Developing a Cost Framework for Smart Building Adoption

Andrew D. Steele

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Carrie Sturts Dossick

Hyun Woo “Chris” Lee

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Abstract

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Andrew D. Steele

Chair of the Supervisory Committee:

Carrie Sturts Dossick

Department of Construction Management

This research explores the various costs associated with smart building adoption, with particular focus on Internet of Things (IoT) enabled building automation systems (BAS). Through a comprehensive literature review and qualitative interviews with industry professionals, the research identifies and validates cost categories from various perspectives, including across the building lifecycle. Three cost frameworks are presented, each offering a unique underlying structure: categorization by building phase, by nature and scope, and by timing and visibility. The final integrated framework presents costs in terms of 1) upfront and visible, 2) hidden and long-term, 3) lifecycle and strategic, and 4) organizational and societal considerations. Central cost themes visible in all the developed frameworks include sensor deployment, data management, cybersecurity, and organizational efficiency. The research addresses gaps in the existing literature, such as the lack of comprehensive cost frameworks. Through an expressed commitment to conducting research in academic and industry partnership, this research develops cost frameworks to be leveraged by industry and researchers alike in the consideration of smart building adoption efforts. This research implements a robust methodology, grounded in literature and sound research practice, to overcome various limitations of this research such as limited sample size and the continually evolving nature of smart building technologies. Further research is encouraged to expand upon the results of these findings to further enhance understanding of BAS cost and develop the quantifiable aspects of smart building adoption and their associated business cases.

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List of Abbreviations

BAS - Building Automation Systems

IoT - Internet of Things

EPG - Energy Performance Gaps

TCO - Total Cost of Ownership

IRB - Institutional Review Board

BIM - Building Information Modeling

DCIM - Data Center Infrastructure Management

BACnet - Building Automation and Control Networks

SBTs - Smart Building Technologies

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Chapter 1: Introduction

This chapter serves as an introduction to Building Automation Systems (BAS) within the context of the Internet of Things (IoT). It also highlights BAS as the keystone element of smart buildings, playing a key role in optimizing operational costs and enhancing environmental sustainability. Although existing research extensively covers the benefits of smart building adoption, details related to the costs of these systems across the building lifecycle are emerging and relatively immature in the literature. The researcher will provide an overview of the research gap, noting that aspects of the existing literature are nascent and that comprehensive cost frameworks are not abundant, thereby introducing unnecessary complexity in smart building adoption. Furthermore, this chapter sets forth a case for this research's relevancy by situating the research objective and goals within their proper technological context and overviewing a path to delivering a better understanding of the costs of smart building adoption and associated implications.

1.1 Background

Building automation systems (BAS), underpinned by Internet of Things (IoT) technology, are becoming increasingly prevalent as they promise to provide a range of benefits, including improved energy efficiency, increased occupant comfort, and reduced operating costs (Lawal & Rafsanjani, 2022). The IoT enables connectivity of everyday 'things' of all types, such as sensors, actuators, and devices, which are often foundational to BAS, within facilities. These components, which traditionally had no internet connectivity, are now interconnected. This interconnectivity brings new levels of data, control, and opportunities for achieving various objectives, such as enhanced operational and sustainability outcomes, to building owners and operators. Green building efforts, often originate from the motivation to reduce building-related energy usage, which accounts for 40% of global energy consumption (Inayat & Raza, 2019).

The literature focuses prevalently on the benefits of these BAS systems and how to make them more efficient. For example, several articles have focused on energy efficiency in smart buildings. Moreno et al. (2014) investigated energy efficiency in BAS and found that IoT technologies allow for real-time visibility of energy consumption and, in turn, immediate optimization of those resources. Iqbal et al. (2018) developed a generic IoT architecture for optimizing electrical energy consumption in smart homes and demonstrated the critical role IoT plays in meeting energy efficiency goals. Arshad et al. (2017) examined green IoT and energy-saving practices and their projections into the future, and identified several green technologies, including energy-efficient devices, energy harvesting, and smart power. Smart power leverages the power of machine learning and Artificial Intelligence (AI) in the development of power distribution. Tushar et al. (2018) observed that IoT can both collect and monitor large datasets, providing opportunities to optimize energy use and reduce costs. These studies suggest that building automation can lead to significant energy savings and reduced operating costs. Moreover, these studies consistently reference the collection of data, creating the opportunity for real time data-driven responses and real-time operational benefits. The overarching theme throughout the literature is that smart building technologies provide the platform for enhanced visibility of energy utilization and real-time reductions when energy is not required, thereby reducing waste.

However, it is also crucial to explore how one can understand the cost of BAS adoption, which is fundamental to business case realization. Understanding cost is an especially important consideration when evaluating of business cases. Appel-Meulenbroek & Danivska (2023) found that “appraising relevant costs” is a consistent theme across a broad study of over 50 research investigations into business case analysis.

There exist uncertainties in deploying BAS, including Energy Performance Gaps (EPG), or lower than expected energy performance when compared to BAS design. EPG refers to the difference between predicted and actual building performance (De Wilde, 2014). These gaps are often significant, and can be between 2 and 5 times the predicted consumption, as energy performance models fail to consider all building energy use appropriately (Menezes et al., 2012). IoT enabled technologies seek to correct this gap by providing real-time monitoring, reporting, and adjustment of BAS; this, in turn, allows for enhanced analysis of energy consumption data and enables the BAS to optimize building efficiency in real-time. EPGs are introduced into buildings by means of sub-optimal implementation or management of BAS; furthermore, the efficacy of these smart building systems relies on proper planning, commissioning, and deployment of systems and can be hindered by adverse, or unoptimized, occupant behavior, such as adjusting temperature setpoints outside recommended ranges or leaving lights and equipment on (Qiang et al., 2023). As BAS monitor building conditions and adjust appropriate building systems in real time, smart buildings can reduce the impact of unoptimized behaviors by limiting their collective impact and align operational practice with energy efficiency and sustainability objectives.

Additionally, the risks on the privacy and security front bring cost implications. IoT devices, and their associated cloud-based platforms connected to BAS, introduce questions regarding data privacy and cybersecurity. Smart buildings, by their very nature, produce, track, and manage large datasets with detailed and sensitive information that can be traced to both individual and organizational behavior. This data carries implications for the maintenance of privacy as well as legal and regulatory compliance challenges, as this information is valuable and subject to leaks and cyberattacks (Boyes et al., 2014). As privacy is breached, cost implications, such as legal liability emerge. Cybersecurity breaches of BAS data drive costs resulting from operational disruption, direct financial losses, and can even impose safety risks (Mayo & Snider, 2016). Therefore, it is paramount that building owners understand these risks and deploy systems and practices to secure their operations. Security breaches and the deployment of various preventative measures bring risk and associated cost.

As discussed, deploying IoT technology within BAS frameworks brings inherent privacy and security concerns. The Target Corporation, for example, experienced the fallout that this can impose when in 2013, cybercriminals exploited the remote access capabilities of IoT enabled BAS through a third-party HVAC vendor's compromised credentials. This case highlights the need to implement robust security protocols with consideration for adequate encryption and timely alignment with security updates. As discussed, BAS collect and transmit scores of data and connect to other network systems. If not properly secured, as in this case, the information and access can result in substantive losses. Millions of credit card and debit card numbers were compromised, along with the personal records of 70 million people. Due to the obscure nature of the cybercriminals' identity, efforts to pursue and obtain recourse by Target were limited (Shu et al., 2017). Costs of smart building adoption materialize in the need to adequately secure these systems. In the event of catastrophic failure, the consequences include costs of legal damages and degradation of brand value.

In addition to understanding the gaps in proposed BAS performance and inherent security concerns, building owners must also understand and acknowledge the associated costs (such as implementation, maintenance, etc.) and risks in order to evaluate the feasibility of adoption. This process includes inventorying both initial and ongoing expenses, which are foundational for sound business planning and competent facility management.

As discussed, building automation (BAS) exists within the framework of the Internet of Things (IoT). IoT is the connection of everyday things to the internet.

> Internet of Things (IoT) is a concept that envisages the connectivity between daily life things by using different types of sensors … that work collaboratively to sense, collect, and transmit important information from their surroundings onto the Internet. IoT is a term that envisions connectivity between physical and digital world by using felicitous technologies. (Arshad et al., 2017)

Optimized and precise facility management and control are obtained through the integrated capability of IoT enhanced BAS. This connectivity within facilities is accelerating and expansive (Siccardi & Villa, 2023). It is especially relevant to understand IoT's impact within the built environment because people spend more than 80% of their time inside buildings (Lv et al., 2019). When BAS is combined with IoT technologies, it optimizes building performance, enhances sustainability, reduces operating costs, and provides opportunities for real-time data driven facilities management (Burak Gunay et al., 2019). This highlights the need to understand the costs of these systems, both upfront and across the building lifecycle. When building owners and operators understand operational costs, such as the management of building automation systems, they are better equipped to drive value and efficiency for their organization.

Real-time facilities management is achieved through real-time data collection of facility conditions such as occupant load, temperature and humidity, and immediate and seamless optimized adjustment of BAS given the building conditions. As this data is collected and fed into systems, they can analyze and present this information to building operators for important operational improvements, such as understanding energy consumption trends and the immediate correction of possible anomalies. The collection and analysis of this occupant feedback allows for an indoor environment to be optimized for higher occupant satisfaction, productivity, and reduced absenteeism, all improving operational efficiency. All of these benefits of real-time facilities management come with cost of implementation, and these cost must be understood evaluate the feasibility and value proposition of smart building adoption (Ergen et al., 2021).

Understanding cost is fundamental to driving smart business decisions, as the availability of quality cost data drives organizational efficiency (Rascolean & Rakos, 2020). Despite the importance of understanding business (and subsequently facilities-related) costs, there are many challenges in accessing and tracking building automation data. Sensing technologies associated with occupant tracking for real-time building system response tend to be spread across multiple unintegrated platforms, such as lighting sensors and HVAC controls (Burak Gunay et al., 2019). These challenges complicate cost identification and tracking, which creates data silos that hinder an integrated view of costs across operations. Without a comprehensive data management approach, it becomes difficult to track costs to individual systems or identify methods to modify operations for cost efficiency. These observations indicate that the scattered nature of these datasets complicates cost identification and tracking.

The siloed and unintegrated nature of BAS datasets complicates efforts to understand and track costs (Burak Gunay et al., 2019). This lack of integrated data can subsequently hinder the business-case analysis required for BAS adoption (Rincon et al., 2017). Rascolean & Sorina Rakos (2020) demonstrate that quality cost data is required to inform business investment decisions. However, the lack of comprehensive cost data, or even an understanding of those categories that drive BAS cost, can impair even the best attempts at total cost of ownership evaluations, resulting in unexpected costs and over-extended budgets. These challenges highlight the need to overcome data access obstacles when understanding BAS cost, a foundational element for smart building adoption. Advocating for system interoperability and the standardization of data protocols will allow cost data to be aggregated across platforms and, therefore aid in understanding cost (Balaji et al., 2018). The development of lifecycle focused cost-frameworks that consider BAS cost (such as the framework produced by this research) can help organizations understand and optimize resource allocation, thereby becoming more efficient (Wong et al., 2005).

Although the literature provides extensive context regarding the benefits, relevancy, and operational efficiencies of BAS, there is a noticeable gap in the comprehensive categorization and associated understanding of cost. A detailed analysis of cost elements during design, deployment, and operations has yet to mature in the literature. Furthermore, as these BAS become increasingly intelligent and connected to the internet (IoT), new costs materialize. These IoT costs are only beginning to be understood and are not extensively documented in the literature. Understanding the lifecycle costs of BAS has some basis in the literature; Wong et al., (2005) noted that smart buildings are more expensive to construct (8%) and operate (5%) than conventional buildings, but a detailed analysis of these cost drivers or evolution of the cost drivers over the last several years is not yet well documented. Additionally, various other factors, such as organizational structure, impact efficiencies, and therefore, ultimately impact cost during BAS adoption. Abuimara et al. (2021) highlight that the successful adoption of smart building management systems often hinges on both technical and non-technical elements, including organizational challenges, which is a key and often overlooked consideration.

To that end, this research proposes to create a comprehensive framework to help building owners and operators categorize these BAS costs within the building lifecycle (planning, design, construction, operations, disposition). These areas include emerging elements as identified in the literature such as sensor deployment, management of new large datasets, cloud and fog computing, software development and support, and human-facing systems and dashboards (Jia et al., 2019). Due to rapid technological advancements of BAS, these costs are considered emerging as these smart devices are novel and increasingly integrated into smart buildings. As the number of these sensors, and the resulting complexity in managing of large datasets also continues to grow, facilities operations become more complex and cost intensive (Tang et al., 2019). These datasets drive new costs related to the storage and analysis of information in the form of cloud and fog computing, and additionally drive overall costs related to the infrastructure investment required to support these services (Chong et al., 2014). After this data is analyzed and integrated into facility management and maintenance systems, additional services are required develop and deploy user interfaces in the form of software, hardware, and maintenance costs (Jia et al., 2019). In developing this comprehensive framework, which categorizes cost elements from across the building lifecycle, this research aims to build a tool for building owners, operators, and researchers to better understand the sources of cost implications in the deployment of these smart systems. This framework can assist in the decision-making process of smart building adoption as it can serve to provide a more informed cost understanding related to these smart building systems.

It is important to understand that, despite the broad implementation and use of BAS / IoT technologies, there remains a significant gap in the literature regarding the understanding of these costs. BAS drives costs during each phase of the building lifecycle; therefore, understanding cost categories should be considered over the entire building lifecycle in order to develop comprehensive cost data that is expedient for decision making.

This lack of clarity makes it difficult for building owners and operators to plan, gain appropriate approvals, and budget for building automation projects. The body of research related to IoT and the built environment extensively details the benefits of building automation, with little information related to costs. In order to conduct a robust cost-benefit analysis both cost and benefit information must be understood (Rincon et al., 2017). Additionally, this absence of comprehensive and cost categorical data hinders research efforts aimed at improving the cost-effectiveness of these systems.

In order to address this gap in the literature, this research seeks to identify and validate the various cost categories of building automation throughout the building lifecycle; during all phases of adoption, BAS drives cost. This research will chronicle and organize these costs into an organized framework. This research aims to complement existing literature by providing cost categorization relevant to BAS, and subsequently smart building adoption. It will deliver a comprehensive framework of the various cost categories associated with building automation systems, which will be organized according to the different phases of the building lifecycle. Specifically, this research examines the cost categories associated with one or more of the various stages of planning, implementing, and operating BAS within the building lifecycle.

By developing a comprehensive framework of the cost categories associated with building automation systems, this research will contribute to a better understanding of the financial implications of implementing these systems. This knowledge will be valuable for building owners and operators who are considering the implementation of building automation systems, as well as for researchers who are studying the cost-effectiveness of these systems.

In summary, BAS, often underpinned by IoT, offer many benefits to building owners, operators, and occupants, including reduced operating costs and optimized comfort; however, understanding the costs to deploy and maintain these systems is critical for adoption. Additionally, challenges around Energy Performance Gaps (EPG), privacy/security, and the integration of siloed data must be addressed. As the adoption of technology in buildings becomes increasingly prevalent, and considering that buildings account for such a large portion of global energy consumption (40%), understanding the cost of these smart building systems becomes critical to efficient business operations. Presently, much of the literature is focused on the benefits of BAS with little consideration given to cost categorization and understanding. As such, the objective proposed by this research is timely considering the landscape: to create a comprehensive framework for categorizing BAS costs throughout the building lifecycle. This research brings value by providing an inventory of elements for owners to consider in smart building adoption and will serve as a basis for researchers in the built environment studying the cost effectiveness of BAS and smart building technologies.

1.2 Importance and Implications of Building Automation Systems (BAS)

BAS and their interconnected IoT technologies serve as the keystone element in transforming traditional facilities into smart buildings. These systems provide scores of valuable and actionable data for enhanced facilities management by connecting billions of devices. These devices sense and then can respond for more efficient operations (Shafique et al., 2020; Spachos et al., 2018). This section will further substantiate the relevancy of understanding BAS systems and their associated cost, as this understanding is fundamental to BAS adoption. This exploration includes understanding: 1) BAS' potential for improving occupant health and well-being; 2) how organizational efficiency and decision-making impact the deployment of these systems; and 3) some of the challenges and future directions in the adoption of BAS.

Smart Building BAS improve the occupant experience indoors. Park & Rhee (2018) highlight how the integration of BAS and IoT technologies aids in real-time occupant localization and the optimization of HVAC systems based on the unique thermal-emitting profiles of individual occupants. Additionally, Verma et al. (2019) provide an overview of the capabilities of IoT-enabled BAS to both monitor and maintain ideal levels of air ventilation as required for ideal occupant health and productivity.

BAS has the potential to drive value by providing data for improved facilities management decision making across the building lifecycle, although organizational efficiency challenges still remain. There is an accelerating integration of BAS and IoT technologies, creating a powerful and often under-utilized opportunity to improve efficiencies during several stages of the building lifecycle, including construction and operations (Tang et al., 2019). Operationally, efficiencies are achieved through the use of BAS and IoT technologies, such as providing real-time monitoring and control of buildings in response to existing or potential issues that the building may encounter, which minimizes disruption and ensures optimal performance (Lawal & Rafsanjani, 2022). Organizational structures that align the roles and responsibilities of the facilities management team with the capabilities of the BAS help realize the true potential of smart building systems. Only when individuals and teams have access to data, systems, tools, and the ability to implement changes within their area of expertise are operations optimized. BAS and smart building technologies should not be viewed as solutions unto themselves, but rather as part of a harmonious system integrating technology and people. These operational efficiencies are only fully realized when deployed within an optimized organizational structure that considers of both the needs of both the technology and the people (Abuimara et al., 2021).

Some of the challenges and future directions in BAS and IoT technology are similar to the suboptimized data interoperability seen with Building Information Modeling (BIM) and IoT, such as the need for standardized data protocols (Tang et al., 2019). An integrated solution that connects BIM to IoT may additionally connect BAS with IoT. Emerging technologies, such as artificial intelligence and machine learning, hold some promise to help resolve these persistent data challenges. Further research efforts to develop and present new ways of categorizing and understanding cost, as provided in this research, will assist in the adoption and efficiency of smart building systems.

In conclusion, the data, and the ability to act on it for optimized facilities operations, including reduced operations costs and improved occupant comfort, make smart building technology and systems highly relevant. Businesses will only be able to fully realize smart building potential to the extent that their organizational structures are optimized. Organizational and data interoperability challenges remain. However, this research takes an important step forward in developing a clearer understanding of BAS and smart building cost, a key consideration in business case analysis that is foundational for system adoption.

1.3 Research Objectives, Scope, and Limitations

The primary objective of this research is to provide a basis for better understanding the cost of smart building adoption. To that end, this research develops a cost framework chronicling these costs. Other subobjectives will also be identified and discussed. The scope of this research encompasses those costs that materialize during all phases of smart building adoption across the building lifecycle. Lastly, the limitations of this research will be detailed. The researcher has considered several limiting factors and will discuss how they are addressed and mitigated according to good research practice, and how this research remains relevant despite these limitations.

1.3.1 Research Objectives

The primary objective of this research is to develop a comprehensive framework of the various cost categories associated with smart building adoption (i.e. building automation systems - BAS) throughout the building lifecycle. The research also includes several subobjectives, including: 1) identifying and validating smart building costs across the building lifecycle, including during the planning, design, implementation, operational, and disposition phases; 2) contributing to the emerging literature on the financial implications of smart building adoption; 3) providing a valuable collection of relevant literature and interview data relevant to building owners, facility operators, and researchers considering the implications of, or researching, the cost-effectiveness of BAS; and 4) engaging industry professionals working in this field and helping to foster a collaborative environment between industry and academia, which is foundational for the success of future research in this emerging field.

1.3.2 Research Scope

The scope of this research is focused on cost categories associated with BAS, smart buildings, and other associated IoT-enabled building technologies across the building lifecycle. This includes the phases of planning, design, implementation, operations, and disposition phases. These costs include, but are not limited to, emerging cost themes as identified in the literature, such as: 1) sensor deployment (Jia et al., 2019); 2) the management of large and complex datasets (Burak Gunay et al., 2019); 3) cloud and fog computing (Chong et al., 2014); 4) software development and associated support (Jia et al., 2019); 5) human-facing systems and associated dashboards (Jia et al., 2019); and 6) the impact of organizational structures on the efficiency of smart building adoption (Abuimara et al., 2021).

This research will also look for and develop cost themes, first identified in literature review, by industry professional qualitative interviews. The initial literature review informed the development of preliminary cost framework and associated narrative synthesis. The execution of semi structured qualitative interviews provides a unique enhancement to this research design in two primary ways: 1) by providing a means for corroboration of data identified in literature via thematic analysis and 2) by identifying emerging themes not yet mature in the literature. More detailed discussion in regard to the researcher’s methods are explored in Chapter 4.

1.3.3 Research Limitations

BAS, especially within the context of IoT, is an emerging field of technology and research. As such, comprehensive and categorial cost data is still immature in the literature (Rincon et al., 2017). However, despite the limitations of the literature, there are many valuable studies that help to better understand this topic and inform the research architecture of this study. To strengthen the quality of this research, themes within the literature have been identified, studied, and reserved for further exploration through research methods beyond the literature review, such as interviews with industry professionals. The immature nature of the literature drives this research to explore the topic at hand through semi-structured interviews. The themes identified in both the literature and the interviews are systematically corroborated to identify consistent themes, allowing the researcher to reexamine the literature in a new light. Although this iterative process alleviates some of the research limitations, it does not remove them entirely. The limitations of the literature are primarily mitigated through an iterative research approach and by acknowledging that themes identified in the research need to be revisited periodically as technological advancements continue to shape this shifting landscape.

In addition to developing a research architecture founded on themes emerging from literature, this research expands on the themes through the collection and analysis of primary data in the form of semi-structured expert interviews. It is important to note that interviews come with their own limitations. The following overview highlights some of the most prominent limitations of interviewing faced by this research. Semi-structured interviews inherently have limitations that must be considered and accounted for, in that 1) they are resource-intensive to organize, conduct, and analyze; 2) they require sufficient sample sizes in order to reach a level of relevance for thematic data saturation; and 3) they must be organized and executed in such a manner that enhances the credibility of qualitative research, including considerations for researcher reflexivity and methods to reduce researcher bias. Despite these limitations of the structured interview, this research method was chosen as it was accessible to the researcher, allowed for validation of themes from literature and is a primary data source, more closely adjacent to industry practice, and as such more responsive in reflecting emerging industry trends.

The researcher acknowledges the following limitations on the collection of interview data as noted. This section explores the nature of these limitations and the efforts employed by the researcher to reduce their impact.

1. **Resource-intensive Nature:** By their very nature, semi-structured interviews require extensive consideration for various logistics, including 1) obtaining university Institutional Review Board (IRB) approval or exemption; 2) deploying an ethical study as required by good research practice and mandated by IRB oversight to protect both the researcher and the subjects, with substantial consideration given to the subjects' right to privacy; 3) selecting appropriate candidates with relevant levels of industry experience; 4) screening, soliciting, and obtaining schedule commitments from interview subjects; 5) transcribing, analyzing, and validating data for proper data relevancy and subsequent inclusion. These themes are documented in the literature as part of the interview process and described as, "a balance of relationship and rigour" (DeJonckheere & Vaughn, 2019). DeJonckheere & Vaughn provide some considerations that were employed by the researcher to overcome the limitations listed above, including developing well thought-out research guides and interview tools, actively listening to respondents, and asking probing questions to further develop responses as relevant to the subject at hand.

2. **Respondent Sample Size Sufficient for Thematic Data Saturation:** In the literature, there is much discussion on the number of qualitative interview respondents required for thematic saturation of the data. Data saturation, at times referred to as the "qualitative research gold standard," is when the themes emerging from the interview results are so universal to the given population that no new themes materialize with further interviews,

and those themes already identified are heavily validated (Hancock et al., 2016). As the sample size of respondents in this research trends towards a smaller data set of 7 total respondents, literature-supported qualitative methods are utilized by this research to mitigate potential limitations imposed by sample size.

These qualitative methods include deploying a purposive selection of respondents, meaning that the subjects were chosen for their ability to provide richly textured information on the subject matter at hand due to their expertise in the research topic (Vasileiou et al., 2018). Additionally, the method of respondent validation was employed to maximize the validity of the data received. Respondent validation mitigates limitations by ensuring findings are credible by reflecting participants' realities and, therefore, reducing researcher bias; confirming that the researcher accurately understands and interprets the respondents' experiences; allowing respondents to clarify potential misinterpretations or oversights for integration into the data analysis process; and involving participants directly in the research process, fostering a collaborative environment between researcher and respondent (Leedy & Ormrod, 2021).

3. **Role of the researcher, reflexivity, and reducing researcher bias:** Understanding how the researcher understands and thinks about the given research topic fundamentally influences all elements of the research. Researchers bring to the study their unique experiences and personal philosophies. This bias is subject to influencing all study designs across disciplines. If unaccounted for, it can cause the findings to trend in directions or ‘find’ conclusions that align with the researchers’ preconceived assumptions

regarding a topic (Smith & Noble, 2014). The researcher in this study has taken inventory of those experiences and opinions that shaped his understanding of smart building adoption and the associated cost landscape by reflecting on their own experience in the planning, deployment, and management of smart building technologies. However, in the study design and execution of the qualitative interviews, the researcher took great care to allow the data to speak for itself and to observe and collect data from respondents in a neutral and objective manner.

Additionally, the nature of technology-centric cost elements, such as those found within BAS and smart buildings, is still emerging and changing in light of constant innovation (Tushar et al., 2018). Furthermore, the regulatory environment and the associated cost impacts thereof are dynamic (Saridaki & Haugbølle, 2019), limiting the researcher's ability to develop a cost framework that can remain relevant over an extended timeframe. The rapidly evolving nature of the research landscape is inherent to all research, especially research within the technology sector (Chong et al., 2014). As such, the researcher recommends continuous and periodic investigation of the cost categories associated with smart building adoption in order to identify new and emerging cost trends.

In summary, there are key limitations to this research, including the emergent nature of BAS and associated IoT technology and the resulting immature status of BAS costs in the literature; the resource intensive nature of organizing and conducting qualitative semi-structured interviews; the ability to obtain sufficient data for saturation in data collection; and the role of the researcher and associated individual bias, all within a rapidly changing technology and regulatory landscape. These limitations have been identified, and strategies to limit their impact have been discussed, including the use of purposive interview candidate selection, respondent validation, and researcher reflexivity and its associated commitment to neutrality. Understanding and presenting literature-based strategies for mitigating their impact on the research increase the overall quality, credibility, and relevance of the research findings.

1.4 Thesis Overview and Structure

Chapter 1: Introduction – Introduces the research topic, background, objectives, scope, and limitations.

Chapter 2: Preliminary Literature Review – Provides an overview of the state of existing literature sufficient to establish a basis for the research question.

Chapter 3: Research Question – Provides the research question, the process of its formation, and limitations of the research.

Chapter 4: Methodology – Provides an overview of the research methodology, including research design, philosophical underpinnings, data collection and analysis, and strategies for enhancing credibility and trustworthiness.

Chapter 5: Results: Detailed Literature Review – Presents the results of the detailed literature review and a discussion of the interview findings.

Chapter 6: Results: Interviews – Presents the results of the industry-focused interviews.

Chapter 7: Discussion – Integrates and discusses the findings from the literature review and interviews, describes the researchers process, and lays forth the implications and contributions of the research.

Chapter 8: Conclusion – Summarizes the main research findings, restates the research objectives and contributions, and provides suggestions for areas for future research and application.

In summary, this thesis overview provides a comprehensive structure for exploring the various cost categories associated with Building Automation Systems (BAS) within the context of the Internet of Things (IoT). By executing a rigorous approach that combines a comprehensive literature review and structured interviews with industry professionals, this research will assist in narrowing the gap in cost understanding for smart building adoption in all phases of the building lifecycle. The iterative process of informing the interviews with literature reviews and vice versa substantiates the relevancy of the research findings. The knowledge obtained from these research findings will allow for a greater understanding of cost management, BAS, smart buildings, and construction and facilities management. Ultimately, the comprehensive cost framework provided by this research will provide a basis for better management and business case formation in the future adoption of smart building systems and associated future research.

Chapter 2: Preliminary Literature Review

This preliminary literature review is a key part of this research design as it situates the research question within the broader context of BAS and IoT. This allows for points of departure for foundational to the relevancy of the research question. A substantive and well considered literature review, as conducted here and revisited in depth in Chapter 5, is a precondition for conducting substantive, thorough, and sophisticated research (Boote & Beile, 2005) It is not sufficient for the literature review to be a mere summary of the latest state of the literature, it must also clearly explain how the state of the literature creates a gap in the literature that is worthy of further exploration (Tay, 2020). This research embraces this charge by explaining the expediency of exploring the gap in the literature and the research question, and that building owners, operators, and researchers are able to understand costs more comprehensively as a result of this exploration, facilitating the adoption of smart building technologies.

Key themes from literature covered in this preliminary literature review include how BAS cost is understood and where the existing literature contains gaps, such as the lack of comprehensive cost frameworks considerate of the building lifecycle, emerging cost elements, the impact of human factors, and the need for further research.

2.1 Current Understanding of BAS Cost

In recent years, as building operators deploy IoT in various applications, including mechanical BAS, conventional buildings are transformed into smart, efficient, and secure facilities (Jia et al., 2019). These smart buildings possess new capabilities, including automated building responses in various building systems (HVAC, lighting, security, etc.) to environmental changes resulting in an enhanced occupant experience and precise operator control to optimize energy consumption and operational costs (Tang et al., 2019) (Burak Gunay et al., 2019). Adjusting building controls based on real-time occupant load requires the deployment of sophisticated sensors and systems, which comes at a cost. The promise of more fully understanding the costs related to BAS adoption is motivated in large part by the potential operational cost savings, such as improved energy efficiency, when BAS systems are deployed (Lawal & Rafsanjani, 2022).

The primary inherent costs associated with BAS include those associated with initial investment and ongoing operations. To that end, the design and construction of smart buildings cost more than conventional projects, although they offer numerous benefits. The implementation of BAS on construction projects, or intelligent building design, is documented to cost 8% more during construction and 5% more for services than conventional buildings; however, despite these additional costs, intelligent buildings are becoming more prevalent as they bolster occupant productivity and reduce ongoing operational costs such as utilities (Wong et al., 2005).

These new systems include, most notably, the deployment of sensors, associated analytics software, and provisions for data management (Rincon et al., 2017). Investment in these sophisticated sensor and controls systems is also required to adjust lighting and temperature based on real-time occupancy (Lawal & Rafsanjani, 2022). Real-time monitoring systems, such as those used in security applications require investment as does compliance with data protection and privacy related regulations (Jia et al., 2019). Smart building adoption is transformative to business operations. Their benefits are briefly discussed in this study and extensively in other literature. To remain relevant and efficient in business, adoption of these systems will become increasingly important. In order to develop the business cases for smart building adoption, cost frameworks of BAS with a total cost of ownership (TCO) perspective must be developed and understood.

2.2 Limitations of Existing Literature

There are, of course, limitations of the existing literature on BAS costs, including: 1) the lack of comprehensive frameworks related to cost, especially during all phases of the building lifecycle; 2) the emergent nature of nascent smart building technologies and the resulting immaturity of literary consideration; and 3) the human factors, such as organizational cultures, impacting BAS adoption. Understanding these limitations is crucial, as it helps inform research design by looking at primary and secondary data sources related to cost in both industry practice and within the literature. Identifying and understanding these limitations allows the research to contribute to closing the research gap, as identified in this literature review.

2.2.1 Lack of Comprehensive Frameworks

In the present literature, there is a lack of categorical and comprehensive cost frameworks that provide cost data considerate of the entire building lifecycle (Rincon et al., 2017). This lack of cost understanding impairs adoption efforts of BAS in various phases, including planning, implementation, and operational phases (Tang et al., 2019). A lifecycle examination of cost and the development of a cost framework that considers all phases of the building lifecycle is needed support optimal facility management decisions (Wong et al., 2005).

A comprehensive cost framework, founded on lifecycle or TCO principles, includes all costs associated with the system, including implementation, operational, and disposition costs. This

TCO cost perspective is requisite to make well-considered decisions that enhance financial planning, approval, and budgeting exercises. Omrany et al. (2021) highlight the dearth of cost frameworks (in this application related to life-cycle energy assessments) and the value that TCO cost frameworks bring to evaluating building system adoption. Facility managers become partners and strategic collaborators with the c-suite when they bring cost data that validates cost-effective allocation of resources for optimized operations. Through this partnership, resource allocation is not only optimized but sustainable building operations practices are also achieved considerate of business objectives, environmental preservation, and underlying social factors (Schneider-Marin et al., 2022).

2.2.2 Identifying and Classifying Emerging Cost Elements

Due to the emergent nature of IoT enabled BAS technologies, there is a limited understanding of cost elements associated with these systems, including sensor deployment, data management, and software development (Jia et al., 2019). As a result of this context, there are also multiple challenges in identifying and classifying the costs associated with the integration of BAS and their often heavily integrated or imbedded IoT technologies (Tang et al., 2019).

2.2.3 Human Factors Impacting the Adoption BAS Systems

The barriers to new technology integration, such as BAS adoption, are often fundamentally related to human factors and organizational in nature. Borhani (2016) overviews the organizationally-rooted difficulties associated with technology adoption (in a construction safety context) within the built environment in their past thesis research, and these previously identified themes are present in this research. Given the nascent nature of these systems, organizational leaders and decision-makers often lack the context to make or adopt optimized organizational structures within the context of smart-building systems (Abuimara et al., 2021). A limited understanding of the impact of human and organizational factors, such as organizational culture, hinders the effectiveness of BAS and its technological adoption (Qiang et al., 2023). Overcoming this limited understanding is a critical step in successful BAS adoption and achieving cost optimization.

2.3 Need for Further Research

In summary, existing literature primarily examines the benefits BAS can provide and strategies for increasing their efficiency (Inayat & Raza, 2019), with little consideration to the lifecycle costs of smart building adoption (Lawal & Rafsanjani, 2022). The costs of smart building adoption are not well documented in the body of knowledge during the design, deployment and operational phases (Wong et al., 2005). There are increasing costs for the integration of BAS with IoT capabilities and due to the emerging nature of these technologies, those cost categories are also not well documented in the literature (Jia et al., 2019). Additionally, other human factors, such as organizational structure and culture, can impact cost and degrade the efficiency of smart building adoption; the associated cost impacts of these factors are still emerging in the literature (Abuarqoub et al., 2017).

To that end, the question emerges, "What are the various costs of smart building adoption?" This research seeks to develop this cost framework for smart building adoption. This preliminary literature review covers the current understanding of BAS costs and highlights how existing literature focuses primarily on the benefits of BAS, indicating a need for further research. The gap in the literature, specifically the lack of comprehensive cost frameworks that consider of the building lifecycle, justifies the research question and objectives. As the concerns detailed within this preliminary literature review are addressed by this research, understanding BAS costs and smart building adoption will allow for pathways to business case formation and, ultimately, implementation. Now that the researcher has established the context for the research question, they will explore it in greater detail in the next chapter.

Chapter 3: Research Question

Chapter 3 establishes the research question, "What are the various costs of smart building adoption?" This chapter provides context for how this research question was developed based on the previously detailed gaps in the literature. It also discusses the scope and limitations of the research, and how these parameters may impact the findings. Additionally, it discusses the boundaries and potential limitations of the research and how these parameters may impact the research findings.

The research question of this thesis, 'What are the various costs of smart building adoption?' was formed to address key gaps as identified in the preliminary literature review. The preliminary literature review discovered the lack of comprehensive cost frameworks considerate of the entire building lifecycle, which exposed a need within the industry to more fully consider long-term strategic aspirations (Parn & Edwards, 2019). This research holds significance and relevance in that BAS and their associated smart building technologies are increasingly prevalent in smart buildings, and that understanding the financial implications of these systems is fundamental to business case creation and subsequent adoption (McLaughlin, 2004). This research will hold value for building owners, operators, and researchers who will be considering the cost associated with smart building adoption. Additionally, the scope and boundaries of this research focuses on identifying and validation cost categories associated with smart building adoption, which take into consideration all phases of the building lifecycle.

3.1 Formulation of Research Question

The formulation of this research question, "What are the various costs of smart building adoption?" arises from the need to address gaps and limitations as identified in the literature.

Some of the primary themes in the preliminary literature review which lead to the formation of this question are: 1) cost frameworks are fundamental in the evaluation of facility systems investment (Rincon et al., 2017); 2) a lack of comprehensive cost frameworks considerate of the entire building lifecycle; 3) limited understanding of cost themes associated with nascent smart building and associated IoT technologies; 4) and then need to further consider the role of human and organizational factors on the broader understanding of cost frameworks. This research question was developed while considering various influencing factors, such as the need to balance research coverage and depth of exploration and the tools present to the researcher to gather primary data.

The research question was carefully crafted to strike a balance between breadth and depth, ensuring that the study would be both comprehensive and focused. Consultations with academic advisors and other mentors and classmates were instrumental in refining the question to an appropriate level of rigor and relevance for a master's thesis.

3.2 Scope and Limitations of Research Question

The research question focuses specifically on identifying and validating the cost categories associated with BAS within the context of smart building adoption, considerate and organized according to the building lifecycle to include the planning, design, implementation, operation, and disposition phases. The research will consider emerging cost elements as identified in both literature and industry-professional interviews. Although this research can be used as a starting point for quantifying cost or building business-cases analyses, it is important to note research related to technology and privacy issues such as this research are subject to changes resulting from innovation and the regulatory environment (Schneider-Marin et al., 2022).

Chapter 4: Methodology

This chapter provides an overview of the research methodology, including a justification of the research design, a comprehensive literature review, and qualitative interviews with professionals knowledgeable of smart buildings and related systems and structures. The philosophical underpinnings of this approach are also explored. The researcher then outlines the data collection and data analysis processes and discusses those protocols employed to enhance the credibility and trustworthiness of the study findings, while maintaining ethical considerations.

As discussed in Chapter 2, the purpose of the literature review, deployed as part of a two-part qualitative research methodology (literature review and interviews), is not merely to provide a summary of the literature, but to situate the research question within the broader context of the existing research. Gaps are then identified, and direction of the research is formed from points of departure from the existing literature. A key purpose of the literature review is to provide a framework for relating previous findings to new findings of the research (Randolph, 2009), as employed by this research and further explored in Chapter 7. The qualitative interviews provide a level of richness with in-depth exploration of experts' insights (Palinkas et al., 2015) on themes first developed in the literature reviews. The integration of these two methods provides a balanced analysis by addressing the research question from multiple methods, which allows for the enhanced validity of these findings by allowing for data triangulation (Almalki, 2016). Furthermore, qualitative research methods are well-adapted for detailed investigation of this multifaceted topic because it allows the researcher to glean insights from subject matter experts' experiences, as well as capture nuances and other contextual factors (Mohajan, 2018) involved in BAS cost considerations.

4.1 Research Design

The structure of this research is underpinned by two pillars: 1) a detailed literature review, and 2) structured interviews with industry professionals. This combined approach serves to validate and expand upon the relevant literature on BAS costs. The literature informs the interview structure, highlighting what is currently understood about costs and the existing gaps therein. This integrated two-step approach leverages existing knowledge in the field by first chronicling what is written and then expanding it to the lived experiences of industry professionals.

4.1.1 Literature Review (Literature Review as a Research Method)

The literature review acts as a critical foundation for this research because it systematically synthesizes the current state of knowledge regarding BAS cost categories from academic and industry sources. However, as technology, including BAS and IoT, is a rapidly changing and evolving field of study, it quickly became apparent during the research design phase that the literature alone may not fully capture the most current perspectives or newly emerging costs from industry practice. As the research delved into interview execution, this initial hypothesis was validated and new findings began to emerge, such as the notion that cost recognition is highly attributable to organizational structure. The following will detail the researcher's process of conducting the literature review, including the literature search protocol, such as article search practices, inclusion and exclusion criteria for literary sources, the extraction process for relevant data from the articles, and the analysis and actions taken as a result of analyzing that data.

To conduct the literature review, themes and keywords from the research topic were identified. Before selecting a research question, various themes and concepts related to smart building technology, BAS, and IoT were considered. Cost, benefits, environmental impacts, sustainability, privacy and cybersecurity costs, risks, opportunities, and business-case related topics were all among the preliminary topics of consideration. The preliminary literature review, in conjunction with consultation from advisors, helped narrow the research focus. With the research focus established, the research question was developed, and the literature search began in earnest. Key words and phrases such as “building automation systems,” “cost,” and “internet of things” were among several search terms deployed on literature search and other search platforms, including the University of Washington Library databases, as they maintain access to scores of reliable and peer-reviewed journal articles. Scholarly articles were also obtained to support the researcher’s methodology or process and to ensure that the readers of this research are aware of the adherence to sound academic practice. As this research deals with emerging technologies, preference was given to articles published in the last 5 years (regarding articles on technological topics); however, due to the limited literature sources (or extended / timeless relevance of literature) in some contexts, articles older than 5 years were at times considered if the article content maintained practical relevance.

The researcher coded relevant scholarly journal articles within the citation and reference manager Zotero and assigned files (such as costs, risks, methodology, etc.) to the articles for streamlined future integration into the research work. As the researcher continued their work, they coded articles into relevant and predefined categories, allowing for quick recall of relevant scholarly sources during the writing process. Additionally, Zotero contains a search function that allows relevant and coded research articles to be recalled and revisited by searching keywords. Using Zotero is a powerful tool in research execution, as it organizes relevant research articles and integrates seamlessly into word processing platforms, allowing for enhanced focus on the research topic at hand (Coar & Sewell, 2010). The citation and reference manager enhances the reliability of research by providing consistency in the references and citations of the works cited and by providing an audit trail of research practices.

The researcher viewed and executed this literature review as an iterative process. The preliminary literature review informed the formation of the research question, "What are the various costs of smart building adoption? That, in turn, drove a quest for more research literature on the topic. The researcher then performed thematic analysis of the literature. As consistent themes began to emerge, such as cost categories as they might appear over the building lifecycle, these concepts were identified and used to develop a preliminary cost framework. Thematic analysis is further deployed on collective literature and interview themes as explored in Subchapter 4.1.3.

This preliminary cost framework formed the basis for the creation of an interview tool. Although the process associated with the execution of qualitative interviews is explored more fully in the next section, it is important to note the interplay between the literature review and qualitative interviews. The interviews both validated findings from the literature review and introduced new topics or concepts related to smart building adoption that were not previously considered. These new concepts and ideas emerging from the interviews were then, in turn, validated and explored within the literature. This iterative process proved very powerful in extracting and exploring themes that likely would not have emerged through a review of the literature alone. One of these themes first discovered in the interviews and later developed through iterative literature review was the impact of organizational culture on the costs of smart building adoption. This theme ultimately became the basis of one narrative synthesis idea guiding the understanding of this research: the organizational culture cost-impact of technology adoption.

Narrative synthesis allows the researcher to develop a theory, which is founded in preliminary data collection, and examine other data sources in light of that theory. This process provides a more coherent and detailed narrative, effectively situating the information within its broader context (Barnett-Page & Thomas, 2009). In deploying narrative syntheses, this research develops various preliminary syntheses and uses them to further understand future research and validate initial theories (Rodgers et al., 2009). As with all good research practice, the researcher makes efforts to control bias in the use of narrative synthesis and will ultimately contribute to a more comprehensive understanding of the research topic.

4.1.2 Qualitative Interviews

Qualitative interviews bring many advantages to this research design due to the exploratory nature of the research question, "What are the various costs of smart building adoption?" and its associated need for in-depth exploration. As this research is an investigation into an emerging field with limited existing knowledge, a qualitative design allows for greater depth and flexibility by allowing the researcher to probe into industry professionals' lived experiences and opinions. Nuances and associated contextual details, which might be missed with other study designs, stand as a flagship feature of these interviews. Additionally, the format of interviews features open-ended questions, which allow for the discovery of unanticipated insights (Hammarberg et al., 2016).

To develop the interview tool, the researcher began with a preliminary literature review, which then informed his development of the research question. This allowed for a generalized understanding of cost category themes across the building lifecycle. The preliminary cost framework resulting from this review thus informed the creation of the interview tool. This preliminary cost framework served as a working theory of cost in the narrative synthesis aspect of the research design. In creating and deploying the interview tool, this research favored open-ended questions in an effort to achieve thematic data saturation. As multiple interview respondents informed the researcher of the same themes, such as cost considerations relating to cybersecurity, the researcher could validate the relevancy of these recurring themes.

Next, the researcher developed the interview protocol in consultation with their academic advisor and thesis committee chair in order to ensure a flow and sequence of questions. The researcher designed the interview tool to strike a balance between being concise and focused, yet comprehensive enough to gather relevant primary data. By developing an interview tool with concise and focused questions, the researcher could then deploy an interview strategy that expedited the recruitment process. The 30-minute protocol allowed the researcher to maintain focus on the primary objective of understanding cost perspectives while requiring minimal time investment from subject recruits. Pilot testing of the interview tool, a key consideration in designing high quality, semi-structured interviews (Kallio et al., 2016), ensured the viability and reliability for deployment.

Once in the interview, the researcher focused on open-ended questions, which allowed for the consideration of subjects not previously explored. Additionally, the researcher recognized that interview respondents, due to their purposive selection, were likely to be broadly connected with other industry experts possessing similar expertise. As such, interview respondents were asked to suggest additional interview leads, further enhancing the availability of primary interview data as this prospecting generated actionable leads. The design of the semi-structured qualitative interview allowed the researcher to efficiently execute this primary data collection in accordance with the agreed-upon terms and timeframes set forth in the research proposal.

Table 1

Respondent	Professional Background	Sector	Area of Expertise	Primary Focus
R1	Architect, Builder, IFMA Fellow	Private	BAS Implementation, Innovation	Decision-making, Storytelling, Integrated Products with Embedded Sensors
R2	Research Scientist	Academic	Smart Buildings, Cybersecurity	Coordination, Collaboration, Interdisciplinary Meetings, Data Governance
R3	Utilities Management and Conservation	Private	BAS Installation, Project Management	Integrated Solutions, Cross-platform Compatibility, Cellular Connectivity, Cybersecurity
R4	BAS Technician, Manager	Private	BAS Operation, Data Management	Simplifying Systems, Identifying Necessary Data Points
R5	Researcher	Academic, Nonprofit	IoT in Built Environment, Smart Campus	Hidden Costs, Human Impacts, Long-term Labor Impacts
R6	Researcher, Policy Analyst	Public	Smart City Development, Technology Procurement	Partnerships, Resource Challenges, Social Equity, Human Capital, Opportunity Costs
R7	Director of Facilities	Academic, Public	Facility Automation Systems, MEP Systems	Standards Implementation, Cybersecurity, Design Review Process, Consistency

This research interviewed a total of seven industry experts recruited to this study by means of purposive sampling. An overview of these seven interview respondents are identified in Table 1. Purposive sampling was chosen in this research design, “for the identification and selection of information-rich cases for the most effective use of limited resources,” and for “the importance of availability and willingness to participate, and the ability to communicate experiences and opinions in an articulate, expressive, and reflective manner” (Palinkas et al., 2015). The researcher’s network connections to interview respondents undoubtably influenced study participation, introducing some biasing factors; however, the subjects also brought extensive industry knowledge and a commitment to sustaining academic advancement and achievement within the field of built environments, as evidenced by their participation.

The researcher received IRB exempt status, recruited for, conducted, and analyzed all interviews. Prior to prospecting for interviews, the researcher obtained IRB exempt status by submitting the research and interview design for review and obtaining formal exempt status. Discussing current topics related to a professional’s livelihood carries inherent professional risk. In alignment with the researcher’s commitment to conducting ethical research and avoiding this risk to the subjects, this research concealed the identity of interview respondents participating in this study. The researcher took notes during interview execution and recorded and transcribed the interview discussions using the electronic meeting platform, Zoom. Interview themes were synthesized from these transcripts and validated through respondent validation.

Respondent validation is a key step ensuring the accuracy and credibility of qualitative interview findings. In this study, the researcher conducted respondent validation by providing the interview participants with a summary of themes synthesized from both the collective set of interviews and individual responses. Respondents were asked to review these themes to confirm the accuracy of the researcher's interpretations. The purpose of this process is twofold: 1) it allows interview participants to provide additional insights and to verify that the interview data as summarized aligns with their experiences and perspectives; 2) it additionally shows a commitment to bring researcher and industry partners into an alliance to further enhance and understand the issues facing the broader facilities management industry.

4.1.3 Thematic Analysis in the Creation of an Integrated Cost Framework

Braun & Clarke (2006) explore the steps in conducting thematic analysis. In this application, themes presented in both the literature and the interviews are considered. This research approached thematic analysis of integrated literature and interview findings iteratively, in a similar fashion to the literature review. Building on a robust familiarization with the data and themes emerging from the preliminary literature review, a preliminary cost framework was developed. This initial framework served as the basis for interview tool creation. The codes developed were aligned with the research objective: to create a comprehensive cost framework for the costs of smart building adoption as observed across the building lifecycle, including the planning, design, implementation, operational, and disposition phases. Research data, in the form of both literature and interview synthesis, were coded according to lifecycle phases. The thematic coding and resulting analysis, as described here result, in the keystone deliverable of this research, which is presented in Section 7.3.

4.2 Philosophical Underpinnings

This qualitative approach aligns with the claims laid forth by Creswell & Miller (2000), who suggest that reality is formed through social constructs and reflects the perceptions of those involved. When implementing this approach, actively involving participants in the validation of research findings is critical. Understanding cost is ultimately most beneficial if it is understood and categorized in the ways demonstrated within industry. As such, this research design allows for interpretivism and social constructivism to prominently carry into the study results.

The understanding of cost frameworks is shaped by a social constructivist paradigm, suggesting that our perception of reality is formed by social constructs and is inherently subjective. Therefore, the involvement of relevant and diverse industry perspectives is not only beneficial, but also mandatory. The researcher should (and in this study does) collaborate with study participants to co-create knowledge and challenge well-established assumptions (Hosking & Pluut, 2014).

These philosophical underpinnings align with the research question and objectives, including the notion that conducting an in-depth exploration of BAS cost categories requires this study to engage with the subjective experiences and perspectives of industry professionals. By developing and deploying an interview tool with open-ended questions, as this study does, these unique perspectives are brought to the forefront, providing value and nuance to the data collected (DeJonckheere & Vaughn, 2019). Additionally, the study subjects play a key role in co-creating the research as they continue to engage with the researcher through respondent validation.

Some notable limitations or challenges are aligned with these philosophical underpinnings including dealing with researcher bias, the generalizability of findings to other contexts, and the commitment to researcher ethics. The researcher must constantly reflect on their own perspectives and how they may influence subject responses and the interpretation of data. By employing research reflexivity and triangulation of data sources, researcher bias can be mitigated. The researcher recognizes that this research has a limited sample size and may not be generalizable to broader populations. Consequently, this study acknowledges this limitation and presents the research as a starting point for further pursuit and understanding of smart building costs. Finally, the researcher is committed to upholding ethical considerations. As such, the study design employs informed and revocable consent and confidentiality.

4.3 Data Collection and Analysis

The preliminary literature review provided the basis and structure for the creation of an interview tool, which was used to conduct seven 30-minute interviews with industry professionals. The results of these interviews were synthesized and provided to the interview respondents for respondent validation. Due to the research schedule, some potential interview recruits were removed from consideration. Some recruits initially showed interest yet were unable to participate due to employer restrictions or scheduling conflicts. Additionally, the interview subjects are professionals with various commitments, which the researcher had to accommodate in order to successfully conduct the interviews.

Once the interviews were completed, the researcher familiarized themselves with the themes within the data by reading and synthesizing the interview transcripts. Codes developed according to the thematic analysis and narrative synthesis were applied to these syntheses. New codes emerged as the interview data were analyzed, providing additional areas of investigation in the literature. Some of the most unexpected results of the interview analysis took form of identifying and coding unexpected themes, especially in regard to organizational culture (efficiency, hidden labor, direct labor / contract) costs not previously considered. These emerging and unexpected themes are further explored in Chapter 7.

4.3.1 Data Collection

Primary data for this research consists of structured interview results from professionals within the built environment who possess knowledge and experience with BAS and IoT technologies. Interview candidates were recruited from diverse facilities backgrounds, including both the public and private sectors, from the researcher's professional and academic networks.

4.3.2 Data Analysis

The researcher synthesized interview transcripts using thematic analysis and triangulation of data (Leedy & Ormrod, 2021), which strengthened the validity and reliability of the research findings. Thematic analysis is a proven qualitative research method which identifies, analyzes, and then reports on patterns within the data. This method allowed for the identification of consistent themes within the interviews related to the cost categories of BAS, and thus provided a comprehensive framework for the research at hand (Braun & Clarke, 2006).

4.4 Enhancing Credibility and Trustworthiness

The credibility of the qualitative research findings is substantiated by means of a robust study design, including the triangulation of data, respondent validation, and researcher introspection. The triangulation of data sources, as demonstrated in the research through the dual data collection strategy of literature review and interviews, strengthens the comprehensiveness and validity of the findings (Moon, 2019). Respondent validation was conducted with interview participants, allowing them to review both their own and the collective findings. In the course of this process, participants strengthened the study's validity and robustness by reviewing, correcting, or providing additional feedback (Leedy & Ormrod, 2021).

4.4.1 Respondent Validation

Respondent validation was sought, which gave interviewees the opportunity to review aggregate interview results and provide commentary. The format of this request for respondent validation was concise in order to ease the burden associated with responding and therefore bolster the response rate. The request for respondent validation was divided into syntheses of both individual collective themes as identified in the interview results. The purpose of this practice is two-fold: 1) to provide interviewees with opportunities to validate and / or refute the results and 2) to allow them to gain primary insights of the research conducted, as partners in research, a benefit of their study contribution.

The interviews and their associated responses and respondent validation were compared and contrasted with a robust literature review. Qualitative research is best suited for addressing this research question, as it allows for an in-depth exploration of the subject with subject matter expert insight.

The data and information validated by the respondents are reviewed to identify additional relevant literature. Those additional relevant literature sources are then incorporated into the literature review. This process allows the literature review to inform the interviews and subsequently for interviews to inform the literature review in a systematically iterative manner. This method allows the findings to be robust and substantial in the final results.

To enhance the quality of this study, the researcher recognizes the importance of researcher reflexivity. As the researcher becomes more aware of their own biases, experiences and expectations related to the research topic, the researcher is better capable of mitigating their impact (Smith & Noble, 2014). The researcher engaged in reflexive note taking and peer debriefing to critically evaluate and minimize the impact of these biases.

4.5 Ethical Considerations

When involving human subjects in research, as this study does, ethical principles must inform both the planning and execution phases. Participants were informed of the nature and goals of the study, their voluntary involvement, the process of informed consent, and their ability to revoke such consent at any time. Confidentiality and anonymity of interviewees shall be maintained, and all proposed interactions with human subjects will be reviewed and validated by the Institutional Review Board (IRB) to ensure ethical compliance.

Chapter 5 Results: Detailed Literature Review

Building upon the preliminary literature review, which Chapter 2 establishes, this chapter's literature review further expands on the prior review and distinctly classifies those cost themes found in the literature. Additionally, concepts emerging from the interviews conducted with industry professionals (as further discussed in Chapter 6) allow for a greater and more robust investigation of the literature. The researcher presents a discussion of how the literature review is informed by the interview and how those sources sought out and found as a result of the interview are explored. The themes and results of both the literature review and interviews are then integrated into a single list of themes related to the costs of smart building adoption, including those results which are novel in the discussion and were not anticipated by the initial literature review.

The objective of the comprehensive literature review is to identify and validate the various cost categories of building automation, as demonstrated in the literature. The literature review is based on various articles that examine building automation systems within the context of the Internet of Things (IoT). The following literature-review-based cost structure adheres to the following criteria: 1) it is comprised of themes that were reoccurring in the literature; 2) it adheres to a central narrative synthesis hypothesis of this research, that cost is best categorized according to phase of the building lifecycle; and 3) it was developed and modified in iterative fashion throughout the research process.

Although the researcher gained new perspectives from conducting qualitative interviews with built-environment professionals, and those perspectives shaped the ongoing literature review philosophy, the themes developed within this chapter are primarily based in the literature. However, the impact of the interviews on the literature review process is significant and warrants further exploration as discussed below. More discussion on the impact of this iterative process between the literature review, its interplay with interviews, and its impact on developing an integrated cost framework for smart building adoption is provided in Chapter 4 and Chapter 7.

The following section provides an outline of the literature-informed cost themes of smart building adoption. It is important to note that these cost themes are to be understood categorially and may not be applicable in all instances of smart building adoption.

5.1 Planning Phase Costs

1. **Building Business Cases:**

   The adoption of smart building technologies often requires quantifiable evidence to demonstrate organizational benefit, which may come in the form of increased efficiency, improved operational output, or the obtainment of environmental sustainability goals. These building cases are most often created by the following two groups:

   Contracted Services: Many firms hire business consultants to document or develop corporate ideologies or visions. Once those visions are developed, these contracted services can help develop the business cases by demonstrating how the adoption of new practices, such as BAS implementation, can help align the organization with those ideologies. Market research and feasibility studies can be provided by contracted services to support business development cases for smart building adoption (Rincon et al., 2017).

Internal Staff: Additionally, internal staff can take on the role of developing those business cases. There are costs associated with training and upskilling internal staff to effectively develop business cases for smart building adoption that must be considered (Abuimara et al., 2021).

2. **Stakeholder Engagement:**

   Engaging stakeholders, including building owners, occupants, facility managers, maintenance staff, and the like, is key to planning a well-adopted plan with robust stakeholder buy-in. This process can include the investment in workshops and surveys which gather relevant feedback needed to shape plan design (Prebanić & Vukomanović, 2023). Additionally, investment into ongoing engagement activities, which begin in the planning stage must be considered (Bal et al., 2013).

5.2 Design Phase Costs

1. **Project Design-related Services:**

   Wong et al. (2005) demonstrated that the design on smart building projects cost 5% more than conventional projects. Although this study reserves the quantitative investigation for future research, smart building project stakeholders should anticipate increased allocation for smart building design and consider how it may have changed in the last 20 years (when this referenced study was conducted) with the proliferation of technology.

2. **Technology Selection:**

   The process of selecting appropriate smart building technologies, in alignment with facility management strategies, such as sensors, control systems, and communication protocols, can incur costs related to research and integration (Lawal & Rafsanjani, 2022).

   Siccardi & Villa (2023) discuss how disparate systems cause a lack of integrated facilities operation and lead to efficiency degradation associated with a lack of interoperability between systems; therefore, investment to fully integrate systems should be considered.

3. **BIM and IoT Integration:** Tang et al. (2019) discuss the opportunity to leverage BIM for the optimizing facility management by linking BIM objects to physical IoT device deployment. Although the introduction of this technology holds promise to lower operating costs, investment is required for its deployment.

4. **Compliance / Regulations / Standardization:**

   Baharetha et al. (2024) mention that the lack of design standards create challenges in the development and construction of smart buildings. Additionally, there are lacking regulations to maintain the privacy and security of users. These elements bring additional risk and cost to smart building adoption due to their emerging nature.

5.3 Implementation Phase Costs

1. **Project Related Installation and Construction Services:**

   Contracted Services: Smart devices and associated network infrastructure for BAS adoption require the hiring of specialized contractors to understand and deliver solutions that can overcome data interoperability challenges (Jia et al., 2019).

   Internal Staff: There are costs associated with training staff to manage the installation process and to effectively operate and maintain new smart systems when deployed (Abuimara et al., 2021).

2. **Commissioning and Testing Costs:**

   Although commissioning costs, as many of these costs, are occurred at several phases of the building lifecycle, the primary implication of these costs are during the implementation or construction phase. Crowe et al., (2020) highlight the importance of investing in commissioning to ensure optimized building operations, including proper function of the BAS systems. Montgomery (2020) explores how commissioning costs are rising along with technology complexity of projects and associated need for a trained workforce.

5.4 Operation Phase Costs

1. **Preventative Maintenance:**

   It should be noted that the costs related to the maintenance of BAS or smart building technologies themselves are limited. The focus of the literature, when discussing smart building technologies and maintenance, tends to be on the emerging operational benefit of using BAS to aid in the predictive maintenance of various building systems (Achouch et al., 2022). However, there is some limited literature on this topic. The researcher will have to rely more heavily on other data sources, such as primary data from interviews, to fully understand this topic.

Katipamula & Brambley (2005) explain that, "poorly maintained, degraded, and improperly controlled equipment wastes an estimated 15% to 30% of energy used in commercial buildings. Much of this waste could be prevented with widespread adoption of automated condition-based maintenance." As controls are central to BAS and the impact is substantive, this emphasizes the need for proper consideration to invest in and maintain these systems. Jia et al. (2019) additionally mention the lifecycle costs of maintaining, replacing, and upgrading IoT-based infrastructure over time.

2. **Facility Operations:**

There are various facility operations costs associated with using BAS, which are related to controls systems and the data generated by BAS. Energy management strategies, which analyze energy consumption patterns and optimize usage through the use of algorithms, lead to operational cost savings (Tushar et al., 2018). This requires the investment and deployment of software, hardware, and experienced technicians.

Floris et al. (2021) discuss data management, storage, and dashboarding considerations when operating a smart building, as these systems generate large datasets that need to be stored, analyzed, and presented in an actionable manner.

3. **Cybersecurity:**

A study by Lawal & Rafsanjani (2022) examined industry trends, benefits, and risks of IoT implementation in residential and commercial buildings. Their findings indicate that BAS (and the associated IoT within) can lead to significant cost savings, which is consistent with other literature. However, this study also highlights the cybersecurity risks that must be managed.

Chong et al. (2014) executed a case study on cloud computing applications in the built environment. They found that cloud-based building automation systems increase stakeholder engagement and involvement and, as such, lead to increased efficiency and reduced operating costs. Furthermore, this article highlights the data security and privacy concerns that accompany these systems, which bring cost implications for mitigation.

Mayo & Snider (2016) demonstrate the importance of cybersecurity in BAS, noting that security breaches may lead to financial losses. Liebowitz (2012) highlights the vulnerabilities of smart meters and the associated financial impact of meter hacking. These risks must be considered from a cost perspective, as their realization can significantly drive up the costs associated with the system.

Boyes et al. (2014) examined how asset management applications and collaboration can be used to manage the cybersecurity of complex BAS. Their findings suggest that effective asset management leads to enhanced cybersecurity and reduced operating costs.

4. **Privacy:**

   Cirigliano et al. (2018) present an extensible CAD framework for indoor localization systems deployment. Building localization systems are smart systems that can assist in wayfinding. According to the study, these systems can help reduce energy consumption by leveraging real-time occupancy sensing. This comes with a host of privacy considerations, as many forms of occupant sensing can be traced back to individual behaviors. Various other smart building applications of indoor localization systems can also drive cost efficiency but must be implemented in a way that is considerate of an occupant's right to privacy and compliant with laws and regulations enforcing such rights. To account for these privacy regulatory requirements, this requires investment in labor or services skilled in supporting such deployment.

5.5 Disposition Phase Costs

Note that the literature contains little information literature explicitly detailing cost considerations related to the disposition of these systems; and as such, the researcher explores other data sources, such as primary data from interviews, to understand these costs more fully.

5.6 Additional Cost Considerations

1. **Organizational:**

   Atkin et al. (2017) discuss how, even when the benefits of adopting new technology are clear, there is still often a low level of support and buy-in. To mitigate this resistance to change, investment in training and marketing campaigns for the adoption are required.

Ghansah et al. (2021) found that there are several barriers to the adoption of smart building technologies (SBTs), including lengthy approval processes for new SBTs. This impacts efficiency and leads to additional costs of adoption.

Overall, this literature-review-based cost framework, organized by building phase, indicates the intricacies and layered consideration of costs throughout the building lifecycle. This is the first of three cost frameworks developed by this research. The interview results will inform a second cost framework. Finally, based on the merits of each data-collection framework, the literature review cost framework, and the qualitative interview cost framework, the researcher will produce a third and final cost framework of smart building adoption. The structure of this literature-review-based cost framework was formed by considering themes found in the preliminary literature review. The theme was in turn developed into a narrative synthesis hypothesis, which is that costs are best considered according to the various phases of the building lifecycle. However, after analyzing the literature within this context, it became clear that several cost categories identified have lifecycle cost considerations. As such, the costs are classified by phase above according to when these costs are primarily anticipated. For instance, it is reasonable to expect that a planning phase cost could appear in the implementation phase, or that other cost considerations such as organization factors are attributable to a distinct phase.

Consistent with the process of narrative analysis, an initial hypothesis structure was explored. Deficiencies in organizing the cost framework in this original manner were identified. As such, future frameworks will be informed by this structure, but will try novel approaches in their respective structures. However, key themes are still relevant and informed by this initial framework including the potential risks associated with building automation systems, such as cybersecurity risks, which must be effectively managed. This framework takes a step forward in better understanding the literature and developing a basis for future cost frameworks, both within and beyond this research. By identifying and validating the various cost categories of building automation demonstrated in the literature, this research provides a comprehensive understanding of the origin of costs associated with smart buildings according to phases of the building lifecycle, and their impact on the overall cost consideration for adoption.

Chapter 6 Results: Interviews

In this chapter, the researcher delivers the results and reviews the implications of the qualitative interviews. These interviews stand as a key pillar of data collection for this research and serve to provide valuable and timely perspectives into the costs of smart building adoption. The benefits of these interviews served many important purposes in this research process, including: 1) validating many themes found in the literature; 2) uncovering new cost themes, later enhanced and validated through continuous literature review; 3) providing new perspectives in ways that costs of BAS are understood; and 4) strengthening the commitment to developing research insights in conjunction with industry partnerships.

The semi-structured interview process allowed for the identification of cost themes not yet mature in the literature. The researcher developed the interview protocol with a focus on open-ended questions that could be explored to uncover unanticipated results. Follow-up questions, as needed, were used to explore these emerging and unanticipated themes. These themes were then coded and analyzed for recurring patterns using thematic analysis. This was an iterative process which led to the development of a second cost framework for BAS adoption, presented later in this chapter.

It should be noted that cost data are subjectively understood, and therefore unique to each individual subject, as demonstrated in the research. For example, one respondent primarily understood BAS related costs as contractible, vendor related costs, whereas other respondents came from perspective of services being performed by in-house labor. Cost frameworks can be organized in a variety of formats. Through the process of narrative synthesis, the researcher developed a primary cost framework schema, organizing cost by the phases of the building lifecycle, as demonstrated in Chapter 5. After fully exploring the literature, with an understanding enhanced by having conducted the interviews, the researcher began to understand the lifecycle nature of many cost themes. As such, a more informed cost framework, aligned with industry perspective, is developed, and deployed to classify the cost themes within the interview results.

Due to the subjective nature of cost understanding, the researcher evaluated the optimal ways to understand, code, and classify various costs. The following cost classification themes were explored: 1) by building phase; 2) by stakeholder impact; 3) by timing and visibility; and 4) by nature and scope. As the industry professionals in the interviews tended to understand costs by nature and scope, this is the lens used to code the interview data. However, timing and visibility is a valuable way to understand costs based on an integrated knowledge of research and interview data. Evaluating the merits of organizing cost by timing and visibility will be reserved for the third and final cost framework within Section 7.2. The key themes that emerged from the interviews are: 1) Direct Technology Costs; 2) Organizational Costs; 3) Lifecycle Costs; 4) Strategic Costs; and 5) Societal Costs.

The framework below has various ideas and contributions attributable to distinct interview respondents. In order to balance the need for respecting interview subjects' anonymity, per the research design and IRB exemption, the researcher coded each interview respondent as R1-R7. Ideas will be attributed to the appropriate respondent with sound research practice, including developing an audit trail, which enhances the replicability of this research (Marian Carcary, 2021).

6.1 Direct Technology Costs

The following are costs which are directly attributable to the investment, acquisition, deployment, and management cost of the costs of smart building IoT-based technologies.

1. **Sensor Deployment and Management:**

   There are often inefficiencies associated with the fragmented deployment of sensors in buildings, especially in campus settings. "The hidden and often underrepresented labor force on campus faces additional hurdles due to the inconsistent deployment of sensor systems." (R5). It was also commonly observed that construction projects would install sensors, and maintenance would not know about it, leading to other costly inefficiencies (R2). Another respondent chose to leverage the capabilities of vendors and integrated solutions, such as sensing capabilities integrated into lighting products, to group and offload costs (R1). These sensors are becoming increasingly cellular-enabled, increasing speed to deployment, but they come with service contracts (R3). Also, advancements in technology are making the costs of sensors decrease. "In the past, we charged about $1000 per point due to the cost of sensors, wiring, and programming. Nowadays, many sensors come integrated with the units, shifting the cost from the BAS budget to the mechanical budget." (R4).

2. **Data Management and Analysis:**

   The primary expenses in data management and analysis are labor-based. "Managing and storing data is a substantial expense. If you do not have a data scientist or data analytics either outsourced or full-time, you will fail as a business." (R2). Data-related costs encompass various aspects, including storage space. "You (must) have to have dedicated space. Hard drive space is getting cheaper by the year. Today's cost of storing a petabyte of data is almost the same as a couple of gigs less than a decade ago." (R3).

3. **Cybersecurity, Privacy and Compliance Costs:**

   Protecting smart building systems requires strong security protocols, dedicated teams, and other security considerations, all of which cost money. This theme was heavily represented in the literature and recurring in the interviews. "Cybersecurity is the number one concern." (R1). "The hidden cost of BAS is cybersecurity, which requires substantial investment to prevent costly attacks." (R7). Additionally, as these cyber risks are realized, the impacts of these breaches are especially damaging. "Municipalities and organizations have paid substantial amounts to hackers due to data breaches." (R6).

4. **User Interface and Dashboard Costs:**

   Dashboard costs include the development, deployment, training, and data considerations for making smart buildings functionally operational. "Graphically seeing the cause and effect, the simulation of actionable items in business, is like seeing a picture worth a thousand words." (R3). Creating these dashboards signifies significant costs, "Creating dashboards and user interfaces has become more important. Systems like DCIM (Data Center Infrastructure Management) provide third-party software for dashboards, adding to the overall cost. The process involves significant labor costs for setup and communication between different systems." (R2). Some respondents opted for more costly systems with enhanced flexibility, "We use automated logic systems and convert other systems to BACnet, programmed by our team. This customization allows flexibility but also incurs higher costs for changes and upgrades." (R7).

6.2 Organizational Costs

These are all the internal expenses incurred by the organization as it adapts to support the deployment of smart building IoT-based technologies.

1. **Human Capital Costs:**

   There is a hidden and often underrepresented labor force, especially on college campuses, facing additional hurdles due to the inconsistent deployment of sensor systems. Many times, the deployment funding of these systems was reserved for well-funded departments, and yet supporting organizations, such as custodians, who relied on this data, could not access it, causing inefficiencies (R5). Also, coordination across various teams is a key consideration in the effective maintenance of BAS sensor systems (R7). Additionally, there is a shortage of skilled workers, driving up the cost of labor in support of these smart technology deployments (R7, R1).

2. **Training and Upskilling Costs:**

   There are upfront costs associated with training, and often individuals must unlearn old methods and embrace new technology (R1). The effective operation of these systems (efficiency is directly related to cost) is founded on extensive training and a knowledgeable support team (R7).

3. **Interdepartmental Collaboration Costs:**

   As departments are becoming increasing interdisciplinary, the establishment of meetings focused on smart building management came with costs, but enhanced operations. "We saw interdisciplinary meetings; formal meetings being set up so people can start talking to one another." (R2).

6.3 Lifecycle Costs

Lifecycle costs represent costs incurred throughout the entire lifecycle of the smart building system.

1. **Installation and Commissioning Costs:**

   When projects are state-funded, there are very specific delivery standards and often the requirement to use non-preferred vendors. This leads to variations in efficiency and installation experience associated with smart building technology (R7).

2. **Operation and Maintenance Costs:**

   Maintaining sensors requires intensive support from a skilled team, which requires investment. "Effective operation and maintenance require a skilled workforce capable of managing and troubleshooting advanced BAS technologies. This includes continuous training and development to keep pace with technological advancements." (R7). Another respondent echoes this sentiment and calls for team training to stay current with emerging technologies. "Effective operation and maintenance require a skilled workforce capable of managing and troubleshooting advanced BAS technologies. This includes continuous training and development to keep pace with technological advancements." (R1). There are also opportunities to invest in predictive maintenance, which require upfront costs, but can yield savings in maintenance operations. Advanced data analytics and machine learning can enhance the predictive maintenance capabilities of BAS, allowing for the identification and correction of problems before they become significant issues(R3). Additionally, owners should be considerate of structuring these systems for enhanced flexibility in operations, which impacts overall operating costs, including the ability to change service contracts if needed. "Owners should be cautious of IoT BAS systems that rely heavily on cloud services. While they can reduce initial costs, they increase dependency on the service provider." (R4).

6.4 Strategic Costs

Strategic costs incorporate less tangible, more deeply rooted, long-term costs associated with a technological conversion within an organization and the associated impact on future costs.

1. **Opportunity Costs:**

   It is important to note that chosen investments, by an organization or society, in certain smart technologies may not always yield the most effective or efficient outcomes. This leads to underutilized or poorly integrated systems which do not meet the broader community or organizational needs (R6).

2. **Retrofit and Integration Costs:**

   Integrating sensors into an existing building can be especially complex. There may be the requirement to work across protocols and undertake lots of internal work to ensure the effective deployment of systems (R7).

6.5 Societal Costs

Societal costs affect the broader impact that organizational decisions impose on the broader community such as social equity.

1. **Social Equity Costs:**

   Sometimes investing in technology is not always the right solution. "Prioritizing technology-driven solutions over more traditional and possibly more effective policy tools, like public transit, can have broader societal implications, distracting from more sustainable options." (R6).

This cost framework is based on the nature and scope of the cost, a common way of understanding costs according to the interview subjects. These interviews emphasized the importance of considering organizational and cybersecurity costs. Additionally, the research brought perspective into cost areas that are more nuanced, and often overlooked, aspects related to opportunity and social equity. The interviews provided this researcher with a level of perspective that compliments and builds upon the themes of the literature review.

Chapter 7: Discussion

This chapter will discuss the implications of the research findings and their relevance to the industry and provide a third and final cost framework for understanding the costs associated with smart building adoption. The researcher will reflect on the identified cost categories and other elements related to cost and cost-effectiveness. The limitations of this study will be discussed, as well as suggestions for areas of other related and expanded research. The researcher's insights and experience on this research journey will also be shared.

7.1 An Integrated Understanding of the Literature Review and Interviews

The researcher enhanced the overall quality of this work in deploying a robust research design with the collection of complimentary yet distinctly different data in the form of literature review and interviews (Abuimara et al., 2021). This duel-natured approach to data collection allowed the research to understand the problem from multiple distinct angles and draw insightful conclusions. There are key cost themes which emerged within the results, aggregating from both data sources. This thematic data saturation of the results underscores the validity and relevancy of this research. As ideas emerged in one source of data, it allowed for understanding and investigation through the other source (Braun & Clarke, 2006). Returning to the literature in a comprehensive literature review and to the interview respondents, with respondent validation, allowed for increasingly enhanced understanding of the BAS cost topics explored.

For example, at the onset of this process, the researcher did not understand elements relating to the subjective nature of cost or the impact of organizational costs. As these themes and elements were uncovered in the interviews, they were further explored in both the literature and the interviews. Also, smart building adoption cost themes began to aggregate consistently from both the literary and interview sources, including those costs related to organizational factors and cybersecurity risks.

This researcher began with a narrative synthesis hypothesis of how to best understand cost, categorized according to the phases of the building lifecycle, due to the inherent lifecycle nature of many of these costs. However, differing perspectives around costs found within the industry suggested that while this initial narrative synthesis hypothesis may be one way to understand cost, there are more optimal and industry-aligned ways for presenting this cost information. As such, the results of the semi-structured qualitative interviews present the cost framework for smart building adoption in a manner more considerate of the nature and scope of the various costs.

The first two cost frameworks developed within Chapters 5 and 6 are independent from one another. This means that the BAS cost frameworks for Chapter 5 is solely substantiated by literature and for Chapter 6, solely by the interviews. The third and final cost framework delivered by this research is an integrated cost framework for smart building adoption, considering both literature and interview data sources.

7.2 Literature Review and Interviews: An Integrated Cost Framework

The following integrated cost framework for smart building adoption supports both literature and interview-based themes. This framework is structured based on the timing and visibility of costs, integrating the best aspects of the first two frameworks, and allowing for a lifecycle perspective on cost (TCO) and a closer look at those costs that may be not as apparent or hidden. Rincon et al. (2017) emphasize the need for cost understanding considerate of building lifecycles to support optimized facility management. Additionally, Tang et al. (2019) point out that while some aspects of smart building projects are highly visible, like the deployment of IoT sensors, the costs of data management, cybersecurity, and training may not be as prominent and therefore less apparent and therefore not considered in budgeting calculations. As cost frameworks, such as those developed and presented in this research, are better understood, facilities managers can make better and more informed decisions around smart building investments.

1. **Upfront and Visible Costs:**

   These are costs that are readily apparent, visible, and anticipated costs incurred during planning and implementation.

   a. Sensor Deployment (Jia et al., 2019); (R1, R2, R3, R4)

   b. Technology Selection (Lawal & Rafsanjani, 2022); (R1)

   c. Installation and Commissioning (R7)

   d. BIM and IoT Integration (Tang et al., 2019)

   e. Planning and Budgeting (Rincon et al., 2017); (R1; R7)

2. **Hidden and long-term costs:**

   These are costs that are not immediately apparent and are typically incurred later in the lifecycle.

   a. Data Management and Analysis (Floris et al., 2021); (R2, R3)

   b. Training and Upskilling (R1, R7)

   c. Organizational Efficiency (R5)

d. Cybersecurity and Privacy (Lawal & Rafsanjani, 2022); (R1, R7)

e. Regulatory Compliance (Baharetha et al., 2024);

f. Long Term Viability of System Upgrades (Jia et al., 2019)

3. **Lifecycle and Strategic Costs:**

   Lifecycle costs are incurred throughout the entire lifecycle of the smart building system.

   - **a.** Operations and Maintenance (R3, R4)
   - **b.** Opportunity Costs (R6)
   - **c.** Retrofit and Integration (R7)
   - **d.** Stakeholder Engagement (Bal et al., 2013); (R7)

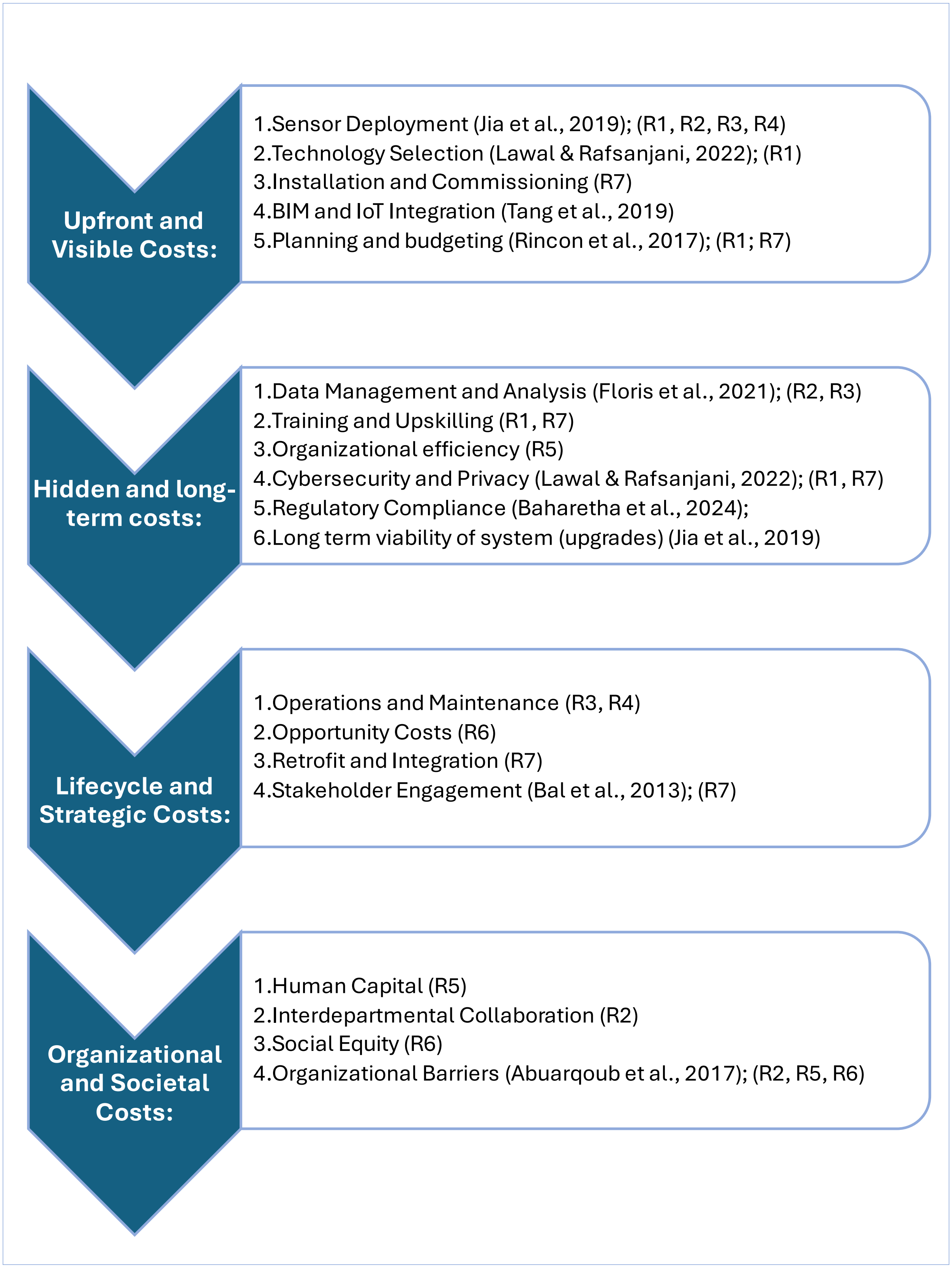
4. **Organizational and Societal Costs:**

   Organizational and societal costs represent those less tangible, more deeply rooted, and long-term costs underlying a sweeping technological adoption, such as BAS.

   - **a.** Human Capital (R5)
   - **b.** Interdepartmental Collaboration (R2)
   - **c.** Social Equity (R6)
   - **d.** Organizational Barriers (Abuarqoub et al., 2017); (R2, R5, R6)

In conclusion, this third and final cost framework examines smart building adoption costs through the lens of timing and visibility of those costs. This integrated framework is presented graphically as a resource for building owners, operators, and researchers in Appendix A. It maintains a balance of the positive attributes of the first framework in providing a lifecycle cost perspective, while aligning more closely with how those within the industry understand and speak of these costs.

Figure 1 Comprehensive and Integrated Cost Framework for Smart Building Adoption



Chapter 8: Conclusion

In this final chapter, the researcher will discuss the results of this research and the significance of these findings. They will also discuss the contribution of this work and the significance of this research in the areas of cost management, building automation, smart buildings, construction, and facility management are discussed. This chapter will also provide a call to action for building operators and owners, researchers, and other built environment professionals to utilize the cost categories identified in this research and build upon the cost concepts developed in this work.

Overall, the combined results of the literature review and interviews, as laid forth in Chapters 5 and 6, assist in providing more defined cost categories within the realm of BAS. As the literature suggests, BAS can lead to significant cost savings, increased efficiency, and reduced energy consumption; however, these benefits come with associated costs. The researcher extensively mapped three different cost frameworks through which one can understand the costs of smart building adoption. With these categories well defined, it provides the basis for further research into the allocation of these costs in a benchmarking fashion.

There are various limitations to this research, which are discussed extensively in the prior chapters, such as the small sample size of interview respondents. However, the researcher employed various literature-based methods to mitigate these limitations, including the purposive selection of interview subjects, the use of various research tools such as narrative synthesis, thematic analysis, respondent validation, and data coding. The researcher's perspectives and practices are explored in depth in this research to increase the transparency of the research process and to provide opportunities for public evaluation and examinations thereof. Ultimately, the researcher's dedication to embodying learning and deploying research best practices, as evidenced in the sound practice, makes the results and findings of these cost insights robust and valid.

As this research focused on qualitative data and categorical data with a limited number of interview subjects, future research is encouraged and welcomed to further corroborate and build upon these research findings. Future studies should expand the number of interview participants, look longitudinally at cost perspectives over time, and begin the collection and analysis of quantifiable cost figures key to smart building adoption.

Works Cited

Abuarqoub, A., Abusaimeh, H., Hammoudeh, M., Uliyan, D., Abu-Hashem, M. A., Murad, S., Al-Jarrah, M., & Al-Fayez, F. (2017). A Survey on Internet of Things Enabled Smart Campus Applications. *Proceedings of the International Conference on Future Networks and Distributed Systems*, 1–7. https://doi.org/10.1145/3102304.3109810

Abuimara, T., Hobson, B. W., Gunay, B., O'Brien, W., & Kane, M. (2021). Current state and future challenges in building management: Practitioner interviews and a literature review. *Journal of Building Engineering*, *41*, 102803. https://doi.org/10.1016/j.jobe.2021.102803

Achouch, M., Dimitrova, M., Ziane, K., Sattarpanah Karganroudi, S., Dhouib, R., Ibrahim, H., & Adda, M. (2022). On Predictive Maintenance in Industry 4.0: Overview, Models, and Challenges. *Applied Sciences*, *12*(16), 8081. https://doi.org/10.3390/app12168081

Almalki, S. (2016). Integrating Quantitative and Qualitative Data in Mixed Methods Research—Challenges and Benefits. *Journal of Education and Learning*, *5*(3), 288. https://doi.org/10.5539/jel.v5n3p288

Appel-Meulenbroek, R., & Danivska, V. (2023). Steps and theories towards more effective business case processes within existing organisations: An inter-disciplinary systematic literature review. *Business Process Management Journal*, *29*(8), 75–100. https://doi.org/10.1108/BPMJ-10-2022-0532

Arshad, R., Zahoor, S., Shah, M. A., Wahid, A., & Yu, H. (2017). Green IoT: An Investigation on Energy Saving Practices for 2020 and Beyond. *IEEE Access*, *5*, 15667–15681. https://doi.org/10.1109/ACCESS.2017.2686092

Atkin, D., Chaudhry, A., Chaudry, S., Khandelwal, A. K., & Verhoogen, E. (2017). Organizational Barriers to Technology Adoption: Evidence from Soccer-Ball Producers in Pakistan*. *The Quarterly Journal of Economics*, *132*(3), 1101–1164. https://doi.org/10.1093/qje/qjx010

Baharetha, S., Soliman, A. M., Hassanain, M. A., Alshibani, A., & Ezz, M. S. (2024). Assessment of the challenges influencing the adoption of smart building technologies. *Frontiers in Built Environment*, *9*, 1334005. https://doi.org/10.3389/fbuil.2023.1334005

Bal, M., Bryde, D., Fearon, D., & Ochieng, E. (2013). Stakeholder Engagement: Achieving Sustainability in the Construction Sector. *Sustainability*, *5*(2), 695–710. https://doi.org/10.3390/su5020695

Balaji, B., Bhattacharya, A., Fierro, G., Gao, J., Gluck, J., Hong, D., Johansen, A., Koh, J., Ploennigs, J., Agarwal, Y., Bergés, M., Culler, D., Gupta, R. K., Kjærgaard, M. B., Srivastava, M., & Whitehouse, K. (2018). Brick: Metadata schema for portable smart building applications. *Applied Energy*, *226*, 1273–1292. https://doi.org/10.1016/j.apenergy.2018.02.091

Barnett-Page, E., & Thomas, J. (2009). Methods for the synthesis of qualitative research: A critical review. *BMC Medical Research Methodology*, *9*(1), 59. https://doi.org/10.1186/1471-2288-9-59

Boote, D. N., & Beile, P. (2005). Scholars Before Researchers: On the Centrality of the Dissertation Literature Review in Research Preparation. *Educational Researcher*, *34*(6), 3–15. https://doi.org/10.3102/0013189X034006003

Borhani, A. S. (2016). Individual and Organizational Factors Influencing Technology Adoption for Construction Safety. *University of Washington, Thesis*.

Boyes, H., Norris, P., & Watson, T. (2014). *Application of asset management in managing cyber security of complex systems*. Asset Management Conference 2014, London, United Kingdom.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Burak Gunay, H., Shen, W., & Newsham, G. (2019). Data analytics to improve building performance: A critical review. *Automation in Construction*, *97*, 96–109. https://doi.org/10.1016/j.autcon.2018.10.020

Chong, H.-Y., Wong, J. S., & Wang, X. (2014). An explanatory case study on cloud computing applications in the built environment. *Automation in Construction*, *44*, 152–162. https://doi.org/10.1016/j.autcon.2014.04.010

Cirigliano, A., Cordone, R., Nacci, A. A., & Santambrogio, M. D. (2018). Toward Smart Building Design Automation: Extensible CAD Framework for Indoor Localization Systems Deployment. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, *37*(1), 133–145. https://doi.org/10.1109/TCAD.2016.2638448

Coar, J. T., & Sewell, J. P. (2010). Zotero: Harnessing the Power of a Personal Bibliographic Manager. *Nurse Educator*, *35*(5), 205–207. https://doi.org/10.1097/NNE.0b013e3181ed81e4

Creswell, J. W., & Miller, D. L. (2000). Determining Validity in Qualitative Inquiry. *Theory Into Practice*, *39*(3), 124–130. https://doi.org/10.1207/s15430421tip3903_2

Crowe, E., Mills, E., Poeling, T., Curtin, C., Bjørnskov, D., Fischer, L., & Granderson, J. (2020). Building commissioning costs and savings across three decades and 1500 North American buildings. *Energy and Buildings*, *227*, 110408. https://doi.org/10.1016/j.enbuild.2020.110408

De Wilde, P. (2014). The gap between predicted and measured energy performance of buildings: A framework for investigation. *Automation in Construction*, *41*, 40–49. https://doi.org/10.1016/j.autcon.2014.02.009

DeJonckheere, M., & Vaughn, L. M. (2019). Semistructured interviewing in primary care research: A balance of relationship and rigour. *Family Medicine and Community Health*, *7*(2), e000057. https://doi.org/10.1136/fmch-2018-000057

Ergen, E., Kula, B., Guven, G., & Artan, D. (2021). Formalization of Occupant Feedback and Integration with BIM in Office Buildings. *Journal of Computing in Civil Engineering*, *35*(1), 04020055. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000940

Floris, A., Porcu, S., Girau, R., & Atzori, L. (2021). An IoT-Based Smart Building Solution for Indoor Environment Management and Occupants Prediction. *Energies*, *14*(10), 2959. https://doi.org/10.3390/en14102959

Ghansah, F. A., Owusu-Manu, D.-G., & Ayarkwa, J. (2021). Project management processes in the adoption of smart building technologies: A systematic review of constraints. *Smart and Sustainable Built Environment*, *10*(2), 208–226. https://doi.org/10.1108/SASBE-12-2019-0161

Hammarberg, K., Kirkman, M., & De Lacey, S. (2016). Qualitative research methods: When to use them and how to judge them. *Human Reproduction*, *31*(3), 498–501. https://doi.org/10.1093/humrep/dev334

Hancock, M., Amankwaa, L., Revell, M., & Mueller, D. (2016). Focus Group Data Saturation: A New Approach to Data Analysis. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2016.2330

Hosking, D., & Pluut, B. (2014). (Re)constructing Reflexivity: A Relational Constructionist Approach. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2010.1140

Inayat, A., & Raza, M. (2019). District cooling system via renewable energy sources: A review. *Renewable and Sustainable Energy Reviews*, *107*, 360–373. https://doi.org/10.1016/j.rser.2019.03.023

Iqbal, J., Khan, M., Talha, M., Farman, H., Jan, B., Muhammad, A., & Khattak, H. A. (2018). A generic internet of things architecture for controlling electrical energy consumption in smart homes. *Sustainable Cities and Society*, *43*, 443–450. https://doi.org/10.1016/j.scs.2018.09.020

Jia, M., Komeily, A., Wang, Y., & Srinivasan, RaviS. (2019). Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Automation in Construction*, *101*, 111–126. https://doi.org/10.1016/j.autcon.2019.01.023

Kallio, H., Pietilä, A., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, *72*(12), 2954–2965. https://doi.org/10.1111/jan.13031

Katipamula, S., & Brambley, M. R. (2005). Methods for Fault Detection, Diagnostics, and Prognostics for Building Systems—A Review, Part I. *HVAC&R Research*, *11*(1), 3–25. https://doi.org/10.1080/10789669.2005.10391123

Lawal, K., & Rafsanjani, H. N. (2022). Trends, benefits, risks, and challenges of IoT implementation in residential and commercial buildings. *Energy and Built Environment*, *3*(3), 251–266. https://doi.org/10.1016/j.enbenv.2021.01.009

Leedy, P. D., & Ormrod, J. E. (2021). *Practical Research Planning and Design* (12th ed.).

Liebowitz, M. (2012, April 10). *Smart Meter Hacks Cost Hundreds of Millions Annually, FBI Says*. NBC News. https://www.nbcnews.com/id/wbna47003851

Lv, Y., Zhou, Y., Wang, H., Zhao, T., Liu, T., He, X., Zhang, L., & Liu, J. (2019). Study on the multivariate prediction model and exposure level of indoor and outdoor particulate concentration in severe cold region of China. *Ecotoxicology and Environmental Safety*, *170*, 708–715. https://doi.org/10.1016/j.ecoenv.2018.12.031

Marian Carcary. (2021). The Research Audit Trail: Methodological Guidance for Application in Practice. *Electronic Journal of Business Research Methods*, *18*(2). https://doi.org/10.34190/JBRM.18.2.008

Mayo, G., & Snider, D. (2016). BAS and Cybersecurity: A multiple discipline perspective. *International Annual Conference of the American Society for Engineering Management, ASEM*. International Annual Conference of the American Society for Engineering Management, ASEM, Concord, NC. https://facilityexecutive.com/2016/08/cyber-security-for-buildings/

McLaughlin, J. (2004). Winning project approval: Writing a convincing business case for project funding. *Journal of Facilities Management*, *2*(4), 330–337. https://doi.org/10.1108/14725960410808294

Menezes, A. C., Cripps, A., Bouchlaghem, D., & Buswell, R. (2012). Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied Energy*, *97*, 355–364. https://doi.org/10.1016/j.apenergy.2011.11.075

Mohajan, H. K. (2018). QUALITATIVE RESEARCH METHODOLOGY IN SOCIAL SCIENCES AND RELATED SUBJECTS. *Journal of Economic Development, Environment and People*, *7*(1), 23. https://doi.org/10.26458/jedep.v7i1.571

Montgomery, R. D. (2020). Creating Safeguards For Rising Building Commissioning Costs. *ASHREA Journal*.

Moon, M. D. (2019). Triangulation: A Method to Increase Validity, Reliability, and Legitimation in Clinical Research. *Journal of Emergency Nursing*, *45*(1), 103–105. https://doi.org/10.1016/j.jen.2018.11.004

Moreno, M., Úbeda, B., Skarmeta, A., & Zamora, M. (2014). How can We Tackle Energy Efficiency in IoT BasedSmart Buildings? *Sensors*, *14*(6), 9582–9614. https://doi.org/10.3390/s140609582

Omrany, H., Soebarto, V., Zuo, J., & Chang, R. (2021). A Comprehensive Framework for Standardising System Boundary Definition in Life Cycle Energy Assessments. *Buildings*, *11*(6), 230. https://doi.org/10.3390/buildings11060230

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. *Administration and Policy in Mental Health and Mental Health Services Research*, *42*(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Park, H., & Rhee, S.-B. (2018). IoT-Based Smart Building Environment Service for Occupants' Thermal Comfort. *Journal of Sensors*, *2018*, 1–10. https://doi.org/10.1155/2018/1757409

Parn, E. A., & 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), 245–266. https://doi.org/10.1108/ECAM-03-2018-0101

Prebanić, K. R., & Vukomanović, M. (2023). Exploring Stakeholder Engagement Process as the Success Factor for Infrastructure Projects. *Buildings*, *13*(7), 1785. https://doi.org/10.3390/buildings13071785

Qiang, G., Tang, S., Hao, J., Di Sarno, L., Wu, G., & Ren, S. (2023). Building automation systems for energy and comfort management in green buildings: A critical review and future directions. *Renewable and Sustainable Energy Reviews*, *179*, 113301. https://doi.org/10.1016/j.rser.2023.113301

Randolph, J. J. (2009). A Guide to Writing the Dissertation Literature Review. *Practical Assessment, Research & Evaluation*, *14*(13).

Rascolean, I., & Sorina Rakos, I. (2020). The Influence of Costs on the Economic Substantiation of the Decision with an Impact on Business Evaluation. *"Ovidius" University Annals. Economic Sciences Series (Online)*, *XX*(1), 1020–1028.

Rincon, J. L., Lavy, S., & Fernandez-Solis, Jose. L. (2017). A Strategic Approach to Target Capital Investment on Facility Assets: Literature Review. *Journal of Facility Management Education and Research*, *1*(1), 30–39. https://doi.org/10.22361/jfmer/76316

Rodgers, M., Sowden, A., Petticrew, M., Arai, L., Roberts, H., Britten, N., & Popay, J. (2009). Testing Methodological Guidance on the Conduct of Narrative Synthesis in Systematic Reviews: Effectiveness of Interventions to Promote Smoke Alarm Ownership and Function. *Evaluation*, *15*(1), 49–73. https://doi.org/10.1177/1356389008097871

Saridaki, M., & Haugbølle, K. (2019). Identifying Contradictions of Integrating Life-Cycle Costing in Design Practices. In I. Lill & E. Witt (Eds.), *10th Nordic Conference on Construction Economics and Organization* (Vol. 2, pp. 33–39). Emerald Publishing Limited. https://doi.org/10.1108/S2516-285320190000002038

Schneider-Marin, P., Winkelkotte, A., & Lang, W. (2022). Integrating Environmental and Economic Perspectives in Building Design. *Sustainability*, *14*(8), 4637. https://doi.org/10.3390/su14084637

Shafique, K., Khawaja, B. A., Sabir, F., Qazi, S., & Mustaqim, M. (2020). Internet of Things (IoT) for Next-Generation Smart Systems: A Review of Current Challenges, Future Trends and Prospects for Emerging 5G-IoT Scenarios. *IEEE Access*, *8*, 23022–23040. https://doi.org/10.1109/ACCESS.2020.2970118

Shu, X., Tian, K., Ciambrone, A., & Yao, D. (2017). *Breaking the Target: An Analysis of Target Data Breach and Lessons Learned* (arXiv:1701.04940). arXiv. http://arxiv.org/abs/1701.04940

Siccardi, S., & Villa, V. (2023). Trends in Adopting BIM, IoT and DT for Facility Management: A Scientometric Analysis and Keyword Co-Occurrence Network Review. *Buildings*, *13*(1), Article 1. https://doi.org/10.3390/buildings13010015

Smith, J., & Noble, H. (2014). Bias in research: Table 1. *Evidence Based Nursing*, *17*(4), 100–101. https://doi.org/10.1136/eb-2014-101946

Spachos, P., Papapanagiotou, I., & Plataniotis, K. N. (2018). Microlocation for Smart Buildings in the Era of the Internet of Things: A Survey of Technologies, Techniques, and Approaches. *IEEE Signal Processing Magazine*, *35*(5), 140–152. https://doi.org/10.1109/MSP.2018.2846804

Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X. (2019). A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends. *Automation in Construction*, *101*, 127–139. https://doi.org/10.1016/j.autcon.2019.01.020

Tay, A. (2020). How to write a superb literature review. *Nature*. https://www-nature-com.offcampus.lib.washington.edu/articles/d41586-020-03422-x

Tushar, W., Wijerathne, N., Li, W.-T., Yuen, C., Poor, H. V., Saha, T. K., & Wood, K. L. (2018). Internet of Things for Green Building Management: Disruptive Innovations Through Low-Cost Sensor Technology and Artificial Intelligence. *IEEE Signal Processing Magazine*, *35*(5), 100–110. https://doi.org/10.1109/MSP.2018.2842096

Vasileiou, K., Barnett, J., Thorpe, S., & Young, T. (2018). Characterising and justifying sample size sufficiency in interview-based studies: Systematic analysis of qualitative health research over a 15-year period. *BMC Medical Research Methodology*, *18*(1), 148. https://doi.org/10.1186/s12874-018-0594-7

Verma, A., Prakash, S., Srivastava, V., Kumar, A., & Mukhopadhyay, S. C. (2019). Sensing, Controlling, and IoT Infrastructure in Smart Building: A Review. *IEEE Sensors Journal*, *19*(20), 9036–9046. https://doi.org/10.1109/JSEN.2019.2922409

Wong, J. K. W., Li, H., & Wang, S. W. (2005). Intelligent building research: A review. *Automation in Construction*, *14*(1), 143–159. https://doi.org/10.1016/j.autcon.2004.06.001

Appendix A: Interview Protocol

0. Introduction:

   a. Thank you for agreeing to this interview, 'Is now still a good time to meet?'

   b. Introduction: Thank you for agreeing to participate in this interview regarding the costs associated with building automation systems (BAS) within the context of the Internet of Things (IoT). Your insights as a facility professional with experience in BAS and IoT technologies are invaluable to this study.

      During our discussion, we'll delve into various cost categories involved in utilizing BAS throughout the building lifecycle, including planning, design, construction, operations, and disposition. Your experiences and perspectives will shed light on challenges in accessing and tracking building automation data, as well as considerations when budgeting for BAS projects.

      Your participation will contribute significantly to advancing knowledge in this field and may benefit future building owners, operators, and researchers. Additionally, this research is foundational for my master's thesis in Construction Management at the University of Washington.

      I want to assure you that your participation is voluntary, and you may withdraw at any time without prejudice. All information provided will be kept confidential, and your identity will remain anonymous in any reports or publications resulting from this study.

      Once again, thank you for your participation and valuable insights. With your permission, I plan on recording this interview to retain as a reference during my research.

   c. Given this introduction do you agree to the interview and associated recording?

      As such I will start the recording. (focus on conversational language)

   d. This interview will be structured into 4 sections:

i. Your Background and Experience

ii. Challenges associated with BAS or IoT enabled BAS

iii. Costs associated with BAS or IoT enabled BAS

iv. Conclusions

1. Background and Experience:
    a. Please describe your experience with Building Automation Systems (BAS) implementation and operation.
2. Challenges: What challenges have you faced in tracking, accessing, planning, or managing BAS or IoT BAS data?
    a. How have you tackled these challenges?
3. Cost: Now I would like to talk about cost. Throughout a comprehensive review of relevant literature, we've identified these cost categories. How do they align with the ways you track costs? For each section focus on current and anticipated future costs of each area.
    a. Sensor deployment and management
    b. Data-related costs (management, etc.)
    c. Cloud computing – and associated hard/software costs.
    d. Dashboard or user interface costs (such as making, using deploying, training, etc.)
    e. Would you add or subtract from these cost categories?
4. Wrap-up: General reflections and conclusion…
    a. What should owners consider when evaluating the adoption of IoT enabled BAS, especially in regard to costs?

   b. Do you feel the cost categories of IoT enabled BAS are evolving? Considering the advancements of technology, the regulatory environment, and industry trends, how do you see cost drivers changing into the future?

5. Do you know of anyone else I should speak to in regard to this topic.
6. Any questions for me?
7. Next steps: I plan to have all interviews executed by [DATE], and a synthesis of my findings distributed to interviewees, such as yourself, by [DATE]. As you are able, please review these synthesized findings and provide commentary as appropriate by [DATE]. Thank you for your participation.

Appendix B: Draft Interview Solicitation

Note: the following solicitation is modeled after a sample found in the 12th ed of Practical Research & Design (Leedy & Ormrod, 2021)

Understanding the Costs of Building Automation Systems (BAS)

You are invited to participate in a study investigating the various cost categories associated with building automation systems (BAS) within the context of the Internet of Things (IoT). I'm reaching out to invite you to participate in a research study on building automation systems.

I am interested in gaining insights into the different cost categories involved in utilizing BAS throughout the building lifecycle, including planning, design, construction, operations, and disposition. The findings of this study will contribute to a better understanding of the costs of implementing BAS, which can be valuable for building owners, operators, and researchers.

As a professional with experience in building automation systems and IoT technologies, your participation in this study will provide valuable insights into the costs associated with BAS implementation and operation.

If you agree to participate, you will be asked to complete an interview session and a request for respondent validation. Respondent validation is a process of validating interview results with the respondent (you). After the interview, I will synthesize the findings and send you a copy. This synthesis will provide you with advance knowledge of my coming research and the opportunity to refute, validate or otherwise comment on the findings. The interview will focus on discussing your experiences and perspectives regarding the cost categories of BAS, challenges in accessing and tracking building automation data, and considerations when budgeting for BAS projects.

The results obtained will contribute to advancing knowledge in the field of building automation systems and may benefit future building owners, operators, and researchers. Additionally, this research underpins my thesis research, foundational for my obtainment of a master's in science in Construction Management at the University of Washington.

Your participation in this study is voluntary, and you may withdraw at any time without prejudice. All information provided will be kept confidential, and your identity will remain anonymous in any reports or publications resulting from this study. Any recordings obtained, if authorized, will be held in confidence.

If you have any questions or concerns about your participation in this study, please contact me Andrew Steele at asteele1@uw.edu or my advisor Carrie Sturts Dossick at cdossick@uw.edu.

By agreeing to participate in this study, you acknowledge that you have read and understood the nature of the study. You retain all legal and human rights, and you may withdraw from the study at any time. Your participation also grants permission for the researchers to obtain relevant information related to building automation systems from you.

Thank you for considering participating in this study.

Andrew Steele | University of Washington