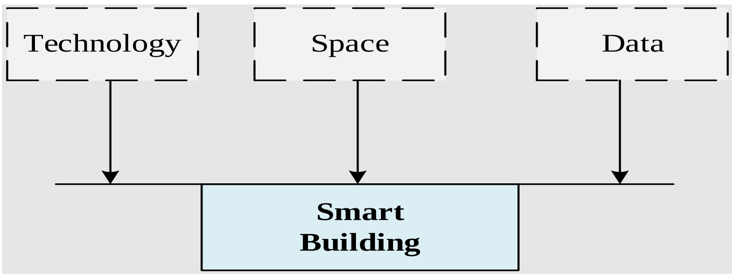


Figure 6-1 Main themes that make a smart building.

6.1.1 Why Soft Systems Methodology?

The results highlight there are divergent views regarding smart buildings. As a result of the nature of the case study and the individuals involved, some complexities relating to how a smart building should behave were revealed, but no solution was suggested as to how to resolve these difficulties. Yet, the interview results highlighted a need to consider the different areas that smart buildings rely on, as these influence the stakeholder’s views on what a smart building is. Also, the literature review summarised that the current use of technology (e.g. IoT) in Smart

Buildings does not acknowledge the different stakeholders' perspectives. Considering and understanding those elements requires looking at each element from a single stakeholder’s perspective to understand the different complexities when combined under one system. Therefore, using SSM will enable representing a holistic and collective view while considering divergent viewpoints. SSM acknowledges the whole situation and the components that make it up (Zhang, 2011; Bernardo, 2018). Therefore, SSM is ideal for methodologically exploring complex, divergent viewpoints and deriving solutions that enhance the situation. Hence, to bridge the gap of understanding a smart building from different views, SSM analysis is used to explore the stakeholders' views to unravel the complexity and how this impacts information sharing in smart buildings.

The study adopts Wilson’s SSM to identify data categories and develop conceptual models that will be used to enhance a situation further by identifying information categories, such as those which can be used to demonstrate the significance of the parts (Wilson, 2017). The SSM analysis begins with a 'rich picture', which provides a holistic view of the current situation, highlighting the individuals involved. Based on the rich picture, CATWOE analysis will be used to illustrate the differing worldviews of the parties involved in this study to derive root definitions. In the context of a systems modelling environment, the real world is represented by these root definitions. After this has been completed, conceptual models are developed to represent the activities that need to be performed to satisfy the different worldviews. Information categories are then derived from the consensus model and mapped onto the developed multi-stakeholder information model to show the information required for a smart building from different stakeholders' views. These steps will be applied to each of the stakeholder groups in turn to understand the different requirements and the divergent views on smart buildings. In turn, this will allow the researcher to bridge the gap in understanding the concept of a smart building from different stakeholders' perspectives.

Finally, SSM operates more detailedly, emphasising the detailed description of problem situations and stakeholders' viewpoints. It involves creating conceptual models that represent the problem context, including human activities, perspectives, and relationships.

6.2 SSM Analysis Conceptualisation

The three main elements in Figure 6-1 highlight the core themes that broadly define the concept of a smart building. However, further analysis of the findings shows sub-themes that are also core requirements (e.g., comfort) that stakeholders see in a smart building. Therefore, it is important to derive how each stakeholder sees a smart building by defining the most important elements that will be used to derive the requirements, the gap in information flow between the different stakeholders and also between the different systems within the building. Therefore, the core components can be extended (Figure 6-2) to capture and summarise the different ways each stakeholder defines smart buildings.

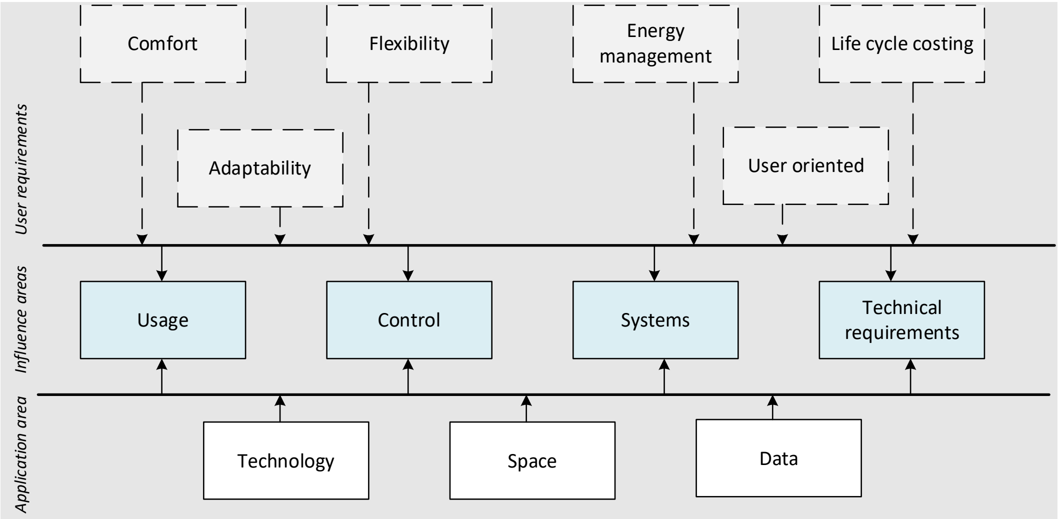


Figure 6-2 Empirical Data Themes and Subthemes.

Some stakeholders will be very interested in integrating technology into the way they perceive smart buildings, while others consider the data which is being collected from them and how it is being used. On the other hand, there are few who perceive a smart building from a space point of view. For example, they are interested in how the space is laid out and used and how reflective the space can be to meet the different requirements of those stakeholders. These are further represented using a rich picture to understand the different requirements of different stakeholders and how they can be looked at from a holistic point of view.

6.2.1 Rich pictures

A soft systems analysis begins with the formation of the 'rich picture', which represents the views of different stakeholders; often, one rich picture is created to represent the views of different stakeholders. However, since each stakeholder defined a smart building from their point of view depending on certain drivers (e.g., experience, role, daily responsibilities), a rich picture representing all the stakeholders was produced to represent their view demonstrated in Figure 6-3, as the requirements differ. The rich picture shows how these influences are very important in determining how each stakeholder considers a smart building, as shown in 6-4. From the rich picture, different stakeholders are influenced by the space they are using (e.g., a staff member from the Millennium Point building would define and view a smart building differently from someone who is using the Curzon building). Depending on the stakeholder group, the occupants' comfort may be viewed differently from the facility manager's view. In this context, rich pictures are initially used to identify an interaction between all stakeholders in buildings (Smart Buildings) to show how stakeholders perceive those requirements differently; thus, the rich pictures must be separated according to their perceptions.

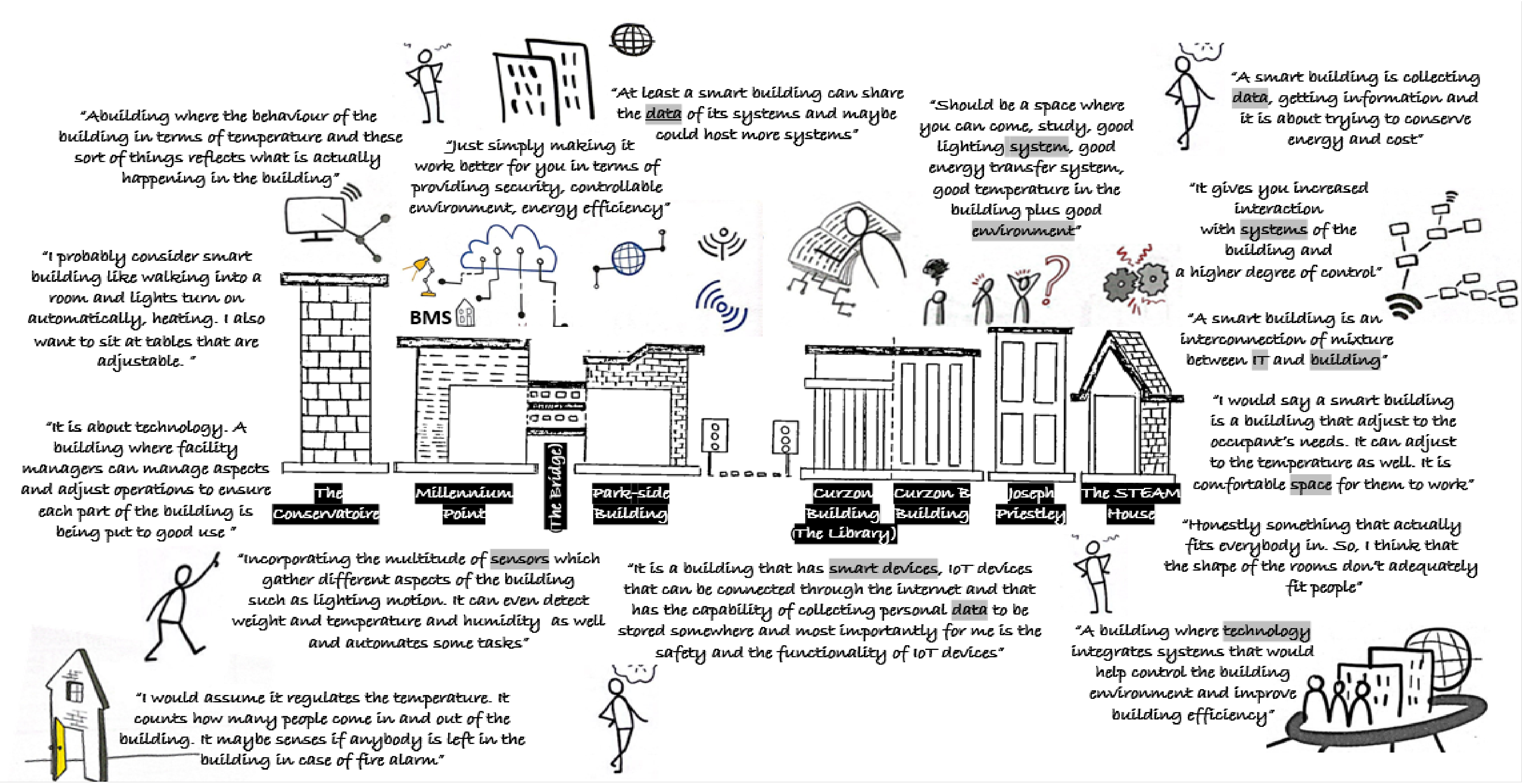


Figure 6-3: Rich Picture of Different Stakeholders' Views of Smart Buildings.

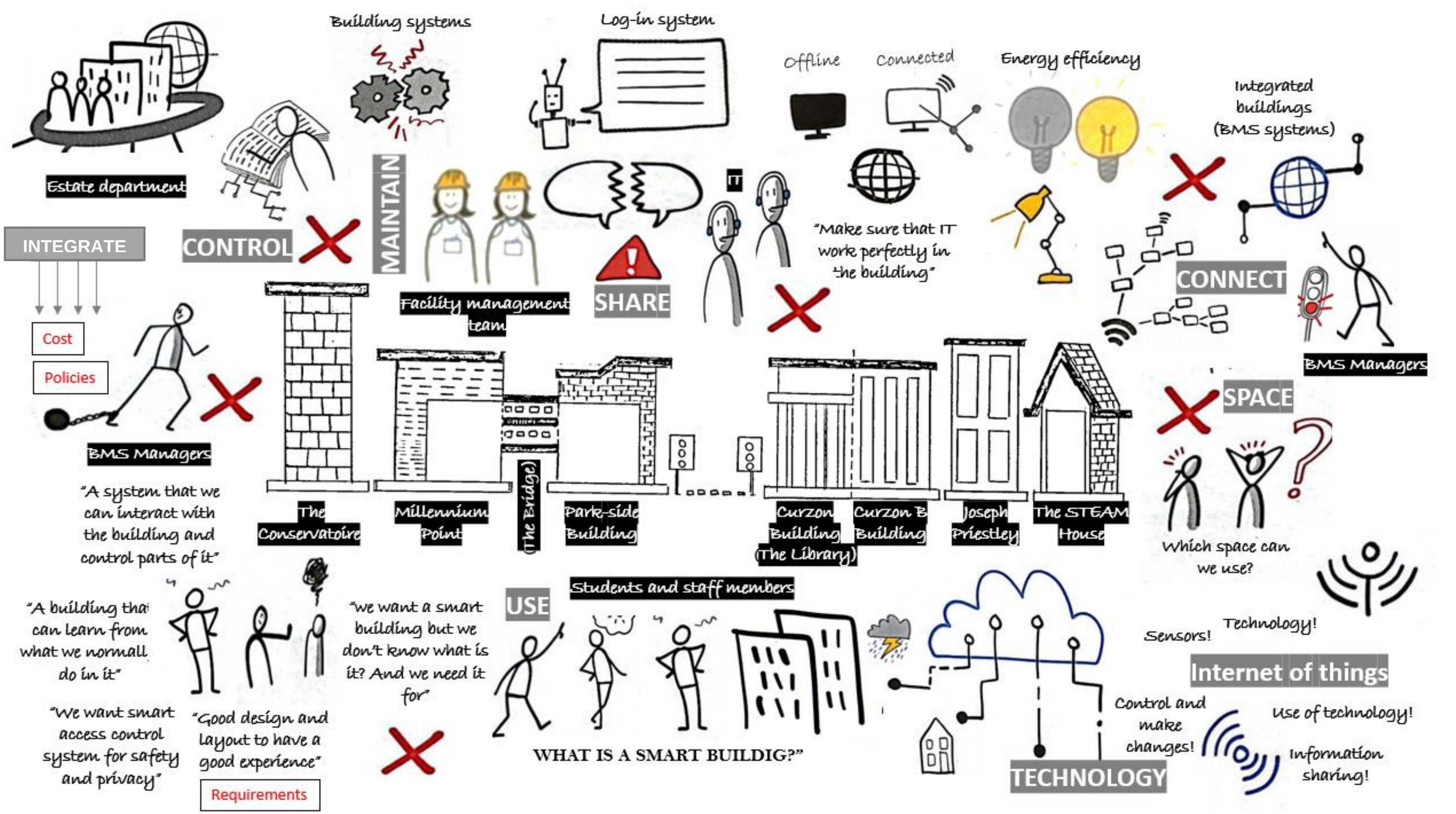


Figure 6-4: Rich Picture of How Different Stakeholders Interact with the Buildings.

Conflicts of stakeholders in smart building can arise when different groups have different goals and priorities. For example, building owners may prioritize cost savings and energy efficiency, while tenants may prioritize comfort and indoor air quality. One potential conflict is that building owners may focus on cost-saving measures such as reducing energy consumption, but these measures may negatively impact the comfort and indoor air quality of tenants. For example, using motion sensors to control lighting and temperature can save energy, but it may also cause discomfort for tenants who feel that the room is too bright or too cold.

Another potential conflict is that building owners may prioritize energy efficiency, but tenants may prioritize other features such as natural light and green spaces. For example, installing highly energy-efficient windows may save energy, but it may also reduce natural light and views for tenants. Additionally, there can be conflicts between the building owner and the facilities management team, as the owner may prioritize cost savings, while the facilities management team may prioritize maintaining the building and ensuring the comfort of the tenants.

These conflicts can be addressed by involving all stakeholders in the planning and design process and ensuring that their concerns are taken into consideration. Additionally, involving all stakeholders in the ongoing operation and maintenance of the smart building can help to identify and address any conflicts as they arise. It's important to note that as smart building technology is relatively new, conflicts of stakeholders are not extensively studied; however, the potential conflicts described above are based on the general understanding of the subject.

6.2.2 CATWOE Analysis and Root Definition

Beyond using 'rich pictures', the second step in SSM is to develop CATWOE analyses and root definitions. By deriving root definitions based on those involved in this case study, the CATWOE analysis tool in SSM is used to represent different approaches to building performance. Five worldviews regarding perspectives on smart buildings were presented in the previous section. In this section, CATWOE will use used to represent these worldviews in a more simplified way. As a useful tool for analysing complex situations, CATWOE can concisely describe the problem at hand. Moreover, it recognises the need for the necessary transformations to meet the needs of different worldviews. *Transformation* is a necessary process for capturing a particular perspective. An analysis of CATWOE also highlights the actors and beneficiaries involved in the delivery of each transformation.

Table 6-1: CATWOE Analysis Based on the Stakeholder Parties Involved in the Case Study with Respect to Their Worldviews on Smart Buildings.

CATWOE	Estate Department (Stakeholders)	Facility Manager (Stakeholder)	Staff (Stakeholder)	IT Specialists (Stakeholder)	Students (Stakeholder)
Customer	All stakeholders	Estate department, users of building systems and IT	All stakeholders	IT specialists, Building Facility Managers.	Facility Managers, and Estates Department.
Actors	Estate Department and Facility Managers	Estate department, Facility Managers	Facility Manager, Staff,	All stakeholders	Students, facility managers
Transformation	To collect how users interact with the building by using their work diaries.	To integrate systems of the buildings with available information of multiple users.	To share information on the required space environment with the facility management.	To share location and usage information of users' IT devices with the IT department.	To share space information (Type, capacity. usage) with all stakeholders.
Weltanschauung	A building with an integrated system would help control the building environment and improve building efficiency.	A building where facility managers can manage spaces and adjust operations to ensure each part of the building is being put to good use.	A building where staff could find a comfortable and interactive environment to do their work.	A building with better interaction between users and our IT network.	A building where students can find the ideal space environment to increase their productivity.
Owners	Estate Department	Facility Manager	Staff	IT Specialists	Students
Environment	Cost, temperature policies, and building specifications.	Privacy, Cost, available resources.	Interactive platform, privacy, and the trust of users sharing personal data.	Privacy, use of technology, and trust.	Privacy and building specifications.

Table 6-1 presents the CATWOE analysis for the various worldviews regarding smart buildings. The transformations required for their worldviews show that communication is a vital element where the IoT plays an important role as one of the actors. In the case study, stakeholders refer to people who use, maintain and manage the building and ensure communication processes in the operational stage of the building. As part of SSM, it is important to establish a root definition for each of the worldviews. Each of the root definitions is represented as a system where each system shows a stakeholder's worldview on smart buildings. In representing worldviews as systems, another complexity with relation to the parts and the whole will be overcome. This is because the outlined systems represent parts and achieve a building that satisfies all the stakeholders.

Table 6-2: Root Definition Derived from the CATWOE Analysis Based on Worldviews on Smart Buildings from the Stakeholders Involved in the Case Study.

Estate Department (Stakeholders)	Facility Manager (Stakeholder)	Staff (Stakeholder)	IT Specialists (Stakeholder)	Students (Stakeholder)
A system owned by the Estate Department for Estate Department and Facility Managers to collect how users interact with the building by using their work diaries to benefit all stakeholders in order to have a building with an integrated system would help control the building environment and improve building efficiency within the constraints of Cost, energy saving policies, and building specification.	A system owned by Facility Manager for Estate department, and Facility Managers to integrate systems of the buildings with available information of multiple user to have a building where facility managers can manage spaces and adjust operations to ensure each part of the building is being put to good use to benefit Estate department, users of building systems and IT in order to have a building where facility managers can manage spaces and adjust operations to ensure each part of the building is being put to good use within the constraints of Privacy, Cost, available resource, and available information.	A system owned by Staff for Facility Manager, Staff, to share information on the required space environment with the facility management to benefit all stakeholders in order to have a building where staff could find a comfortable and interactive environment to do their work within the constraints of interactive platform, privacy, and the trust of users sharing personal data.	A system owned by IT Specialists for all stakeholders to share location and usage information of users' IT devices with the IT department to benefit IT specialists, Building Facility Managers in order to have a building with better interaction between users and our IT network within the constraints of Privacy, use of technology, and trust.	A system owned by Students for Students, and Facility Managers to share space information (Type, capacity. usage) with all stakeholders to benefit Students, Facility Managers and Estate Department in order to have a building where students can find the ideal space environment to increase their productivity within the constraints of Privacy and building specifications.

As shown in Table 6-2, each root definition of the different worldviews on smart buildings is defined as a system. In this case study, it is expected that addressing each of these systems will result in a better understanding of the different needs of stakeholders associated with smart buildings, and that will be satisfactory to all stakeholders. Providing satisfaction to each of these systems requires satisfying the 'Transformation' process outlined in Table 6-1. A number of activities are required for each transformation to be successful. The proposed activities will be presented as a conceptual model as the next step in the soft systems analysis process.

6.2.3 Conceptual Models and Consensus Model

As a next step, conceptual models will be developed, which represent the activities needed to satisfy the needs of different worldviews represented by different systems. In a conceptual model, the activities required to transform a system are outlined, and their sequence is depicted. Each activity within the conceptual model includes at least one input and at least one output. An input can be either information (e.g. Outlook time-tabling system) or an activity (e.g. Contacting contractors for required maintenance). Conceptual models are measured by their efficiency, effectiveness, and efficacy. As a result of these measures, a conceptual model appears to be purposeful in nature since external factors control the activities.

Table 6-1 refers to the transformation processes, which are:

- To collect *information* on how users interact with the building by using their work diaries.
- To provide *integration* of building systems with information available to a variety of users.
- To share *information* on the required space environment with the facility management.
- To connect *information* on users' IT devices with the IT department and building systems (e.g. location and usage information).

- To share space information (Type, capacity. usage) with all stakeholders.

For each conceptual model, the arrows going into the box represent the input to the process, whereas the arrows coming out of the box represent the output. The red inputs represent external constraints that would affect the process of the system. The conceptual models for each of the five transformation processes are shown in Figures 6-5, Figure 6-6, 6-7, and.

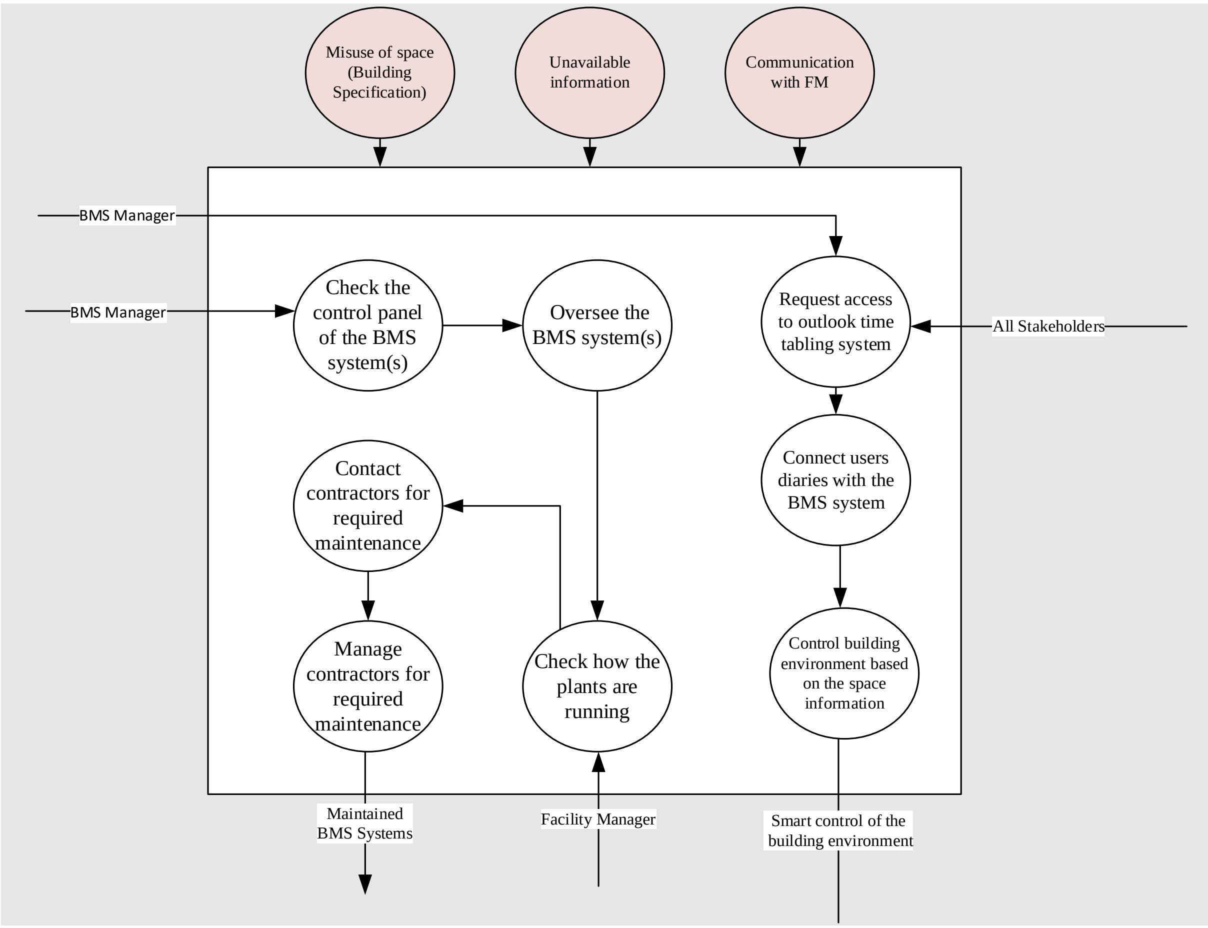


Figure 6-5 Conceptual Model to Collect Information From Users Based on the BMS Manager's Worldview of Smart Buildings.

The above conceptual model (Figure 6-5) shows the activities that are required to satisfy the BMS manager's worldview of a smart building. It is important to indicate that achieving the perspective perceived by the BMS manager on smart buildings is currently driven by sharing information with other stakeholders in the building. The activities outlined in the conceptual model are those that have been applied considering a number of external constraints which may affect certain processes in the system. In order to develop the activities corresponding to each conceptual model, both the worldview and feedback from the interviews were taken into consideration. In the conceptual models (Figure 6-5), the activities indicated by an arrow are those that have already been identified and/or implemented by other stakeholders. For instance, the facility manager carries out the activity 'Check how the plants are running'.

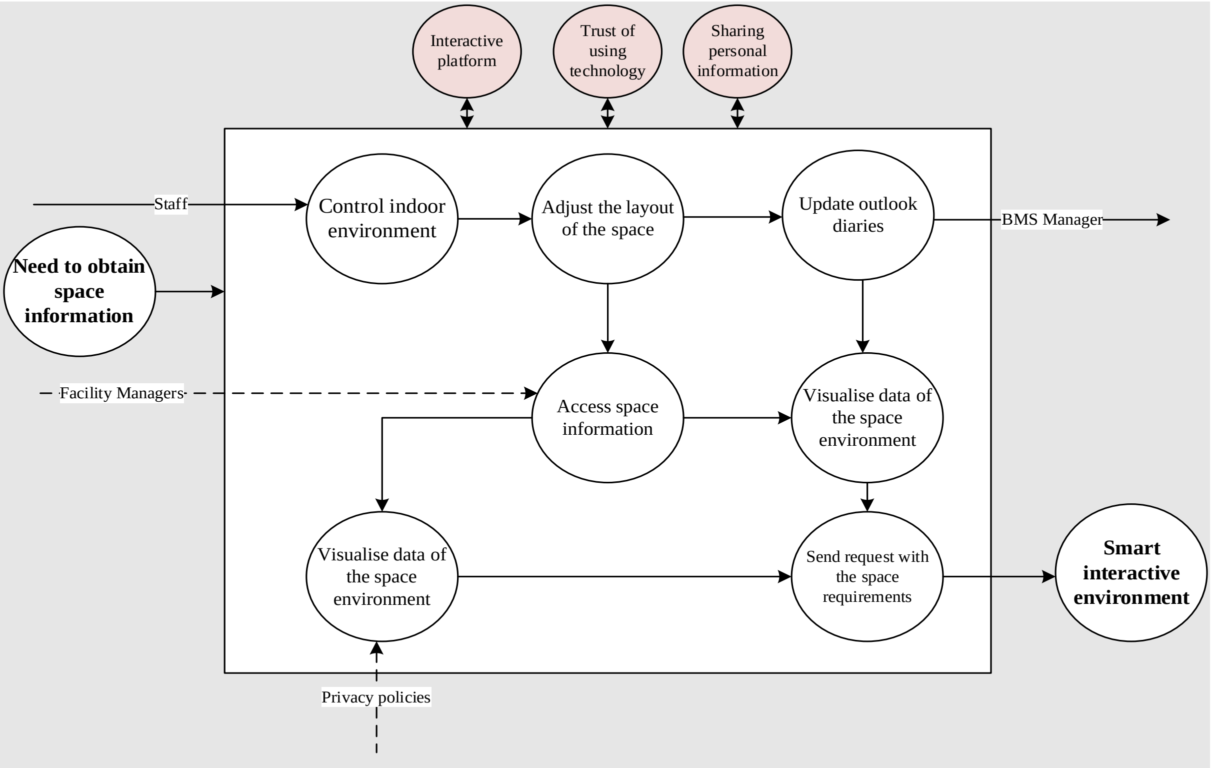


Figure 6-6 Conceptual Model Based on a Staff Member's World View of Smart Buildings.

Figure 6-6 shows the conceptual model that represents the staff member's worldview on smart buildings. The proposed activities show that the staff member's involvement in sharing and obtaining data within the workspace is as important as the person who will be using it. Accessing the information for the used space assists the development of an interactive smart.

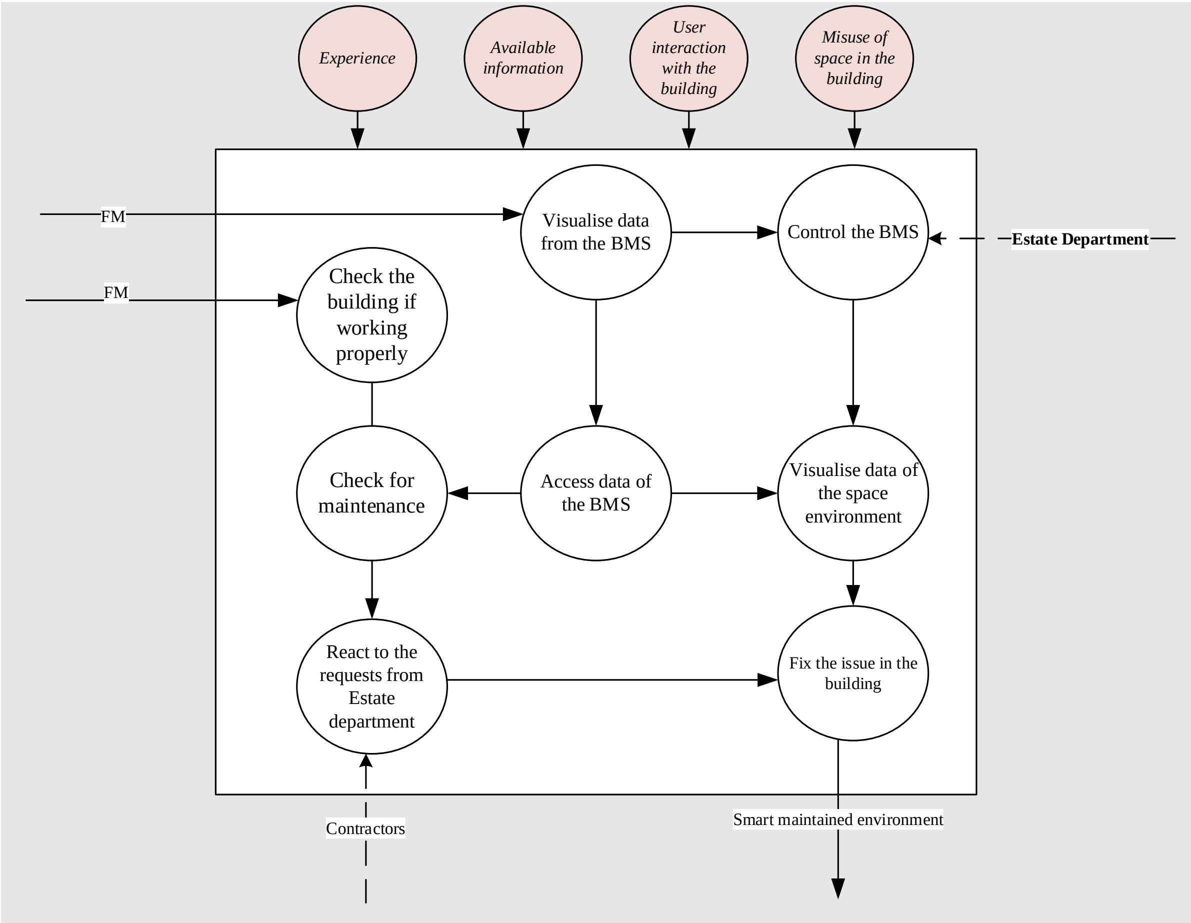


Figure 6-7 Conceptual Model Based on a Facility Manager's World View of Smart Buildings.

Figure 6-7 shows the conceptual model that represents the facility manager's worldview on smart buildings. According to the proposed activities, the involvement of the staff members in sharing and obtaining data within the workspace is imperative since they are the ones who will be using it. In order to develop an interactive smart space, it is necessary to access the information regarding the used space. From a facility manager's perspective, communicating with all stakeholders within a building is crucial. Building a shared information environment between different stakeholders in the building involves activities such as checking how the building is performing and communicating with the estate department.

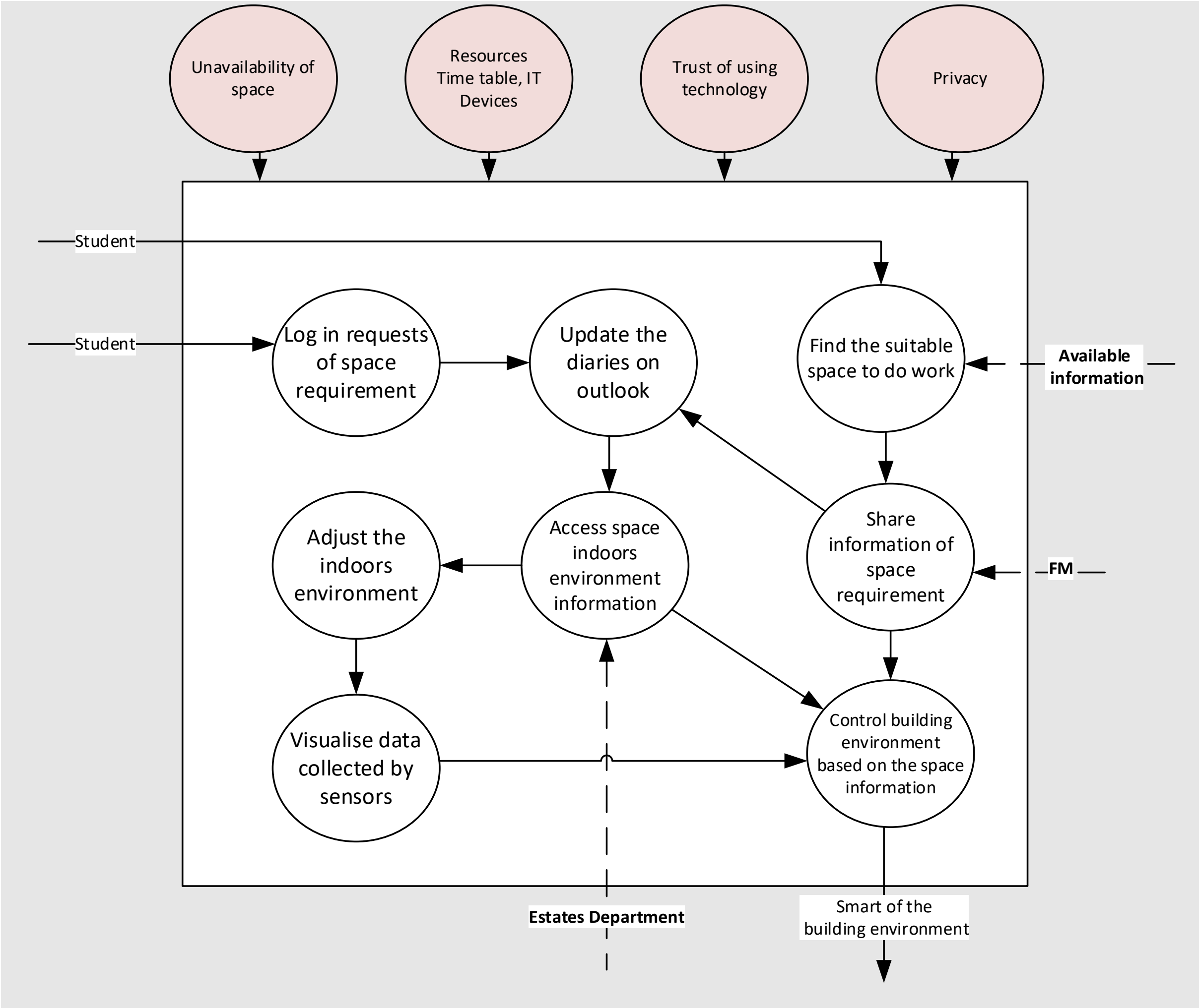


Figure 6-8 Conceptual Model Based on a Student's World View of Smart Buildings.

The students' worldview of smart buildings (Figure 6-8) illustrates that specifying their usability and desirability includes controlling space, data, and technology to be involved in the building and enhance their experience. The estate department must evaluate both the input provided by the facility manager and students. This is because their inputs may influence the sustainability of the building's operation or impose additional costs, thereby necessitating the activity 'update the diary on outlook'.

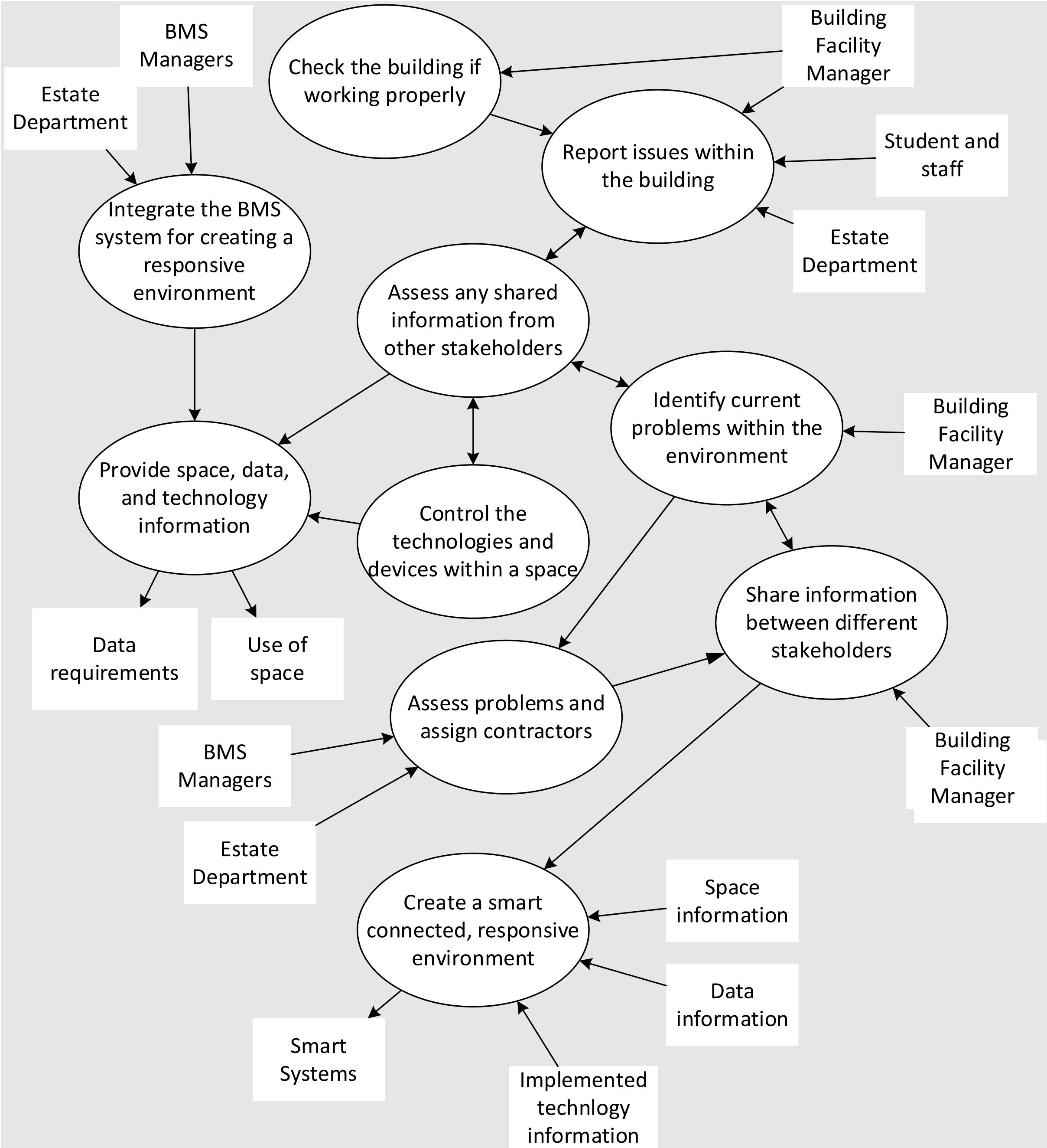


Figure 6-9 The consensus model combining the five conceptual models in the case study.

In order to combine all the activities presented in the three conceptual models, a consensus model is formed (Figure 6-9). For the consensus model to be successful, consistency and prioritizing are vital to ensuring that all perspectives of space, data, and technology are satisfied. It is evident from the case study that while using the consensus approach, different worldviews are taken into account to better understand how space, data and technology operate so that different experiences can be considered when considering a smart building.

6.2.4 Activities and Information Categories

Based on the consensus model, information categories are considered for each of the activities described. As each activity represents a process that forms the new system necessary to satisfy the different worldviews concerning smart buildings, it is important to emphasise that each activity requires at least one input and one output. The inputs and outputs for each activity are outlined in Table 6-3:

Table 6-3: Activities from the conceptual models and their stakeholders.

Activities \ Stakeholders	BMS Manager	Estate Department	Staff and Students	Power Manager	Facility Manager	IT Staff and
Access to user locations.						√
Assign and supervise contractors.				√		
Automate facilities and processes in spaces.					√	
Check maintenance.					√	
Check panel control.	√	√		√		
Check plant.	√			√		
Check the status of the building.					√	
Connect diaries with BMS.		√				
Connect space.	√					
Get access to lighting sensor data.			√			
Get access to temperature sensor data.			√			
Get network access point information.						√
Install sensors.						√

Integrate BMS systems.				√		
Locate devices.						√
Maintain equipment.						√
Manage contractors.	√					
Oversee systems	√	√		√		
Report to BMS manager.		√				
Request access.						
Request access to space data.			√		√	
Send information to other departments.		√			√	√
Share information with the estate department.						√
Access BMS data.					√	
Visualise updates on IT devices' data.						√
Visualise updates on space data					√	
React to requests from the estate department.					√	

6.2.5 Conclusion of SSM Analysis for The Case Study

This case study looked at soft systems analysis for the case study. Soft systems analysis aimed to further look into information requirements that are needed to understand the different views on smart buildings. The role of space, data, and technology representations in different views of smart buildings was also considered. Soft systems analysis showed that looking into representations of smart buildings has increased identifying further understanding of what influences understanding and moving towards smart buildings. This is because it showed that representations have limitations in terms of representing different processes within smart buildings. Conceptual models showed that communicating representations of smart buildings to those who use the building is vital to capture different concerns and represent the significance of different parts (e.g., facility location as part of usability and maintenance concerns). The analysis provides further information requirements, which can be used to bridge the gap between data, technology and space. The findings from soft systems showed that there is a need to represent smart buildings in a way that supports recognising the significance of different parts in order to inform the processes carried out between the different stakeholders of space at the operational stage.

6.3 Conclusions and summary

This chapter discusses soft systems analysis for the case study in this thesis: Educational Building, City Centre Campus in the UK. Information sharing and stakeholder requirements are in conflict, according to the results of the previous chapter. Consequently, it is difficult, if not impossible, to represent requirements through data, and this problem is complicated by stakeholders' differing perspectives using reductionist and/or holistic perspectives of the smart building. A soft systems analysis was conducted to understand the problem and bridge the gap between stakeholders' expectations and information sharing. A motivation for bridging this gap is to explore different information requirements for IoT to supplement smart buildings' data requirements.

Using findings from the previous chapter, reductionist and holistic perspectives on smart buildings are developed according to the stakeholders involved in the study. Building facility management teams develop system specifications based on the entire system. If the system is a smart building, the data (building systems) supporting its maintenance are specified. In order to achieve maximum value from knowing information from different stakeholders, a building system (part) must function in order to meet the needs of the user in terms of energy efficiency and operation (see Section 6.2.3, Figure 6-6) or minimize as many issues as possible (see Section 5.4.3.1).

In this example, the building facility management team's view of a building is reductionist. A building's facility management team is equally influenced by its parts and its overall structure.

Besides using the building (as a whole), they also monitor and manage its various components (e.g. building systems) to ensure that it serves its intended purpose and complies with stakeholders' expectations. For example, a reductionist view is concerned with maintaining different parts of a building, whereas a holistic view is concerned with ensuring that the building operates effectively to meet the requirements of stakeholders (whole) (see ‘P5, MPB’ in Section 5.4.4.1). These examples indicate that a facility management team's view of a building can be both reductionist and holistic, depending on how they perceive the building. Its entire structure influences a building's occupant, and they only become aware of its parts when they experience its whole, for example, how the building provides a place for them to do their work (see ‘P7, PSB’ and ‘P10, JPB’ in Section 5.4.5.4). Therefore, occupants are holistic in their perception of smart buildings since they only become aware of a specific component (e.g. using the light or gathering data of a specific system) in response to an emergent characteristic (e.g. comfort). According to the above examples, different stakeholders perceive smart buildings differently because they see parts and wholes differently. This illustrates the complexity of viewing the entire system of a smart building, which contributes to the gap between stakeholders' needs and information sharing. To achieve an understanding of the smart building that pleases all stakeholders, soft systems analysis for the case study must take different worldviews into account. Based on the identified information requirements, it is necessary to consider further activities that involve the owners, managers, and users of the building.

The case study also illustrated that space, data, and technology are key factors affecting the views of stakeholders who own, use, and manage the building, so exploring different views on space was necessary. In the case study (Educational building, City centre campus), soft systems analysis demonstrated the importance of considering different views of space to demonstrate the impact of different parts. The information requirements identified showed that many parts influence space operation differently depending on the stakeholder. Moreover, the soft systems analysis for the case study also examined representations of data gathered from technology systems and parts that influence views on technology. The study also showed that technology representations need to be rich in information in order to support the recognition of the significance of different parts for different stakeholders. Soft system analysis provided a comprehensive view of gaps between information sharing and stakeholders' requirements, but it can also be argued that identifying information requirements is reductionist. The identification of information requirements, however, is useful because it recognises the limitations of using modelling technologies, such as IoT, to support smart buildings. The next chapter discusses an approach that supports recognising the significance of different parts identified in this chapter and how it supports informing data requirements in IoT systems to support the operation of smart buildings.

7 Development of the MSIM

7.1 Introduction

As mentioned in previous chapters, smart buildings are critical to the rapidly growing IoT ecosystem. Integrating various technologies into a building can improve the occupants' performance, energy efficiency, and comfort. However, creating a smart building requires a holistic approach encompassing several critical elements. These elements include technology, stakeholders, data, and processes.

As presented in (Figure 7-1), the first element, technology, is crucial to developing a smart building. Several technologies, such as sensors, actuators, controllers, and communication protocols, are employed to create a smart building. These technologies work together to ensure that the building is automated, intelligent, and efficient. However, the technology alone is not enough to make a building smart. It needs to be integrated with the other elements to create an effective system. The second element, stakeholders, encompasses all the individuals or organisations that have a vested interest in the building. This includes the building owner, occupants, facility managers, maintenance personnel, and contractors. As the results in Chapter 6 revealed, it is essential to identify all the stakeholders and understand their requirements, objectives, and roles in the building. Understanding the stakeholders' requirements is crucial to operating a smart building that meets their requirements.

The third element, data, is critical to the operation of a smart building. Data is collected from various sources, including sensors, equipment, and building management systems. The data is analysed to provide insights into the building's performance, energy usage, and occupant behaviour. As shown in the results of Chapter 4, the data is used to optimise the building's performance, improve energy efficiency, and enhance occupant comfort. However, this type of data only refers to the data that technology can capture. This led to the need to understand the fourth element (processes), which refers to the set of procedures, protocols, and rules that govern the building's operation. Processes are essential to ensure that the building operates efficiently and effectively. The processes include the automation of various building functions, such as lighting, HVAC, and security systems. Processes are critical to ensuring that the building meets the stakeholders' needs and operates as intended.

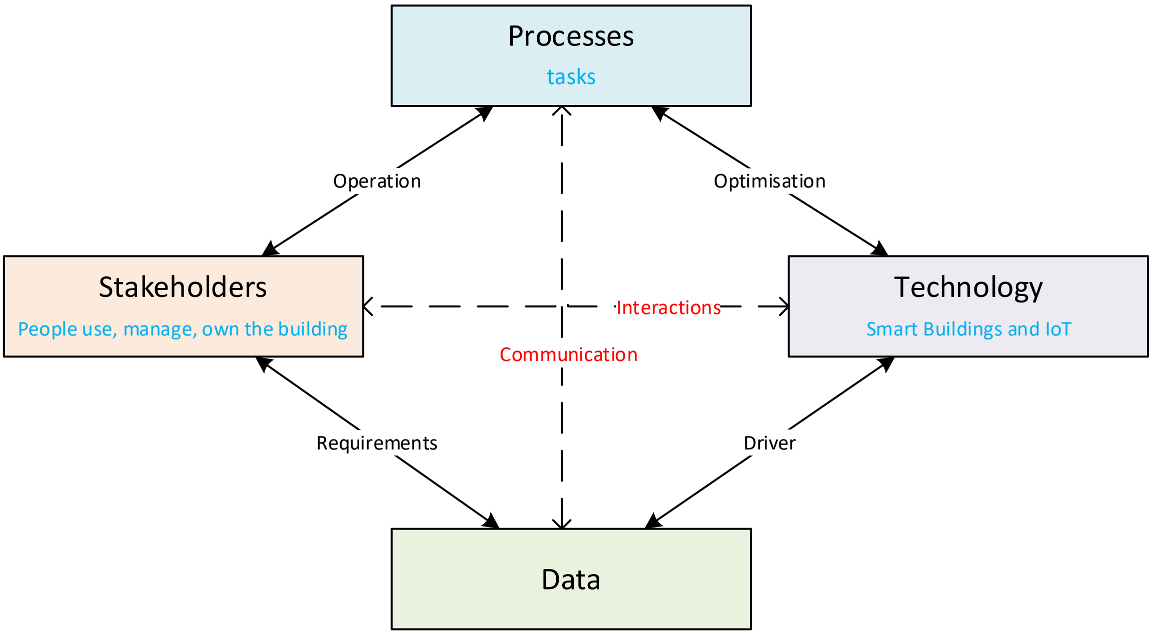
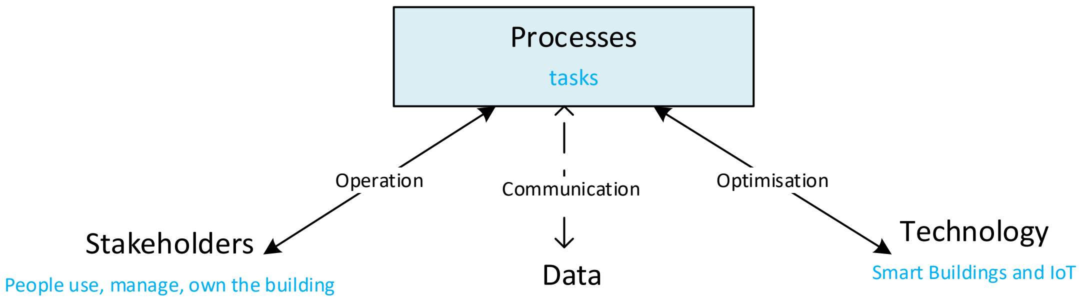


Figure 7-1: Socio-Technical Approach in Smart Building.

Figure 7-1 integrates the four elements discussed above to create a smart building and provide a holistic approach to building operation. The framework is based on systems thinking principles, which recognise that a building is a complex system with multiple interdependent components. The framework provides a structured approach to designing and operating a smart building. It ensures that all the critical elements are integrated and optimised to achieve the building's objectives. The framework enables stakeholders to collaborate and work together to design and operate a smart building that meets their requirements.

In conclusion, this chapter discusses that creating a smart building requires a holistic approach that encompasses several critical elements, including technology, stakeholders, data, and processes. The framework contributes to the development of the Multi-Stakeholder Information Model (MSIM), which enables stakeholders to collaborate and work together to operate a smart building that meets their requirements. The chapter will provide a detailed analysis of each element of the framework, including technology, stakeholders, data, and processes. The analysis will explore each element's key concepts, principles, and best practices. The chapter will also discuss the interdependencies between the elements and how they can be integrated to create a smart building. Finally, the chapter will present the MSIM, which provides a structured approach to designing and operating a smart building that incorporates all four elements of the framework in Figure 7-1.

7.2 Smart Buildings Processes



Processes play a crucial role in creating a smart building, as they govern the building's operation and ensure that it operates efficiently and effectively. Processes interact with the other elements of the system in several ways, including through optimization, communication, and operations. Sony and Naik, (2020) propose a framework that takes the consideration of Socio-Technical Systems theory while designing the horizontal, vertical, and end-to-end integration for sustainable implementation industry 4.0. It was the first study that applied socio-technical systems in this domain. However, besides that, it assumes that the system can be understood from its interactions between the various parts of the system. However, the major limitation of this study is that the principles of integration of socio-technical systems theory and principles of Industry 4.0 are considered at a theoretical level. On the other hand, in this thesis, the same approach is applied to a case study in order to ensure that the data collected is in accordance with each element of the framework. Firstly, processes interact with technology through optimisation, and Processes are designed to automate various building functions, such as lighting, HVAC, and security systems. These processes use technology such as sensors, controllers, and communication protocols to optimise the building's performance. For example, a process can use temperature sensors to adjust the HVAC system to maintain a comfortable temperature for the building's occupants. Similarly, lighting systems can be automated to adjust the lighting levels based on the time of day and the occupancy of the building. In other studies, (Peña *et al.*, 2016; Žigart *et al.*, 2018; Ateeq *et al.*, 2019) proposed frameworks concerned with a specific application and limited to meeting specific stakeholder requirements within smart buildings. This thesis, however, developed a framework to encompass all the components and systems of smart buildings (Chapter 4, Figure 4-4).

Secondly, processes interact with data through communication. Processes rely on data to operate effectively, and they communicate with data sources such as sensors, building management systems, and equipment to collect and analyse data. Processes can use this data to make decisions about the building's operation, such as adjusting HVAC settings based on occupancy levels or optimising lighting levels to reduce energy consumption. Effective communication between processes and data sources is critical to ensuring that the building operates efficiently and effectively. The majority of studies focused on the data which can be collected by sensors and systems in the building and neglected the stakeholders' requirements which cannot be captured with technology or technology can meet (Koh *et al.*, 2018; Rehman, Ullah and Kim, 2019; Liu, Zhang and Wang, 2020). Therefore, this creates a growing recognition that smart buildings must incorporate multiple stakeholders' requirements and perspectives beyond technology and system performance. For instance, in their study of smart buildings in the context of sustainability, Mok, Shen, and Yang (2018) emphasised the importance of engaging multiple stakeholders to understand their different requirements and priorities for sustainability performance. They argue that such stakeholder engagement can help to ensure that building systems are effective and sustainable over the long term. Other studies by (Sava *et al.*, 2018; Parn and Edwards, 2019) also highlighted the need to consider different users' perspectives in the design and implementation of smart building systems. The authors noted that while sensor-based data can provide valuable insights into building performance, it is equally important to consider "soft data," such as user feedback and preferences, in order to improve user satisfaction and engagement with the design of smart buildings.

This thesis differs by suggesting a holistic approach to smart building operation, one that takes into account the diverse perspectives and requirements of multiple stakeholders. This can involve collecting additional data directly from stakeholders and engaging them in the operation process to ensure that the resulting systems are effective, sustainable, and user-friendly. This approach noted that smart building systems should be operated with a "stakeholders-centric approach," where stakeholders such as occupants, facility managers, and owners are involved in the operation process to ensure that the systems meet their requirements and preferences.

Finally, processes interact with stakeholders through operations. Processes are designed to meet the needs and objectives of the building's stakeholders, including the building owner, occupants, facility managers, maintenance personnel, and contractors. Other studies claim that processes can provide various services to stakeholders, such as automated maintenance schedules, security systems, and energy management (Chinchero, Alonso and Ortiz T, 2020). However, this study argues that effective operations require processes to be designed with the stakeholders' requirements (Chapter 5) in mind, and stakeholders must be able to interact with processes effectively to achieve their objectives.

In conclusion, processes are a critical element of the smart building system, and they interact with the other elements of the system in several ways. Processes interact with technology through optimization, data through communication, and stakeholders through operations. The effective design and operation of processes require understanding the building's stakeholders' requirements, objectives, and roles. Integrating processes with the other elements of the system is essential to creating a smart building that meets the stakeholders' requirements and operates efficiently and effectively, as highlighted in the developed model in Figure 7-8.

7.3 Technology in Smart Buildings

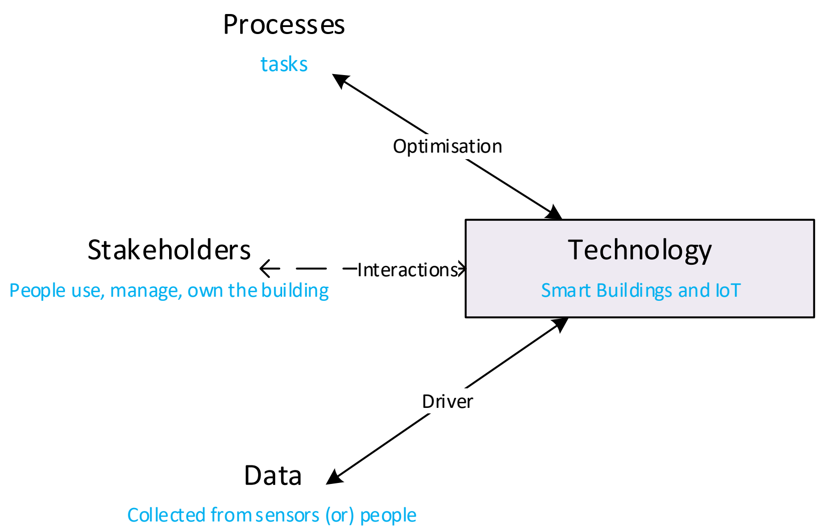
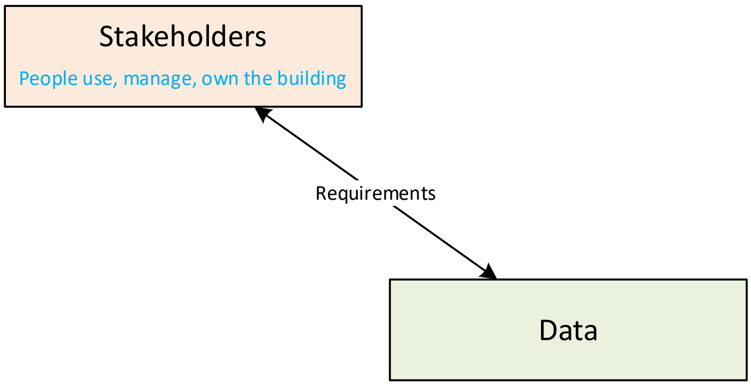


Figure 7-1 shows that technology is interconnected with data through drivers. Technology collects, stores, and analyses data about the building's operation. This data can include information about energy consumption, occupancy levels, and equipment performance.

Processes use this data to make decisions about the building's operation. Data is a critical component of smart building technology, as it enables processes to make informed decisions about the building's operation. For example, in a study by Ateeq *et al.*, (2019), data-driven optimisation techniques were used to improve the energy efficiency of a smart building. The study demonstrated that processes could be optimised to reduce energy consumption while maintaining a comfortable environment for occupants by collecting and analysing data on energy consumption and occupancy levels. Similarly, a study by Zhang *et al.*, (2020) showed that by collecting and analysing data on indoor and outdoor temperature, humidity, and airflow, processes could be optimised to maintain a comfortable environment for occupants while reducing energy consumption. Furthermore, in a study by Aliero *et al.*, (2022), data analytics and machine learning techniques were used to predict the energy consumption of a smart building. These studies demonstrate the importance of data as the main driver of smart building technology. Without the correct data, processes cannot be optimised to operate efficiently and effectively. On the other hand, this thesis study focused on the data based on the stakeholders' requirements, which can be met by depending just on technology, pointing to the necessity to collect, store, and analyse data effectively based on different stakeholders' perspectives to enable smart building technology to connect as it supposed to be. Furthermore, this study promotes technology interaction with stakeholders through communication. Technology is used to provide information and services to a few building's stakeholders, such as facility managers, maintenance personnel, and contractors, which should be shared with other stakeholders, including the building owner and occupants. This communication can take various forms, such as dashboards, alerts, reports or face-to-face.

To summarise this section, systems react to the data fed to them. Some of these data are based on space, data, and technology misuse. Therefore, this process results in providing undesired environments for multiple stakeholders, which can affect their experience in the building. The interest in looking into different types of data, for example, the requirements collected from multiple stakeholders, became necessary to ensure that information is shared between all parts of the proposed framework.

7.4 Stakeholders in Smart Buildings



This study investigates the potential value of incorporating stakeholders' perspectives within IoT in smart buildings. Therefore, a number of challenges in implementing IoT within a workplace have been explained in Chapter 2. However, most challenges neglect the multiple stakeholders' interaction with IoT systems, which is one of the important challenges in implementing IoT in buildings. This has enabled the researcher to investigate how stakeholders react to such challenges in depth.

Chapter 5 highlights the importance of stakeholders' requirements and their role in data connectivity in smart building systems. Effective data connectivity is essential for the efficient operation of smart buildings, which can lead to cost savings and reduced energy consumption (Fan *et al.*, 2020). However, this thesis focuses on the element that for data to be recognized by the system, it must first meet the requirements of stakeholders, including building owners, facility managers, and occupants. The requirement-gathering process is critical in ensuring that the data is relevant and useful to stakeholders. It involves identifying the stakeholders' requirements and expectations, defining the scope of the project, and specifying the data requirements (Greenwood and Kassem, 2016). Through this process, stakeholders can communicate their requirements, preferences, and priorities, which will help guide the selection of appropriate data sources and technologies to support the smart building system. Once the requirements are defined, the smart building system must feed and understand the data. This involves collecting, processing, and analysing data from various sources, such as sensors, meters, and other IoT devices. The data is then used to automate building operations, optimize energy consumption, and improve occupant comfort and productivity (Ma *et al.*, 2018). However, not all data can be recognized by the system, and some data may require further processing or sharing with other stakeholders. For example, data from legacy systems or incompatible data formats may need to be converted or integrated with other systems to enable interoperability (Dave *et al.*, 2018). In such cases, stakeholders must collaborate to ensure that the data is transformed into a format that can be recognized by the system and used to achieve the desired outcomes.

This study promotes the process connectivity of stakeholders and data as it is critical to smart building systems' success. Stakeholders' requirements play a vital role in ensuring that the data is relevant and useful to support the smart building system. However, for the data to be recognized and utilized by the system, it must go through processes and be shared with other stakeholders to ensure ultimate connectivity.

7.5 Requirements of Stakeholders in Smart Buildings

When considering viewing a smart building, the targeted stakeholders showed interest in three drivers. The following section will highlight these drivers and how they are linked to the information model:

7.5.1 Space Concepts in Smart Buildings.

The amount of space available in a building is one of the most important aspects of a building. According to Section 5.4.3, the environment in a building plays a crucial role in delivering the correct and desired experience to stakeholders. There is always going to be an interest in the characteristics of a space and how they are used to achieve the desired experience from stakeholders. Based on a study by Ye *et al.*, (2009), the most important stakeholder requirements have been consolidated; they have been linked to the technical work packages of a building project proposed in their study. There are two types of technical requirements concerning technology implemented in smart buildings: systems technical requirements and construction technical requirements. It is important to note that these system and constructional requirements apply to almost all requirements' themes. In the event of a higher expectation of energy usage (energy management), the requirements for the system will change. A life cycle costing approach is also important when dealing with building systems. As a result, building systems are implemented based on their total lifespan rather than their initial cost. Therefore, the design and technical requirements of building systems influence comfort levels.

An example of this would be the vision/expectations of stakeholders regarding new work environment concepts. Figure 7-1 illustrates the main characteristics of high-performance building spaces and their relationship to the six key requirements. The authors have developed a comprehensive requirement development process that includes methodology and procedure, requirement generation, verification, consolidation, and actualisation.

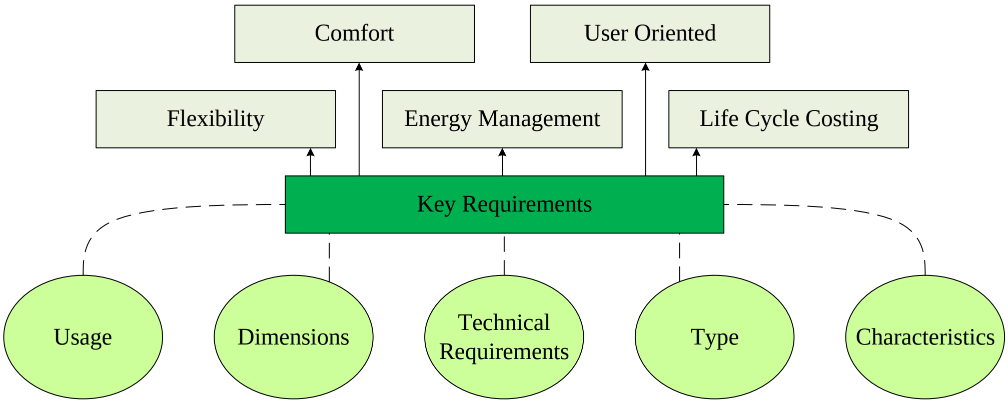


Figure 7-2: Features in space concepts and their links to the key requirement themes.

This approach has been used to collect and analyse the current state of stakeholder requirements in European countries within their targeted project. The project focuses on developing new technologies, processes, products, and solutions organised into six key areas to meet stakeholder requirements. According to the methodology used in this thesis, data collection led to the development of three themes, which have been used to identify the requirements of different stakeholders.

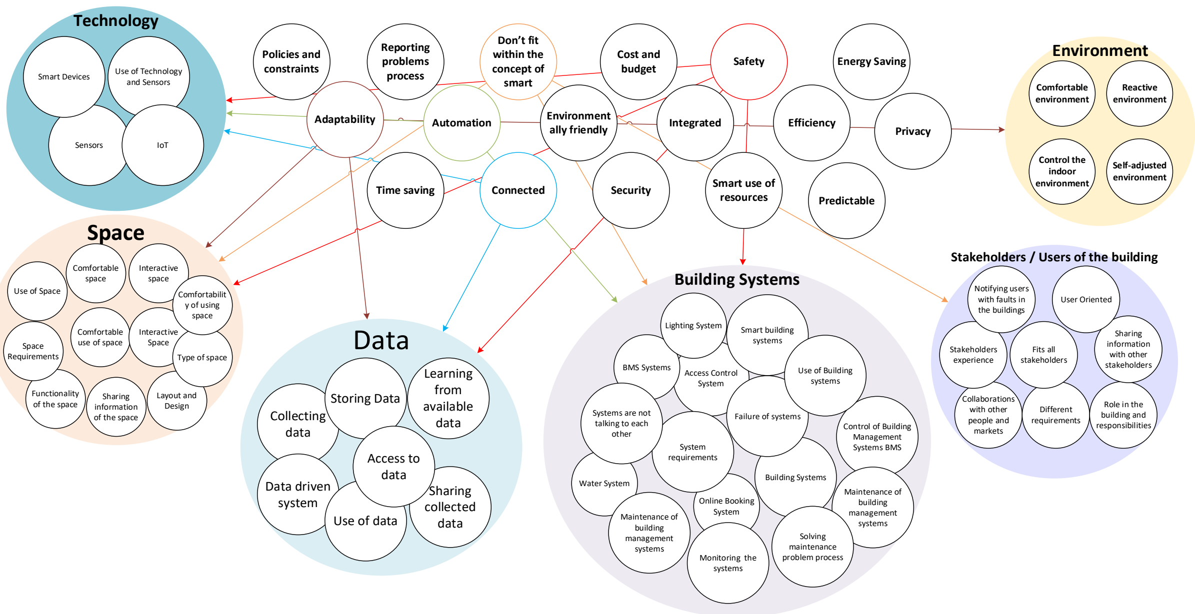


Figure 7-3: Codes form the stakeholders' requirements analysis in Chapter 5.

According to Figure 7-3, the difference is that this study focuses primarily on the operation of the building, where some of the themes proposed in similar studies are irrelevant. The dimensions and measurements of space are required to complete a construction during the design stage, but they are not as important during the operational phase.

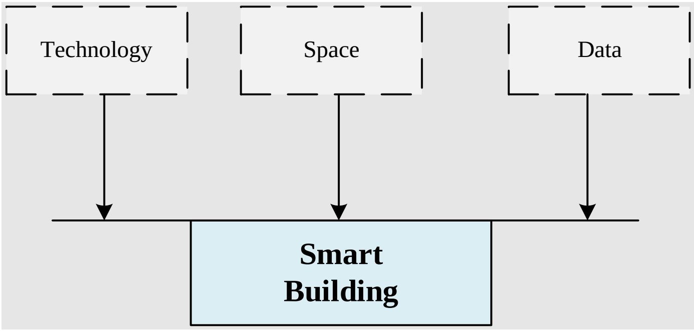


Figure 7-4: The Drivers of Smart Building Based on the Stakeholders Analysis.

This study differs as it focuses on three main drivers (Technology, Space, and Data). These drivers shape stakeholders' expectations for building automation systems, impact the design and layout of buildings, and influence data collection and analysis requirements. Understanding these drivers is critical for developing effective smart building solutions that can meet stakeholders' expectations and deliver maximum benefits.

Firstly, technology is an essential driver that shapes stakeholders' expectations and requirements. New technologies such as the (IoT), cloud computing, and artificial intelligence (AI) have enabled the collection and analysing of massive amounts of data in real-time. These technologies have also allowed for the developing of sophisticated building automation systems that can optimize energy consumption, enhance occupant comfort, and improve overall building performance. As a result, stakeholders' expectations for building automation systems have increased, and they now expect advanced technologies that can support a range of functions, from security to energy management. Secondly, space is another driver that influences stakeholders' requirements. The design and layout of a building can impact its functionality, energy efficiency, and occupant comfort. Stakeholders' requirements for smart building systems are often shaped by the unique features of their building space, including its size, shape, location, and existing infrastructure. For example, a building with a complex layout may require more advanced sensor networks to monitor and control building systems. In contrast, a building located in a hot and humid climate may require more advanced air conditioning and ventilation systems to maintain a comfortable indoor environment. Thirdly, data is a crucial driver that shapes stakeholders' requirements. As smart building systems generate vast amounts of data, stakeholders' requirements for data collection, processing, and analysis have increased. Stakeholders expect systems that can collect and analyse data from multiple sources, such as occupancy sensors, energy meters, and weather stations. They also require data analytics tools that can provide real-time insights into building performance, identify areas of energy waste, and predict future energy usage. Furthermore, stakeholders expect data security and privacy measures to be in place to protect their sensitive information. During the development of the MSIM, it was clear that information would be shared between implanted technology and the building. In this case, IoT was the primary lens used to identify the process of technology in spaces inside smart buildings. It was discussed that the purpose of this study is to understand how different stakeholders view these drivers. Despite disagreements between stakeholders regarding how technology should behave in smart buildings, technology remained a common area of agreement.

7.6 Development of the MSIM

7.6.1 Technical Part: Multi-Stakeholder Information Model.

In smart buildings, the technical part begins with the process of gathering information and handling sensors at the physical layer. The data collected by buildings today can be collected by various types of sensors (Figure 7-5). Such data can be used to improve the building environment to satisfy users.

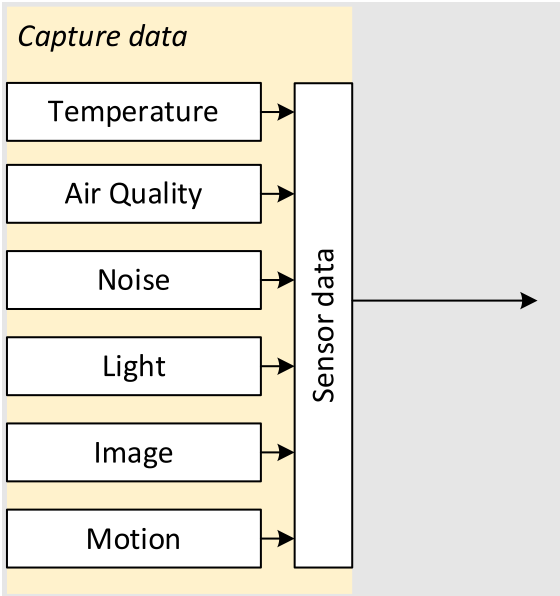


Figure 7-5 Model Processes: Sensor data level.

The second section of the technical par is the IoT processes and how data is being cleaned, synthesised, analysed and processed. In Chapter 4, IoT frameworks mainly influenced this part of smart buildings. As mentioned before, the implemented smart building technology goes through a number of processes to satisfy the application. Therefore, modelling the IoT process is not considered when developing the model. The data is being fed to the system when (generating additional data), for example, weather information or timetabling system is what users can control and change in this process (Figure 7-6).

However, this process can be used for any data fed to the model, which does not have to be from sensors. For example, when data is collected from different sources unrelated to IoT, it will be subjected to the same cleaning, structuring, and processing processes. The data needs to be fed to the systems within the smart building to meet multiple stakeholders' different requirements. As a result, this study focuses on the process between different systems and stakeholders to create an environment where information can be shared and used to enhance the experience of all participants. Therefore, there are three possible outcomes: either to estimate internal states and parameters or to compare predicted outcomes with measured responses to select the most appropriate scenario. In this process, the output of the sensors plays a significant role in determining the outcome.

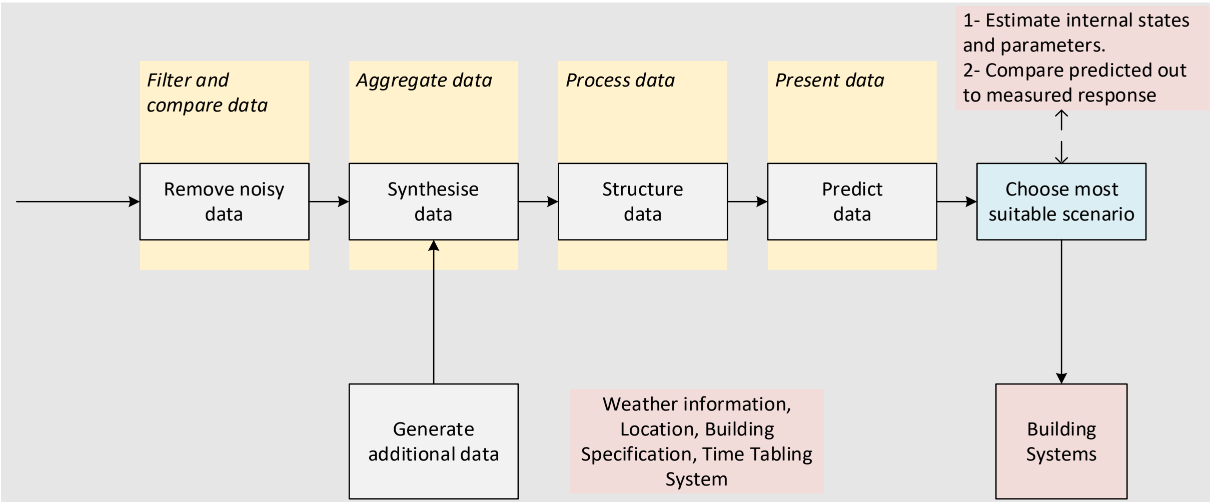


Figure 7-6 Model processes: IoT processes within a smart building.

Social Part: Multi-Stakeholder Information Model.

As for the social component, three main drivers (technology, space, and data) affect the requirements of different stakeholders. As discussed before, creating a smart environment should only depend on the technical part. Sometimes, it is not the system that fails in delivering the desired environment, but it is just the people not using the building as it should be. Therefore, to have a multi-stakeholder model that incorporates different stakeholders' different requirements in the building, this study looked at the abstract level of different requirements to be met within smart buildings. As a result, each of those will lead to scenarios to show how the different information between (the IT managers, the Estate Department, the power managers, the staff and the students) connected to each other. As a result, the system will have an information map to be able to identify issues and solutions within processes in their building environment (Figure 7-7).

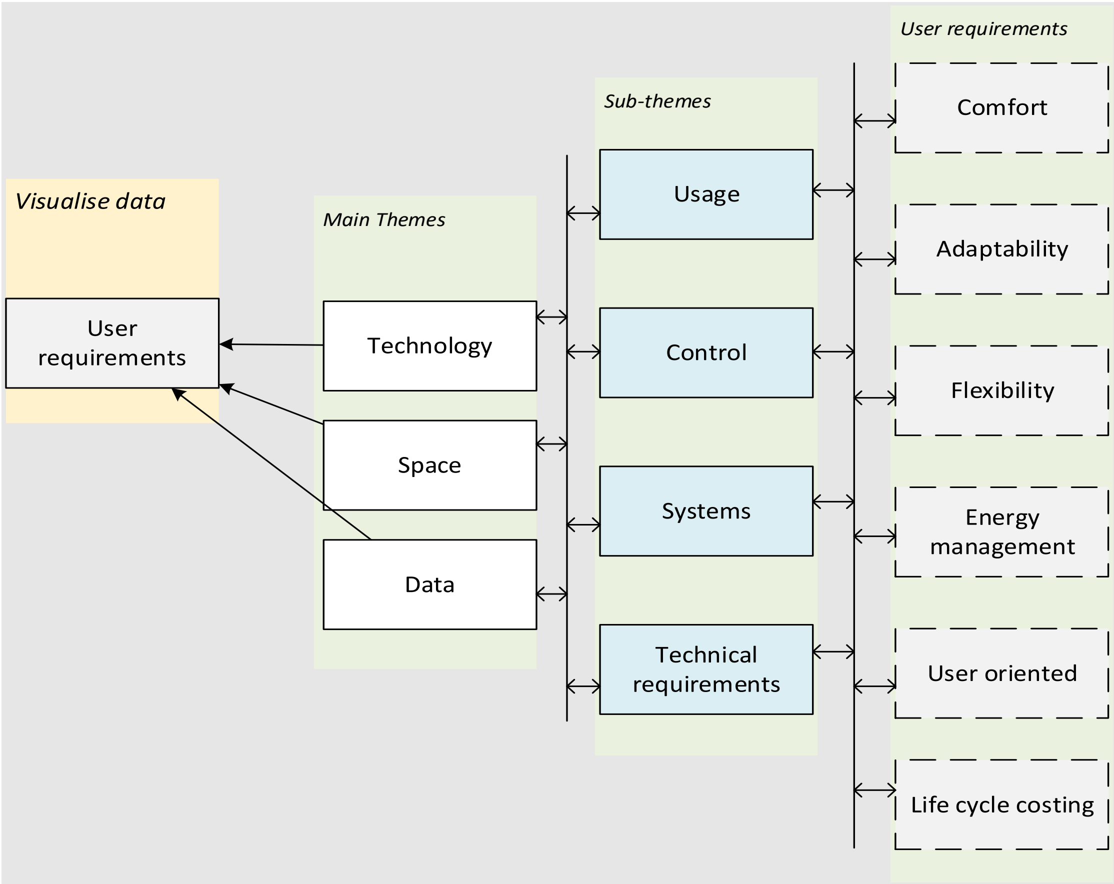


Figure 7-7: Model processes: Stakeholders requirements.

7.6.2 Integrating The Social and Technical Parts of The MSIM

The developed information model works as a lens to understand and assist the process within smart buildings. The novelty of this model is within the consideration of the two parts involved in the process of sharing information within a smart building. It considers the technical part, which consists of the IoT systems and the different systems in the building and how they are integrated and connected, as well as the social part, which consists of the stakeholders' different requirements in the building. This approach is generated based on a socio-technical approach where the human and the technical parts are considered in the process, looking at systems in general. The MSIM works by looking at three main drivers (Technology, Data and Space). These three drivers represent the different requirements of different stakeholders in the building. Therefore, stakeholders view a smart building in terms of these three elements, considering which is most important.

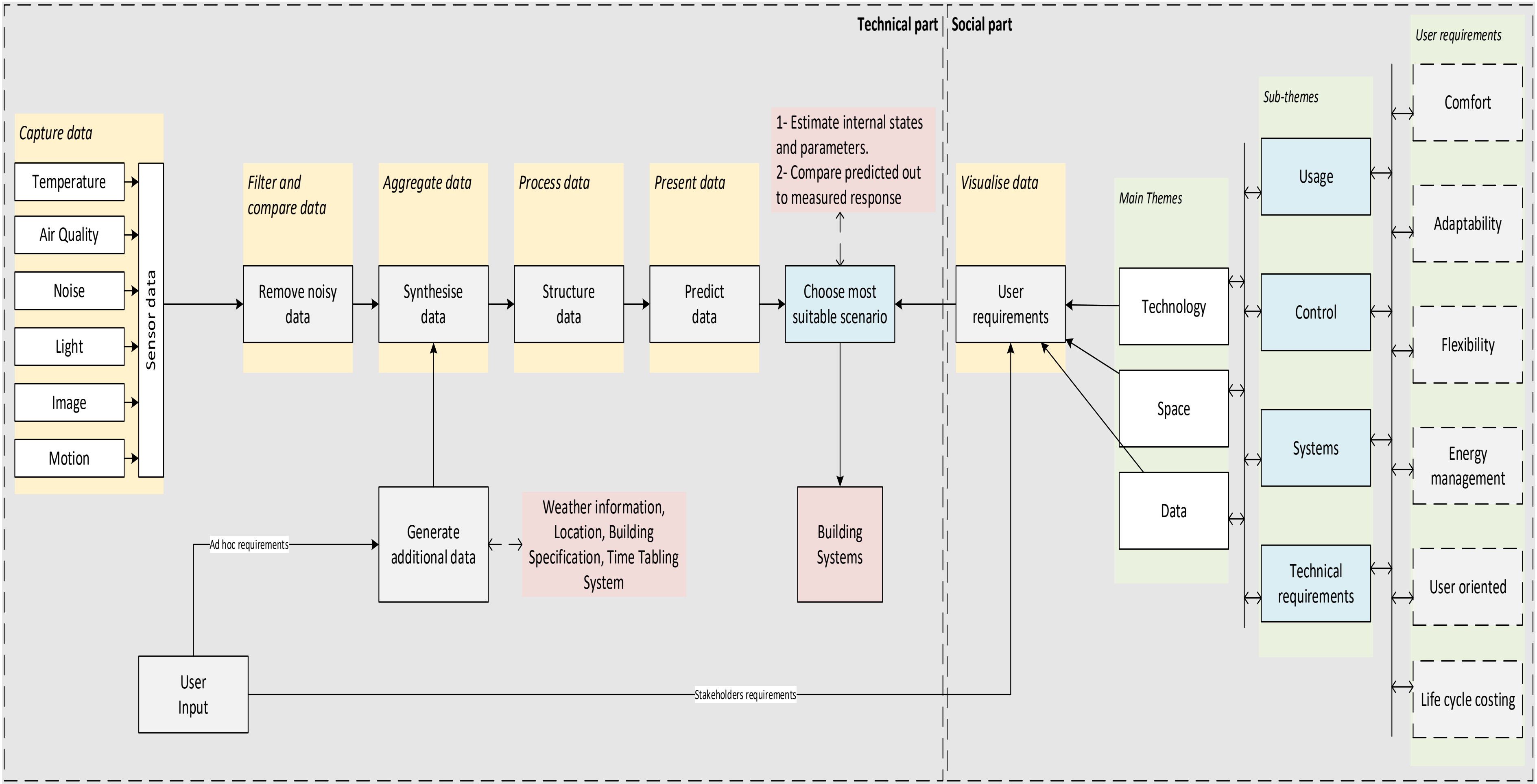


Figure 7-8: Multi-Stakeholder Information Model to Drive Process Connectivity in Smart Buildings.

This model reduces the number of processes involved in making a decision in smart buildings by combining and looking at each process through the lens of (Technology, Space, and Data). Further explanation of each process in the MSIM and how it can promote process connectivity in smart building environments are presented in the next five processes:

1. Capture data: This process involves the collection of data from various sources, including sensors, devices, and platforms. In a smart building environment, data can be captured from various sources, such as occupancy, temperature, humidity, lighting, and energy meters. By capturing data from multiple sources, the MSIM can provide a holistic view of the building's performance and enable stakeholders to make informed decisions.
2. Filter and compare data: Once data is captured, it needs to be filtered and compared to identify patterns and anomalies. This process involves the use of algorithms and machine learning to analyse data and detect trends. By filtering and comparing data, the MSIM can identify potential issues and provide early warning signals to stakeholders.
3. Aggregate data: Aggregating data involves combining data from multiple sources to create a more comprehensive view of the building's performance. This process enables stakeholders to gain insights into the overall functioning of the building and identify areas that need improvement.
4. Process data: Once data is aggregated, it needs to be processed to extract insights and create actionable information. This process involves the use of analytics tools and machine learning algorithms to identify patterns and make predictions. By processing data, the MSIM can provide stakeholders with real-time insights into the building's performance and enable them to make data-driven decisions.

5. Present data: Presenting data involves visualizing information in a meaningful way so that stakeholders can easily understand it. This process involves the use of dashboards and visualizations to represent data in a clear and concise way. By presenting data, the MSIM can enable stakeholders to identify areas of concern and take corrective action quickly.
6. Choose the most suitable scenario: Finally, MSIM selects the most suitable scenario based on user requirements and the lens of technology, space, and data. This process involves considering a range of factors, such as energy efficiency, occupant comfort, and maintenance requirements. The MSIM can enable stakeholders to optimise the building's performance and achieve their goals by choosing the most suitable scenario.

MSIM is designed to promote process connectivity and enhance information sharing in smart building environments by enabling seamless communication and collaboration between all parts of the system. By capturing, filtering, aggregating, processing, and presenting data, the MSIM provides stakeholders with real-time insights into the building's performance and enables them to make data-driven decisions based on the technical and social side of the system. Additionally, by choosing the most suitable scenario based on user requirements, the MSIM can help stakeholders optimise the building's performance and achieve their goals.

7.7 Validation and reliability

This section aims to present the validation process of the multi-stakeholder model developed in this chapter. In order to meet Research Objective 4, the validation process is intended to demonstrate the proposed model's value, effectiveness, and applicability. This will incorporate the views of building stakeholders to ensure that it fulfils the expectations of the end-users. The developed information model will be validated using case scenarios based on the facility management team's experiences during the in-use phase of a smart building.

7.7.1 Use-Cases Background

Many studies use interviews to elicit requirements, but few structured methods exist for conducting use case interviews. (Cockburn, 1997) uses a concrete interview process to elicit and specify use cases. Interviewing experts are most useful when they already have a thorough understanding of how the system under design should behave from the user's perspective. Experimental evidence Somé (2005) shows that using the static interview approach from scratch is significantly faster than using a less structured use case workshop or interview (compared to a less structured use case workshop or interview). As compared to the static interview process, the dynamic interview process (Kawaguchi and Motoda, 1991) uses reused use case contents and saves considerable time (approximately 40% for our experiment). As a result of the interview processes, use cases can be used as input for further approaches (e.g. Space information) that can help present or parse use cases. Using scenario analysis, Eibeck et al. (2020) examine possible outcomes under given starting conditions in order to evaluate potential events. Alternative worlds are sometimes referred to as scenarios. Scenarios are processes in which initial settings vary, and simulation and optimisation results are assessed. This chapter explains how use case scenarios are chosen to validate the developed model.

7.7.2 The Use of Use-Case Scenarios

The multi-stakeholder information model will be used to inform the processes within the case scenario to support satisfying the different stakeholders' different requirements. As part of this study, the following criteria were used to select participants that were required for the validation process:

- Members of the facility management team and estate department team working on different buildings of the chosen case study of this research.

- The chosen members of the teams must have access to data from the building management systems.
- The members must be part of the decision-making and maintenance process of systems within the buildings.

The process flow and planned sections of this chapter can be seen in Figure 7-9. The chapter's structure is presented to guide the reader through the sections and subsections.

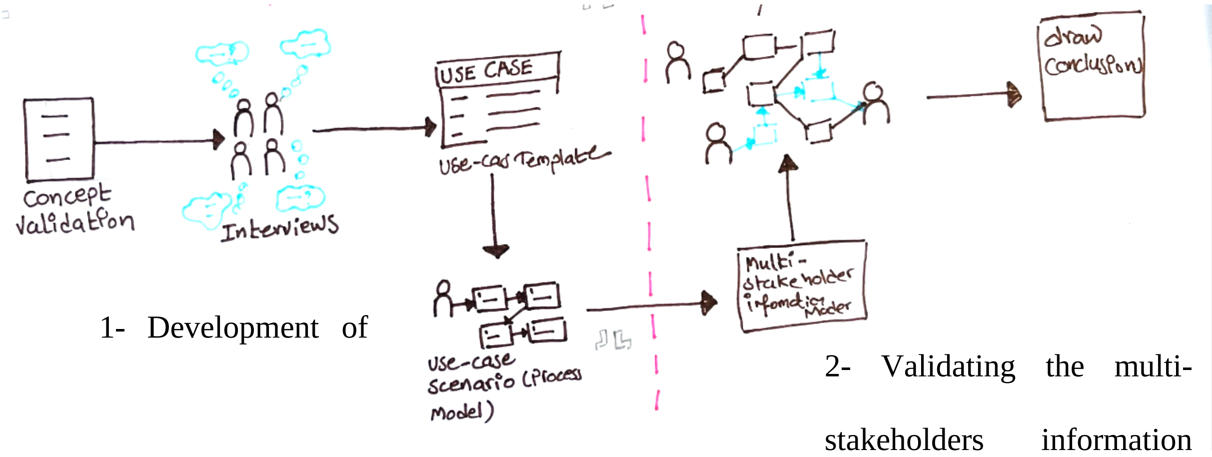


Figure 7-9: Framework for Validation Process.

The chapter is divided into the following sections and subsections:

1- **Development of the Use-Cases:** the process to capture the processes based on the requirements collected from each stakeholder (Islam and Omasreiter, 2005). It gives both scenarios between the users and the system and scenarios specifying the interactions between actors modelled inside the system (Cockburn, 1997). Section 8-1 also discusses the methodology used to develop the use-case scenarios and why a certain methodology was chosen for validation (Mattingly and Rao, 1998).
   - Use case development: Participants (Building stakeholders)
   - Use case development: Implementation (Semi-structured interviews)
   - Use case development: Findings (Use case templates / Scenarios)

2- **Model Validation:** Verifying that the model developed for this research meets the requirements of its users. Section 8-2 discusses the objective for the validation, how it was conducted, how data was extracted, and what findings were presented. Validation encompasses two primary purposes: effectiveness and applicability. The applicability and effectiveness of the model are embodied by using the multi-stakeholders information model as a lens to identify better-connected processes for users. Finally, a discussion with the facility management and the estate department team was carried out, and the details were given by the end of the validation section.

7.7.3 Development of Use Cases

Use cases have been utilised in developing process scenarios for this study (Basri et al., 2016) to ensure capturing the correct information processes between different stakeholders and building systems. Use cases provide the basis for a scenario-driven model of analysis. The actors used in this analysis model are not generally synchronised with the components in the later process-based design model. It depends upon the behaviours of each stakeholder and whether a corresponding process or component can be carried out to respond to a specific issue within the building (Fleisch, 1999). Specifically, it was used to obtain participants' views regarding concepts and understand the meaning behind these views in order to improve the processes in subsequent iterations.

Generally, a use case represents a complete series of actions initiated by an actor and the system. All of the existing uses of the system are listed in the use cases. As a result, a scenario-driven analysis model can be developed. It should be noted that the actors used in this analysis model do not generally correspond to the components in the later component-based design model. In the later component-based design process, if a corresponding component for each actor is available in the component library or if more than one library component must be selected and interconnected to design the required behaviour, it depends on the behaviour of the actor.

7.7.4 Development of use cases: Participants

The facility management and the estate department teams agreed to collaborate and participate in this research. The facility management team are the correspondents' team within buildings who interact with the systems of the buildings and maintain spaces within them. Facility management teams are the eyes and hands of other building management teams. The other team is the estate department team, who have control of the data of the buildings. They also act as the decision-making team of processes within the building to ensure operation efficiency around the buildings. The estate department team offices are based in the Joseph Priestley building, and they have access to data from the BMS systems of all the buildings in Birmingham City University, city centre campus.

Table 7-1: Percipients, their job titles, and their roles in the buildings.

Participant name	Job title within BCU	Role in the building (Duties)	Participant department
P15	Energy Manager	Manage energy consumption and the subsequent carbon emissions Reduce consumption. Reduce our carbon emissions related to energy consumption. Managing the infrastructure, the metering infrastructure. Get involved with the building management system staff.	Estates and Facilities
P16	Facilities Assistant	Manage the building's fabricant systems. Provide facilities support. Reactive maintenance. Assess maintenance requests. Get involved with the building management system staff.	Facilities

As shown in Table 7-1, the team members working in the building have main job titles, as represented in the second column in Birmingham City University. However, in the building operation duties specifically, each member of the team has a more defined role, as shown in column three. The last column in the table states the team in which the members are working. The members during validation processes are chosen depending on their level of engagement with a building as the stakeholders who have access to and control of building management systems.

7.7.5 Development of use cases: Implementation (Semi-structured interviews)

The researcher adopted Islam et al., (2015) use case template Table: 7-2 based on Cockburn's (1997) formalised definition of use cases in order to capture the processes based on the requirements collected from each stakeholder. In his view, use cases encompass both scenarios between the user and the system and scenarios specifying the interactions between actors modelled inside the system. A similar extended view of use cases has been introduced by Mattingly and Rao (1998), which denotes scenarios between actors inside a system as collaboration cases. For simplicity, this research refers to both use cases and collaboration cases uniformly as a use case.

Table: 7-2 Use case template.

Use case ID	The use case number (e.g., 1, 2, 3).
Use case Name	The use case name should contain the actor and the goal achieved by the actor.
Short description	Summary of the use case in one sentence.
Preconditions	Conditions that have to be true before the primary path starts.
Primary Path	Steps of the most usual scenario (normal case). Steps are ordered with a sequence number.
Alternative Paths	Describes alternative steps (often refer to steps of the main scenario).
Postconditions	Conditions that indicate the successful completion of the use case.

Use cases are usually presented as scenarios in which actors are linked to a goal leading to the completion of a responsibility. The general template includes the use-case name, scope, level, pre-and post-conditions, actions, and other characteristics that allow for consideration of the functional requirements and scope of the project (Altaf *et al.*, 2021). Traditionally, use-case analysis is used to write narratives for misuse cases and to identify security requirements (Ur Rehman and Gruhn, 2018). No guidelines or principles should be followed in writing a use case, so it is an approach with wide open ends.

For instance, the creation of use cases for a new building system requires reflections on the relevant daily operation situations that must be considered. In this context, interviewing is used to elicit processes from stakeholders. The researcher interviews the chosen participants (e.g., facilities manager) because they should know how the system should behave. Furthermore, there is little knowledge about how they are used to generate a complete and accurate specification of requirements. Interview techniques are used in this chapter to specify and acquire the processes for a smart building system based on stakeholder requirements.

The interview technique was developed to acquire processes of a specific system responding to a stakeholder requirement and reuse the same approach on a different stakeholder with different requirements. In the validation, this research will primarily focus on the processes of systems and stakeholders used to respond to an issue or a need. Also, a brief outline of the dynamic process will be given. When considering the interview process, the researcher also needs to look at the type of system for which the information process model is created. A brief summary of the interview process is provided below:

- The researcher had to find expert users of building management systems and make an individual appointment before conducting the interview.

- The system description (of course, not case-based) was given to each stakeholder before the interview, as the stakeholder must have sufficient knowledge about the system to participate in the interview process.
- In addition to the predetermined question sequence shown above, the interviewer had an interviewing tool.
- The interviewee and interviewer conducted an interview as described in this chapter.
- Upon completing the interview, the researcher obtained the use case specification stored in a database of the interview tool and could be used for future approaches, such as the dynamic model.

7.7.6 Development of use cases: Findings

This section presents the findings gathered from the data collected using the semi-structured interview method with the participants indicated in Table 7-1. This section will detail how each interview was conducted with a specific stakeholder group.

a) Facility Assistant

The Facility assistant is responsible for assessing maintenance requests and reactive maintenance (Table: 7-2). He mentioned:

"*My role is to manage the buildings' fabricant systems, and also provide facility support, reactive maintenance, and I assess maintenance requests depending on the skill that requires my attendance or whether requires an engineer or a contractor to deal with repairs*" (P16, SHB).

The above-mentioned quotation explains the participant's daily roles and responsibilities, which contributes to identifying the use case name and the short description for the use case.

Following this, the interviewer asks about the primary path for processes the participant usually takes to deal with the issue: What are the usual processes taken to react to a temperature failure in one of the spaces in the building? (P16, SHB). The participant's answers:

"*The initial reaction will depend on how it was discovered whether it is a member of staff, and they put it on the system. Sometimes they call us directly, but if it goes through the system, the Helpdesk will contact us, and then we will attend to see what the issue is, and sometimes when it is not a member of staff and we are doing building inspection and see the issue*." (P16, SHB).

The above-mentioned quotation shows the initial process of how teams react to an issue within a space. It is clear that reporting an issue has to come from the facility management team or another actor (stakeholder) within the building. The interview continued to identify the primary path in the use-case for the processes taken to deal with a temperature issue in the building (Table: 7-2).

Table 7-3 Use case 1 (P16, SHB).

Use case ID	Use case 1
Use case Name	Facility Assistant (P16), reacting to a temperature issue in the building.
Short description	The facility assistant manages the building systems and ensures they are maintained efficiently in case of failure.
Preconditions	The issue must be reported to the facility team.
Primary Path	1- Report issue (by a stakeholder). 2- Attend the space. 3- Assess the situation (Facility management team) 4- Assess the damages (Facility management team) 5- Raise it on the Helpdesk 6- The helpdesk contacts engineers and contractors 7- Guide the maintenance process 8- Keep the teams informed about when the room is ready for reuse.
Alternative Paths	4a- Fix the damage (in case if it is minor)
Postconditions	The issue is fixed, and all stakeholders are informed.

In use-case one, one of the key findings is that the first step of reporting an issue is done manually by a building user (stakeholder). Though there is smart technology in the space and data may be accessed through BMS systems in the building, these systems are only used to evaluate issues after they have been discovered. As the participant mentions:

"*If someone raises an issue with temperature, I would check the BMS system and see the temperature in that room (Space) and see if there were any issues in the room (Space)*" (P16, SHB).

The researcher asks the following question to ensure that the BMS system is used within the assessing process: The BMS system is part of assessing the issue?

"*Yes, depending on the issue or the problem, I would look at the BMS and check a certain zone (Space) where the problem is*" (P16, SHB).

The above responses (P16, SHB) showed that the BMS system is important for the initial assessment of the issue. The use of the BMS software can determine the functionalities of the components of the system. However, the participant agrees that without physical attendance to assess the issue, the system is not enough to depend on to assess the issue. His view indicated the importance of the social element in the system rather than depending on the technical part as a separate element from functionality:

"*The BMS was the first point of call when you got an issue to do with airflow, temperature, aircon and that sort of thing, and then a physical check is your next step because without a physical step, all that software means nothing, you have to physically look at the issue, you have to physically feel it*" (P16, SHB).

The primary purpose of the use-case template is to determine the processes used to develop the use-case scenario, which is based on the reuse of the use-case processes in a dynamic process model. The basic notion of this process is that the researcher searches for the model that fits the functions of the developed multi-stakeholders information model and wishes to specify during the validation stage. This requires a database of use cases and a classification of these use cases. During the first part of the interview, the interviewer asked appropriate questions to form the use cases template from the participant's view and experience. The dynamic process utilises a collection of standard processes from a specific use case. The building system function domain relevant to the use case is the temperature and air flow sensors within the BMS system, which consists of, for example, space data. After retrieving possibly relevant use cases, the researcher uses the multi-stakeholder process model to assess the processes and identify alternative paths to the use-case scenario Figure 7-10.

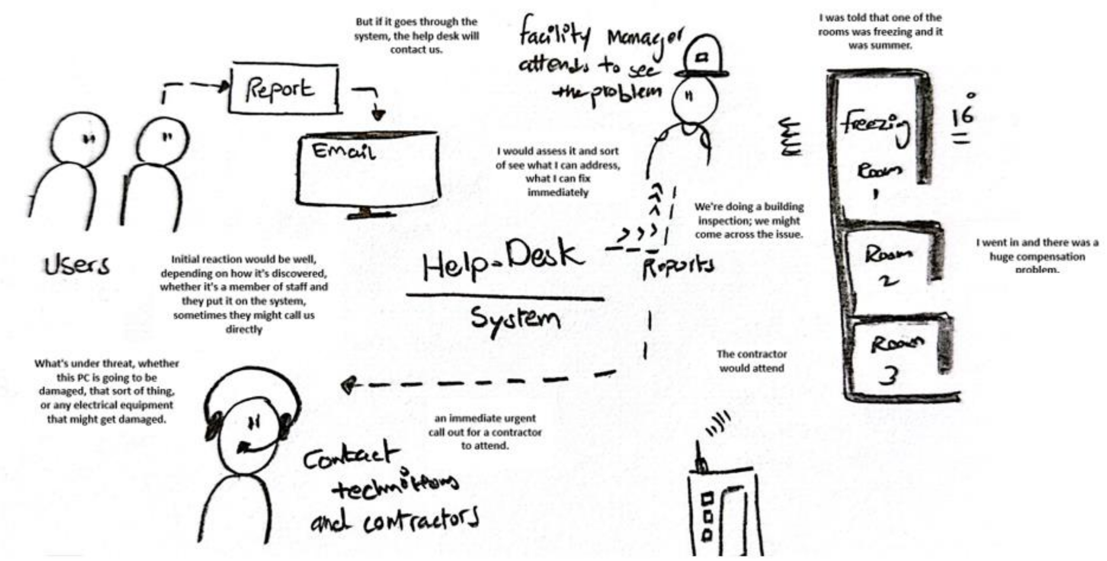


Figure 7-10: Use-case scenario (P16, SHB).

b) Energy Manager

The second participant in this stage is the energy manager. The energy manager is one the people who are responsible for dealing with issues raised in the building. She mentioned: "*I get involved with the building management system staff*."

"*I also do the supplier management, the procurement, data analysis, financial stuff, like budgeting invoice payment, doing the validation side of it. Yeah, basically anything to do with energy and carbon. That's me in a nutshell*." (P15, JPB)

The above quotation explains the daily roles and responsibilities of the participants that contribute to identifying the use case name and the short description of the use case. In the following question, the interviewer asks about the primary path for processes that the participant usually follows in order to resolve the issue:

"*The technicians there (Conservatoire building) were experiencing a large fluctuation in the relative humidity, so I got involved to see what we could do about that obviously*" (P15, JPB)

The quotation above clarifies the initial process and where the report came from. It was reported that another stakeholder had experienced something odd with the system. Relatively, the energy manager got involved to assess the situation and solve the issue raised in the system, as explained in the following quotation:

"*What we can do about that basically, so the first thing I would do is contact the technician to experience the problem that they've already logged in for humidity and temperature in certain areas of buildings. We deployed some further loggers, so I bought further loggers, deployed them and got downloads from those that just sort an idea of what was actually happening in the spaces and then looked at what air handling units delivered condition data, which parts of the building so I could say in this room in this room and in this room are all served by this air handling unit and they're all the experiencing the same or different issues*" (P15, JPB)

Based on the above quote, it is evident how the participant depends on technology and the building management systems to assess the issues raised in the building. In the previous interview with the facility assistant, assessing the issue was preferred to be done by physical attendance in the space rather than just depending on the building management systems. The interview continues to identify the primary path in the use-case for the processes taken to deal with a temperature issue in the building (Table 7-4).

Table 7-4: Use case 2 (P15, JPB).

Use case ID	Use case 2
Use case Name	Energy Manager (A.H), reacting to a temperature issue in the building.
Short description	The energy manager manages energy consumption and the subsequent carbon emissions.
Preconditions	The issue must be reported by a stakeholder in the building.
Primary Path	1- Report issue (by a stakeholder). 2- Check building management systems. 3- Attend the space. (Building walk rounds) 4- Assess the occupancy status. Are there any open windows? 5- Identified a few problems in the building. (Occupants were not aware of where and how they store their equipment). 6- Got the BMS specialists to come and look at the air handling units. 7- Fix the issue.
Alternative Paths	3a- Request for the facility management team to attend.
Postconditions	The issue is fixed, and all stakeholders are informed.

In this use case, the initial report was primarily generated by the technicians who use musical instruments in the building, who had noticed that some of their equipment was out of tune. As it was mentioned by the energy manager in the interview:

"*It manifested itself through the instruments going out of tunes and in some extreme cases the soundboards wood crack so there was physical damage to wooden instruments because of the relative humidity fluctuations*" (P15, JPB)

The above-mentioned quotation illustrates how the first process was generated. A stakeholder is mainly the used actor to inform there is an issue with the system. The energy manager states that the best is to have those issues raised by other users in the building. When the participant was asked: How would you know there is a temperature failure in this room through the systems?

"*By using the BMS to determine that, then it would be a case of just browsing BMS indeed see either an alarm going off that some controller or some part of the system was at fault. But the occupancy usually the best to know that something's not right to be shared with us*" (P15, JPB)

The above quotation shows how the energy manager depends on other stakeholders and users of the building to report an issue rather than on the BMS. This statement shows an agreement with the previous participant (P16, SHB) when he was asked about the role of technology (BMS) systems in dealing with issues raised in the building.

Further, it is important to illustrate the results of all those processes by illustrating how the problem has been resolved and how other stakeholders have been informed. Concerning the issue raised for Use Case 2, the problem identified was primarily a space problem, as the space was not being utilized in the way it should be. This is due to the fact that other stakeholders were not aware of the locations in which they could store their musical equipment. Hence, they are unaware of the technology implemented in their space. As a result, the energy manager (P15, JPB) ran a campaign to inform students about the appropriate spaces to store equipment within the building. As explained by (P16, JPB), the traffic light campaign was to show that spaces with red streakers are for no storing in this space. In the space with the amber streakers, you can store some equipment. Spaces with green streakers are suitable for storing equipment in those spaces. As mentioned in the quotation below:

"*The outputs of that were Conservatoire identified a few problems within the building so people weren't aware of where it was supposed to be humid to control them where I wasn't. So there's confusion about where they could leave instruments. So, I devised a poster campaign with the traffic light system to say: Red, don't leave your instrument here is not relative humidity controlled. Amber is not too bad, but it's not really a controlled space. Green is a controlled space; make sure you close doors make sure you close windows; otherwise, you're going to affect the environment, and it means that the system is going to have to work harder to bring the hip relative humidity to what we wanted to be because you're influencing it with outside moisture and airflow and all the rest of it*" (P15, JPB).

The above quotation illustrates the importance of sharing information with different stakeholders concerning space information or what sort of technology and sensors are deployed to facilitate the use and operation of space within a building. It also shows processes to be taken by different stakeholders in order to obtain a smart use for the space, such as asking the occupants not to leave doors or windows open within a space or stakeholders should use this space for storing their equipment. This aspect of sharing information with multiple stakeholders determines how the space should be used and maintained. After retrieving possibly relevant processes within the case study, the researcher draws the process model to be used later for assessment to identify alternative paths to the use-case scenario (Figure 7-11).

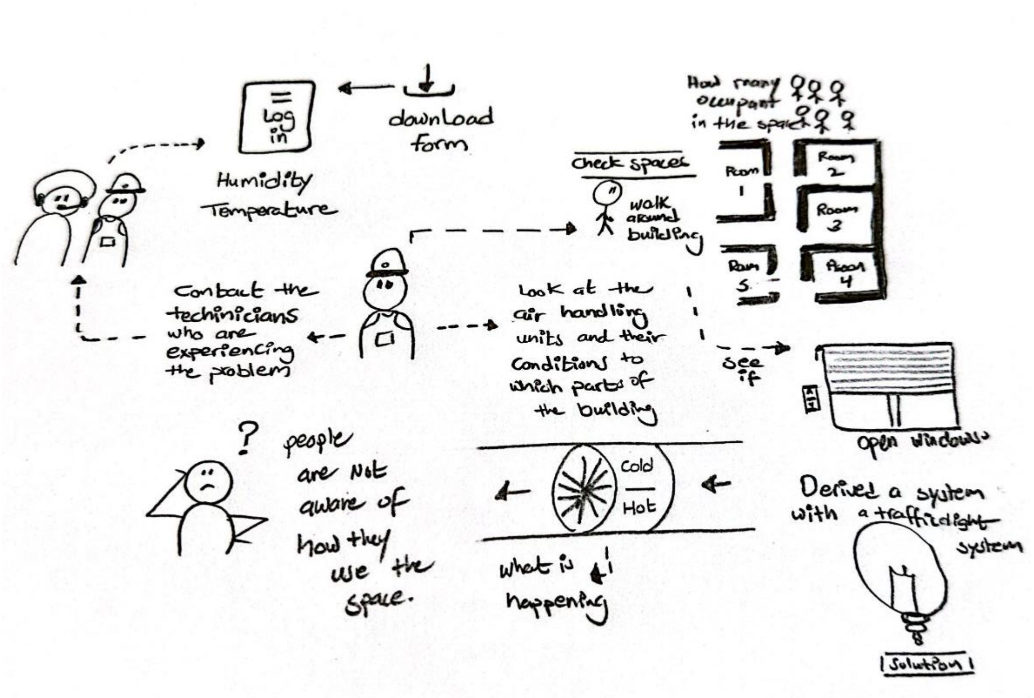


Figure 7-11: Use-case scenario (P16, SHB).

7.7.6.1 Development of Use Cases: Discussion

A significant part of the validation process consisted of gathering usability processes and putting them in a use-case scenario. In this stage, data was collected to provide a real-life scenario of users' experiences on how processes were applied to respond to an issue within the building based on decision-making stakeholders' (experts') decisions. This study collected data to provide comparison points between processes using a multi-stakeholder information model. In particular, to highlight the alternative paths once the use-case scenario has been turned into a process model that can be implemented in the validation stage. This would highlight how particular stakeholders would use the developed model to assess and see if certain issues could be resolved in an efficient way. The replies from (P15, JPB) and (P16, SHB) summarises the views. The participants' experiences were mainly process-driven and focused on resolving issues rather than relying on technology to accomplish what was expected. The views emphasised the importance of incorporating the views and perspectives of various users in the building. Hence, most of the issue reports are coming from different stakeholders. It can also be concluded that the development of the use cases showed that even though the two participants used similar processes, they looked at the problem from their point of view. In other words, a stakeholder will assess the issue from three approaches: Technology, which refers to the systems implemented in the building. Space refers to the indoor environment and rooms in the building, and Data refers to the information obtained from systems and other stakeholders. It resulted in reactive views of usability within the building management systems and spaces that depend on integrating multiple perspectives when an issue or a problem is found in the building.

7.8 Validating the Multi-stakeholders Information Model

Forming the use case scenarios leads to the process being limited to following a set of smart criteria or relying on a set of drivers for issues in the building to be resolved. As a result, it might be beneficial to review the findings from Chapter 6 (see Figure 6-1) in order to understand how (Space, technology, and data) could enhance the process of resolving issues within the building. The following quotation by (P15, JPB) is evidence that there is a need to consider those areas from different stakeholders' points of view when considering a smart building.

> "*different information they need and how they are connected to each other. So at the end, I will have that map, and I will discover like, maps or route for how processes should be.*"
>
> (P15, JPB).

Validation aims to determine if the developed information model can be used as a guide to assess current building processes. In addition, how different stakeholders will be involved in the process and how satisfied they will be with the recommended change.

7.8.1 Results and Findings

The findings of the validation are based on the scenario presented by the two participants within the building. The first scenario was responding to an issue within the building. The issue was regarding a fault in humidity in one of the buildings of the case he chose for this research. As a result, the participant highlighted several processes which were undertaken to overcome the issue regarding the humidity fall within the building. However, the process seems to be done manually and is not related to the means of smart building processes. In other words, they did not consider the different drivers mentioned in this chapter of this study.

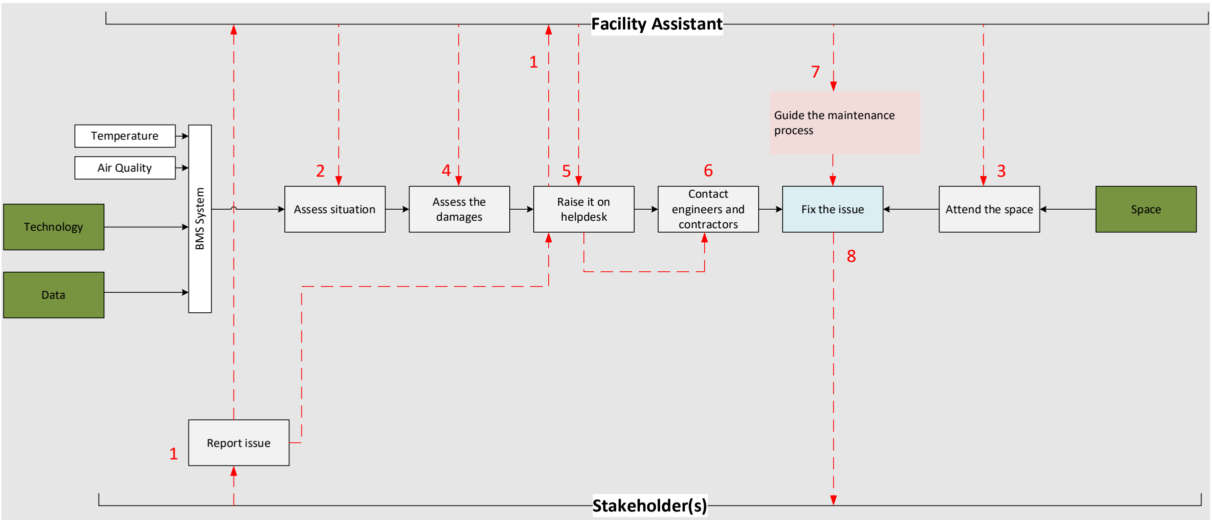


Figure 7-12 Using the multi-stakeholder model as a lens to enhance the process connectivity of the space (Use case 1).

As can be seen from (Figure 7-12) concerning use case one (Table 7-3), the processes after using the models consider looking at the drivers for different stakeholders involved in the process (Highlighted green). In this case, information will be available to respond to issues quickly and avoid repeating the same problem in other spaces around the building. The shared information within the system (Space, data, and technology) is collected from different approaches and stakeholders in the building.

Following the use of the models (Use case 1), the processes in (Figure 7-13) consider the drivers for different stakeholders in the process (highlighted in green). Information will be available in this case to address issues quickly and prevent the recurrence of the same problem in other areas of the building in the future. Information shared within the system is about (Space, data, and technology) that is obtained from the different systems and stakeholders within the building.

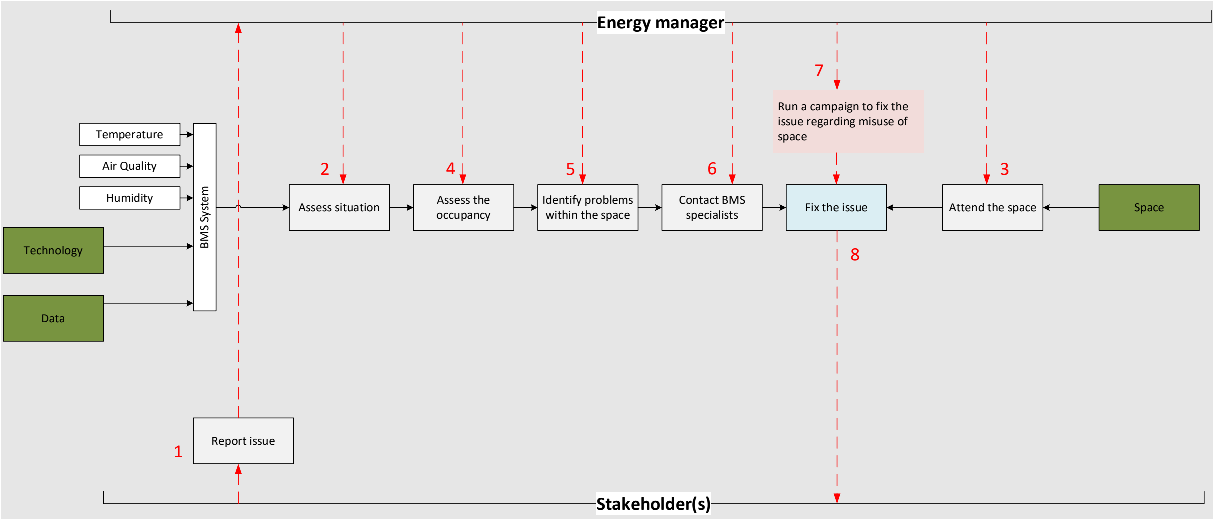


Figure 7-13 Using the multi-stakeholder model as a lens to enhance the process connectivity of the space (Use case 2).

According to the developed model, Technology, Data, and Space represent the requirements of various stakeholders in the building. For example, in the first use case, it took considerable time for the processes to incorporate all those requirements to achieve the desired outcome. According to the power manager:

"People weren't aware of where was supposed to be humidity controlled and where it wasn't. So there's confusion about where they could leave instruments." (P16, SHB).

The preceding quotation illustrates the need for information about space to be clear and accessible to all stakeholders to ensure effective use of the space.

In conclusion, both participants agreed on the usefulness of the developed model in terms of defining new processes of looking at the building from a variety of lenses to include multiple stakeholders in the process of sharing information.

7.9 Experiment

In an open space office, the temperature is a crucial factor that can impact the productivity and well-being of the employees. Setting the appropriate temperature can create a comfortable working environment and positively affect the quality of work, satisfaction, and overall performance of the employees. This experiment aims to assess the current temperature of an open space office that accommodates 40 employees and determine the optimal temperature for enhanced productivity and satisfaction. **Error! Reference source not found.** shows the temperature of different rooms on floor one in the building. The red room is the room where the experiment is taking space.

7.9.1 Assessment of the situation

The facility manager will receive a complaint about the temperature from an employee. The facility manager will check the temperature using the Building Management System (BMS) to assess the current temperature of the office space. Suppose the temperature is not at the desired level. In that case, the facility manager will visit the space to assess the situation and ensure that the data provided by the BMS are correct.

(1) The initial step is to check the temperature of the room.

"I will check the building management system to see the temperature that is shown in the computer" (P16, SHB).

Figure 7-14: First Floor STEAM house HVAC System Data Based on The BMS system (Steam House – Floor One).

The facility manager will collect data on the current temperature in the office space and the number of employees present. The data will be collected at different times of the day to assess the impact of external factors such as sunlight and changes in occupancy.

(2) Secondly, the room must be assessed from the perspective of others.

"Then I will physically go to the room and check with a laser thermometer and also my physical presence, feeling the room myself to get the idea whether it is comfortable for me or comfortable for someone else." (P16, SHB).

The facility manager will use the data collected to determine the optimal temperature for the office space. The optimal temperature will be based on factors such as employee comfort, energy efficiency, and the impact on other spaces around the office.

"Sometimes the system is reading the temperature wrong, and that is why we need to physically attend the room." (P16, SHB).

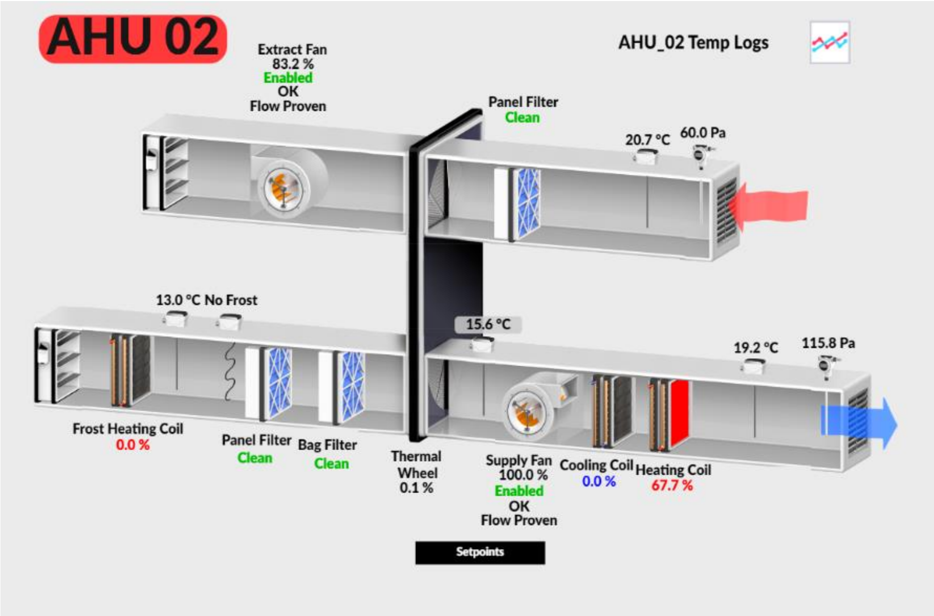


Figure 7-15: Air Handlining Units Based on the BMS System (at The Time of The Experiment).

(3) Include other stakeholders in the process.

The facility manager will contact the energy manager to see if the change in temperature will impact other spaces around the office and whether it is possible to implement the change. If the change is feasible, the facility manager will adjust the temperature using the BMS and monitor the impact on the workspace.

> *"I will contact the engineers who are handling the heating units in the building; the reason is that they need to help me make the decision to change the temperature and make sure that this change would not affect the surrounding environment. Also, sometimes it is a cost issue, so their input is necessary to ensure the energy consumption stays within the standard level."* (P16, SHB).

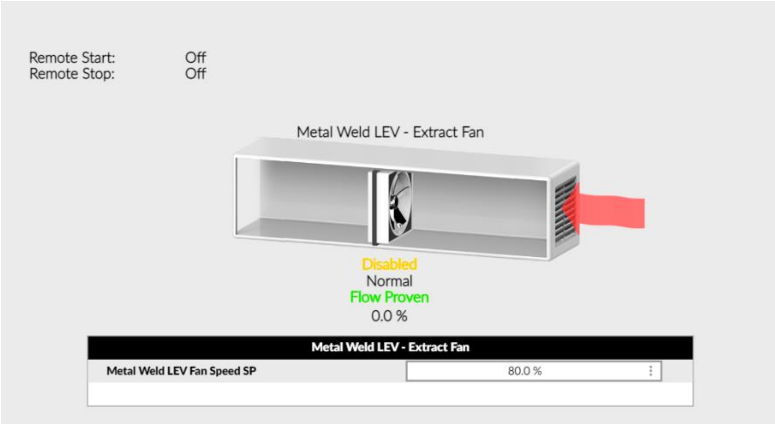


Figure 7-16: Air Handlining Units (a) Based on the BMS System (at The Time of The Experiment).

> *"We have to consider the impact that will affect the sounding rooms as sometimes we have to compensate other areas in order to make up the difference for the change we are making for the room"* (P16, SHB).

By optimising the temperature in an open space office, the quality of the workspace can be enhanced for all stakeholders, including employees, facility managers, and energy managers.

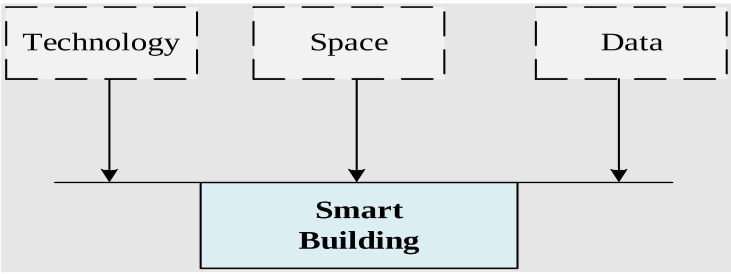


Figure 7-17: Drivers Based on Stakeholders' Requirements.

The facility manager evaluated the impact of the temperature change on the workspace by collecting data on employee satisfaction, productivity, and energy consumption. The data has shown that the temperature change positively impacted the workspace. The following quote illustrates the impact of considering the other stakeholders' views.

“Being physically their gave me a sense of how the occupants are using the space and what they are feeling so I could make a decision based on that.” (P16, SHB).

In conclusion, the experiment demonstrated the importance of process connectivity in enhancing the quality of a workspace. By optimizing the temperature in an open space office, the quality of the workspace was improved for all stakeholders. The experiment provided valuable insights for facility and energy managers on creating a comfortable and productive workspace while ensuring energy efficiency.

*“Technology allows us to have a quick glimpse of what is supposed to happen, but like I have said, faults happen, so the technology is telling us the temperature is 21 degrees, and this is what it is supposed to be, but being in the room showed that it is not. There is a problem with the technology rather than the temperature itself. Taking the approach of this model, I believe we do need a human interaction to check these faults physically because **sometimes the technology does not provide the connectivity between stakeholders we are looking for**.”* (P16, SHB).

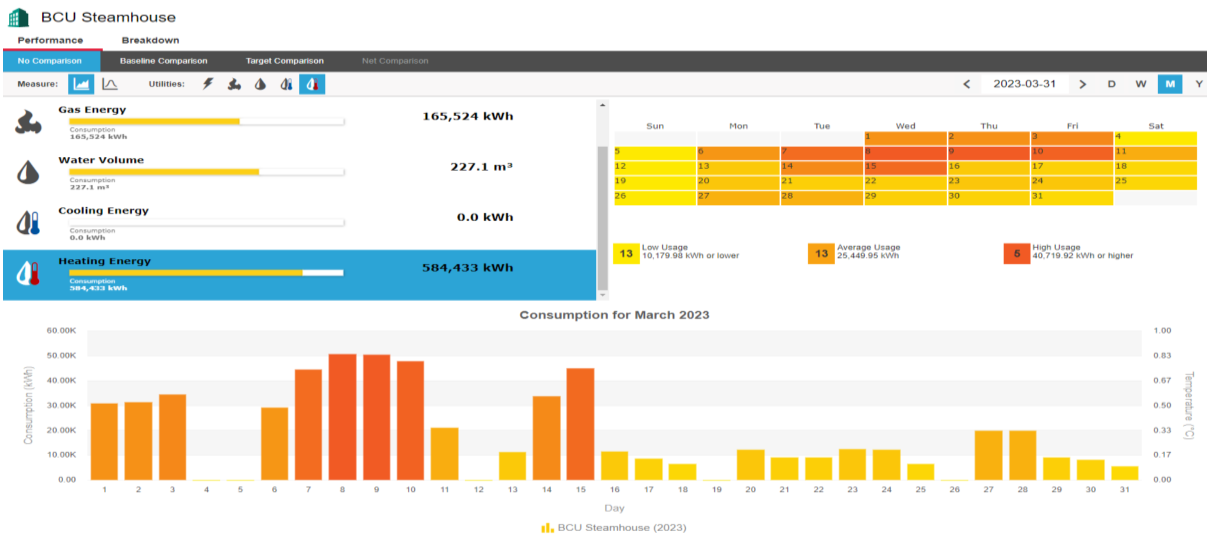


Figure 7-18: BMS system visualisation.

The argument from the interview of this experiment demonstrates the limitations of relying solely on technology to gather information and make decisions. Although technology can provide quick glimpses of what is expected to happen, it is not always accurate or reliable. According to the technology, the temperature in the room should be 21 degrees, but the actual reading contradicts that. In this case, the temperature may be the problem, not the technology. (P16, SHB) believes that human interaction is necessary to physically check for faults due to the fact that technology may not provide the level of connectivity between stakeholders that is desirable. Therefore, it is possible to overlook the insights and perspectives that human stakeholders can contribute by relying solely on technology. According to the stakeholders, human involvement is as important as technological solutions in a holistic approach.

In In response to this need for better information-sharing and problem-solving, the Multi-stakeholder Information Model was developed. In this model, different stakeholders involved in decision-making have different perspectives and requirements. The analysis incorporates information from three key drivers: data, technology, and space. As a result of considering these drivers, the Multi-stakeholder Information Model improves information sharing between different stakeholders and systems. It provides a comprehensive understanding of the requirements, concerns, and insights from various perspectives. Considering the broader perspective of processes instead of solely focusing on the data from building systems opens up new possibilities for solving problems. Thus, the model facilitates better decision-making and addresses the limitations of technology by incorporating human interactions and perspectives.

7.10 Chapter Summary

Chapter 7 discusses smart buildings' concepts, processes, technology, stakeholders, and requirements. The chapter begins with an introduction to smart buildings and their benefits. It then delves into the processes involved in making a building smart, including automation and data collection. The next section of the chapter explores the various technologies used in smart buildings, such as sensors, IoT devices, and building management systems. The section also touches on the benefits and challenges of using these technologies.

Additionally, the chapter discusses the stakeholders in smart buildings, including building owners, managers, occupants, and service providers. It then highlights each stakeholder's requirements regarding space concepts, such as privacy, security, and flexibility. The chapter then introduces the Multi-Stakeholder Information Model (MSIM), which manages information in smart buildings. The MSIM is divided into two parts: technical and social. The technical part deals with data and systems management, while the social part focuses on the people and their interactions within the building. The chapter also explains how the social and technical parts of the MSIM are integrated to provide a holistic view of the building's operations. The integration enables stakeholders to make informed decisions about the building's management, thus improving its overall efficiency and sustainability.

Finally, the chapter then moves on to discuss the validation of the MSIM and presents the results and findings of the validation process. The validation aimed to identify potential flaws in the MSIM and ensure its reliability in practical applications. The final section of the chapter describes an experiment conducted to test the MSIM's reliability further. The initial assessment of the experiment is presented, which outlines the goals, procedures, and expected outcomes of the experiment. Overall, Chapter 7 demonstrates the importance of validating and ensuring the reliability of the MSIM to maximise its potential benefits in managing information in smart buildings. The use-case scenarios and experimental tests provide a comprehensive and practical approach to validating the MSIM.

8 Discussion and Conclusions

8.1 Introduction

A smart building can be realised through the use of the Internet of Things (IoT). A gap exists between data requirements and stakeholders' expectations. Systems thinking was used to show that it could be a problem between 'the parts' and 'the whole' to understand this gap. An understanding of the problem was gained through the use of soft systems analysis. The information requirements that can bridge the gap between stakeholders and data (information sharing) have been identified through the use of soft systems. A richer picture is provided by exploring several themes in chapter 7 (the discussion chapter).

As a result, different understandings of the parts and the holistic view of smart buildings are perceived differently by different stakeholders, as shown by the first theme. In addition to providing a holistic view of the problem, soft systems can better understand these abstractions. In the second theme, IoT is examined in smart buildings, where current tools such as IoT lack the capability to represent many emergent characteristics that influence information sharing. Using conceptual models (Wilson, 1990) to represent information requirements has provided a richer understanding of what influences stakeholders' views.

As a concept, the third theme illustrates the importance of considering space, data, and technology in order to view a smart building because it simplifies levels of complexity between individual parts and the whole. It also provides a medium through which different stakeholders can interpret a smart building in different ways. Currently, smart building representations only present the physical system of a building, which does not provide a profound understanding of the building as a whole. As part of a soft systems analysis, different parts that influence smart buildings are examined, and information requirements are identified that can help bridge the gap between stakeholders and information sharing.

Last but not least, the final theme focused on space, data, and technology as information and proposed a solution for bridging the gap between information sharing and experience based on the requirements identified using soft systems. Based on the information categories identified from the soft systems analysis, a Multi-stakeholders' Information Model was constructed, which represents different information requirements through entities and attributes. This model proposes an 'informating system (Zuboff, 1988), which recognizes the significance of different parts and provides a better understanding of emerging characteristics that affect experiences.

The developed information model MSIM responds to the main research question in this research, which seeks to improve the connectivity between processes in smart buildings. The model suggests the need to provide a set of generic requirements to accommodate all stakeholders' needs and can support more informed decisions about how to implement IoT technologies in smart buildings. This chapter explains how the research objectives were achieved, to provide research contributions, and to provide a summary of limitations and opportunities for future research.

8.2 Discussion

The concept of smart buildings, enabled by the Internet of Things (IoT), promises a future where our built environment seamlessly integrates technology to enhance efficiency, sustainability, and overall quality of life. However, realising the full potential of smart buildings encounters a substantial gap between the data requirements and stakeholders' expectations. This thesis burrows into the complexities of this gap, employing systems thinking and soft systems analysis to highlight the root causes and propose solutions.

The Multi-Stakeholder Information Model (MSIM) (See Figure 7-8) is designed to promote process connectivity in smart building environments. It extends the features stated by Jia *et al.*, (2019b) in their model, such as visualising environmental or energy use data for stakeholders, which is a basic feature most systems already have. In their model, a building system could automatically adjust schedules based on occupancy status if the information became available. There may, however, be a need for more information about the energy consumption patterns of stakeholders. The MSIM is different as it is concerned with multiple stakeholders' requirements as it is built around two main components: the technical side and the social side. The technical side consists of a series of processes that capture, filter, compare, aggregate, process, and present data, which is similar to some models presented by Kejriwal and Mahajan (2016), Fayyaz, Rehman and Abbas (2019), and Liu et al., (2020) who focused on the IoT technical processes in smart buildings. However, Jia *et al.*, (2019b) argue that it is still being investigated how certain environmental parameters influence occupant comfort levels and energy consumption. They conclude that in order to provide potential users with concealed conclusions or optimised suggestions, data analysis results from domain researchers must be added to indicate what processes are missing in which aspect of buildings. The MSIM offers processes that are based on the system view, where all processes are taken into account from a holistic perspective, thus addressing the social as well as the technical aspects of the process. The social side of the model is focused on user input, data generation, and user requirements. The model aims to create a cohesive and connected system that can support a range of stakeholders and use cases. In a smart building environment, the MSIM would work by leveraging a range of technologies, sensors, and devices to capture data from various sources. This data would be filtered and compared to identify patterns and differences. The aggregated data form the MSIM would be processed to extract insights and create actionable information that could be presented to stakeholders in a meaningful way. The most suitable scenario would be chosen based on stakeholder requirements and the lens of technology, space, and data. To promote process connectivity, the MSIM would enable seamless communication and collaboration between all parts of the system. This would include sensors, devices, platforms, and stakeholders. Data would be shared in real-time, allowing stakeholders to make informed decisions and take timely actions. The model developed by Waidyasekara and Madhusanka, (2019) supports the processes of a facility manager in an IoT smart building environment. Although the MSIM supported a range of use cases (presented in chapter 8) based on the facility management team, including energy management, occupancy monitoring, asset tracking, and predictive maintenance. Therefore, more insights on stakeholders especially the social side are captured within the MSIM, thus, enabling stakeholders to input data and generate insights based on their requirements. This would include feedback on the performance of the system, as well as suggestions for improvement.

The MSIM is a model for promoting process connectivity in smart building environments. It includes looking at the processes from the technical side and the processes generated from the human side based on their requirements. By leveraging a range of technologies, sensors, and devices, the MSIM enables seamless communication and collaboration between all parts of the system. The social side of the MSIM enables stakeholders to input data and generate insights based on their requirements.

The MSIM addresses the gap that stems from the divergent perceptions of what constitutes a "smart building" among different stakeholders, including engineers, building occupants, facility managers, and technology providers. Some stakeholders see a smart building as a sum of its technological components, emphasising discrete elements such as sensors, HVAC systems, and energy management tools. Others view it as a unified, integrated system that aims to create a holistic experience for occupants. The MSIM bridges this gap by using systems thinking, which offers a powerful approach. It encourages users of MSIM to consider the interconnections between various components and how they contribute to the overall objectives of a smart building. This shared understanding recognises that both the concept's discrete components and the holistic experience are integral.

In the same way, Soft systems analysis provided a structured framework for addressing this complex challenge. It allowed stakeholders to engage in open dialogues, articulate their viewpoints, and identify areas of commonality and divergence. Importantly, it uncovered the information requirements necessary to bridge the gap between stakeholders, helping define the data that should be collected and shared within a smart building ecosystem.

Smart buildings are complex systems where the entire system's behaviour evolves over time, influenced by factors such as occupant behaviour and environmental conditions. Conventional IoT technologies often focus on monitoring discrete parameters and elements, potentially overlooking these emergent properties. However, the challenge in the domain of smart buildings is the limitation of a current IoT framework that represents the emergent characteristics. Emergent characteristics refer to properties or behaviours that arise from interactions among various components and systems within a building. These characteristics often go above the simple sum of individual elements, making them challenging to predict or model using traditional approaches. To address these limitations, the MSIM provide a means to represent and explore the complex, non-linear relationships and emergent properties within smart buildings. Soft systems analysis as a lens contributes by helping stakeholders identify and understand emergent characteristics, define information requirements, and facilitate iterative modelling.

The interplay between space, data, and technology is crucial in shaping the smart building landscape. Space encompasses the physical environment, while data forms the foundation, and technology enables smart buildings to function. Recognizing these elements as integral components and understanding their interactions is essential for simplifying complexity and accommodating diverse stakeholder interpretations.

A holistic perspective is promoted when designing, implementing, and managing smart buildings. Instead of viewing them solely as collections of physical components or IoT devices, they should be seen as integrated systems where space, data, and technology work together to achieve overarching objectives. Soft systems analysis plays a vital role in examining the various influencing parts within a smart building ecosystem. It helps stakeholders understand the interdependencies between space, data, and technology, as well as how these elements collectively contribute to the building's functionality.

Constructing a Multi-Stakeholders' Information Model (MSIM) is proposed as a critical solution to bridge the gap between information sharing and stakeholder experience. This model goes beyond a data schema and provides a comprehensive representation of information requirements, considering the diverse needs and perspectives of stakeholders. Entities and attributes are identified within the MSIM, recognizing the significance of different parts within the smart building ecosystem. The model serves as a bridge between information sharing and stakeholder experience, aligning the data collected with stakeholders' objectives and expectations, ultimately leading to more informed decision-making and improved outcomes.

8.3 Research Objectives

This research aims to develop a multi-stakeholder information model to drive process connectivity within IoT in Smart Buildings. These contexts reflect an equal level of interrelationship between the social and technical subsystems. The perception towards the critical factors that impact the outcome of a smart building from the perspective of multiple stakeholders working in different buildings on a university campus (Birmingham City University). The following section audits the delivery of the pre-set research objectives:

8.3.1 Research Objective One

Research objective (1): To identify the current issues and problems concerning IoT frameworks in smart buildings in the literature. The purpose of conducting a systematic literature analysis for IoT frameworks in smart buildings is to understand the reason behind the development of different IoT frameworks for the same domain (Smart buildings) by different authors. In addition, it aims to understand the involvement of the different stakeholders of smart buildings in sharing information within the processes in the analysed frameworks. **A**n analysis of selected criteria based on the definition of IoT frameworks by the researcher was used to analyse and develop a generic framework of IoT in smart buildings to meet this objective. The data was collected using the Scopus search engine with the following keywords (Smart buildings, Internet of Things, IoT, Frameworks, Model). The framework's findings, results, and discussion (Chapter 3) informed the development of the multi-stakeholder information model. Finally, this objective justified the need for a generic IoT framework in smart buildings and proposed one as the first contribution to this study.

8.3.2 Research Objective Two

Research objective (2): To identify the key stakeholders' requirements within the IoT processes in smart buildings in order to map and analyse them. The literature review (Chapter 2) highlights the different requirements of the stakeholders in smart buildings and how these requirements are not met and considered by the different technologies implemented in the buildings. In addition, the analysis of the IoT frameworks within smart buildings (Chapter 3) showed that processes within the analysed frameworks do not consider the different requirements of multiple stakeholders in smart buildings. Also, the requirements that existed in the literature were not sufficient to be used to enrich the developed information model for this study. Therefore, this objective collected empirical data based on a case study (Commercial building, University Campus) to understand the different requirements of multiple stakeholders of smart buildings. The data was collected using semi-structured interviews and was analysed using thematic analysis based on themes generated from the transcripts using NVivo. After a critical discussion of the results of the empirical data, the finding of requirements related to (Space, Data, and Technology) was used to enrich the information model and finalise the developments of the multi-stakeholder information model (Chapter 7, Figure 7-8).

8.3.3 Research Objective Three

Research objective (3): To develop an information model for the purpose of improving the connectivity between processes in smart buildings. That is done in combination between objective one and objective two, as the data collected to satisfy both objectives was used to develop and enrich the model. In this objective, the study used socio-technical systems as a lens to develop the model. This objective looked at the technical side of processes with IoT in smart buildings as well as the human side of processes extracted from the requirements of different stakeholders using soft systems analysis (Chapter 6). This Multi-stakeholder information model was primarily developed from the literature and informed by the analysis of the different data collected for his research (Objective 1 and 2). This objective was satisfied by combining the two approaches of the technical and the social sides of the model applied in a smart building environment.

8.3.4 Research Objective Four

Research objective (4): To validate the developed model using a high educational building as use-case scenarios within a case study. The validation process of the multi-stakeholder model developed in Chapter 7 in order to meet Research Objective 4. The proposed model was demonstrated to be useful, valuable, and applicable during the validation process. As part of this process, the views of building stakeholders were incorporated to ensure that it meets the end user's expectations. Validation of the developed information model was conducted using case scenarios developed based on the experience of the facility management team during the in-use phase of a smart building.

8.4 Summary of Research Contributions

The contributions of this research are summarised in Figure 8-1, categorised as practical, theoretical, and methodological contributions in the following sections.

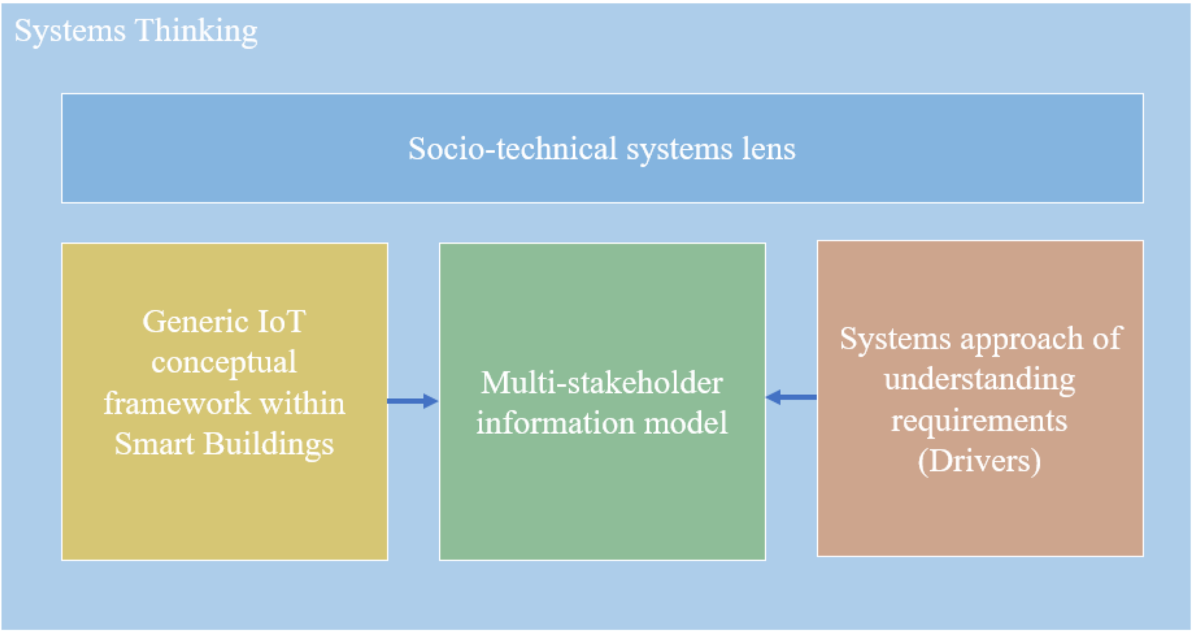


Figure 8-1: Research Contributions.

8.4.1 Practical Contributions

The information model (Figure 7-8) developed in this research enables meeting the demand for different stakeholders' information needs with IoT-enabled smart buildings. The conceptual model proposes enriched drivers that should be considered when exploring the different stakeholders' requirements to enable information sharing. The model also suggests the need to provide a set of generic requirements to accommodate all stakeholders' needs instead of focusing on specific stakeholder group requirements. In addition, future IoT-enabled smart building implementors can use the information model to enhance the stakeholders' experience within smart buildings by considering different requirements, as stated in the problem in Chapter One.

Furthermore, various stakeholders' requirements need to be met in an IoT-enabled smart building environment to ensure effective processes such as data collection, data analysis, and acting on data. However, the fulfilment of these requirements may differ depending on the technology and nature of the processes involved. The Multi-Stakeholders Information Model for IoT-enabled Smart Buildings (MSIM) plays a crucial role in informing different stakeholders about the importance of considering additional requirements based on three key drivers (Technology, Data, and Space). The three drivers guide the decision-making process regarding how the environment within the IoT-enabled smart building can meet all stakeholders' requirements. These drivers could be related to specific roles, goals, objectives, or priorities set by the stakeholders involved.

A key benefit of the MSIM is that IoT implementors within buildings can make informed decisions about how to implement IoT technologies in smart buildings. The MSIM serves as guiding information that helps stakeholders evaluate the different options available, assess the information-sharing paths, and determine the most appropriate approach to achieve stakeholders' objectives while ensuring effective information-sharing and collaboration in the smart building environment.

The developed MSIM can benefit decision-makers in smart buildings, which includes building management teams and facility managers. As an information model, MSIM can be an effective mechanism for continual improvements and monitoring the processes with different information flows in smart buildings. MSIM, beyond facility/building managers, can inform IoT system developers by providing more insight into embedded processes, information handling capability and selecting appropriate architecture that meets the diverse needs of stakeholders.

8.4.2 Theoretical Contributions

The thesis presented a systematised analysis of different IoT frameworks within smart buildings, resulting in an improved mapping between different requirements of stakeholders and IoT-enabled systems in a smart building. This resulted in an improved theoretical contribution to the development of a generic IoT framework. This was initiated with the development of the summarised IoT framework following a systematic review of developed IoT frameworks in smart buildings. The framework resulting from this review can act as a guideline for future researchers to consider the important elements needed when considering IoT frameworks in smart buildings. More importantly, this can holistically inform researchers and practitioners of complex parts/components that sit within the architecture of IoT systems. This addresses the problem presented in Chapter One: the current IoT framework does not address all stakeholders' requirements. The framework worked as a guideline to form the technical side of the Multi-stakeholder processes model.

It also provides guidelines for designing and implementing IoT systems, helping researchers align with stakeholder needs and best practices while incorporating essential elements and functionalities. Furthermore, developing the framework proposes criteria for evaluating IoT frameworks' performance and effectiveness. Researchers can compare different frameworks to IoT technology in smart buildings using a generic set of evaluation criteria. As a result, the framework aids researchers in identifying research gaps and areas for further exploration, guiding them towards new opportunities and challenges related to IoT-enabled smart buildings. Lastly, the generic IoT framework encourages collaboration among researchers, accelerating the development of IoT solutions for smart buildings and encouraging innovation. The adoption of the generic IoT framework enables researchers to build on each other's work, exchange ideas, and make positive contributions to the field.

8.4.3 Methodological Contribution

This study was innovative in applying a system thinking approach to analyse the requirements of a smart building. The use of systems thinking in this research supported unfolding the complexity behind the embedded processes as part of the IoT framework to understand how it responds to different stakeholders. This demonstrated the importance of looking at a smart building from an abstraction level and using systems thinking when defining a smart building to ensure that processes are responding to different stakeholders' requirements.

The use of socio-technical systems in this research has methodologically provided an understanding of the synergy between stakeholders, technology, and processes. This resulted in developing three key drivers when looking at the different requirements that benefit IoT frameworks in terms of understanding and unfolding further complexities that can emerge due to requirements from stakeholders, technological advancements, and IoT-enabled smart buildings. The benefits of applying STS explain that stakeholders, technologies, and processes may differ significantly, so adaptation or modification may be necessary. Therefore, In future studies, researchers should determine whether the specific insights and drivers identified in this study apply to their own contexts.

8.5 Limitation and Future Work

In smart building environments, the Multi-Stakeholder Information Model (MSIM) holds promise for enhancing process connectivity. However, there are several limitations and areas for future research. Data quality is an important component of MSIM since it is dependent on accurate and reliable data to be effective. Therefore, processes are needed to ensure consistent definitions and clean the data. The model depends on the data gathered from the BMS (Technical side), resulting in collecting large amounts of data from the BMS (Technical side). Therefore, data security is another concern that prevents security breaches and privacy violations crucial to protect data from unauthorised access. In addition, MSIM faces challenges due to integrating various technologies, sensors, and devices. It may be necessary to invest significant effort and resources in order to achieve seamless integration if technical complexities arise. An important factor in MSIM's success is user acceptance and adoption. Stakeholders must accept it to utilise it effectively; otherwise, they may not recognise its value. Future work should focus on updating the requirements of different stakeholders in the MSIM within a different context and expanding its potential to address these requirements. Another area for research is optimising the MSIM to reduce data processing requirements and improve efficiency. It can involve applying machine learning algorithms to identify patterns and reduce the amount of data being processed. The MSIM's relevance and applicability can be enhanced with customisation by developing different use-case scenarios within the different contexts of a smart building, which is crucial to its success in meeting the unique needs of different stakeholders and use cases. The user experience should also be considered by ensuring that the MSIM is intuitive, user-friendly, and easy to navigate. Building managers and building facility teams will be more likely to adopt and utilise the framework if the user experience is positive.

9 Reference

Ahmed, V., Alnaaj, K. A. and Saboor, S. (2020) 'An investigation into stakeholders' perception of smart campus criteria: The American University of Sharjah as a case study', Sustainability (Switzerland), 12(12). doi: 10.3390/su12125187.

Ahvar, S. et al. (2017) 'Ontology-based model for trusted critical site supervision in FUSE-IT', Proceedings of the 2017 20th Conference on Innovations in Clouds, Internet and Networks, ICIN 2017, pp. 313–315. doi: 10.1109/ICIN.2017.7899430.

Akadiri, P. O., Chinyio, E. A. and Olomolaiye, P. O. (2012) 'Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector', Buildings, 2, pp. 126–152. doi: 10.3390/buildings2020126.

Akhtar, P. et al. (2018) 'The Internet of Things, dynamic data and information processing capabilities, and operational agility', Technological Forecasting and Social Change, 136(April 2017), pp. 307–316. doi: 10.1016/j.techfore.2017.04.023.

Al Dakheel, J. et al. (2020) 'Smart buildings features and key performance indicators: A review', Sustainable Cities and Society. Elsevier Ltd. doi: 10.1016/j.scs.2020.102328.

Al-Ali, A. R. et al. (2020) 'Digital twin conceptual model within the context of internet of things', Future Internet, 12(10), pp. 1–15. doi: 10.3390/fi12100163.

Alam, S., Chowdhury, M. M. R. and Noll, J. (2011) 'Interoperability of security-enabled Internet of Things', Wireless Personal Communications, 61(3), pp. 567–586. doi: 10.1007/s11277-011-0384-6.

Aldrich, H. and Herker, D. (1977) 'Boundary Spanning Roles and', 2(2), pp. 217–230.

Aldrich, H. and Herker, D., 1977. Boundary spanning roles and organization structure. Academy of management review, 2(2), pp.217-230.

Al-Fuqaha, A. et al. (2015) 'Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications', IEEE Communications Surveys and Tutorials, 17(4), pp. 2347–2376. doi: 10.1109/COMST.2015.2444095.

Aliero, M. S. et al. (2022) 'Systematic Review Analysis on Smart Building: Challenges and Opportunities', Sustainability (Switzerland). MDPI. doi: 10.3390/su14053009.

Alrashed, S. (2020) 'Key performance indicators for Smart Campus and Microgrid', Sustainable Cities and Society, 60. doi: 10.1016/j.scs.2020.102264.

Al-Shammari, H. Q. et al. (2020) 'Service Embedding in IoT Networks', IEEE Access, 8, pp. 2948–2962. doi: 10.1109/ACCESS.2019.2962271.

Altaf, M. et al. (2021) ‘Value Analysis in Construction Projects with BIM implementation: A Systematic Review’, 2021 International Conference on Decision Aid Sciences and Application, DASA 2021, pp. 51–56. doi: 10.1109/DASA53625.2021.9682253.

Ammar, M., Russello, G. and Crispo, B. (2018a) ‘Internet of Things: A survey on the security of IoT frameworks’, Journal of Information Security and Applications, 38, pp. 8–27. doi: 10.1016/j.jisa.2017.11.002.

Ammar, M., Russello, G. and Crispo, B. (2018b) ‘Internet of Things: A survey on the security of IoT frameworks’, Journal of Information Security and Applications, 38, pp. 8–27. doi: 10.1016/j.jisa.2017.11.002.

Anjana, M. S. et al. (2019) ‘Fractal IoT: A scalable IoT framework for energy management in connected buildings’, TESCA 2019 - Proceedings of the 2019 1st ACM International Workshop on Technology Enablers and Innovative Applications for Smart Cities and Communities, co-located with the 6th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, pp. 10–17. doi: 10.1145/3364544.3364826.

Apanaviciene, R., Vanagas, A. and Fokaides, P. A. (2020) ‘Smart building integration into a smart city (SBISC): Development of a new evaluation framework’, Energies, 13(9). doi: 10.3390/en13092190.

Arditi, D., Mangano, G. and De Marco, A. (2015) ‘Assessing the smartness of buildings’, Facilities, 33(9–10), pp. 553–572. doi: 10.1108/F-10-2013-0076.

Ateeq, M. et al. (2019) ‘Multi-parametric analysis of reliability and energy consumption in IoT: A deep learning approach’, Sensors (Switzerland), 19(2), pp. 1–20. doi: 10.3390/s19020309.

Audi, R., 2011. Rationality and religious commitment. OUP Oxford.

Avis, J. (2018) ‘Socio-technical imaginary of the fourth industrial revolution and its implications for vocational education and training: a literature review’, Journal of Vocational Education and Training, 70(3), pp. 337–363. doi: 10.1080/13636820.2018.1498907.

Bagaa, M. et al. (2020) ‘A Machine Learning Security Framework for Iot Systems’, IEEE Access, 8, pp. 114066–114077. doi: 10.1109/ACCESS.2020.2996214.

Baghchesaraei, O. R. and Baghchesaraei, A. (2016) ‘Smart buildings: Design and construction process’, Journal of Engineering and Applied Sciences, 11(4), pp. 783–787. doi: 10.3923/JEASCI.2016.783.787.

Balta-Ozkan, N., Boteler, B. and Amerighi, O. (2014) ‘European smart home market development: Public views on technical and economic aspects across the United Kingdom, Germany and Italy’, Energy Research and Social Science, 3(C), pp. 65–77. doi: 10.1016/J.ERSS.2014.07.007.

Bandara, S. et al. (2016) ‘Access control framework for API-enabled devices in smart buildings’, Proceedings - Asia-Pacific Conference on Communications, APCC 2016, pp. 210–217. doi: 10.1109/APCC.2016.7581479.

Barret, P. and Baldry, D., 2003. Current Good Practice in Facilities Management. Facilities Management: Towards Best Practice (2nd ed., p. 304). Oxford: Blackwell Publishing.

Bashir, M. R. and Gill, A. Q. (2017) ‘Towards an IoT big data analytics framework: Smart buildings systems’, Proceedings - 18th IEEE International Conference on High Performance Computing and Communications, 14th IEEE International Conference on Smart City and 2nd IEEE International Conference on Data Science and Systems, HPCC/SmartCity/DSS 2016, pp. 1325–1332. doi: 10.1109/HPCC-SmartCity-DSS.2016.0188.

Basri, S. et al. (2016) ‘Using static and dynamic impact analysis for effort estimation; Using static and dynamic impact analysis for effort estimation’. doi: 10.1049/iet-sen.2015.0043.

Batool, K. and Niazi, M. A. (2017) ‘Modeling the internet of things: a hybrid modeling approach using complex networks and agent-based models’, Complex Adaptive Systems Modeling, 5(1). doi: 10.1186/s40294-017-0043-1.

Baxter, G. and Sommerville, I. (2011) ‘Socio-technical systems: From design methods to systems engineering’, Interacting with Computers, 23(1), pp. 4–17. doi: 10.1016/j.intcom.2010.07.003.

Bell, D., 2006. An introduction to cybercultures. Routledge.

Bellagente, P. et al. (2015) ‘Adopting IoT framework for Energy Management of Smart Building: A real test-case’, 2015 IEEE 1st International Forum on Research and Technologies for Society and Industry, RTSI 2015 - Proceedings, pp. 138–143. doi: 10.1109/RTSI.2015.7325084.

Benoliel, J.Q., 1996. Grounded theory and nursing knowledge. Qualitative health research, 6(3), pp.406-428.

Benson, K. E. et al. (2018) ‘Firedex: A prioritized IoT data exchange middleware for emergency response’, Proceedings of the 19th International Middleware Conference, Middleware 2018, pp. 279–292. doi: 10.1145/3274808.3274830.

Berat Sezer, O. et al. (2016) ‘An extended IoT framework with semantics, big data, and analytics’, Proceedings - 2016 IEEE International Conference on Big Data, Big Data 2016, pp. 1849–1856. doi: 10.1109/BigData.2016.7840803.

Bergin, M., Wells, J.S. and Owen, S., 2008. Critical realism: a philosophical framework for the study of gender and mental health. Nursing Philosophy, 9(3), pp.169-179.

Berman, P.S., Jones, J., Udry, J.R. and National Longitudinal Study of Adolescent Health, 2000. Research design.

Bernardo, H. (2018) 'A Combined Value Focused Thinking-Soft Systems Methodology Approach to Structure Decision Support for Energy Performance Assessment of School Buildings'. doi: 10.3390/su10072295.

Bhaskar, R., Collier, A., Lawson, T. and Norrie, A., 1998. Critical realism. In Proceedings of the standing conference on realism and human sciences, Bristol, UK (Vol. 4, pp. 1-0).

Bombieri, N. et al. (2015) 'Addressing the Smart Systems design challenge: The SMAC platform', Microprocessors and Microsystems, 39(8), pp. 1158–1173. doi: 10.1016/j.micpro.2015.05.013.

Bonetto Jr, S. (2018) 'Smart building systems optimization: Integration and interoperability in smart buildings enhance value and reduce risks for the building owner', Consulting-specifying engineer, 55(8), p. 42.

Bora, G. et al. (2014) 'OSI Reference Model: An Overview', International Journal of Computer Trends and Technology, 7(4), pp. 214–218. doi: 10.14445/22312803/ijctt-v7p151.

Bracken, L. J. et al. (2013) 'Concepts of hydrological connectivity: Research approaches, Pathways and future agendas', Earth-Science Reviews, 119, pp. 17–34. doi: 10.1016/j.earscirev.2013.02.001.

Braun, V. et al. (2008) 'Using thematic analysis in psychology Using thematic analysis in psychology', 0887(2006). doi: 10.1191/1478088706qp063oa.

Bryman, A. and Bell, E. (2004) Business Research Methods. Oxford: Oxford University Press

Buckman, A. H., Mayfield, M. and Beck, S. B. M. (2014a) 'What is a smart building?', Smart and Sustainable Built Environment, 3(2), pp. 92–109. doi: 10.1108/SASBE-01-2014-0003.

Buckman, A. H., Mayfield, M. and Beck, S. B. M. (2014b) 'What is a smart building?', Smart and Sustainable Built Environment, 3(2), pp. 92–109. doi: 10.1108/SASBE-01-2014-0003.

Buer, S.V., Strandhagen, J.O. and Chan, F.T., 2018. The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. International journal of production research, 56(8), pp.2924-2940.

Burhan, M. et al. (2018) 'IoT elements, layered architectures and security issues: A comprehensive survey', Sensors (Switzerland), 18(9), pp. 1–37. doi: 10.3390/s18092796.

Burke, M. E. (2007) 'Making choices: Research paradigms and information management: Practical applications of philosophy in IM research', Library Review, 56(6), pp. 476–484. doi: 10.1108/00242530710760373.

Burke, M.E., 2007. Making choices: research paradigms and information management: Practical applications of philosophy in IM research. Library review, 56(6), pp.476-484.

Burnham, J. F. (2006) 'Scopus database: A review', Biomedical Digital Libraries, 3, pp. 1–8. doi: 10.1186/1742-5581-3-1.

Capozzoli, A., Lauro, F. and Khan, I. (2015) 'Fault detection analysis using data mining techniques for a cluster of smart office buildings', Expert Systems with Applications, 42(9), pp. 4324–4338. doi: 10.1016/j.eswa.2015.01.010.

Carrillo, E. et al. (2015) 'IoT framework for smart buildings with cloud computing', 2015 IEEE 1st International Smart Cities Conference, ISC2 2015. doi: 10.1109/ISC2.2015.7366197.

Casado-Mansilla, Di. et al. (2018) 'A Human-Centric Context-Aware IoT Framework for Enhancing Energy Efficiency in Buildings of Public Use', IEEE Access, 6, pp. 31444–31456. doi: 10.1109/ACCESS.2018.2837141.

Castleberry, A. and Nolen, A. (2018) 'Thematic analysis of qualitative research data: Is it as easy as it sounds?', Currents in Pharmacy Teaching and Learning, 10(6), pp. 807–815. doi: 10.1016/j.cptl.2018.03.019.

Chang, T. W. et al. (2020) 'A network sensor fusion approach for a behaviour-based smart energy environment for co-making spaces', Sensors (Switzerland), 20(19), pp. 1–20. doi: 10.3390/s20195507.

Checkland, P. (2000) 'Soft Systems Methodology : A Thirty Year Retrospective a', 58, pp. 11–58.

Checkland, P. and Scholes, J., 1999. Soft systems methodology in action. John Wiley & Sons.

Chinchero, H. F., Alonso, J. M. and Ortiz T, H. (2020) 'LED lighting systems for smart buildings: a review', IET Smart Cities, 2(3), pp. 126–134. doi: 10.1049/iet-smc.2020.0061.

Christiansson, P. et al. (2011) 'User participation in the building process', Electronic Journal of Information Technology in Construction, 16(February), pp. 309–334. doi: 10.1007/978-1-4419-9607-7_3.

Ciribini, A. L. C. et al. (2017) 'Tracking Users' Behaviors through Real-time Information in BIMs: Workflow for Interconnection in the Brescia Smart Campus Demonstrator', Procedia Engineering, 180, pp. 1484–1494. doi: 10.1016/j.proeng.2017.04.311.

Clarke, V. et al. (2013) 'Teaching thematic analysis: Overcoming challenges and developing strategies for effective learning'.

Clements-Croome, D. (2013) 'Lessons from nature for sustainable architecture', Intelligent Buildings:Design, Management and Operation, (September), pp. 25–45.

Clements-Croome, D. et al. (2018) 'Research Roadmap for Intelligent and Responsive Buildings'. Available at: https://research.chalmers.se/publication/505880 (Accessed: 19 July 2022).

Cockburn, A. (1997) Structuring Use cases with goals Structuring Use cases with goals Structuring Use Cases with Goals. Available at: https://www.researchgate.net/publication/2807676.

Conti, M. et al. (2016) 'Mind the plug! Laptop-user recognition through power consumption', IoTPTS 2016 - Proceedings of the 2nd ACM International Workshop on IoT Privacy, Trust, and Security, Co-located with Asia CCS 2016, pp. 37–44. doi: 10.1145/2899007.2899009.

Conti, M. et al. (2018) 'Internet of Things security and forensics: Challenges and opportunities', Future Generation Computer Systems, 78, pp. 544–546. doi: 10.1016/j.future.2017.07.060.

Creswell, J.W. and Zhang, W., 2009. The application of mixed methods designs to trauma research. Journal of Traumatic Stress: Official publication of the international society for traumatic stress studies, 22(6), pp.612-621.

Creswell, J.W., 2013. Steps in conducting a scholarly mixed methods study.

Cruzes, D. S. and Dybå, T. (2011) 'Recommended steps for thematic synthesis in software engineering', International Symposium on Empirical Software Engineering and Measurement, (7491), pp. 275–284. doi: 10.1109/esem.2011.36.

Darby, S. J. (2018) 'Smart technology in the home: time for more clarity', Building Research and Information, 46(1), pp. 140–147. doi: 10.1080/09613218.2017.1301707.

Dave, B. et al. (2018) 'A framework for integrating BIM and IoT through open standards', Automation in Construction, 95(July), pp. 35–45. doi: 10.1016/j.autcon.2018.07.022.

Davis, L. and Dawe, M. (2001) 'Collaborative Design with Use Case Scenarios', pp. 146–147. doi: 10.1145/379437.379472.

Davis, M. C. et al. (2014) 'Advancing socio-technical systems thinking: A call for bravery', Applied Ergonomics, 45(2 Part A), pp. 171–180. doi: 10.1016/j.apergo.2013.02.009.

Denzin, N.K., Lincoln, Y.S. and Giardina, M.D., 2006. Disciplining qualitative research. International journal of qualitative studies in education, 19(6), pp.769-782.

Drisko, J. W. (2020) 'Qualitative research synthesis: An appreciative and critical introduction', Qualitative Social Work, 19(4), pp. 736–753. doi: 10.1177/1473325019848808.

Drummond, A. and Alves, E. D. (2013) 'Perfil socioeconômico e demográfico e a capacidade funcional de idosos atendidos pela Estratégia Saúde da Família de Paranoá, Distrito Federal', Revista Brasileira de Geriatria e Gerontologia, 16(4), pp. 727–738. doi: 10.1590/s1809-98232013000400007.

Eckelman, M. J. et al. (2018) 'Life cycle energy and environmental benefits of novel design-for-deconstruction structural systems in steel buildings', Building and Environment, 143(April), pp. 421–430. doi: 10.1016/j.buildenv.2018.07.017.

Effingham, N., 2013. An introduction to ontology. John Wiley & Sons.

Ettler, P. et al. (2015) 'From building blocks to the embedded condition monitoring system', IFAC-PapersOnLine, 28(10), pp. 135–140. doi: 10.1016/j.ifacol.2015.08.121.

Fabi, V., Spigliantini, G. and Corgnati, S. P. (2017) 'Insights on Smart Home Concept and Occupants' Interaction with Building Controls', Energy Procedia, 111(September 2016), pp. 759–769. doi: 10.1016/j.egypro.2017.03.238.

Fan, C. and Xiao, F. (2017) 'Assessment of Building Operational Performance Using Data Mining Techniques: A Case Study', Energy Procedia, 111(September 2016), pp. 1070–1078. doi: 10.1016/j.egypro.2017.03.270.

Fan, C. et al. (2020) 'Improving cooling load prediction reliability for HVAC system using Monte-Carlo simulation to deal with uncertainties in input variables', Energy and Buildings, 226, p. 110372. doi: 10.1016/j.enbuild.2020.110372.

Fântână, G. I. and Oae, S. A. (2021) 'Evolution of Smart Buildings', International Journal of Energy, 15, pp. 41–43. doi: 10.46300/91010.2021.15.7.

Fayyaz, H., Rehman, Z. U. and Abbas, S. (2019) 'An IoT Enabled Framework for Smart Buildings Empowered with Cloud Fog Infrastructures', 3rd International Conference on Innovative Computing, ICIC 2019, (Icic). doi: 10.1109/ICIC48496.2019.8966715.

Fazenda, P. et al. (2014) 'Using reinforcement learning to optimize occupant comfort and energy usage in HVAC systems', Journal of Ambient Intelligence and Smart Environments, 6(6), pp. 675–690. doi: 10.3233/AIS-140288.

Feige, A., Wallbaum, H. and Krank, S. (2011) 'Harnessing stakeholdermotivation: Towards a Swiss sustainable building sector', Building Research and Information, 39(5), pp. 504–517. doi: 10.1080/09613218.2011.589788.

Fleisch, W. (1999) Applying Use Cases for the Requirements Validation of Component-Based Real-Time Software. doi: 10.1109/ISORC.1999.776354.

Flick, U. (2015) 'Qualitative Inquiry—2.0 at 20? Developments, Trends, and Challenges for the Politics of Research', Qualitative Inquiry, 21(7), pp. 599–608. doi: 10.1177/1077800415583296.

Fok, C. L. et al. (2011) 'Challenges of satisfying multiple stakeholders: Quality of service in the internet of things', Proceedings - International Conference on Software Engineering, (January), pp. 55–60. doi: 10.1145/1988051.1988062.

Fossey, E., Harvey, C., McDermott, F. and Davidson, L., 2002. Understanding and evaluating qualitative research. Australian & New Zealand journal of psychiatry, 36(6), pp.717-732.

Frauley, J. and Pearce, F., 2007. Critical realism and the social sciences. Heterodox Elaborations. Toronto, Buffalo and London.

Froufe, M. M. et al. (2020) 'Smart buildings: Systems and drivers', Buildings, 10(9). doi: 10.3390/buildings10090153.

Gagnaire, P. A. (2020) 'Comparative genomics approach to evolutionary process connectivity', Evolutionary Applications, 13(6), pp. 1320–1334. doi: 10.1111/eva.12978.

Garzone, G., Guermouche, N. and Monteil, T. (2018) ‘Autonomic Management Approach for Dynamic Service Based IoT Systems’, 2018 International Symposium on Networks, Computers and Communications, ISNCC 2018. doi: 10.1109/ISNCC.2018.8530975.

GhaffarianHoseini, Ali et al. (2017) ‘Application of nD BIM Integrated Knowledge-based Building Management System (BIM-IKBMS) for inspecting post-construction energy efficiency’, Renewable and Sustainable Energy Reviews, 72, pp. 935–949. doi: 10.1016/J.RSER.2016.12.061.

Ghaffarianhoseini, Amirhosein et al. (2016) ‘What is an intelligent building? Analysis of recent interpretations from an international perspective’, Architectural Science Review, 59(5), pp. 338–357. doi: 10.1080/00038628.2015.1079164.

Ghosal, A. and Halder, S., 2018. Building intelligent systems for smart cities: issues, challenges and approaches. Smart Cities: Development and Governance Frameworks, pp.107-125.

Gibson, W. and Brown, A., 2009. Working with qualitative data. Sage.

Goddard, W. and Melville, S., 2004. Research methodology: An introduction. Juta and Company Ltd.

Gorard, S., Hordosy, R. and See, B.H., 2013. Narrowing down the determinants of between-school segregation: An analysis of the intake to all schools in England, 1989–2011. Journal of School Choice, 7(2), pp.182-195.

Gough, D., Thomas, J. and Oliver, S. (2019) ‘Clarifying differences between reviews within evidence ecosystems’, Systematic Reviews. BioMed Central Ltd. doi: 10.1186/s13643-019-1089-2.

Graven, K. (2015) ‘Intelligent Building Technology : The Evolution of the AV Consultant’.

Greenwood, D. and Kassem, M. (2016) SUPPORTING BUILDING OWNERS AND FACILITY MANAGERS IN THE VALIDATION AND VISUALISATION OF ASSET INFORMATION MODELS (AIM) THROUGH OPEN STANDARDS AND OPEN TECHNOLOGIES, Journal of Information Technology in Construction (ITcon). Available at: http://www.itcon.org/2016/27.

Gregory, R. W. et al. (2011) ‘Theorizing in Design Science Research : Inductive versus Deductive Approaches’, pp. 1–17.

Haddadi, A. et al. (2016) ‘The Concept of Value for Owners and Users of Buildings – A Literature Study of Value in Different Contexts’, Procedia - Social and Behavioral Sciences, 226. doi: 10.1016/j.sbspro.2016.06.202.

Hakim, A. El (2018) ‘Internet of Things (IoT) System Architecture and Technologies’, (March), pp. 0–5.

Haller, S. and Magerkurth, C. (2011) ‘The Real-time Enterprise: IoT-enabled Business Processes’, IETF IAB Workshop on Interconnecting Smart Objects with the Internet, (March), pp. 1–3. doi: 10.1.1.227.9881.

Hayward, J., Cardinal, D. and Jones, G., 2004. Epistemology: the theory of knowledge. John Murray (Publishers) Ltd.

Herazo, B. and Lizarralde, G. (2016) ‘Understanding stakeholders’ approaches to sustainability in building projects’, Sustainable Cities and Society, 26, pp. 240–254. doi: 10.1016/J.SCS.2016.05.019.

Hernández-Ramos, J. L. et al. (2015) ‘SAFIR: Secure access framework for IoT-enabled services on smart buildings’, Journal of Computer and System Sciences, 81(8), pp. 1452–1463. doi: 10.1016/j.jcss.2014.12.021.

Hietaharju, P., Ruusunen, M. and Leivisk, K. (2018) ‘A dynamic model for indoor temperature prediction in buildings’, Energies, 11(6). doi: 10.3390/en11061477.

Hu, W. et al. (2018) ‘ITCM: Toward Learning-Based Thermal Comfort Modeling via Pervasive Sensing for Smart Buildings’, IEEE Internet of Things Journal, 5(5), pp. 4164–4177. doi: 10.1109/JIOT.2018.2861831.

Irshad, K. et al. (2020) ‘An IoT-based thermoelectric air management framework for smart building applications: A case study for tropical climate’, Sustainability (Switzerland), 12(4), pp. 1–18. doi: 10.3390/su12041564.

Islam, S. and Omasreiter, H. (2005) ‘Systematic use case interviews for specification of automotive systems’, in Proceedings - Asia-Pacific Software Engineering Conference, APSEC, pp. 17–24. doi: 10.1109/APSEC.2005.102.

Jansson, G., Schade, J. and Olofsson, T. (2013) ‘Requirements management for the design of energy efficient buildings’, Journal of Information Technology in Construction, 18(January), pp. 321–337.

Jha, D. N. et al. (2019) ‘IoTSim-Edge: A simulation framework for modeling the behaviour of IoT and edge computing environments’, arXiv, pp. 1–19.

Jia, M. et al. (2019a) ‘Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications’, Automation in Construction, 101(February), pp. 111–126. doi: 10.1016/j.autcon.2019.01.023.

Jia, M. et al. (2019b) ‘Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications’, Automation in Construction, 101, pp. 111–126. doi: 10.1016/j.autcon.2019.01.023.

Jia, R. et al. (2018) ‘Design Automation for Smart Building Systems’, Proceedings of the IEEE, 106(9), pp. 1680–1699. doi: 10.1109/JPROC.2018.2856932.

Kaboub, F., 2008. Positivist paradigm. Encyclopaedia of counselling, 2(2), p.343.

Kaklauskas, A. et al. (2010) ‘Model for a Complex Analysis of Intelligent Built Environment’, Automation in Construction, 19(3), pp. 326–340. doi: 10.1016/j.autcon.2009.12.006.

Kanter, T., Rahmani, R. and Mahmud, A. (2014) ‘Conceptual Framework for Internet of Things’ Virtualization via OpenFlow in Context-aware Networks’, 10(6). Available at: http://arxiv.org/abs/1401.7437.

Kassem, M. et al. (2015) ‘BIM in facilities management applications: A case study of a large university complex’, Built Environment Project and Asset Management, 5(3), pp. 261–277. doi: 10.1108/BEPAM-02-2014-0011.

Kawaguchi, A. and Motoda, H. (1991) Interview-based knowledge acquisition using dynamic analysis. doi: 10.1109/64.97791.

Kejriwal, S. and Mahajan, S. (2016) ‘Smart buildings: How IoT technology aims to add value for real estate companies’, Deloitte University Press, (4), pp. 34–45. Available at: http://www2.deloitte.com/us/en/pages/technology-media-and-telecommunications/topics/the-internet-of-things.html.

Khalil, M., Esseghir, M. and Merghem-Boulahia, L. (2020) ‘An IoT environment for estimating occupants’ thermal comfort’, IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC, 2020-Augus. doi: 10.1109/PIMRC48278.2020.9217157.

Kiduk, Y. and Meho, L. I. (2006) ‘Citation analysis: A comparison of google scholar, scopus, and web of science’, in Proceedings of the ASIST Annual Meeting. doi: 10.1002/meet.14504301185.

Kim, B. et al. (2019) ‘Spinal code: Automatic code extraction for near-user computation in fogs’, ACM International Conference Proceeding Series, pp. 87–98. doi: 10.1145/3302516.3307356.

Kim, D. et al. (2022) ‘Design and Implementation of Smart Buildings: A Review of Current Research Trend’, Energies. MDPI. doi: 10.3390/en15124278.

Kim, J. and Lee, J. W. (2014) ‘OpenIoT: An open service framework for the Internet of Things’, 2014 IEEE World Forum on Internet of Things, WF-IoT 2014, pp. 89–93. doi: 10.1109/WF-IoT.2014.6803126.

Kim, J., Schiavon, S. and Brager, G. (2018) ‘Personal comfort models – A new paradigm in thermal comfort for occupant-centric environmental control’, Building and Environment, 132(November 2017), pp. 114–124. doi: 10.1016/j.buildenv.2018.01.023.

Koh, J. et al. (2018) ‘Scrabble: Transferrable semi-automated semantic metadata normalization using intermediate representation’, BuildSys 2018 - Proceedings of the 5th Conference on Systems for Built Environments, pp. 11–20. doi: 10.1145/3276774.3276795.

Koparan, T. and Yilmaz, G. K. (2015) 'The Effect of Simulation-based Learning on Prospective Teachers' Inference Skills in Teaching Probability', Universal Journal of Educational Research, 3(11), pp. 775–786. doi: 10.13189/ujer.2015.031101.

Kramp, T., van Kranenburg, R. and Lange, S. (2013) Introduction to the internet of things, Enabling Things to Talk: Designing IoT Solutions with the IoT Architectural Reference Model. doi: 10.1007/978-3-642-40403-0_1.

Krishna, M. B. and Verma, A. (2016) 'A framework of smart homes connected devices using Internet of Things', Proceedings of the 2016 2nd International Conference on Contemporary Computing and Informatics, IC3I 2016, pp. 810–815. doi: 10.1109/IC3I.2016.7918794.

Krishnamurthy, K., Singh, P. and Sriraman, N. (2019) 'GeoBMS: Hybrid cloud/on-premise architecture for building energy optimization', Global IoT Summit, GIoTS 2019 - Proceedings, (i), pp. 0–5. doi: 10.1109/GIOTS.2019.8766402.

Larsen, L. G. et al. (2012) 'Directional connectivity in hydrology and ecology', Ecological Applications, 22(8), pp. 2204–2220. doi: 10.1890/11-1948.1.

Lawal, K. and Rafsanjani, H. N. (2022) 'Trends, benefits, risks, and challenges of IoT implementation in residential and commercial buildings', Energy and Built Environment. KeAi Communications Co., pp. 251–266. doi: 10.1016/j.enbenv.2021.01.009.

Lawrenz, F. et al. (2018) 'Promoting evaluation capacity building in a complex adaptive system', Evaluation and Program Planning, 69(April 2017), pp. 53–60. doi: 10.1016/j.evalprogplan.2018.04.005.

Le, D. N., Le Tuan, L. and Dang Tuan, M. N. (2019) 'Smart-building management system: An Internet-of-Things (IoT) application business model in Vietnam', Technological Forecasting and Social Change, 141(December 2018), pp. 22–35. doi: 10.1016/j.techfore.2019.01.002.

Lee, I. and Lee, K. (2015) 'The Internet of Things (IoT): Applications, investments, and challenges for enterprises', Business Horizons, 58(4), pp. 431–440. doi: 10.1016/j.bushor.2015.03.008.

Leonidou, E. et al. (2020) 'An integrative framework of stakeholder engagement for innovation management and entrepreneurship development', Journal of Business Research, 119, pp. 245–258. doi: 10.1016/j.jbusres.2018.11.054.

Lexartza-Artza, I. and Wainwright, J. (2009) 'Hydrological connectivity: Linking concepts with practical implications', Catena, 79(2), pp. 146–152. doi: 10.1016/j.catena.2009.07.001.

Li, W. et al. (2021) 'Motivations, barriers and risks of smart home adoption: From systematic literature review to conceptual framework', Energy Research and Social Science. Elsevier Ltd. doi: 10.1016/j.erss.2021.102211.

Liau, C. H., Shen, W. W. and Su, K. P. (2006) 'Venlafaxine-associated serotonin syndrome and manic episode in a geriatric depressive patient [5]', Psychiatry and Clinical Neurosciences, 60(1), pp. 121–122. doi: 10.1111/j.1440-1819.2006.01473.x.

Lima, E. G. et al. (2020) 'Smart and sustainable cities: The main guidelines of city statute for increasing the intelligence of Brazilian cities', Sustainability (Switzerland), 12(3). doi: 10.3390/SU12031025.

Liu, Y. et al. (2019) 'Intelligent Edge Computing for IoT-Based Energy Management in Smart Cities', IEEE Network, 33(2), pp. 111–117. doi: 10.1109/MNET.2019.1800254.

Liu, Z., Zhang, A. and Wang, W. (2020) 'A framework for an indoor safety management system based on digital twin', Sensors (Switzerland), 20(20), pp. 1–20. doi: 10.3390/s20205771.

Louis, J. and Rashid, K. (2018) 'Utilizing building information models as operating systems for smart homes', Proceedings of the Human-Habitat for Health (H3): Human-Habitat Multimodal Interaction for Promoting Health and Well-Being in the Internet of Things era - 20th ACM International Conference on Multimodal Interaction, ICMI 2018, pp. 16–19. doi: 10.1145/3279963.3281658.

Lowe, R., Chiu, L. F. and Oreszczyn, T. (2018) 'Socio-technical case study method in building performance evaluation', Building Research and Information, 46(5), pp. 469–484. doi: 10.1080/09613218.2017.1361275.

Ma, M. et al. (2018) 'Toward Energy-Awareness Smart Building: Discover the Fingerprint of Your Electrical Appliances', IEEE Transactions on Industrial Informatics, 14(4), pp. 1458–1468. doi: 10.1109/TII.2017.2776300.

Ma, Z., Badi, A. and Jørgensen, B. N. (2016) 'Market opportunities and barriers for smart buildings', 2016 IEEE Green Energy and Systems Conference, IGSEC 2016, (November 2016). doi: 10.1109/IGESC.2016.7790078.

Maatoug, A., Belalem, G. and Mahmoudi, S. (2019) 'Fog computing framework for location-based energy management in smart buildings', Multiagent and Grid Systems, 15(1), pp. 39–56. doi: 10.3233/MGS-190301.

Malatji, M., Von Solms, S. and Marnewick, A. (2019) 'Socio-technical systems cybersecurity framework', Information and Computer Security, 27(2), pp. 233–272. doi: 10.1108/ICS-03-2018-0031.

Mammeri, Z. and Younus, M. U. (2020) 'Software-Defined Networking for Smart Buildings: Advances and Challenges', 2018(November), pp. 31–42. doi: 10.1007/978-3-030-30911-4_3.

Manogaran, G. et al. (2018) 'A new architecture of Internet of Things and big data ecosystem for secured smart healthcare monitoring and alerting system', Future Generation Computer Systems, 82, pp. 375–387. doi: 10.1016/j.future.2017.10.045.

Marikyan, D., Papagiannidis, S. and Alamanos, E. (2019) 'A systematic review of the smart home literature: A user perspective', Technological Forecasting and Social Change, 138, pp. 139–154. doi: 10.1016/J.TECHFORE.2018.08.015.

Marinakis, V. and Doukas, H. (2018) ‘An advanced IoT-based system for intelligent energy management in buildings’, Sensors (Switzerland), 18(2). doi: 10.3390/S18020610.

Mattingly, 6.L. and Rao, H., 1998. Writing effective use cases and introducing collaboration cases. Journal of Object-Oriented Programming, 11(6), pp.77-+.

McGlinn, K. et al. (2010) ‘Simcon: A tool to support rapid evaluation of smart building application design using context simulation and virtual reality’, Journal of Universal Computer Science, 16(15), pp. 1992–2018.

Menassa, C. C. and Baer, B. (2014) ‘A framework to assess the role of stakeholders in sustainable building retrofit decisions’, Sustainable Cities and Society, 10, pp. 207–221. doi: 10.1016/j.scs.2013.09.002.

Miles, M.B. and Huberman, A.M., 1994. Qualitative data analysis: An expanded sourcebook. sage.

Minoli, D., Sohraby, K. and 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), pp. 269–283. doi: 10.1109/JIOT.2017.2647881.

Mishra, L., Gupta, T. and Shree, A. (2020) ‘Online teaching-learning in higher education during lockdown period of COVID-19 pandemic’, International Journal of Educational Research Open, 1(August), p. 100012. doi: 10.1016/j.ijedro.2020.100012.

Mok, K.Y., Shen, G.Q. and Yang, R., 2018. Stakeholder complexity in large scale green building projects: A holistic analysis towards a better understanding. Engineering, Construction and Architectural Management.

Monti, L. et al. (2022) ‘Edge-Based Transfer Learning for Classroom Occupancy Detection in a Smart Campus Context’, pp. 1–16.

Motawa, I. and Almarshad, A. (2013) ‘A knowledge-based BIM system for building maintenance’, Automation in Construction, 29, pp. 173–182. doi: 10.1016/j.autcon.2012.09.008.

Moustakas, C. (2011) Phenomenological research methods, Phenomenological research methods. Sage publications. doi: 10.4135/9781412995658.

Myers, J.E., Sweeney, T.J. and White, V.E., 2002. Advocacy for counseling and counselors: A professional imperative. Journal of Counseling & development, 80(4), pp.394-402.

Myers, M.D. and Avison, D. eds., 2002. Qualitative research in information systems: a reader. Sage.

Ng, I. et al. (2015) ‘Contextual variety, Internet-of-Things and the choice of tailoring over platform: Mass customisation strategy in supply chain management’, International Journal of Production Economics, 159, pp. 76–87. doi: 10.1016/j.ijpe.2014.09.007.

Nuutinen, M. et al. (2022) 'Making a Building Smart with a Co-Created and Continuously Evolving Enjoyable Service Entity—Insights from a Collaborative Study', Smart Cities, 5(1), pp. 1–21. doi: 10.3390/smartcities5010001.

Obrecht, T. P. et al. (2019) 'Comparison of health and well-being aspects in building certification schemes', Sustainability (Switzerland), 11(9). doi: 10.3390/SU11092616.

Omar, O. (2018) 'Intelligent building, definitions, factors and evaluation criteria of selection', Alexandria Engineering Journal, 57(4), pp. 2903–2910. doi: 10.1016/J.AEJ.2018.07.004.

Orlikowski, W.J. and Baroudi, J.J., 1991. Studying information technology in organizations: Research approaches and assumptions. Information systems research, 2(1), pp.1-28.

Pacheco, J. and Hariri, S. (2016) 'IoT security framework for smart cyber infrastructures', Proceedings - IEEE 1st International Workshops on Foundations and Applications of Self-Systems, FAS-W 2016, pp. 242–247. doi: 10.1109/FAS-W.2016.58.

Pacheco, J. et al. (2018) 'IoT security framework for smart water system', Proceedings of IEEE/ACS International Conference on Computer Systems and Applications, AICCSA, 2017-Octob, pp. 1285–1292. doi: 10.1109/AICCSA.2017.85.

Pacheco, J., Benitez, V. H. and Pan, Z. (2019) 'Security framework for IoT end nodes with neural networks', International Journal of Machine Learning and Computing, 9(4), pp. 381–386. doi: 10.18178/ijmlc.2019.9.4.814.

Page, M. J. et al. (no date) 'The PRISMA 2020 statement: an updated guideline for reporting systematic reviews'. doi: 10.1136/bmj.n71.

Palattella, M. R. et al. (2016) 'Internet of Things in the 5G Era: Enablers, Architecture, and Business Models', IEEE Journal on Selected Areas in Communications, 34(3), pp. 510–527. doi: 10.1109/JSAC.2016.2525418.

Panteli, C., Kylili, A. and Fokaides, P. A. (2020) 'Building information modelling applications in smart buildings: From design to commissioning and beyond A critical review', Journal of Cleaner Production, 265, p. 121766. doi: 10.1016/J.JCLEPRO.2020.121766.

Pappachan, P. et al. (2017) 'Towards Privacy-Aware Smart Buildings: Capturing, Communicating, and Enforcing Privacy Policies and Preferences', Proceedings - IEEE 37th International Conference on Distributed Computing Systems Workshops, ICDCSW 2017, pp. 193–198. doi: 10.1109/ICDCSW.2017.52.

Park, H. and Rhee, S. B. (2018) 'IoT-Based Smart Building Environment Service for Occupants' Thermal Comfort', Journal of Sensors, 2018. doi: 10.1155/2018/1757409.

Parn, E. A. and Edwards, D. (2019) 'Cyber threats confronting the digital built environment: Common data environment vulnerabilities and block chain deterrence', Engineering, Construction and Architectural Management, 26(2), pp. 245–266. doi: 10.1108/ECAM-03-2018-0101.

Pašek, J. and Sojková, V. (2019) ‘Facility management of smart buildings’, International Review of Applied Sciences and Engineering, 9(2), pp. 181–187. doi: 10.1556/1848.2018.9.2.15.

Peña, M. et al. (2016) ‘Rule-based system to detect energy efficiency anomalies in smart buildings, a data mining approach’, Expert Systems with Applications, 56, pp. 242–255. doi: 10.1016/j.eswa.2016.03.002.

Perera, C. et al. (2013) ‘Semantic-driven configuration of internet of things middleware’, Proceedings - 2013 9th International Conference on Semantics, Knowledge and Grids, SKG 2013, pp. 66–73. doi: 10.1109/SKG.2013.9.

Perumal, T., Sulaiman, M. N. and Leong, C. Y. (2013) ‘ECA-based interoperability framework for intelligent building’, Automation in Construction, 31, pp. 274–280. doi: 10.1016/J.AUTCON.2012.12.009.

Pourzolfaghar, Z., Mcdonnell, P. and Helfert, M. (2017) ‘Barriers to Benefit from Integration of Building Information with Live Data from IOT Devices during the Facility Management Phase’, CITA BIM Gathering, (November), p. 5. Available at: http://doras.dcu.ie/22126/1/Barriers_to_Benefit_from_Integration-14-Sep-17.pdf.

Prokhorov, O., Pronchakov, Y. and Fedorovich, O. (2020) ‘Intelligent multi-service platform for building management’, ATIT 2020 - Proceedings: 2020 2nd IEEE International Conference on Advanced Trends in Information Theory, pp. 62–67. doi: 10.1109/ATIT50783.2020.9349312.

Raghavan, S. et al. (2020) ‘Data Integration for Smart Cities: Opportunities and Challenges’, Lecture Notes in Electrical Engineering, 603(August), pp. 393–403. doi: 10.1007/978-981-15-0058-9_38.

Ramprasad, B. et al. (2018) ‘Leveraging existing sensor networks as IoT devices for smart buildings’, IEEE World Forum on Internet of Things, WF-IoT 2018 - Proceedings, 2018-Janua, pp. 452–457. doi: 10.1109/WF-IoT.2018.8355121.

Ray, P. P. (2018) ‘A survey on Internet of Things architectures’, Journal of King Saud University - Computer and Information Sciences, 30(3), pp. 291–319. doi: 10.1016/j.jksuci.2016.10.003.

Rehman, M. A. U., Ullah, R. and Kim, B. S. (2019) ‘NINQ: Name-integrated query framework for named-data networking of things’, Sensors (Switzerland), 19(13), pp. 1–30. doi: 10.3390/s19132906.

Robert, J. et al. (2017) ‘Open IoT ecosystem for enhanced interoperability in smart cities-example of métropole de lyon’, Sensors (Switzerland), 17(12), pp. 1–21. doi: 10.3390/s17122849.

Ruddell, B. L. and Kumar, P. (2009) ‘Ecohydrologic process networks: 1. Identification’, Water Resources Research, 45(3), pp. 1–23. doi: 10.1029/2008WR007279.

Saidi, S. et al. (2018a) ‘Integrated infrastructure systems—A review’, Sustainable Cities and Society, 36(August 2017), pp. 1–11. doi: 10.1016/j.scs.2017.09.022.

Saidi, S. et al. (2018b) ‘Integrated infrastructure systems—A review’, Sustainable Cities and Society, 36(August 2017), pp. 1–11. doi: 10.1016/j.scs.2017.09.022.

Samuel, S. S. I. (2016) ‘A review of connectivity challenges in IoT-smart home’, 2016 3rd MEC International Conference on Big Data and Smart City, ICBDSC 2016, pp. 364–367. doi: 10.1109/ICBDSC.2016.7460395.

Santhi Sri, T. et al. (2016) ‘A review on the state of art of Internet of Things’, International Journal of Advanced Research in Computer and Communication Engineering ISO, 3297(7), pp. 189–193. doi: 10.17148/IJARCCE.2016.5738.

Saralegui, U., Antón, M. Á. and Ordieres-Meré, J. (2017) ‘Taking advantage of an existing indoor climate monitorization for measuring occupancy’, WSEAS Transactions on Environment and Development, 13(August), pp. 327–334.

Saunders, M. N., Saunders, M., Lewis, P., and Thornhill, A. (2011) Research methods for business students, 5/e. Pearson Education India.

Sava, G. N. et al. (2018) ‘Integration of BIM Solutions and IoT in Smart Houses’, Proceedings - 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe, EEEIC/I and CPS Europe 2018, pp. 1–4. doi: 10.1109/EEEIC.2018.8494628.

Saxena, P. (2013) ‘OSI Reference Model – A Seven Layered Architecture of OSI Model’, International Journal of Advanced Research in Computer Science and Software Engineering, 3(8), pp. 338–346.

Scotland, J., 2012. Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. English language teaching, 5(9), pp.9-16.

Shabha, G. (2006) ‘A critical review of the impact of embedded smart sensors on productivity in the workplace’, Facilities, 24(13–14), pp. 538–549. doi: 10.1108/02632770610705301.

Shen, W. et al. (2010) ‘Systems integration and collaboration in architecture, engineering, construction, and facilities management: A review’, Advanced Engineering Informatics, 24(2), pp. 196–207. doi: 10.1016/j.aei.2009.09.001.

Shih, C. et al. (2016) ‘Designing CPS/IoT applications for smart buildings and cities’, IET Cyber-Physical Systems: Theory & Applications, 1(1), pp. 3–12. doi: 10.1049/IET-CPS.2016.0025.

Silva, L. (2007) ‘Epistemological and theoretical challenges for studying power and politics in information systems’, Information Systems Journal, 17(2), pp. 165–183. doi: 10.1111/j.1365-2575.2007.00232.x.

Simoneau, P. (2006) 'The OSI Model : Understanding the Seven Layers of Computer Networks', Global Knowledge e-series, 4(3), pp. 1–11.

Sinopoli, J. (2010) 'What Is a Smart', Intelligent Buildings, (February 2016), pp. 1–5. Available at: https://www.youtube.com/watch?v=y0rbbvsV3nc (Accessed: 19 July 2022).

Somé, S. S. (2005) 'Use Cases based Requirements Validation with Scenarios *'. doi: 10.1109/RE.2005.75.

Sony, M. and Naik, S. (2020a) 'Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model', Technology in Society, 61(April), p. 101248. doi: 10.1016/j.techsoc.2020.101248.

Sony, M. and Naik, S. (2020b) 'Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model', Technology in Society, 61. doi: 10.1016/j.techsoc.2020.101248.

Sosa, E., 2017. Epistemology. In Epistemology. Princeton University Press.

Soultatos, O. et al. (2018) 'Towards a Security, Privacy, Dependability, Interoperability Framework for the Internet of Things', IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks, CAMAD, 2018-Septe. doi: 10.1109/CAMAD.2018.8514937.

Ståhlbröst, A., Bergvall-Kåreborn, B. and Eriksson, C. I. (2015) 'Stakeholders in smart city living lab processes', 2015 Americas Conference on Information Systems, AMCIS 2015, pp. 1–11.

Stake, R.E., 1995. The art of case study research. sage.

Tan, L. and Wang, N. (2010) 'Future Internet: The Internet of Things', ICACTE 2010 - 2010 3rd International Conference on Advanced Computer Theory and Engineering, Proceedings, 5, pp. V5-376-V5-380. doi: 10.1109/ICACTE.2010.5579543.

Terry, G. et al. (2017) 'Thematic Analysis', The SAGE Handbook of Qualitative Research in Psychology, pp. 17–36. doi: 10.4135/9781526405555.n2.

Tortonesi, M. et al. (2019) 'Taming the IoT data deluge: An innovative information-centric service model for fog computing applications', Future Generation Computer Systems, 93, pp. 888–902. doi: 10.1016/j.future.2018.06.009.

Towne, L. and Shavelson, R.J., 2002. Scientific research in education. National Academy Press Publications Sales Office..

Ullah, F. et al. (2017) 'Semantic interoperability for big-data in heterogeneous IoT infrastructure for healthcare', Sustainable Cities and Society, 34, pp. 90–96. doi: 10.1016/j.scs.2017.06.010.

Ur Rehman, S. and Gruhn, V. (2018) ‘An approach to secure smart homes in cyber-physical systems/Internet-of-Things’, 2018 5th International Conference on Software Defined Systems, SDS 2018, pp. 126–129. doi: 10.1109/SDS.2018.8370433.

Uviase, O. and Kotonya, G. (2018) ‘IoT architectural framework: Connection and integration framework for IoT systems’, Electronic Proceedings in Theoretical Computer Science, EPTCS, 264, pp. 1–17. doi: 10.4204/EPTCS.264.1.

Verma, A. et al. (2019) ‘Sensing, Controlling, and IoT Infrastructure in Smart Building: A Review’, IEEE Sensors Journal. Institute of Electrical and Electronics Engineers Inc., pp. 9036–9046. doi: 10.1109/JSEN.2019.2922409.

Vijayan, D. S. et al. (2020) ‘Automation systems in smart buildings: a review’, Journal of Ambient Intelligence and Humanized Computing. doi: 10.1007/s12652-020-02666-9.

Villegas-Ch, W., Palacios-Pacheco, X. and Luján-Mora, S. (2019a) ‘Application of a smart city model to a traditional university campus with a big data architecture: A sustainable smart campus’, Sustainability (Switzerland), 11(10). doi: 10.3390/su11102857.

Villegas-Ch, W., Palacios-Pacheco, X. and Luján-Mora, S. (2019b) ‘Application of a smart city model to a traditional university campus with a big data architecture: A sustainable smart campus’, Sustainability (Switzerland), 11(10). doi: 10.3390/su11102857.

Waidyasekara, A. and Madhusanka, N. (2019) INTEGRATING INTERNET OF THINGS (IOT) AND FACILITIES MANAGER IN SMART BUILDINGS: A CONCEPTUAL FRAMEWORK. Available at: https://www.researchgate.net/publication/333747134.

Wainwright, D., 1997. Can sociological research be qualitative, critical and valid?. TQR, 3(2), pp.1-17.

Wainwright, D., 1997. Can sociological research be qualitative, critical and valid?. TQR, 3(2), pp.1-17.

Wang, T., Ali, A. S. and Au-Yong, C. P. (2022) ‘Exploring a body of knowledge for promoting the building information model for facility management’, Ain Shams Engineering Journal, 13(4). doi: 10.1016/j.asej.2022.101717.

Wang, Z. et al. (2012) ‘Integration of plug-in hybrid electric vehicles into energy and comfort management for smart building’, Energy and Buildings, 47, pp. 260–266. doi: 10.1016/j.enbuild.2011.11.048.

Watson, R. et al. (2018) ‘Harnessing Difference: A Capability-Based Framework for Stakeholder Engagement in Environmental Innovation’, Journal of Product Innovation Management, 35(2), pp. 254–279. doi: 10.1111/jpim.12394.

Weyrich, M. and Ebert, C. (2016) ‘Reference architectures for the internet of things’, IEEE Software, 33(1), pp. 112–116. doi: 10.1109/MS.2016.20.

While, D., Krasniewicz, J. and Cox, S. (2018) ‘Challenges in developing a generic monitoring framework for pan European energy usage and environmental monitoring’, Proceedings of Computing Conference 2017, 2018-Janua, pp. 475–484. doi: 10.1109/SAI.2017.8252140.

Whitmore, A., Agarwal, A. and Da Xu, L. (2015) ‘The Internet of Things—A survey of topics and trends’, Information Systems Frontiers, 17(2), pp. 261–274. doi: 10.1007/s10796-014-9489-2.

Williams, M. and Moser, T. (2019) The Art of Coding and Thematic Exploration in Qualitative Research, International Management Review.

Wilson, B. and Van Haperen, K., 2017. Soft systems thinking, methodology and the management of change. Bloomsbury Publishing.

Wilson, C., Hargreaves, T. and Hauxwell-Baldwin, R. (2015) ‘Smart homes and their users: a systematic analysis and key challenges’, Personal and Ubiquitous Computing, 19(2), pp. 463–476. doi: 10.1007/S00779-014-0813-0.

Wirtz, B. W., Weyerer, J. C. and Schichtel, F. T. (2019) ‘An integrative public IoT framework for smart government’, Government Information Quarterly, 36(2), pp. 333–345. doi: 10.1016/j.giq.2018.07.001.

Woo, J. H. and Menassa, C. (2014) ‘Virtual Retrofit Model for aging commercial buildings in a smart grid environment’, Energy and Buildings, 80, pp. 424–435. doi: 10.1016/j.enbuild.2014.05.004.

Ye, J. et al. (2009) ‘Stakeholders’ requirements analysis for a demanddriven construction industry’, Electronic Journal of Information Technology in Construction, 14(January 2014), pp. 629–641.

Yin, R. K. (1981). The case study as a serious research strategy. Science communication, 3(1), pp. 97 – 114.

Yin, R. K. (2013) Case study research: Design and methods. Fifth ed. Sage Publications.

Yin, R. K. (2014) Case study research: Design and methods. Fifth ed. Sage Publications.

Yun, J. and Won, K. H. (2012) ‘Building environment analysis based on temperature and humidity for smart energy systems’, Sensors (Switzerland), 12(10), pp. 13458–13470. doi: 10.3390/s121013458.

Zachariadis, E.E., Tarantilis, C.D. and Kiranoudis, C.T., 2010. An adaptive memory methodology for the vehicle routing problem with simultaneous pick-ups and deliveries. European Journal of Operational Research, 202(2), pp.401-411.

Zhang, B. Q. (2011) ‘A N A PPLICATION OF S OFT S YSTEMS M ETHODOLOGY ON A H OLISTIC L EVEL : R ECOMMENDATIONS FOR D EVELOPING AND I MPLEMENTING G REEN ICT S TRATEGIES IN N EW Z EALAND’, (August).

Zhang, G., Li, Y. and Deng, X. (2020) 'K-means clustering-based electrical equipment identification for smart building application', Information (Switzerland), 11(1), pp. 1–18. doi: 10.3390/info11010027.

Zhang, J., Wei, B. and Cheng, J. (2020) 'HARaaS: HAR as a service using wifi signal in IoT-enabled edge computing: Poster abstract', SenSys 2020 - Proceedings of the 2020 18th ACM Conference on Embedded Networked Sensor Systems, pp. 681–682. doi: 10.1145/3384419.3430469.

Zhang, X. et al. (2018) 'Sustainable urban transformations towards smarter, healthier cities: Theories, agendas and pathways', Journal of Cleaner Production, 173, pp. 1–10. doi: 10.1016/J.JCLEPRO.2017.10.345.

Zhang, X. et al. (2020) 'An IoT-Based Thermal Model Learning Framework for Smart Buildings', IEEE Internet of Things Journal, 7(1), pp. 518–527. doi: 10.1109/JIOT.2019.2951106.

Zhu, X. et al. (2017) 'Autonomic Identity Framework for the Internet of Things', Proceedings - 2017 IEEE International Conference on Cloud and Autonomic Computing, ICCAC 2017, pp. 69–79. doi: 10.1109/ICCAC.2017.14.

Žigart, M. et al. (2018) 'Environmental impact assessment of building envelope components for low-rise buildings', Energy, 163, pp. 501–512. doi: 10.1016/j.energy.2018.08.149.

Zikria, Y. Bin et al. (2018) 'Internet of Things (IoT): Operating System, Applications and Protocols Design, and Validation Techniques', Future Generation Computer Systems, 88(August), pp. 699–706. doi: 10.1016/j.future.2018.07.058.

Zuboff, S., 1988. In the age of the smart machine: The future of work and power. Basic Books, Inc.

10 Appendix

10.1 Appendix (1): Justification of Using the OSI Reference Model as a Lens to Analyse IoT Architecture and Framework (*White paper*).

The meaning of a reference model is a conceptual design of how communications should be presented. It underpins the different processes needed to build an effective communication and explains these processes in a logical grouping way called layers. Any logical communication system designed in this manner, it is known as layered architecture. The OSI model is a set of guidelines which are used to develop and implement application that run on a network. It also presents a conceptual framework which used to create and implement networking standards, devices, and internetworking schemes (Bora et al., 2014).

The Open System Interconnection 'OSI' model

The Open System Interconnection (OSI) model is an interface between two systems i.e., a sender and a receiver. The OSI model was mainly developed to give a better understanding of a network complexity, simplify network training for developers, and provide a simple network troubleshooting. The OSI model is not a real network architecture. It describes functions of computing as a general set of rules and requirements to support interoperability between two systems. The communication between the two systems in the OSI model is described in seven different layers and what they must do: Physical, Data Link, Network, Transport, Session, Presentation, and Application (Madan, 2014).

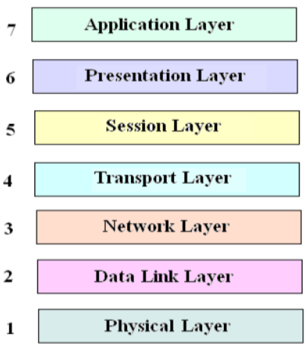


Fig 1. OSI seven layers.

It is a guideline of presenting how a message travels from a device to another. It explains a layered approach that where a subsystem of communication is broken down into sever different layers, each having a specific role. The layers of the OSI model are as presented in fig. 1 (Bora et al., 2014).

The general role of the OSI model

Nearly all networks that is used today are built according to the Open System Interconnection (OSI) standard (Tyson, n.d.). This model works as a reference defining how a message should be delivered and received between two points of telecommunication network. Simoneau, (2006) briefly underpins the benefits and the general role of the OSI model as understanding the big picture of how networks work, helps understand the how hardware and software components work together, separating networks into small pieces that can assist troubleshooting, gives a better definition for the terms that networking professionals use by comparing the basic functional relationships on different network, aids users understand new trends of technology as they develop, and helps in interpreting vendors explanations of product functionality.

The functions of the OSI model layers

Saxena, (2014) explained the functions of the seven layers of the OSI model, which are briefly listed in the following:

Physical Layer

The main function of the physical layer is to convert signals (electrical impulse, light signals, radio signals) into bits that can be adjusted and transmitted to the Data Link Layer to allow for multiple users to use the same connection.

Data Link Layer

The main function of the Data Link Layer is to convert the Data bits into frames. It is also responsible for detecting errors.

Network Layer

The network layer responsible of organising the data and reassembling it for transfer. The most important function that the network deals with is determining a network path and logical addressing.

Transport Layer

The main function of this layer is to control the flow of information between points on a network. It ensures complete data transfer.

Session Layer

This layer sets a session that works as an environment between programs and the two parts of the model (sender/receiver) to create and control the communication.

Presentation Layer

Presentation Layer

The main function of this layer is Data representations, Date encryption, and converting the computer code to network formatted code. It make data ready to be sent across a network by formatting and encrypting it.

Application Layer

This layer is the supporter for applications and end-user where data is often interacted in a form of i.e., a website, chat programs and so on.

The role of the OSI model in this research

The role of the Open System Interconnection in this research is to be used as a lens to analyse different Internet of Things (IoT) frameworks and architectures. The OSI reference model has divided the network communication into smaller pieces which are explained in a seven layered framework.

The OSI model reference architecture makes it easier for users to understand how network protocols are designed. It was also designed to ensure that different types of devices and communication tools are compatible even when they are being manufactured in different places and by different manufacturers (Kumar et al., 2014). The seven layered model show the different processes and medium taking a place in each layer of the model, which will be used to compare a number of Internet of Things (IoT) frameworks and Architectures.

Saxena, (2014) states that “Each layer is made up of entities, each belongs to one system. Entities in the same layer are termed as entities.” This research will look into the OSI model from a system point of view, and will be treating each layer as a sub-system. Each subsystems consists of input, a numbers of processes and sub-processes, and an output.

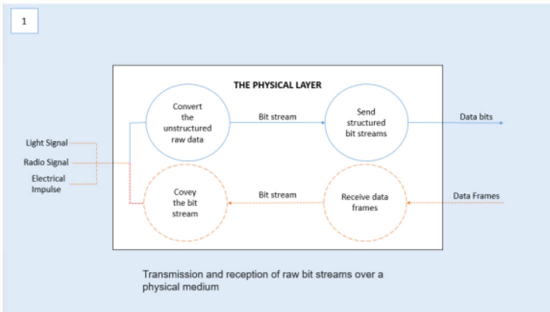
Justification of using the OSI model.

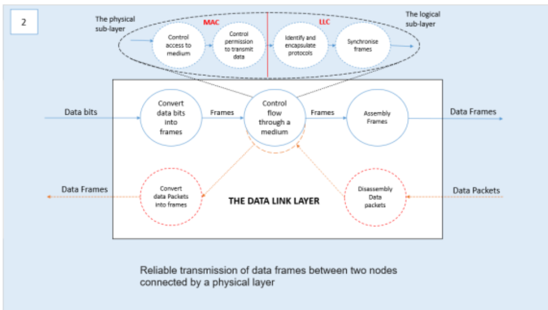
Windpassinger, (2018) states that the OSI network model ease the process to implement a communication by separating it into the above previously mentioned seven layers. Therefore, it helps in understanding IoT communications and related standards as well. He suggests that the Open System Interconnection can be used a framework to understand Internet of things (IoT).

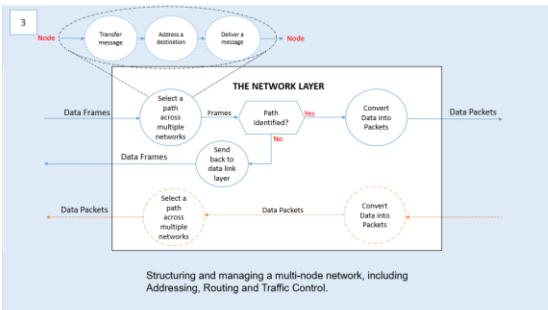
Mensah, (2017) suggests that based on the OSI model, Internet of Things (IoT) could have been applied without any further architectural modelling. However, there were some limitations regarding IoT features and issues such as interoperability, connectivity and communications, and integration and security.

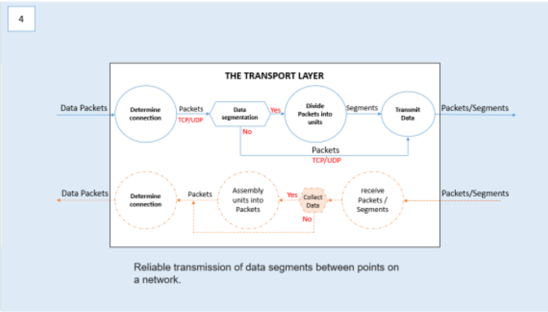
Weyrich & Ebert, (2016) say that the Internet of Things—Architecture (IoT-A) gives a detailed view of the IoT’s information technology aspects. Many standardization is happening in M2M communication, and secure communication stacks. This standardization is based on a modified Open Systems Interconnection (OSI) stack and proposes specifications for the data link, adaptation, network, and transport layers.

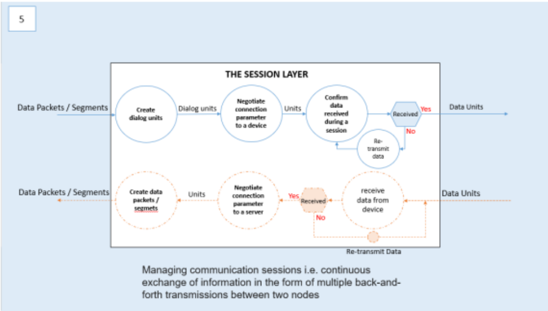
By looking into the layers of the OSI and how they are similar to many IoT frameworks and Architectures layers, especially within the low level layers (the physical, the Data Link layer, and the network layer), this research will use the OSI reference model layers as a lens to analyse different IoT frameworks and architectures.

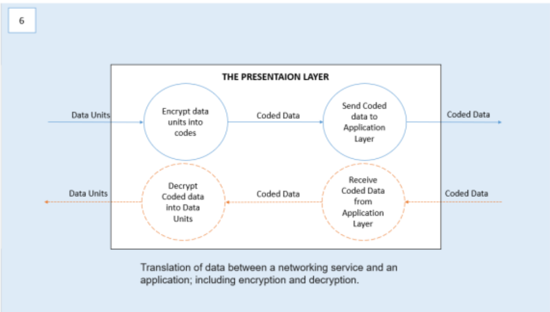


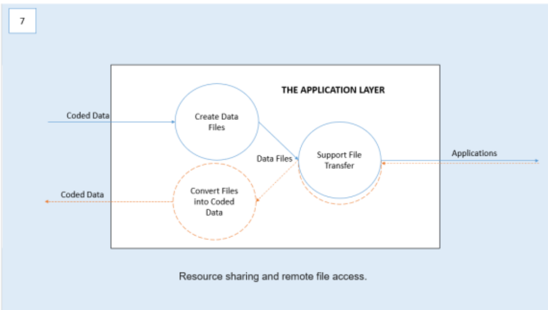












Bora, G., Bora, S., Singh, S. & Arsalan, S.M. (2014). *OSI Reference Model : An Overview ABSTRACT :* 7 (4). p.pp. 214–218.

Kumar, S., Dalal, S. & Dixit, V. (2014). *THE OSI MODEL : OVERVIEW ON THE SEVEN LAYERS OF COMPUTER NETWORKS*. 2 (3). p.pp. 461–466.

Madan, A. (2014). *OSI Reference Model*. 4 (9). p.pp. 55–59.

Mensah, S. (2017). *INTERNET OF THINGS : A Review on Connectivity Gateway Protocols and Semantic Interoperability*.

Saxena, P. (2014). *OSI Reference Model – A Seven Layered Architecture of OSI Model*. (10). p.pp. 1145–1156.

Simoneau, P. (2006). Expert Reference Series of White Papers The OSI Model : Understanding the Seven Layers of Computer Networks The OSI Model : Understanding the Seven Layers of Computer Networks. *Expert Reference Series of White Papers*. p.pp. 1–11.

Weyrich, M. & Ebert, C. (2016). *Reference Architectures for the Internet of Things*.

10.2 Appendix (2): Screened Studies of IoT frameworks in Smart Buildings.

Authors	Title	Year	Author(s) Keywords	Document Type	Smart Buildings and IoT	Framework or Model
Zaimen K., Brahmia M.-E.-A., Dollinger J.-F., Moalic L., Abouaissa A., Idoumghar L.	A overview on WSN deployment and a novel conceptual BIM-based approach in smart buildings	2020	BIM; Multi-objective optimization; Sensors Deployment; Smart Buildings; WSN	Conference Paper	√	
Zhang Y., Xu J., Wang Z., Geng R., Choo K.-K.R., Perez-Diaz J.A., Zhu D.	Efficient and Intelligent Attack Detection in Software Defined IoT Networks	2020		Conference Paper	√	
Stjelja D., Jokisalo J., Kosonen R.	From electricity and water consumption data to information on office occupancy: A supervised and unsupervised data mining approach	2020	Cluster analysis; Data-driven; Machine learning; Occupancy prediction; Smart building; Smart meter	Article	√	
Chew M.Y.L., Teo E.A.L., Shah K.W., Kumar V., Hussein G.F.	Evaluating the roadmap of 5g technology implementation for smart building and facilities management in singapore	2020	5G technology; AI; AR/VR; BIM; Drone; Smart building; Smart facilities management	Article	√	
Prokhorov O., Pronchakov Y., Fedorovich O.	Intelligent multi-service platform for building management	2020	Artificial intelligence; Building management system; Internet of Things; Machine learning; Smart building	Conference Paper	√	√
Debauche O., Mahmoudi S., Moussaoui Y.	Internet of Things Learning: A Practical Case for Smart Building automation	2020	automation; Demonstrator; General Public; Internet of Things; IoT; Smart building	Conference Paper		
Chan F., Lam T.	Neuron - Digital console innovative by Arup	2020		Conference Paper	√	
Ferguson M.K., Boovaraghavan S., Agarwal Y.	Vista: Spatial Data Representation for Smart Buildings	2020	Data Visualization; Smart Buildings; Visual Inference	Conference Paper	√	
Juacaba Neto R.C., Mérindol P., Theoleyre F.	A Multi-Domain Framework to Enable Privacy for Aggregated IoT Streams	2020		Conference Paper	√	
Zhang J., Wei B., Cheng J.	HARaaS: HAR as a service using wifi signal in IoT-enabled edge computing: Poster abstract	2020	CSI; edge computing; human activity recognition; IoT; wifi	Conference Paper	√	√
Chakrabarty S., Engels D.W., Wood L.	Consumer Frameworks for Smart Environments	2020		Conference Paper		√
Stolojescu-Crisan C., Butunoi B.-P., Crisan C.	IoT Based Intelligent Building Applications in the Context of COVID-19 Pandemic	2020	automation; BMS; COVID 19; Internet of Things; Smart buildings	Conference Paper	√	
Jha D.N., Michalak P., Wen Z., Ranjan R., Watson P.	Multiobjective Deployment of Data Analysis Operations in Heterogeneous IoT Infrastructure	2020	Analytic hierarchical process (AHP); Internet of Things (IoT); smart healthcare; streaming data	Article	√	
Lunardi R.C., Alharby M., Nunes H.C., Zorzo A.F., Dong C., Moorsel A.V.	Context-based consensus for appendable-block blockchains	2020	appendable-block; Blockchain; Consensus; IoT	Conference Paper	√	
Naji N., Abid M.R., Benhaddou D., Krami N.	Context-aware wireless sensor networks for smart building energy management system	2020	Finite State Machine (FSM); Internet of Things (IoT); Microgrid (MG); Smart Energy-Efficient Buildings (SEEB); Smart Grid (SG); Wireless mesh network (WMN); Wireless Sensor Network (WSN); XBee	Article	√	
Hakiri A., Sellami B., Ben Yahia S., Berthou P.	A SDN-based IoT Architecture Framework for Efficient Energy Management in Smart Buildings	2020	Context-Awareness; Energy efficiency; Internet of Things; Service Function Chaining; Smart Building; Software Defined Networking	Conference Paper	√	

Sauer D., Jumar R., Lutz R., Schlachter T., Schmitt C., Hagenmeyer V.	Towards smart buildings: A versatile acquisition setup for indoor climate data	2020	Climate data; Internet of Things; Living lab implementation; LoRaWAN; Measurement network; Smart buildings	Conference Paper	√	
Yu K., Chen D.	SmartAttack: Open-source Attack Models for Enabling Security Research in Smart Homes	2020	Adversarial Machine Learning; Attack Models; Deep Learning; IoT security; User Privacy	Conference Paper	√	√
Rinaldi S., Ferrari P., Flammini A., Pasetti M., Sisinni E., Tagliabue L.C., Ciribini A.C., Martinelli F., Mangili S.	A Cognitive Strategy for Renovation and Maintenance of Buildings through IoT Technology	2020	Building Automation; cognitive building; Energy Efficiency; fieldbus; Internet of Things; Konnex; predictive maintenance	Conference Paper	√	
Del-Valle-Soto C., Velazquez R., Garzon-Castro C.L., Valdivia L.J.	Energy-efficiency model for a smart building: A real application	2020	Energy Consumption; Internet of Things; Sleeping Algorithms; Wireless Sensor Networks	Conference Paper	√	
Dahmane W.M., Brahmia M.-E.-A., Dollinger J.-F., Ouchani S.	A BIM-based framework for an Optimal WSN Deployment in Smart Building	2020	BIM; Genetic Algorithm; IoT; Multi-objective optimization; NSGA; Sensors Deployment; Smart Building; WSN	Conference Paper	√	
Rosati C.A., Cervo A., Fantuzzi C.	Air Quality Monitoring in a BIM model by means of a IoT Sensors Network	2020	Air Quality Sensors; BIM; Digital Twin; IoT; Smart building	Conference Paper	√	
Casado-Vara R., Sittón-Candanedo I., De la Prieta F., Rodríguez S., Calvo-Rolle J.L., Venayagamoorthy G.K., Vega P., Prieto J.	Edge Computing and Adaptive Fault-Tolerant Tracking Control Algorithm for Smart Buildings: A Case Study	2020	adaptive closed loop; algorithm design and analysis; control system; Edge computing; IoT; non-linear control; smart buildings	Article		
Liu Z., Zhang A., Wang W.	A framework for an indoor safety management system based on digital twin	2020	Building information modelling; Digital twin; Indoor safety management system; Internet of Things; Support vector machines	Article	√	√
Al-Ali A.R., Gupta R., Batool T.Z., Landolsi T., Aloul F., Nabulsi A.A.	Digital twin conceptual model within the context of internet of things	2020	Big data analytics; Digital twins; Internet of Things; Smart cities	Article	√	√
Chang T.-W., Huang H.-Y., Hung C.-W., Datta S., McMinn T.	A network sensor fusion approach for a behaviour-based smart energy environment for co-making spaces	2020	Ambient agents; Internet of things; Smart buildings; Solar energy; User behaviour; Wireless sensor networks	Article	√	√
El-Aal S.A., Gad-Elrab A.A.A., Zaghrout A.A.S., Ghali N.I.	Context-aware reasoning model using deep learning and fog computing for waste management in IoTs environments	2020	Context reasoning; Fog computing; IoTs; Waste management	Article		
Maselli G., Piva M., Restuccia F.	HyBloSE: Hybrid blockchain for secure-by-design smart environments	2020	blockchain; IoT; security; smart building	Conference Paper	√	√
Gaonkar P., Lonkar A., Sasirekha G.V.K., Bapat J., Das D.	Comfort Management System for Smart Buildings: An Open-Source Scalable Prototype	2020	Comfort; Elasticsearch; Internet of Things (IoT); IoT Analytics; Kibana; Logstash; Optimization; Smart Buildings	Conference Paper	√	
Elkhoukhi H., NaitMalek Y., Bakhouya M., Berouine A., Kharbouch A., Lachhab F., Hanifi M., El Ouadghiri D., Essaaidi M.	A platform architecture for occupancy detection using stream processing and machine learning approaches	2020	context-awareness; Internet of Things; machine learning; real-time data processing; Smart buildings	Conference Paper	√	
Chatzinikolaou E., Pispidikis I., Dimopoulou E.	A SEMANTICALLY ENRICHED and WEB-BASED 3D ENERGY MODEL VISUALIZATION and RETRIEVAL for SMART BUILDING IMPLEMENTATION USING CITYGML and DYNAMIZER ADE	2020		Conference Paper	√	

Pathmabandu C., Grundy J., Chhetri M.B., Baig Z.	An Informed Consent Model for Managing the Privacy Paradox in Smart Buildings	2020	Informed consent; IoT; Privacy policies; Privacy Preservation; Privacy threats; Smart Buildings; Smart Homes; Voice-Assistants	Conference Paper	√	
Katsarou K., Ounoughi C., Mouakher A., Nicolle C.	STCMS: A Smart Thermal Comfort Monitor for Senior People	2020	bi-directional LSTM; classification; DNN-based architecture; elderly people; prediction framework; sensor data; smart building; Thermal comfort; time-series	Conference Paper	√	
Kosovic I.N., Mastelic T., Ivankovic D.	Using Artificial Intelligence on environmental data from Internet of Things for estimating solar radiation: Comprehensive analysis	2020	Hybrid model; Internet of things; Machine learning; Soft sensors; Solar radiation; Sustainable environment	Article	√	
Alrashed S.	Key performance indicators for Smart Campus and Microgrid	2020	Internet of things (IoT); Resource allocations; Smart Campus; Smart grid; Smart homes; Smart technologies	Article	√	
Onu E., Mireku Kwakye M., Barker K.	Contextual Privacy Policy Modeling in IoT	2020	Context; Cyber-physical systems; Cyberspace; IoT; IoT Privacy Taxonomy; Privacy Formalization; Privacy Policy	Conference Paper	√	
Rasolroveicy M.	A Self-Adaptive Blockchain Framework to Balance Performance, Security, and Energy Consumption in IoT applications	2020		Conference Paper	√	
Khalil M., Esseghir M., Merghem-Boulahia L.	An IoT environment for estimating occupants' thermal comfort	2020	E-health; IoT; Machine learning; Morris analysis; Predicted mean vote; Thermal comfort	Conference Paper	√	√
Pozo A., Alonso Á., Salvachúa J.	Evaluation of an iot application-scoped access control model over a publish/subscribe architecture based on fiware	2020	Access control; CoAP; IAACaaS; Identity management; IoT; OAuth 2.0; Publish & subscribe; Security	Article	√	
Hatzivasilis G., Papadakis N., Hatzakis I., Ioannidis S., Vardakis G.	Artificial intelligence-driven composition and security validation of an internet of things ecosystem	2020	Dependability; Dynamic system composition; Event calculus; Internet-of-things; IoT; JADE; JESS; Metrics; Moving target defenses; OSGi	Article	√	
Angsuchotmetee C., Chbeir R., Cardinale Y.	MSSN-Onto: An ontology-based approach for flexible event processing in Multimedia Sensor Networks	2020	Event processing; Multimedia sensors; Ontology; Reasoning; Semantic interoperability	Article	√	
Lujic I., De Maio V., Brandic I.	Resilient Edge Data Management Framework	2020	data; data flow architecture; Edge computing; forecasting; Internet of Things; solution reference architectures; storage	Article		
Ferry N., Nguyen P.H., Song H., Rios E., Iturbe E., Martinez S., Rego A.	Continuous deployment of trustworthy smart IoT systems	2020	DecSecOps; Deployment; DSL; IoT; MDE; Models@run. time	Article	√	
Edirisinghe R., Woo J.	BIM-based performance monitoring for smart building management	2020	Building information modelling (BIM); Game engine; IoT	Article		
Hoomod H.K., Amory Z.S.	Temperature prediction using recurrent neural network for internet of things room controlling application	2020	Long Short Term Memory; Prediction; Recurrent Neural Network; Room temperature	Conference Paper	√	
Bedi G., Venayagamoorthy G.K., Singh R.	Development of an IoT-driven building environment for prediction of electric energy consumption	2020	Computational intelligence; Electric energy consumption prediction; Elman recurrent neural network (RNN); Internet of Things (IoT); Smart building	Article	√	
Papatsimpa C., Bonarius J.H., Linnartz J.P.M.G.	Human Centric IoT Lighting Control based on Personalized Biological Clock Estimations	2020	biological clock; circadian rhythms; sensor network; smart building	Conference Paper	√	
Jha D.N., Alwasel K., Alshoshan A., Huang X., Naha R.K., Battula S.K., Garg S., Puthal D., James P., Zomaya A., Dustdar S., Ranjan R.	IoTSim-Edge: A simulation framework for modeling the behavior of Internet of Things and edge computing environments	2020	edge computing; Internet of Things; simulation; software	Conference Paper	√	√
Thomas J.A.	Prediction of Heat Demand for Building Energy Managers: An IoT and Control Perspective	2020	energy management; General Additive Models; Internet of Things; short-term load forecasting; smart buildings	Conference Paper	√	

Ahmadi E., Noorollahi Y., Mohammadi-Ivatloo B., Anvari-Moghaddam A.	Stochastic operation of a solar-powered smart home: Capturing thermal load uncertainties	2020	Energy storage; Smart home; Solar renewable; Stochastic operation; Thermal load	Article	√	
Chelyshkov P.	Potential for the Application of Cyberphysical Integration of Building Systems in Design Automation Systems	2020	building system; construction; cybernetics; cybernetics of building systems; cyberphysical building system; cyberphysical system; information modeling; Internet of things; life cycle management; smart building; smart city	Conference Paper	√	
Goel U., Sonanis R., Rastogi I., Lal S., De A.	Criticality Aware Orderer for Heterogeneous Transactions in Blockchain	2020	blockchain; criticality; deadline; heterogeneous transactions; ordering service	Conference Paper	√	
Balakrishna P., Rani B.M.S., Swapna Sri V.N., Krishna T.V.	Analysis of aproficient smart building using iot	2020		Article		
Nagendra V., Bhattacharya A., Yegneswaran V., Rahmati A., Das S.	An Intent-Based Automation Framework for Securing Dynamic Consumer IoT Infrastructures	2020	Conflict detection and resolution.; Consumer IoT security; Intent-based policy and automation framework	Conference Paper	√	
Ha Q.P., Metia S., Phung M.D.	Sensing Data Fusion for Enhanced Indoor Air Quality Monitoring	2020	extended fractional Kalman filter; indoor air quality; Internet-of-Things; Sensing fusion	Article	√	
Li Y., Jha D.N., Aujla G.S., Morgan G., Zomaya A.Y., Ranjan R.	IoTWC: Analytic Hierarchy Process Based Internet of Things Workflow Composition System	2020	Analytic Hierarchy Process; Internet of Things; Multi-criteria Decision Making; Workflow Composition	Conference Paper	√	
Massano M., Patti E., Macii E., Acquaviva A., Bottaccioli L.	An online grey-box model based on unscented kalman filter to predict temperature profiles in smart buildings	2020	Building simulation; Grey-box model; Parameter estimation; Thermal dynamics; Unscented Kalman Filter	Article	√	
Wofford L., Wyman D., Starr C.W.	Do you have a naïve forecasting model of the future?	2020	Business environment; Complexity; Disruption; Resiliency; Sustainability; Technological innovation	Article		
Panwar N., Sharma S., Gupta P., Ghosh D., Mehrotra S., Venkatasubramanian N.	IoT Expunge: Implementing Verifiable Retention of IoT Data	2020	data deletion; internet of things; smart building; user privacy; verification	Conference Paper		√
Achenkunjujohn A., Venkatesh Kumar P.	A new concept of smart universities using internet of things (IoT)	2020	IoT; RFID; Sensors; Smart buildings; Smart Education; Smart University; Smartvehicles; WSN	Article		
Wang Q., Wang Q., Jin S., Zhu H., Wang X.	A hierarchical game model for computation sharing in smart buildings	2020	computation sharing; Cournot game; incomplete information; Stackelberg game	Article	√	
Ahlawat B., Sangwan A., Sindhu V.	IoT system model, challenges and threats	2020	Challenges; DOS attack; IOT; Model of IOT; Security attacks	Article		
Kaur A., Auluck N.	A Fog based Building Fire Evacuation Framework	2020	Cloud computing; Cloud data center; Fog computing; Internet of Things; Micro data center; Smart building	Conference Paper	√	
Sarkar S., Wankar R., Srirama S.N., Suryadevara N.K.	Serverless Management of Sensing Systems for Fog Computing Framework	2020	fog computing; sensing systems; serverless computing; smart building; Wireless sensor network	Article	√	√
Carli R., Cavone G., Othman S.B., Dotoli M.	IoT based architecture for model predictive control of HVAC systems in smart buildings	2020	Heating ventilation and air conditioning system; Internet of things; Model predictive control; Predicted mean vote; Smart buildings	Article	√	
Srivastava H.K., Dwivedi R.K.	Energy Efficiency in Sensor Based IoT using Mobile Agents: A Review	2020	Client Server; Energy efficiency; Internet of Things; Mobile Agent; Wireless Sensor Network	Conference Paper	√	
Arshad J., Azad M.A., Abdeltaif M.M., Salah K.	An intrusion detection framework for energy constrained IoT devices	2020	Constrained IoT devices; Industrial IoT; Internet of Things (IoT); Intrusion detection; Performance evaluation	Article	√	
Xu H., He Y., Sun X., He J., Xu Q.	Prediction of thermal energy inside smart homes using IoT and classifier ensemble techniques	2020	Classifier ensemble; Edge computing; Internet of Things; Machine learning; Predictive model; Smart home	Article	√	

Irshad K., Almalawi A., Khan A.I., Alam M.M., Zahir M.H., Ali A.	An IoT-based thermoelectric air management framework for smart building applications: A case study for tropical climate	2020	Carbon emission; Energy consumption; Internet of things; Thermal management; Thermoelectric air conditioning	Article	√	√
Meenaakshi Sundhari R.P., Jaikumar K.	IoT assisted Hierarchical Computation Strategic Making (HCSM) and Dynamic Stochastic Optimization Technique (DSOT) for energy optimization in wireless sensor networks for smart city monitoring	2020	Dynamic Stochastic Optimization Technique (DSOT); Energy-constrained sensor node; Hybridized IoT assisted Hierarchical Computation Strategic Making (HCSM); IoT; Smart city monitoring; Wireless sensor network	Article		√
Aljumah A., Kaur A., Bhatia M., Ahamed Ahanger T.	Internet of things-fog computing-based framework for smart disaster management	2020		Article	√	
Bashir M.R., Gill A.Q., Beydoun G., McCusker B.	Big data management and analytics metamodel for IoT-enabled smart buildings	2020	Big data management; IoT; Metamodel; Smart buildings	Article	√	
Rehman S.U., Javed A.R., Khan M.U., Nazar Awan M., Farukh A., Hussien A.	PersonalisedComfort: a personalised thermal comfort model to predict thermal sensation votes for smart building residents	2020	ASHRAE; deep learning; healthcare; human thermal comfort; HVAC smart buildings; IoT; smart cities	Article	√	√
Zhang X., Pipattanasomporn M., Chen T., Rahman S.	An IoT-Based Thermal Model Learning Framework for Smart Buildings	2020	Building energy management (BEM); building thermal model; Internet of Things (IoT); smart buildings	Article	√	√
Altaf A., Abbas H., Iqbal F., Khan M.M.Z.M., Daneshmand M.	Robust, Secure and Adaptive Trust-Oriented Service Selection in IoT-Based Smart Buildings	2020	Direct observation; IoT; Malicious; Naive Bayesian; Recommendations; Smart Building.; Trust	Article	√	
Vijayan D.S., Rose A.L., Arvindan S., Revathy J., Amuthadevi C.	Automation systems in smart buildings: a review	2020	Elderly people care; Energy management; Fire management; HVAC; IoT; Smart building	Article		
Gautam K., Puri V., Tromp J.G., Nguyen N.G., Van Le C.	Internet of Things (IoT) and Deep Neural Network-Based Intelligent and Conceptual Model for Smart City	2020	Deep learning; Internet of things (IoT); Neural network; Smart city	Conference Paper	√	
Kychkin A.V., Deryabin A.I., Vikentyeva O.L., Shestakova L.V.	Adaptive iot-based hvac control system for smart buildings	2020		Conference Paper		
Hakiri A., Sallemi B., Ghandour F., Ben Yahia S.	Secure, Context-Aware and QoS-Enabled SDN Architecture to Improve Energy Efficiency in IoT-Based Smart Buildings	2020	Context-awareness; Energy efficiency; Internet of Things; Service Function Chaining; Smart building; Software defined networking	Conference Paper		
Alfarraj O.	Internet of things with bio-inspired co-evolutionary deep-convolution neural-network approach for detecting road cracks in smart transportation	2020	Deep learning network; Deep-convolution networks; Internet of things (IoT); Road cracks; Smart mobile sensors; Smart transportation	Article		
Rehman M.A.U., Ullah R., Kim B., Nour B., Mastorakis S.	CCIC-WSN: An Architecture for Single Channel Cluster-based Information-Centric Wireless Sensor Networks	2020	Battlefield Surveillance System.; Clustering; Indexes; Internet of Things; Internet of Things; Named Data Networking; Smart buildings; Storms; Synchronization; Wireless communication; Wireless sensor networks; Wireless Sensor Networks	Article		√
Sanjuan E.B., Cardiel I.A., Cerrada J.A., Cerrada C.	Message Queuing Telemetry Transport (MQTT) Security: A Cryptographic Smart Card Approach	2020	Internet of Things (IoT); javacard; message queuing telemetry transport (MQTT); mutual authentication; smart card	Article		
Tao X., Conzon D., Ferrera E., Li S., Goetz J., Maillet-Contoz L., Michel E., Diaz-Nava M., Baouya A., Chehida S.	Model based methodology and framework for design and management of next-gen IoT systems	2020	Brain-IoT; Digital Twin; Internet of Things; Model-Based System Engineering	Conference Paper		

Bataille G., Gouranton V., Lacoche J., Pelé D., Arnaldi B.	A unified design & development framework for mixed interactive systems	2020	Cyber-physical systems; Human-machine interaction; Hybrid interactive systems; Internet of things; Mixed interactive systems; Mixed reality; Natural user interfaces	Conference Paper	√	
Al-Shammari H.Q., Lawey A.Q., El-Gorashi T.E.H., Elmirghani J.M.H.	Service Embedding in IoT Networks	2020	Energy efficiency; IoT; MILP; queuing; service oriented architecture (SOA); smart buildings; virtualization	Article	√	√
Zhang G., Li Y., Deng X.	K-means clustering-based electrical equipment identification for smart building application	2020	Building Internet of Things; Equipment identification; Euclidean distance; K-means clustering	Article	√	√
Cejka S., Kintzler F., Mullner L., Knorr F., Mittelsdorf M., Schumann J.	Application lifecycle management for industrial iot devices in smart grid use cases	2020	Application Lifecycle Management; Cyber-physical System; Dependability; Software Management; Software Rollout	Conference Paper	√	
Maati B., Saidouni D.E.	CIoTAS protocol: CloudIoT available services protocol through autonomic computing against distributed denial of services attacks	2020	Autonomic computing; CloudIoT paradigm; DDoS attacks; Diagnosable; S2aaS model; Self-healing	Article		
Bagaa M., Taleb T., Bernabe J.B., Skarmeta A.	A Machine Learning Security Framework for Iot Systems	2020	artificial intelligence; Internet of Things; NFV; orchestration and MANO; SDN; security	Article	√	√
Vähäkainu P., Lehto M., Kariluoto A.	IoT -based adversarial attack's effect on cloud data platform services in a smart building context	2020	Adversarial attacks; Artificial intelligence; Artificial intelligence-based applications; Attack vectors; Cloud service; Data platform	Conference Paper	√	
Algarni F., Ullah A., Aloufi K.	Enhancing the Linguistic Landscape with the Proper Deployment of the Internet of Things Technologies: A Case Study of Smart Malls	2020	Big data; Digital transformation; Energy efficiency; IoT; Linguistic landscapes; RTOS; Smart environment	Conference Paper		
Sebastian A.	Child Count Based Load Balancing in Routing Protocol for Low Power and Lossy Networks (Ch-LBRPL)	2020	Bottleneck problem; Child count; Internet of Things; Load balancing; Multi DODAG; RPL	Conference Paper		
Al-Shammari H.Q., Lawey A.Q., El-Gorashi T.E.H., Elmirghani J.M.H.	Resilient Service Embedding in IoT Networks	2020	Energy efficiency; Internet of Things; mixed integer linear programming; queuing; resilience; service-oriented architecture; smart buildings; virtualization	Article	√	
Thangamani A., Ganesh L.S., Tanikella A., Meher Prasad A.	IoT Based Climate Control Systems Diffusion in Intelligent Buildings - A System Dynamics Model	2020	Energy efficient comfort; Internet of Things; Smart buildings; System dynamics; Technology diffusion	Conference Paper		
Sai Y., Zhang T., Huang X., Ding C.	Analysis of digital twins and application value of power engineering based on BIM	2020	Comprehensive informationization; Digital twins; Project management; Smart building	Conference Paper		
Thangamani A., Ganesh L.S., Tanikella A., Prasad A.M.	Occupant Adoption of IoT Based Environment Service in Office Spaces: An Empirical Investigation	2020	Energy efficient comfort; Energy related occupant behavior; Internet of Things; Smart building; Technology adoption	Conference Paper		
Mishra S., Rajwanshi S., Hota C.	Internet of things based occupancy detection using ensemble classifier for smart buildings	2020	Differential Evolution Optimization; Ensemble Learning; Occupancy Detection; Occupancy Modelling; Wireless Sensor Networks	Article		
Casado-Vara R., De la Prieta F., Rodriguez S., Sitton I., Calvo-Rolle J.L., Venayagamoorthy G.K., Vega P., Prieto J.	Adaptive Fault-Tolerant Tracking Control Algorithm for IoT Systems: Smart Building Case Study	2020	Adaptive closed-loop; Algorithm design and analysis; Control system; IoT; Non-linear control	Conference Paper		
Raghavan S., Simon B.Y.L., Lee Y.L., Tan W.L., Kee K.K.	Data Integration for Smart Cities: Opportunities and Challenges	2020	Data Sharing and Integration; Heterogeneity; Internet of Things; Smart City	Conference Paper	√	√
Alduailij M.A., Petri I., Rana O., Alduailij M.A., Aldawood A.S.	Forecasting peak energy demand for smart buildings	2020	ANN; ARIMA; Energy forecasting; Peak demand; Smart buildings; Time series	Article	√	
Rahman A., Islam M.J., Rahman Z., Reza M.M., Anwar A., Parvez	DistB-Condo: Distributed Blockchain-based IoT-SDN Model for Smart Condominium	2020	Blockchain; Blockchain; Computer architecture; IoT; Network function virtualization; NFV; OpenFlow; Privacy;	Article	√	

Mahmud M.A., Nasir M.K., Noor R.M.			Protocols; SDN; Security; Security; Smart cities; Smart Condominium; Smart Contact; Throughput			
Vähäkainu P., Lehto M., Kariluoto A.	Influence of attack vectors on generic artificial intelligence – Assisted smart building feedback loop system	2020	Adversarial attacks; Artificial intelligence; Artificial intelligence-based applications; Attack vectors; Cloud service; Data platform	Conference Paper	√	
Navarro R.C., Ruiz A.R., Chaparro J.D., Villanueva Molina F.J., Santofimia Romero M.J., Alises D.V., Lopez Lopez J.C.	A proposal for modeling indoor–outdoor spaces through IndoorGML, open location code and OpenStreetMap	2020	IndoorGML; Open location code; OpenStreetMap; Smart building; Smart city; Space representation	Article	√	
Gajewski M., Mongay Batalla J., Mastorakis G., Mavromoustakis C.X.	Anomaly traffic detection and correlation in Smart Home automation IoT systems	2020		Article	√	
Vähäkainu P., Lehto M., Kariluoto A.	Utilization of sophisticated cryptography methods in providing security in cyber-physical context	2020	Artificial intelligence; Cryptography; Cyber-physical system; Cybersecurity; ML based feedback loop	Conference Paper		
Soic R., Vukovic M., Skocir P., Jezic G.	Context-Aware Service Orchestration in Smart Environments	2020	Context-awareness; Human–computer interaction; Industry 4.0; IoT; RFID; Service orchestration; Smart environments; Software agents	Conference Paper		
Hasan B., Hasbullah H., Purnama W., Kustiawan I.	Training and development of Internet of Things creative industry entrepreneurship models for UPI students	2019		Conference Paper	√	
Jain R., Klai K., Tata S.	Formal modeling and verification of scalable process-aware distributed iot applications	2019	Business process; Colored petri nets; Distributed deployment; Formal method; Internet of things; Node-red	Conference Paper	√	
Allik A., Muiste S., Pihlap H.	Movement Based Energy Management Models for Smart Buildings	2019	automation; geofencing; global positioning system; Internet of things; location based services	Conference Paper	√	
Mansour E., Chbeir R., Arnould P.	EQL-CE: An event query language for connected environment management	2019	Event Query Language; Internet of Things; Sensor Networks	Conference Paper		
Cho J.Y., Kim J., Kim K.-B., Ryu C.H., Hwang W., Lee T.H., Sung T.H.	Significant power enhancement method of magneto-piezoelectric energy harvester through directional optimization of magnetization for autonomous IIoT platform	2019	Autonomous; Lorentz force; Magnetic field; Piezoelectric energy harvester; Power cable; Wireless sensor network	Article		
Anjana M.S., Ramesh M.V., Devidas A.R., Athira K.	Fractal IoT: A scalable IoT framework for energy management in connected buildings	2019	Connected buildings; Energy management; IoT Framework; Microgrid; Self-sustainable community; Smart Building	Conference Paper	√	√
Koh J., Hong D., Nagare S., Boovaraghavan S., Agarwal Y., Gupta R.	Who can access what, and when?: Understanding minimal access requirements of building applications	2019	Access control; IoT; Smart buildings	Conference Paper	√	
Liu R., Wang Z., Garcia L., Srivastava M.	RemedioT: Remedial actions for internet-of-things conflicts	2019	Environment safety; IoT conflicts; Smart Environment	Conference Paper	√	
Kurt J.-C., Benjamin K., Tayana E.	Improving local revenue mobilization capacity through data-driven strategy CIVITAX Pilot 2019	2019	Connected buildings; Energy management; IoT Framework; Microgrid; Self-sustainable community; Smart Building	Conference Paper		
Babu N.T.R., Stewart C.	Revisiting online scheduling for AI-driven internet of things	2019		Conference Paper	√	
Fayyaz H., Rehman Z.U., Abbas S.	An IoT Enabled Framework for Smart Buildings Empowered with Cloud Fog Infrastructures	2019	cloud computing; Fog computing; internet of things (IoT); smart buildings; smart cities	Conference Paper	√	√
Casado-Vara R., Canal-Alonso A., Rey A.M.-D., De La Prieta F., Prieto J.	Smart buildings IoT networks accuracy evolution prediction to improve their reliability using a lotka-volterra ecosystem model	2019	Algorithm design; Bio-inspired system evolution; Internet of things; Lotka-volterra model; Predator-prey system	Article	√	

Sicari S., Rizzardi A., Coen-Porisini A.	How to evaluate an Internet of Things system: Models, case studies, and real developments	2019	application case study; flow-based programming; Internet of Things; Node-RED	Article	√	
Tang X., Mandal S.	Indoor occupancy awareness and localization using passive electric field sensing	2019	Dividing rectangular (DIRECT) search; electric field sensing; Internet of Things (IoT); maximum likelihood (ML); occupancy; physiological signals; sensor networks; smart buildings; source localization	Article	√	
Spencer B., Al-Obeidat F., Alfandi O.	Accurately forecasting temperatures in smart buildings using fewer sensors	2019	Energy efficiency; Feature selection; Internet of things; Model predictive control; Sensor networks; Temperature forecast	Article		
Wall A., Butzin B., Golatowski F., Rethfeldt M., Timmermann D.	Software-Defined Security Architecture for Smart Buildings using the Building Information Model	2019		Conference Paper	√	
Bran C., Hernandez C., Gomez A.	System based on sensor dots for monitoring smart buildings	2019	Embedded processor; IoT; LEED; Sensor dot; Transport network	Conference Paper	√	
Conzon D., Rashid M.R.A., Tao X., Soriano A., Nicholson R., Ferrera E.	BRAIN-IoT: Model-Based Framework for Dependable Sensing and Actuation in Intelligent Decentralized IoT Systems	2019	BRAIN-IoT; Complex Adaptive Systems; IoT platforms; IoT System Behavior Modeling; Privacy Impact Assessment	Conference Paper	√	
Araujo E., Dantas J., Matos R., Pereira P., MacIel P.	Dependability evaluation of an iot system: A hierarchical modelling approach	2019		Conference Paper	√	
Idrissi M.E., Elbeqqali O., Riffi J.	A Review On Relationship Between Iot- Cloud Computing - Fog Computing (Applications And Challenges)	2019	BigData; Cloud computing; Fog computing; Internet of things; Radio Frequency Identification	Conference Paper		
Ahdan S., Susanto E.R., Rachmana Syambas N.	Proposed design and modeling of smart energy dashboard system by implementing iot (internet of things) based on mobile devices	2019	internet of things; smart building; smart home	Conference Paper	√	√
Eini R., Abdelwahed S.	Learning-based Model Predictive Control for Smart Building Thermal Management	2019	Artificial neural network; Heating/cooling system; Learning-based model predictive control; Model-based control; Occupancy estimation; Smart building management and control	Conference Paper	√	
Albataineh M., Jarrah M.	DEVS-Based IoT Management System for Modeling and Exploring Smart Home Devices	2019	control devices; DEVS formalism; IoT; monitoring; smart home devices	Conference Paper	√	
Guidara A., Derbel F., Fersi G., Bdiri S., Jemaa M.B.	Energy-efficient on-demand indoor localization platform based on wireless sensor networks using low power wake up receiver	2019	Duty cycling; Energy conservation; Indoor localization; On-demand communication; Wake up receiver; Wireless sensor networks	Article	√	
Zou H., Zhou Y., Arghandeh R., Spanos C.J.	Multiple Kernel Semi-Representation Learning with Its Application to Device-Free Human Activity Recognition	2019	Device-free; human activity recognition; multiple kernel semi-representation learning (MKSRL); WiFi	Article	√	
Giallonardo E., Poggi F., Rossi D., Zimeo E.	Resilient reactive systems based on runtime semantic models	2019	context-Awareness; model@runtime; reactive systems; resilience; semantics	Conference Paper	√	
Alexakos C., Komninos A., Anagnostopoulos C., Kalogeras G., Savvopoulos A., Kalogeras A.	Building an industrial IoT infrastructure with open source software for smart energy	2019	Industrial IoT; IoT architecture; Open source software; Smart energy	Conference Paper	√	
Aliberti A., Bottaccioli L., Macii E., Di Cataldo S., Acquaviva A., Patti E.	A non-linear autoregressive model for indoor air-temperature predictions in smart buildings	2019	Artificial neural network; Energy efficiency; Indoor air-temperature forecasting; Nonlinear autoregressive model; Smart building	Article	√	
Meyfroyt T.M.M., Boon M.A.A., Borst S.C., Boxma O.J.	Performance of large-scale polling systems with branching-type and limited service	2019	Cycle times; Flexible k-limited service; Polling models; Queue lengths	Article	√	

Aguilera J.J., Kazanci O.B., Toftum J.	Thermal adaptation in occupant-driven HVAC control	2019	Adaptive thermal model; HVAC control; Participatory sensing; Personal thermal comfort; Smart buildings; Thermal comfort	Article		√
Panwar N., Sharma S., Wang G., Mehrotra S., Venkatasubramanian N., Diallo M.H., Sani A.A.	IoT Notary: Sensor Data Attestation in Smart Environment	2019		Conference Paper		
Zakharov A., Romazanov A., Shirokikh A., Zakharova I.	Intellectual Data Analysis System of Building Temperature Mode Monitoring	2019	building thermal model; energy efficiency; Internet of Things; smart building; temperature mode	Conference Paper	√	
Shomaji S., Ganji F., Woodard D., Forte D.	Hierarchical Bloom Filter Framework for Security, Space-efficiency, and Rapid Query Handling in Biometric Systems	2019		Conference Paper		
Siountri K., Skondras E., Vergados D.D.	Towards a Smart Museum using BIM, IoT, Blockchain and Advanced Digital Technologies	2019	Blockchain; Building Information Modeling (BIM); Internet of Things (IoT); Smart Buildings	Conference Paper	√	
Pan Z., Hariri S., Pacheco J.	Context aware intrusion detection for building automation systems	2019	Context awareness; Data mining; Internet of Things; Intrusion detection; Network security; Supervised learning	Article	√	√
Pacheco J., Benitez V.H., Pan Z.	Security framework for IoT end nodes with neural networks	2019	Access control; Internet of things; Neural networks; Threat detection	Article	√	√
Foster B., Wahyu A.P., Reyta F., Saputra J.	The role of smarthome technology for improving supply chain and perceived value on housing retailer	2019	Housing; IoT; Monitoring; Perceived Value; Retailers; Smart Home; Supply chain	Article	√	
Antón M.Á., Ordieres-Meré J., Saralegui U., Sun S.	Non-invasive ambient intelligence in real life: Dealing with noisy patterns to help older people	2019	Ambient assisted living; Ambient intelligence; IoT; Machine learning; Smart building	Article	√	
Sharma S., Nanda M., Goel R., Jain A., Bhushan M., Kumar A.	Smart cities using internet of things: Recent trends and techniques	2019	IoT; Sensor System Integration; Smart Cities; Smart citizens; Smart technology	Article		
Rehman M.A.U., Ullah R., Kim B.-S.	NINQ: Name-integrated query framework for named-data networking of things	2019	Commands; Internet of things; Named-Data Networking; Pull and Push Support; Query; Smart building	Article	√	√
Wang W., Meratnia N., Seraj F., Havinga P.J.M.	Privacy-aware environmental sound classification for indoor human activity recognition	2019	Computational E-ciency; Internet Of Things; Linear Predictive Cepstral Coecients; Mel Frequency Cepstral Coecients; Privacy-aware Environmental Sound Recognition; Smart Buildings; Support Vector Machine; Voice Bands Stripping; Web Crawling	Conference Paper	√	
Corici A.A., Shashi Y., Corici M., Shrestha R., Guzman D.	Enabling dynamic iot security domains: Cellular core network and device management meet authentication framework	2019	5G; Access Control; Bootstrap; Connectivity; IoT; M2M; Token validation	Conference Paper	√	
Andrade T., Bastos D.	Extended reality in iot scenarios: Concepts, applications and future trends	2019	Augmented Reality; Extended Reality; Internet of Things; Mixed Reality; Virtual Reality	Conference Paper		
Wang Z., Lu T.	Evaluation of control strategy for smart air-conditioning system based on stochastic hybrid automata	2019	Smart air conditioning system; Stohasti hybrid automata; Strategy evaluation	Article		
Cech H.L., Grobmann M., Krieger U.R.	A fog computing architecture to share sensor data by means of blockchain functionality	2019	Blockchain; Data-sharing; Fog-computing; MultiChain	Conference Paper	√	
Chen C.-C.	Incorporating smart technologies and resilience into healthy living environment designs	2019	Climate change; Resilient design; Smart green building; Smart technology	Article		
Krishnamurthy K., Singh P., Sriraman N.	GeoBMS: Hybrid cloud/on-premise architecture for building energy optimization	2019	Building Configuration Optimization; Energy Management; Hybrid Cloud; Smart Buildings; Sustainability	Conference Paper	√	√
Laurini E., Rotilio M., Lucarelli M., De Berardinis P.	Technology 4.0 for buildings management: From building site to the interactive building book	2019	Black box; Building book; HBIM; Internet of things; Smart building site; Technology 4.0	Conference Paper		

Rinaldi S., Bonafini F., Ferrari P., Flammini A., Sisinni E., Bianchini D.	Impact of data model on performance of time series database for internet of things applications	2019	Internet of things; Performance analysis; Smart building; Smart city; Time series database	Conference Paper	√	
Rashid K.M., Louis J., Fiawoyife K.K.	Wireless electric appliance control for smart buildings using indoor location tracking and BIM-based virtual environments	2019	Automation; Control; Home control; Kalman filter; Point-and-click; Sensors; Smart appliance; Smart appliances; Ultra-wideband; User interface	Article		
Zhang T., Ardakanian O.	A domain adaptation technique for fine-grained occupancy estimation in commercial buildings	2019	domain adaptation; occupancy detection; recurrent neural networks; smart building	Conference Paper	√	
Yin X., Ma T., Yin L., Tian F., Lyu B.	Optimization for Demand Side Management with PAR in Smart Building	2019	Demand side management; Fairness; Load scheduling; NB-IoT; Smart building	Conference Paper		
Ahmadi-Assalemi G., Al-Khateeb H.M., Epiphaniou G., Cosson J., Jahankhani H., Pillai P.	Federated Blockchain-Based Tracking and Liability Attribution Framework for Employees and Cyber-Physical Objects in a Smart Workplace	2019	Anomaly Detection; Authenticity; Digital Witness; Insider threart; IoT; Monitoring; Non-repudiation; Smart building; Smart City	Conference Paper		
Le D.N., Le Tuan L., Dang Tuan M.N.	Smart-building management system: An Internet-of-Things (IoT) application business model in Vietnam	2019	Internet-of-Things; Sensors; Smart-building management system; Vertical integration	Article	√	√
Zhang W., Hu W., Wen Y.	Thermal comfort modeling for smart buildings: A fine-grained deep learning approach	2019	Deep learning; smart building; smart city; thermal comfort	Article	√	
Almaguer-Angeles F., Murphy J., Murphy L., Portillo-Dominguez A.O.	Choosing machine learning algorithms for anomaly detection in smart building iot scenarios	2019		Conference Paper	√	
Subbarao V., Srinivas K., Pavithr R.S.	A survey on internet of things based smart, digital green and intelligent campus	2019	IoT; Learning Management System; R Sensor; Smart building; Smart campus; Smart learning	Conference Paper	√	√
Liu X., Wei X., Guo L.	DIMLOC: Enabling high-precision visible light localization under dimmable LEDs in smart buildings	2019	Indoor navigation; Internet of Things; light emitting diodes (LEDs); visible light communication	Article	√	
Marcello F., Pilloni V.	Sensor-Based Activity Recognition Inside Smart Building Energy and Comfort Management Systems	2019	action recognition; activity prediction; Activity recognition; Smart Building	Conference Paper	√	
Dine G., Sahingoz O.K.	Smart Home Security with the use of WSNs on Future Intelligent Cities	2019	Cyber-Physical Systems; Sensor Coverage; Smart Cities; Smart Homes; WSNs	Conference Paper	√	
Papatsimpa C., Linnartz J.-P.	Distributed fusion of sensor data in a constrained wireless network	2019	Efficient transmission; Internet of Things (IoT); Sensor fusion; Smart building; Wireless sensor networks	Article	√	
Liu Y., Yang C., Jiang L., Xie S., Zhang Y.	Intelligent Edge Computing for IoT-Based Energy Management in Smart Cities	2019		Article	√	√
Ying J., Pahlavan K.	Precision of RSS-Based Localization in the IoT	2019	Cramer Rao lower bound openparen (CRLB); Internet of Things (IoT); Localization	Article		
Khattak H.A., Farman H., Jan B., Ud Din I.	Toward Integrating Vehicular Clouds with IoT for Smart City Services	2019		Article	√	
Zhang X., Cai M., Pipattanasomporn M., Rahman S.	A Power Disaggregation Approach to Identify Power-Temperature Models of HVAC Units	2019	demand response; HVAC; Internet of Things; power disaggregation; smart building	Conference Paper	√	
[No author name available]	A Survey Analysis and Model Development for Internet of Things (IoT) System for City Buildings: Dhaka City, Bangladesh Perspective	2019	Cyber-Physical system; Internet of Things; Multi-agent system; Survey	Conference Paper	√	
Rahman M.S., Kabir M.H., Datta P.P., Kabir I.	Social internet of things (SIoT) system model simulation for city buildings: Bangladesh	2019	Bluetooth Low Energy (BLE); Building Management System (BMS); Internet of Things; Smart Building; Social Network	Conference Paper	√	
Kim B., Heo S., Lee G., Song S., Kim J., Kim H.	Spinal code: Automatic code extraction for near-user computation in fogs	2019	Fog Computing; Internet of Things; IoT	Conference Paper	√	√

Carrera J.L.V., Zhao Z., Braun T., Li Z.	Real-time Smartphone Indoor Tracking Using Particle Filter with Ensemble Learning Methods	2019	Ensemble Learning Methods; Hidden Markov Model; Indoor Localization; Internet of Things; Particle Filter	Conference Paper	√	
Chen B., Eck B., Fusco F., Gormally R., Purcell M., Sinn M., Tirupathi S.	Castor: Contextual IoT time series data and model management at scale	2019	big data; cloud; IoT; model management; prediction; time series management	Conference Paper		
Sembroiz D., Careglio D., Ricciardi S., Fiore U.	Planning and operational energy optimization solutions for smart buildings	2019	Comfort; Energy; ILP; Internet of things; Optimization; Simulation; Smart buildings; Wireless sensor network	Article	√	
Song S., Park S.O., Lee S.I., Park J.H.	Mission-oriented service development using capability-based semantic recommendation for the internet of things	2019	Capability-based semantic matching; Mission service; Ontology, IoT; Recommendation	Article		
Shetty S.S., Hoang D.C., Gupta M., Panda S.K.	Learning desk fan usage preferences for personalised thermal comfort in shared offices using tree-based methods	2019	Desk fans; Internet of things; Machine learning; Personal thermal comfort; Smart buildings; Tree-based methods	Article	√	
Pacheco J., Tunc C., Hariri S.	Security Framework for IoT Cloud Services	2019	Anomaly Behavior Analysis; Cloud Computing; Internet of Things; Threat Detection	Conference Paper		√
Ateeq M., Ishmanov F., Afzal M.K., Naeem M.	Multi-parametric analysis of reliability and energy consumption in IoT: A deep learning approach	2019	Deep learning; Energy consumption; IEEE 802.15.4; Internet of things; Packet delivery ratio; Prediction; Wireless sensor networks	Article	√	√
Wei X., Wang T., Tang C.	Throughput Analysis of Smart Buildings-oriented Wireless Networks under Jamming Attacks	2019	Collision probability; Internet of things; Jamming; Smart buildings; Stochastic geometry; Throughput; Throughput internet of things	Article	√	
Maatoug A., Belalem G., Mahmoudi S.	Fog computing framework for location-based energy management in smart buildings	2019	energy management; fog computing; IoT; Smart buildings; user's location	Article	√	√
Gao X., Pishdad-Bozorgi P., Shelden D.R., Tang S.	A Scalable Cyber-Physical System Data Acquisition Framework for the Smart Built Environment	2019		Conference Paper	√	√
Zhang K., Yang K., Li S., Jing D., Chen H.-B.	ANN-Based outlier detection for wireless sensor networks in smart buildings	2019	artificial neural network; Outlier detection; thermal controlling; wireless sensor networks	Article	√	
Kumar S., Hu Y., Andersen M.P., Popa R.A., Culler D.E.	Jedi: Many-to-many end-to-end encryption and key delegation for IoT	2019		Conference Paper		√
Shah S.A., Seker D.Z., Rathore M.M., Hameed S., Ben Yahia S., Draheim D.	Towards Disaster Resilient Smart Cities: Can Internet of Things and Big Data Analytics Be the Game Changers?	2019	Big data analytics; disaster management; disaster resilient smart city; geo-social media analytics; Hadoop; Internet of Things; smart city; smart data analytics; spark	Article		√
Hadri S., Naitmalek Y., Najib M., Bakhouya M., Fakhri Y., Elaroussi M.	A comparative study of predictive approaches for load forecasting in smart buildings	2019	Building occupancy; Iot/big data technologies; Load forecasting; Machine learning; Smart building; Statistical approaches	Conference Paper	√	
Wang Z., Kong L., Chen G., Ni M.	NnD: Shallow Neural Network Based Collision Decoding in IoT Communications	2019		Conference Paper		
Jin W., Kim D.	Improved resource directory based on DNS name self-registration for device transparent access in heterogeneous iot networks	2019	Domain name system; Hypertext transfer protocol; Internet of Things; Interworking proxy; Open connectivity foundation; Resource directory; Transparent access	Article	√	
Lokshina I.V., Greguš M., Thomas W.L.	Application of integrated building information modeling, iot and	2019	Digital technologies; Integration; Management; Monitoring; Security; Smart building; System design	Conference Paper	√	
Dy Buncio D.	BIM as the digital enabler for smart cities	2019	BIM; Data; Integrated Design; IoT; Prefabrication; Virtual Reality	Conference Paper		
Lenjani A., Dyke S., Bilionis I., Yeum C.M., Choi J., Lund A., Maghareh A.	Hierarchical convolutional neural networks information fusion for activity source detection in smart buildings	2019		Conference Paper		
Giallonardo E., Poggi F., Rossi D., Zimeo E.	Context-aware reactive systems based on runtime semantic models	2019	Context modeling; Context-awareness; Ontologies; Semantic modeling; Semantic sensor networks	Conference Paper		

Fatehah M., Mezhuyev V.	Design and process metamodels for modelling and verification of safety-related software applications in smart building systems	2018	Cyber-physical system; Domain-specific modelling language; Metamodeling; Model-driven architecture; Smart building	Conference Paper		
Pacheco A., Cano P., Flores E., Trujillo E., Marquez P.	A Smart Classroom Based on Deep Learning and Osmotic IoT Computing	2018	Cloud Computing; Deep Learning; Internet of Things; Mobile Edge Computing; Smart Buildings; Smart Living	Conference Paper	√	
Karpenko A., Kinnunen T., Madhikermi M., Robert J., Främling K., Dave B., Nurminen A.	Data exchange interoperability in iot ecosystem for smart parking and EV charging	2018	Data exchange; Ecosystem; Internet of things; Interoperability; Messaging standards; O-DF; O-MI; Smart city	Article		
Sok K., Colin J.N., Po K.	Blockchain and Internet of Things opportunities and challenges	2018	Blockchain; Internet of Things; Security; Smart contract; Threats	Conference Paper		
Muztoba M., Voleti R., Karabacak F., Park J., Ogras U.Y.	Instinctive Assistive Indoor Navigation using Distributed Intelligence	2018	Assistive technologies; Human-machine interface; IoT devices; Wearable computers	Article		
Casado-Vara R., Vale Z., Prieto J., Corchado J.M.	Fault-tolerant temperature control algorithm for IoT networks in smart buildings	2018	Algorithm design and analysis; Control system; Fault-tolerant control; IoT (Internet of Things); Nonlinear control	Article	√	
Benson K.E., Bouloukakis G., Grant C., Issarny V., Mehrotra S., Moscholios I., Venkatasubramanian N.	Firedex: A prioritized IoT data exchange middleware for emergency response	2018	Emergency response; Event prioritization; Publish/subscribe middleware; Queueing networks; SDN; Utility functions	Conference Paper	√	√
Patil A.A., Badgujar V.S.	A Comprehensive Survey on Theoretic Perspective Providing Future Directions on IoT	2018	Artificial Intelligence; lnternet of Things; Machine Learning; Pattern Learning; Smart Building; Smart Lighting	Conference Paper	√	
Karpenko A., Kinnunen T., Framling K., Dave B.	Open IoT ecosystem for smart EV charging	2018	ecosystem; Internet of Things; interoperability; messaging standards; O-DF; O-MI; smart city	Conference Paper	√	
Fujiu A., Hamada T., Sumitomo T., Koshizuka N.	CAACS: Context-aware access control system for physical space in smart building	2018	access control; context-awareness; physical space; smart building	Conference Paper	√	
Saralegui U., Anton M.A., Arbelaitz O., Muguerza J.	An IoT sensor network to model occupancy profiles for energy usage simulation tools	2018	behaviour modelling; data analysis; IoT; occupancy profiles; sensor networks; smart building	Conference Paper	√	
Garzone G., Guermouche N., Monteil T.	Autonomic Management Approach for Dynamic Service Based IoT Systems	2018		Conference Paper	√	√
Koh J., Balaji B., Sengupta D., McAuley J., Gupta R., Agarwal Y.	Scrabble: Transferrable semi-automated semantic metadata normalization using intermediate representation	2018	Machine learning; Metadata schema; Smart buildings	Conference Paper	√	√
Soultatos O., Spanoudakis G., Fysarakis K., Askoxylakis I., Alexandris G., Miaoudakis A., Nikolaos Petroulakis E.	Towards a Security, Privacy, Dependability, Interoperability Framework for the Internet of Things	2018	dependability; interoperability; privacy; security	Conference Paper	√	√
Sylla A.N., Louvel M., Rutten E., Delaval G.	Modular and Hierarchical Discrete Control for Applications and Middleware Deployment in IoT and Smart Buildings	2018	Application; Discrete Event Systems; Smart Building; Software Systems	Conference Paper	√	
Paul D., Chakraborty T., Datta S.K., Paul D.	IoT and Machine Learning Based Prediction of Smart Building Indoor Temperature	2018	Edge Computing; IoT; Multi-Variate Forecasting models; On-line Learning; Predictive model; Smart Building	Conference Paper	√	
Pacheco A., Flores E., Sanchez R., Almanza-Garcia S.	Smart Classrooms Aided by Deep Neural Networks Inference on Mobile Devices	2018	Deep Neural Networks; Machine Learning; Mobile Edge Computing; Smart buildings	Conference Paper	√	
Tronchin L., Manfren M.	Energy Network Modelling Approaches for Multi-Scale Building Performance Optimization	2018	automation; energy efficiency; energy modelling; IoT; network models	Conference Paper	√	
Sava G.N., Pluteanu S., Tanasiev V., Patrascu R., Necula H.	Integration of BIM Solutions and IoT in Smart Houses	2018	Building Automation; Building Control; Building Information Model; Energy Efficiency; Energy Model;	Conference Paper	√	√

			Integration; Internet of Things; Optimazation; Smart Building			
Zou H., Zhou Y., Yang J., Spanos C.J.	Towards occupant activity driven smart buildings via WiFi-enabled IoT devices and deep learning	2018	Device-free human activity recognition; Energy efficiency; WiFi	Article	√	
Diallo M.H., Panwar N., Mehrotra S., Sani A.A.	Trustworthy Sensing in an Untrusted IoT Environment	2018		Conference Paper	√	
Hu W., Wen Y., Guan K., Jin G., Tseng K.J.	ITCM: Toward Learning-Based Thermal Comfort Modeling via Pervasive Sensing for Smart Buildings	2018	Internet of Things (IoT); machine learning; neural network (NN); pervasive sensing; reinforcement learning (RL); smart building; thermal comfort modeling; wearables	Article	√	√
Sharma H., Haque A., Jaffery Z.A.	An efficient solar energy harvesting system for wireless sensor nodes	2018	Battery Charging; DC-DC Converters; Maximum Power Point Tracking (MPPT); Smart Cities; Solar Energy Harvesting; Wireless Sensor Nodes	Conference Paper		
Novelli L., Jorge L., Melo P., Koscianski A.	Application Protocols and Wireless Communication for IoT: A Simulation Case Study Proposal	2018	Application Protocols; IoT; LPWA; Simulation; WSN	Conference Paper	√	
Agrawal R., Verma P., Sonanis R., Goel U., De A., Kondaveeti S.A., Shekhar S.	Continuous security in IoT using blockchain	2018	Blockchain; Continuous security; Digital crypto-token; Internet of Things	Conference Paper		
Sharma H., Haque A., Jaffery Z.A.	Modeling and optimisation of a solar energy harvesting system for wireless sensor network nodes	2018	Battery charging; DC-DC Converters; Maximum power point tracking (MPPT); Smart cities; Solar energy harvesting; Wireless Sensor Nodes	Article		
Tamani N., Ahvar S., Santos G., Istasse B., Praca I., Brun P.-E., Ghamri Y., Crespi N., Becue A.	Rule-based model for smart building supervision and management	2018	BMS; Existential rules; FUSE-IT; Internet of Things (IoT); Knowledge bases; Ontology; SAREF; SSN	Conference Paper	√	
Van Rensburg P.A.J., Snyders A.J., Ferreira H.C.	Modeling of Coupling Diversity for Extra-Low-Voltage Power-Line Communication Networked LED Lighting in Smart Buildings	2018	Coupling circuits; lighting control; modeling; network topology; smart homes	Article	√	
Zou H., Zhou Y., Yang J., Jiang H., Xie L., Spanos C.J.	DeepSense: Device-Free Human Activity Recognition via Autoencoder Long-Term Recurrent Convolutional Network	2018	Device-free; Human activity recognition; Internet of Things; WiFi	Conference Paper	√	
Vishwanath A., Tripodi S., Chandan V., Blake C.	Enabling real-world deployment of data driven pre-cooling in smart buildings	2018	data driven modelling; demand management; Internet of Things (IoT); pre-cooling; Smart buildings	Conference Paper	√	
Raut G., Deshmukh U.	Renewable Energy Using Smart Grid Embedded System in an Internet of Thing	2018	Internet of Things; Renewable Energy; Sensors; Smart Grid; Wireless transmission	Conference Paper	√	
Yang R., Zhao J., Chen X.	Uwb wireless connection for building water supply leakage monitoring system	2018	Leakage monitoring; Smart building; UWB	Article		
Lee J.-L., Tyan Y.-Y., Wen M.-H., Wu Y.-W.	Applying ZigBee wireless sensor and control network for bridge safety monitoring	2018	bridge safety monitoring; data analysis; data science; Internet of things; wireless sensor network; ZigBee	Article	√	
Dharur S., Swaminathan K.	Efficient surveillance and monitoring using the ELK stack for IoT powered Smart Buildings	2018	Data Visualization; Data Warehousing; Elasticsearch; Intel Galileo; Internet of Things; Kibana; Logstash; Smart Building	Conference Paper	√	
Shih C.-S., Lee K.-H., Chou J.-J., Lin K.-J.	Data-driven IoT applications design for smart city and smart buildings	2018	Distributed Systems; Embedded Software; Internet-of-Things; Networking	Conference Paper	√	
Ma M., Lin W., Zhang J., Wang P., Zhou Y., Liang X.	Discover the fingerprint of electrical appliance: Online appliance behavior learning and detection in smart homes	2018	appliance load monitoring; behavior learning; classification; fingerprint extraction; internet of things; smart home	Conference Paper	√	
Szilagyi I., Wira P.	An intelligent system for smart buildings using machine learning and semantic technologies: A hybrid data-knowledge approach	2018	Building management systems; Intelligent systems; Internet of things; Knowledge-based systems; Machine learning; Neural networks; Semantic technologies; Smart buildings	Conference Paper	√	

Agavanakis K., Papageorgas P.G., Vokas G.A., Ampatis D., Salame C.	Energy trading market evolution to the energy internet a feasibility review on the enabling internet of things (IoT) cloud technologies	2018	big data; BMS; Chat Bots; cloud; CPS; demand response; demand side management; DER; document-based database; energy awareness; Energy trading; HAN; Internet of things; IoT; micro-services; middleware; NoSQL; prosumers; RES; Smart Buildings; VPP	Conference Paper		
Ramprasad B., Mcarthur J., Fokaefs M., Barna C., Damm M., Litoiu M.	Leveraging existing sensor networks as IoT devices for smart buildings	2018	big data; building information model; internet of things; sensor networks; smart buildings	Conference Paper	√	√
Papatsimpa C., Linnartz J.P.M.G.	Energy efficient communication in smart building WSN running distributed Hidden Markov chain presence detection algorithm	2018		Conference Paper	√	
Mohammadi M., Al-Fuqaha A., Guizani M., Oh J.-S.	Semisupervised Deep Reinforcement Learning in Support of IoT and Smart City Services	2018	Bluetooth low energy indoor localization; deep learning; deep reinforcement learning (DRL); indoor positioning; Internet of Things (IoT); IoT smart services; reinforcement learning; semisupervised deep reinforcement learning; smart city	Article	√	
Ma M., Lin W., Zhang J., Wang P., Zhou Y., Liang X.	Toward Energy-Awareness Smart Building: Discover the Fingerprint of Your Electrical Appliances	2018	Activity learning; appliance load monitoring (ALM); classification algorithm; fingerprint extraction; Internet of Things; smart building	Article	√	√
Pouke M., Virtanen J.-P., Badri M., Ojala T.	Comparison of two workflows for Web-based 3D smart home visualizations	2018		Conference Paper	√	
Attia M., Haidar N., Senouci S.M., Aglzim E.-H.	Towards an efficient energy management to reduce CO2 emissions and billing cost in smart buildings	2018	CO2 emissions; Electricity cost; Internet of things (IoT); Linear programming; Nonrenewable energies; Renewable energies; Smart buildings	Conference Paper	√	
Kim J., Schiavon S., Brager G.	Personal comfort models – A new paradigm in thermal comfort for occupant-centric environmental control	2018	Data-driven modeling; Internet of things; Machine learning; Occupant-centric environmental control; Personal thermal comfort; Smart buildings	Article	√	√
Pacheco J., Ibarra D., Vijay A., Hariri S.	IoT security framework for smart water system	2018	Anomaly Behavior Analysis; Internet of Things; Smart City; Smart Water	Conference Paper	√	√
Ruano A., Silva S., Duarte H., Ferreira P.M.	Wireless sensors and IoT platform for intelligent HVAC control	2018	HVAC systems; IoT platforms; Model-based predictive control; Smart buildings; Wireless sensors	Article	√	
Milis G.M., Panayiotou C.G., Polycarpou M.M.	Semantically Enhanced Online Configuration of Feedback Control Schemes	2018	Cyber-physical systems; feedback control; Internet of Things (IoT); semantic composition; semantic knowledge models	Article	√	
Marinakis V., Doukas H.	An advanced IoT-based system for intelligent energy management in buildings	2018	Energy efficient; IoT; Rules; Semantic web; Smart building; Smart city	Article	√	
Ying J., Pahlavan K., Li X.	Precision of RSS-based indoor geolocation in IoT applications	2018		Conference Paper	√	
Qolomany B., Al-Fuqaha A., Benhaddou D., Gupta A.	Role of Deep LSTM Neural Networks and Wi-Fi Networks in Support of Occupancy Prediction in Smart Buildings	2018	ARIMA; IoT services; LSTM; Machine Learning; Smart Buildings; Smart Homes; Time series; Wi-Fi networks	Conference Paper	√	
Yun M., Ustun E., Nadeau P., Chandrakasan A.	Thermal energy harvesting for self-powered smart home sensors	2018	energy harvesting; Internet of Things; IoT; sensor; smart building; TEG; thermoelectric generator	Conference Paper	√	
Silva E.M., Agostinho C., Jardim-Goncalves R.	A multi-criteria decision model for the selection of a more suitable Internet-of-Things device	2018	Decision; Internet-of-Things; IoT; Model; Multi-Criteria	Conference Paper	√	
Guerriero A., Kubicki S., Berroir F., Lemaire C.	BIM-enhanced collaborative smart technologies for LEAN construction processes	2018	Building Information Modeling; Construction; IoT; Lean Management; Smart Building	Conference Paper	√	

Bekiroglu K., Srinivasan S., Png E., Su R., Poolla K., Lagoa C.	An Internet of Things compliant model identification methodology for smart buildings	2018		Conference Paper	√	
Li Z., Braun T., Zhao X., Zhao Z., Hu F., Liang H.	A Narrow-Band Indoor Positioning System by Fusing Time and Received Signal Strength via Ensemble Learning	2018	ensemble learning; Indoor positioning; Internet of Things; software defined radio	Article		
Park H., Rhee S.-B.	IoT-Based Smart Building Environment Service for Occupants' Thermal Comfort	2018		Article	√	√
Al-Sudani A.R., Gao S., Wen S., Al-Khiza'ay M.	Secure and privacy preserving RFID based access control to smart buildings	2018	Privacy preservation; RFID; Security; Smart buildings	Conference Paper		
Villemaud G., Hutu F., Belloche P., Kninech F.	Wireless transmission in ventilation (HVAC) ducts for the internet of things and smarter buildings: Proof of concept and specific antenna design	2018	Empirical model; HVAC; IoT; Waveguide	Conference Paper	√	
Papatsimpa C., Linnartz J.P.M.G.	Distributed Sensor Fusion for Activity Detection in Smart Buildings	2018	Energy efficiency; Internet of Things (IoT); Sensor fusion; Smart buildings	Conference Paper		
Alulema D., Criado J., Iribarne L.	A cross-device architecture for modelling authentication features in iot applications	2018	Digital TV; Internet of things; Model engineering; Security; T-Health	Article		
Belgaum M.R., Alansari Z., Jain R., Alshaer J.	A framework for evaluation of cyber security challenges in smart cities	2018	Cyber security; Internet of things; Smart cities	Conference Paper	√	
Cantarero R., Rubio A., Trapero C., Santofimia M.J., Villanueva F.J., Villa D., Lopez J.C.	A common-sense based System for Geo-IoT	2018	Common sense; Geo-IoT; Indoor spatial data models; IoT; Mapping; Modelling; Multi-Sensor Information System; OGC IndoorGML; Smart building	Conference Paper	√	
Cirigliano A., Cordone R., Nacci A.A., Santambrogio M.D.	Toward smart building design automation: Extensible CAD framework for indoor localization systems deployment	2018	Indoor localization; Internet of Things; Performance optimization; Smart buildings design automation	Article	√	
Mace J.C., Morisset C., Pierce K., Gamble C., Maple C., Fitzgerald J.	A multi-modelling based approach to assessing the security of smart buildings	2018	Adversary model; Co-simulation; Cyber-physical systems; INTO-CPS tool chain; Methodology	Conference Paper	√	
Fiawoyife K., Louis J.	Electrical appliance control for smart buildings using real-time location tracking and virtual environments	2018	Appliance control; Internet of things; Real-time tracking; Smart homes	Conference Paper	√	
Kim J., Schiavon S., Brager G.	Personal comfort models - New paradigm in thermal comfort for occupant-centric environmental control	2018	Internet of Things; Machine learning; Occupant-centric environmental control; Personal thermal comfort; Smart buildings	Conference Paper	√	√
Shchetinin E.Yu., Popova E.A.	Smart buildings energy savings with gradient boosting algorithm	2018	BEMS; Big Data; BMS; Consumption; Efficiency; Energy production; Energy saving; GBM; Optimization; Renewables; Smart buildings; Smart meters	Conference Paper		
Spencer B., Alfandi O., Al-Obeidat F.	A Refinement of Lasso Regression Applied to Temperature Forecasting	2018	Energy Efficiency; Feature Selection; Home Sensor Network; Internet of Things; Lasso regression; Model Predictive Control; Temperature Forecasting	Conference Paper	√	
Al-Sudani A.R., Gao S., Wen S., Al-Khiza'ay M.	Checking an authentication of person depends on RFID with thermal image	2018	IOT; Kinect; RFID authentication; Smart building; Thermal image	Conference Paper		
Ngoko Y., Cérin C.	Automated Planner for Energy-Efficient Buildings	2017	Demand Response; Demand Side Management; Service coordination in IoT; Service oriented architecture for smart-buildings	Conference Paper	√	
Das S.K., Mukherjee A.	IoT based smart home management to enhance the services to the occupancies and minimized energy demand by controlling appliances using wireless motes	2017	Ambient Intelligence; Intelligent Houses; IoT; Smart Houses; Ubiquitous computing; WSN	Conference Paper	√	
Hosseinzadeh S., Larijani H., Curtis K., Wixted A., Amini A.	Empirical propagation performance evaluation of LoRa for indoor environment	2017	3D ray-tracing model; COST231 model; indoor propagation estimation; Internet of Things (loT); ITU model; log-	Conference Paper		

			distance model; LoRa propagation; LPWAN; Motley-Keenan model			
Abid M.R., Lghoul R., Benhaddou D.	ICT for renewable energy integration into smart buildings: IoT and big data approach	2017	Big Data; High Performance Computing; Internet of Things; Smart Grids; Wireless Sensor Networks	Conference Paper	√	
Joy J., Gerla M.	Privacy risks in vehicle grids and autonomous cars	2017	Autonomous Vehicles; Connected Vehicles; Internet of Vehicles; Vehicle Privacy	Conference Paper		
Pacheco J., Zhu X., Badr Y., Hariri S.	Enabling Risk Management for Smart Infrastructures with an Anomaly Behavior Analysis Intrusion Detection System	2017	anomaly behavior analysis; cyber security; IoT; risk management; threat model	Conference Paper		√
Zhu X., Badr Y., Pacheco J., Hariri S.	Autonomic Identity Framework for the Internet of Things	2017	Autonomic Computing; Blockchain; Identity Management; Internet of Things; Security; Self-Discovery	Conference Paper	√	√
Dharur S., Hota C., Swaminathan K.	Energy efficient IoT framework for Smart Buildings	2017	Analytics; Intel Galileo; Internet of Things; Machine Learning; RStudio; Smart Building	Conference Paper	√	
Nesa N., Banerjee I.	IoT-Based Sensor Data Fusion for Occupancy Sensing Using Dempster-Shafer Evidence Theory for Smart Buildings	2017	Classification; data fusion; Internet of Things (IoT); monitoring; predictive models; sensors; smart buildings	Article	√	
Bottaccioli L., Aliberti A., Ugliotti F., Patti E., Osello A., Macii E., Acquaviva A.	Building Energy Modelling and Monitoring by Integration of IoT Devices and Building Information Models	2017	BIM; Building Information Model; Internet of Things; Smart Building; Software Architecture; Thermal Energy Modelling and Simulation	Conference Paper	√	
Suri K., Gaaloul W., Cuccuru A., Gerard S.	Semantic framework for internet of things-aware business process development	2017	Business process management; Internet of things (IoT); Ontology; Process modeling; Resource management; Semantics	Conference Paper		√
Pappachan P., Degeling M., Yus R., Das A., Bhagavatula S., Melicher W., Naeini P.E., Zhang S., Bauer L., Kobsa A., Mehrotra S., Sadeh N., Venkatasubramanian N.	Towards Privacy-Aware Smart Buildings: Capturing, Communicating, and Enforcing Privacy Policies and Preferences	2017	Internet of Things; IoT; Privacy; Privacy Policies; Privacy-aware; Smart Buildings; User Preferences	Conference Paper	√	√
Floarea D., Sgarciu V.	LED Smart Illumination with DFID Indoor Positioning	2017	Internet of things; LED; REST; RFID; Smart building; Web of things; Web services	Conference Paper	√	
Sun Y., Wu T.-Y., Li X., Guizani M.	A Rule Verification System for Smart Buildings	2017	anomaly detection; knowledge-based; rule conflict; rule verification; smart building; Wireless sensor-actuator networks	Article	√	
Couloumb D., El Kaed C., Garg A., Healey C., Healey J., Sheehan S.	Energy efficiency driven by a storage model and analytics on a multi-system semantic integration	2017	Energy Efficiency; Energy Storage Model; IoT; Ontology; Semantic; Smart Building	Conference Paper	√	√
González-Vidal A., Ramallo-González A.P., Terroso-Sáenz F., Skarmeta A.	Data driven modeling for energy consumption prediction in smart buildings	2017	black-box models; data analytics; data-driven models; grey-box models; smart buildings	Conference Paper	√	
Das R.B., Bozdog N.V., Bal H.	Cowbird: A Flexible Cloud-Based Framework for Combining Smartphone Sensors and IoT	2017	Context aware computing; Internet of Things; Mobile cloud computing models; Mobile phone sensing	Conference Paper		√
Francis J., Oltramari A., Munir S., Shelton C., Rowe A.	Poster abstract: Context intelligence in pervasive environments	2017	Ontologies; Rules Based Engines; Semantic Sensor Networks	Conference Paper		
Ahvar S., Santos G., Tamani N., Istasse B., Praca I., Brun P.-E., Ghamri Y., Crespi N.	Ontology-based model for trusted critical site supervision in FUSE-IT	2017		Conference Paper	√	√
Moreno M.V., Terroso-Saenz F., Gonzalez-Vidal A., Valdes-Vela	Applicability of Big Data Techniques to Smart Cities Deployments	2017	Big data; Internet of Things (IOT); predictive models; smart city; transit-card mining	Article	√	

M., Skarmeta A.F., Zamora M.A., Chang V.						
Koh J., Ray S., Hodges J.	Information Mediator for Demand Response in Electrical Grids and Buildings	2017	IoT; Semantic Interoperability; Semantic Mediation; Smart Building; Smart Grid	Conference Paper		√
Xu W., Gao B., Ahmed M., Duan M., Wang B., Mohamad S., Bermak A., Lee Y.-K.	A wafer-level encapsulated CMOS MEMS thermoresistive calorimetric flow sensor with integrated packaging design	2017		Conference Paper	√	
Alippi C., Ntalampiras S., Roveri M.	Model-Free Fault Detection and Isolation in Large-Scale Cyber-Physical Systems	2017	Change detection algorithms; clustering methods; cyber-physical systems; hidden Markov models	Article		
Bashir M.R., Gill A.Q.	Towards an IoT big data analytics framework: Smart buildings systems	2017	Apache flume; Apache spark; Big data; Cloudera; Digital-physical ecosystems; IoT; Real time data analytics; Smart building	Conference Paper	√	√
Gyrard A., Patel P., Datta S.K., Ali M.I.	Semantic web meets internet of things and web of things	2017	Data Interoperability; Internet of Things (IoT); Ontologies; Semantic Web of Things (SWoT); Web of Things (WoT)	Conference Paper		
Mock R., Lopez L., Zipper C., Schönenberger M.	Resilience assessment of internet of things: A case study on smart buildings	2017		Conference Paper		
Patti E., Mollame A., Erba D., Dalmasso D., Osello A., Macii E., Acquaviva A.	Information Modeling for Virtual and Augmented Reality	2017	augmented reality; BIM; building management; distributed systems; Internet of Things; middleware; pervasive computing; smart building; virtual reality	Article	√	
Mihailescu R.-C., Persson J., Davidsson P., Eklund U.	Towards collaborative sensing using dynamic intelligent virtual sensors	2017		Article		
Spencer B., Al-Obeidat F., Alfandi O.	Selecting Sensors when Forecasting Temperature in Smart Buildings	2017	Energy Efficiency; Feature Selection; Home Sensor Network; Internet of Things; Model Predictive Control; Temperature Forecasting	Conference Paper	√	
Abate A.	Verification of networks of smart energy systems over the cloud	2017	(Quantitative) probabilistic verification; Aggregations of large populations; Autonomy; Bisimulations; Blackouts; Correct-by design synthesis; Cyber-physical systems; Distributed control; Electricity demand-response; Energy and power networks; Feedback controllers; Games; Hybrid models; Internet of things; Model learning; Nondeterminism; Ormal abstractions; Partial observations; Photovoltaic panels; Policy and strategy synthesis; Real-time systems; Safety and performance; Security; Smart buildings and smart grids; Statistical verification; Stochastic processes; Systems of systems; Thermostatically controlled loads	Conference Paper		
Saralegui U., Antón M.Á., Ordieres-Meré J.	Taking advantage of an existing indoor climate monitorization for measuring occupancy	2017	Climate sensors; Domestic occupancy; Health monitoring; Internet of things; Machine learning; Pattern analysis; Smart buildings	Article	√	√
Cooper P.B., Maraslis K., Tryfonas T., Oikonomou G.	An intelligent hot-desking model harnessing the power of occupancy sensing data	2017	Hotdesking; Intelligent buildings; Office buildings; Office management; Productivity; Smart buildings	Article	√	
Pacheco J., Hariri S.	IoT security framework for smart cyber infrastructures	2016	Attack vector; Cyber security; Fog computing; Internet of things; Smart infrastructures; Threat model	Conference Paper	√	√
Bogdan P., Pajic M., Pande P.P., Raghunathan V.	Making the Internet-of-Things a reality: From smart models, sensing and actuation to energy-efficient architectures	2016	Autonomy; Compact yet accurate models; Internet-of-things; Manycore; Network control; Networks-on-chip	Conference Paper		√

Burkert M., Esdohr J., Krumm H.	A small-scale model house evaluation platform for building automation systems	2016		Conference Paper	√	
Al-Ali A.R.	Internet of Things Role in the Renewable Energy Resources	2016	6LoWPAN; internnet of things; smart cities; Smart energy; smart grid	Conference Paper	√	
Bandara S., Yashiro T., Koshizuka N., Sakamura K.	Access control framework for API-enabled devices in smart buildings	2016	access control; authentication; device API; smart buildings	Conference Paper	√	√
Bogdan P., Pajic M., Pande P.P., Raghunathan V.	Making the internet-of-Things a reality: From smart models, sensing and actuation to energy-efficient architectures	2016	Autonomy; Compact Yet Accurate Models; Internet-of-Things; Manycore; Network Control; Networks-On-Chip	Conference Paper		√
Wang H.-R., Hsu C.-Y., Jian T.-R., Chen A.-Y.	On the design and implementation of an innovative smart building platform	2016	IoT; LAQI; PMV; Self-configure; smart building	Conference Paper	√	
Suthokumar G., Tharmakulasingam J., Johnnirajh A., Subendran P., Dias D.	Smart building - Towards the insight remotely	2016	Activity Detection; Energy usage; MQTT; PIR; Ubiquitous Sensors; WSN	Conference Paper	√	
Li X., Duraisamy K., Bogdan P., Majumder T., Pande P.P.	Network-on-Chip-Enabled Multicore Platforms for Parallel Model Predictive Control	2016	Cognitive architectures; model predictive control (MPC); networks-on-chip (NoCs); nonlinear control; wireless NoC (WiNoC)	Article	√	
Pan Z., Pacheco J., Hariri S.	Anomaly behavior analysis for building automation systems	2016	Anomaly Behavior Analysis; Building Automation System; Fog computing; Internet of Things; Intrusion Detection System	Conference Paper	√	
Lin K., Chen M., Deng J., Hassan M.M., Fortino G.	Enhanced Fingerprinting and Trajectory Prediction for IoT Localization in Smart Buildings	2016	Fingerprint; Internet of Things (IoT); Markov chain; mobile positioning; smart building	Article	√	
Conti M., Nati M., Spolaor R., Rotundo E.	Mind the plug! Laptop-user recognition through power consumption	2016	Energy consumption; Internet of Things; Intrusion detection; Machine learning; Smart building; Smart meter; User identification	Conference Paper	√	√
Moreno M.V., Dufour L., Skarmeta A.F., Jara A.J., Genoud D., Ladevie B., Bezian J.-J.	Big data: the key to energy efficiency in smart buildings	2016	Big data; Energy efficiency; Internet of things; Smart buildings	Article	√	
Shin E.-J., Ghosh D., Gupta A., Singh G.P., Joshi N., Kobsa A.	Message of interest: A framework of location-aware messaging for an indoor environment	2016	indoor positioning; Internet of Things; location based messaging; smart buildings	Conference Paper	√	
Zhang B., Baillieul J.	Control and communication protocols based on packetized direct load control in smart building microgrids	2016	Direct load control; electricity market; energy procurement; energy quantization; microgrid	Article	√	
Jemal A., Ktait H., Ben Halima R., Jmaiel M.	OoDAAS: Ontology-driven analysis for self-adaptive ambient systems	2016	Analysis; Ontology; Reasoning; Semantic sensor network; Smart building	Conference Paper	√	
Krishna M.B., Verma A.	A framework of smart homes connected devices using Internet of Things	2016	Energy efficient smart buildings; Multi-device smart home; secure smart home; Smart Home; smart locks; smart office	Conference Paper	√	√
Gusmanov K., Khanda K., Salikhov D., Mazzara M., Mavridis N.	Jolie Coog buildings: Internet of things for smart building infrastructure supporting concurrent apps utilizing distibuted microservices	2016	Cloud Computing; Distributed Architectures Concurrent Applications; Energy Management; Internet of Things; Jolie; Microservices; Smart Buildings	Conference Paper	√	
Beebe J.	Integration of lift systems into the internet of things and the need for an open standard information model	2016	Information model; Internet of Things; Open standards; Semantic interoperability; Smart lift/elevator services	Conference Paper	√	
Hicks L., Hedley Y.-L., Elshaw M., Altahhan A., Palade V.	Smartphone based human activity and postural transition classification with deep stacked autoencoder networks	2016	Artificial neural networks; Deep learning; Human activity recognition; Machine learning	Conference Paper		
McCreary F., Zafiroglu A., Patterson H.	The contextual complexity of privacy in smart homes and smart buildings	2016	Contextual integrity; Design; Experience framework; Internet of things; Privacy; Social context; User research; UX strategy	Conference Paper	√	

Koo B., Kong S., Cho H., Choi L.	WACA: WearAble device based home control assistant framework	2016	Device control; Smart building; Smart home; Smart watch; Wearable; Wearable device	Conference Paper	√	
Carrillo E., Benitez V., Mendoza C., Pacheco J.	IoT framework for smart buildings with cloud computing	2015	Cloud Computing; Internet of Things; Smart Buildings; Smart City	Conference Paper	√	√
Bellagente P., Ferrari P., Flammini A., Rinaldi S.	Adopting IoT framework for Energy Management of Smart Building: A real test-case	2015	Energy Management System; Internet of Things; Smart Building; Smart Grid; System interoperability	Conference Paper	√	√
Isikdag U.	BIM and IoT: A synopsis from GIS perspective	2015	BIM; GIS; Integration; IoT; Sensors	Conference Paper	√	
Lilis G., Conus G., Kayal M.	A distributed, event-driven building management platform on web technologies	2015	Building Management; Cloud Computing; Events; IoT; Message Queues; Publish Subscribe; Smart Building; Smart Grid	Conference Paper	√	
Cherifi N., Grimaud G., Vantroys T., Boe A.	Energy Consumption of Networked Embedded Systems	2015	Embedded System; Embedded Web Server; Energy Consumption; Internet of Things; Power Measurement	Conference Paper		
Moreno M.V., Skarmeta A.F., Dufour L., Genoud D., Jara A.J.	Exploiting IoT-based sensed data in smart buildings to model its energy consumption	2015	Big Data; Data Modelling; Energy Efficiency; Internet of Things; Smart Buildings	Conference Paper	√	
Tepić S., Pejić P., Domšić J., Mihaldinec H., Džapo H.	IBMS - Intelligent Building Management System Framework	2015	intelligent building management; Internet-of-Things; sensor networks; smart sensors and actuators	Conference Paper	√	
Ghayvat H., Mukhopadhyay S., Gui X., Suryadevara N.	WSN- and IOT-based smart homes and their extension to smart buildings	2015	Attenuation loss; Behavioral detection; Interference; IOTs; SNR (signal to noise ratio); Wellness function	Article	√	
Hernández-Ramos J.L., Moreno M.V., Bernabé J.B., Carrillo D.G., Skarmeta A.F.	SAFIR: Secure access framework for IoT-enabled services on smart buildings	2015	Internet of things; Security framework; Smart buildings; User-centric services	Conference Paper	√	√
Moreno M.V., Skarmeta A.F., Venturi A., Schmidt M., Schuelke A.	Context sensitive indoor temperature forecast for energy efficient operation of smart buildings	2015	Data Modeling; Smart Buildings; Thermal Comfort	Conference Paper	√	
Moreno M.V., Zamora M.A., Skarmeta A.F.	An IoT based framework for user-centric smart building services	2015	Context awareness; Energy efficiency; Indoor positioning; Smart buildings; User-centric	Article	√	
Akkaya K., Guvenc I., Aygun R., Pala N., Kadri A.	IoT-based occupancy monitoring techniques for energy-efficient smart buildings	2015	Big data; Data fusion; Data mining; Energy efficiency; Hidden Markov model (HMM); HVAC; Localization; Markov chain; Occupancy monitoring; Position estimation; Positioning; WiFi; Wireless location estimation; WLAN	Conference Paper	√	
Piscitello A., Paduano F., Nacci A.A., Noferi D., Santambrogio M.D., Sciuto D.	Danger-system: Exploring new ways to manage occupants safety in smart building	2015		Conference Paper	√	
Ridi A., Gisler C., Hennebert J.	Processing smart plug signals using machine learning	2015	Appliance identification; Intrusive load monitoring (ILM); Signal length impact	Conference Paper	√	