

The New Work of Building Operations in the Digital Age: The Impact of IoT and Digital Twins  
on Facility Management and Operational Practices

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**Abstract**

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The technological revolution which many have coined Industry 4.0 has been marked by digital transformation which is reshaping the ways we live and work in a fundamental way. The built environment industries have been no exception to this digital transformation as technologies like Internet of Things (IoT) and Digital Twins (DT) are being integrated into building operations to help solve many industry wide issues that have prevailed for decades. The integration of IoT and DT technologies into the operations phase of the building lifecycle have the potential to aid in reducing climate impacts, increasing building visibility, enhancing energy management, and increasing the overall precision and control that facility management (FM) organizations have in the buildings and campuses they manage. However, digital technologies such as IoT systems and DTs are difficult to implement and involve a higher level of commitment to systems operation and maintenance than the traditional building control systems which are prevalent in many facilities today. In addition, the digitalization of the operations phase has not been studied as

holistically as other building lifecycle phases such as design and construction, making the integration of digital tools a more difficult task. Shifts to move away from existing control systems/practices and implement IoT systems or DTs to manage building operations will involve shifts in the ways people work and interact with the building's technology and each other. What is unknown is the types of shifts that are needed to fully realize the potential of IoT and DT technology for building operations and management. The objective of this research was to identify and understand the shifts to existing FM practices from both an organizational and technological perspective that are required for the management of buildings when FM organizations shift to the use of IoT systems or DTs for operations management. This research additionally aims to understand how theories of digitalization from design and construction phases apply to the operations phase. This research used qualitative case study methods and two case studies were conducted with operations organizations. This research identifies key organizational shifts needed for integrating IoT and DTs into building operations, emphasizing breaking down disciplinary silos, developing new technical skills while leveraging institutional knowledge, new leadership requirements to guide the organizational transition, and the need to challenge entrenched and habitual standards and practices. Technical insights include new practices in configuring IoT devices, managing networks and security, and utilizing IoT capabilities for analytics and troubleshooting. The study also highlights parallels with theories of digitalization across building lifecycle phases and contributes new insights, advancing the body of knowledge in digitalization for operations.

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## **Chapter 1: Introduction**

### **1.1: Identifying The Problem**

The 21st century has been defined by digitalization and technology as it has changed almost every aspect of how our society lives, communicates, and conducts business. Just forty years ago, the internet was in its nascence and ubiquitous technologies like cell phones were a rare commodity. Now people have powerful computers that they carry with them everywhere they go. This unprecedented development of technology brought with it the realization that data is powerful, and utilizing this new abundance of data can lead to major process improvements in a diverse range of disciplinary sectors. Data has become essential as organizations begin to realize their potential to inform decision-making, improve existing processes, achieve new goals, and increase profits. Digitalization is defined as the process of transforming the structure, processes, skills, and culture of an organization so it can use digital technologies for services, products, and experiences that create business value (El Sawy et al., 2016). Other researchers define the process of digitalization similarly, such as Legner et al. (2017) who define digitalization as “the manifold sociotechnical phenomena and processes of adopting and using these technologies in broader individual, organizational, and societal contexts” (pg. 301). Overall, digitalization refers to the process of digital transformation within an organization, as opposed to digitization, which refers to the process of converting analog signals into a digital platform (Tilson et al., 2010). The industry sectors that support the built environment, such as Architecture, Engineering, and Construction (AEC) as well as Facility Management (FM), which are sometimes combined to be referred to as Architecture, Engineering, Construction, and Operations (AECO), are no exception to the technological revolution which many have coined

Industry 4.0. The Industry 4.0 has been guiding a digital transformation that is changing work and operations in a substantial way (Ghobakhloo, 2020, Fernandez et al., 2024).

Integrated digital technologies, like Internet of Things (IoT) systems and digital twins (DT), have a clear application to building life cycle management and opportunities for integration exist in almost all phases. Within a building's life cycle, the operations phase is often the longest and typically most environmentally impactful. As found by previous studies, the operational phase of a building's life cycle consumes the highest amount of energy (80-85%), and it is the highest contributor to greenhouse gas emissions (>50%) (Sharma et al., 2011). Within the United States, buildings are some of the leading consumers of energy as they account for around 40% of the energy consumption nationwide (energy.gov). When a building is completed and enters the operations phase, it is typically handed over to a FM group who is responsible for maintaining the building's common operations as well as activities associated with the reuse, repair, and refurbishment of existing systems to extend the building's lifespan. Traditionally, the operations phase has taken a backseat to the more glamorous and interesting design and construction phases. Within the built environment realm, this has historically placed the FM discipline low in attention, recognition, funding, and respect in comparison to the other disciplines (Atkin and Brooks, 2021).

With the increased realization that the current prevailing practices in FM are outdated, under-resourced, and inefficient, coupled with the rapid development of digital technologies, digital tools have come to the forefront as a potential solution to the generally universal problems of reactive maintenance, high energy demand, high costs, and a lack of systematic information organization, storage, and exchange within the facilities/operations disciplines (Akcamete et al., 2010). Other researchers in the field describe the opportunities for digital technologies to incite

change in the current state of FM around major issues such as linear and siloed processes, static systems, and work-intensive rather than data-intensive strategies (Atta, 2021). Historically, digitalization in the FM industry has included the integration of various building management systems such as building automation systems (BAS), computerized maintenance management systems (CMMS), energy management systems (EMS), and computer aided facility management (CAFM) systems (Araszkievicz, 2017, Becerick-Gerber et al., 2021). To define these terms, a BAS consists of “a system in a building that controls and monitors building services” (Domingues et al., 2016, pg. 2). A CMMS, similarly to a CAFM, is defined as “a tool to support maintenance strategy based on an information system and a set of functions that process data to produce indicators to support maintenance” (Lopes et al., 2016, pg. 269), and an EMS is a computerized system that can manage energy usage in a building or facility in an automatic or semi-automatic fashion based on things like control logics or installed functions (Lee and Cheng, 2016). In the past few decades, the FM industry has additionally seen the integration of other digital tools such as geographic information systems (GIS) and building information management (BIM) (Kang and Hong, 2015). More recently, the FM industry has shifted its attention towards integrating Internet of Things (IoT) technologies and digital twins (DT) into buildings, which are the primary subjects of investigation in this study. The integration of such technologies aimed to enhance the efficiency and effectiveness of building management and maintenance during their operational phase.

However, digital information management technologies such as IoT systems and DTs are difficult to implement and involve a higher level of commitment to systems operation and maintenance than the traditional building control systems which are prevalent in many facilities today (Almatared et al., 2024). These existing building control systems (discussed above),

including CMMS, CAFM, BAS, and EMS, come with established methods of operation and maintenance procedures which have aided in shaping the typical FM practice in the preceding decades, requiring that the operations sector adapt and catch up to the new operational realities of integrated digital technologies (Fernandez et al., 2024). Such existing building management systems are useful tools in practice, however are characterized by a lack of interoperability which makes them unable to communicate or exchange any form of information (Araszkiwicz, 2017, Becerick-Gerber et al., 2021), a critical component to the use of IoT systems and DTs with real-time data capabilities. These older building control systems are additionally often characterized by manual data entry, disparate data repositories, and infrequent updates (Mannino et al, 2021, Becerick-Gerber et al., 2021), which clash with the organizational and technological requirements of maintaining and operating IoT systems or DTs. Shifts to move away from this and implement IoT systems or DTs to manage building operations will involve shifts and changes in the ways people work and interact with the building's technology and each other. What is unknown is the types of shifts that are needed to fully realize the potential of IoT and DT technology for building operations and management. We know from digital transformation in the construction phase as well as others that these types of shifts are both technical as well as organizational (Anderson et.al, 2012, Won et al., 2013). What is emerging in the adoption of IoT and DT systems to replace or complement existing building control systems is a shift in practice in the operations sphere, and it is these shifts that often dramatically change the paradigm on existing methods of work and operations (Atta, 2021).

## 1.2: Research Objective

The objective of this research was to identify and understand the shifts in FM practices from both an organizational and technical perspective which are required for the management of buildings when FM organizations transition to the use of IoT systems or DTs for building management. This objective is important due to the general lack of literature around FM and the operations phase in regards to digitalization and its impact on existing organizations and their operational practices. Studies that have been published in this realm indicate that the management of the operations phase of the building lifecycle is often marked by a lack of data interoperability (Araszkievicz, 2017), is divided disciplinarily (Atkins, 2021), and rather stagnant and conservative with change around the use of new systems and digital tools (Anderson et al., 2012). This suggests that the design and construction phases and the operations phase likely share many parallels in digitalization. These similarities in structure and culture may lead to comparable tensions around digital adoption. When analyzing analogous technological transitions in design and construction phases, an idea which will be greatly expanded on in Chapter 2, existing studies show that both technical and non-technical factors, including things such as effective collaboration, organizational structure, and willingness to share information were regarded as critical success factors to the adoption of novel digital technologies into existing organizations (Won et al., 2013). Similar investigations in the adoption of new technologies into design and construction phases have come to similar conclusions (Dossick and Neff, 2011, Leite et al. 2016, Khanzode et al., 2008, Dossick et al., 2019, Ahmed, 2018, Azouz et al., 2014), indicating that FM organizations will likely have to shift their practices both organizationally and technologically in order to adequately adopt IoT or DT systems into their existing organizations. With this research, the organizational and technological shifts required

for FM teams were examined and outlined in the integration of IoT and DTs into existing FM organizations.

The research questions for this study included the following:

**Broad questions:**

1. How do facility management organizations change/adapt their management and maintenance practices in order to leverage IoT systems and digital twins?
2. How do theories of digitalization from studies in the design and construction phases apply to the operations phase?

**Specific Questions:**

3. What shifts in organizational practices are needed for facility management teams to leverage IoT technologies?
4. What new practices are necessary for facility management teams to ensure the technological feasibility of IoT systems?
5. Does the use of a digital twin require the same shifts in organizational practices as IoT, and are there additional changes or unique considerations that emerge when analyzing the use of digital twins in facility management practices?

### **1.3: Terminology Defined**

This dissertation focuses on two types of technologies in FM: the Internet of Things (IoT), and Digital Twins (DT). This section introduces these two terms and defines the relationship between them.

#### **1.3.1: What is the Internet of Things (IoT)?**

The term “Internet of Things” was first coined by Ashton in 2009 to link radio-frequency identifications in Proctor and Gamble’s supply chain with internet connectivity for the purpose of logistics (Ashton, 2009). However, since its original conception, the IoT concept has expanded dramatically and there are many definitions to explain the term in various industry sectors and use cases. In concept, IoT is “a network of physical things which are connected through the Internet and able to generate, extract, and record data for real-time monitoring and decision-making in a variety of applications” (Lawal and Rafsanjani, 2022, pg. 252). According to the International Organization for Standardization (ISO), IoT is defined as “infrastructure of interconnected entities, people, systems and information resources together with services which processes and reacts to information from the physical world and virtual world” (ISO/IEC 20924:2024, sec. 3.2.8). IoT connectivity infrastructure is based on various technologies including ambient intelligence, internet protocol, communication technologies, WiFi, Bluetooth, ZigBee, embedded devices, or wireless sensor networks and applications (Reaidy et al., 2015). IoT devices, for example smart meters or temperature/humidity/occupancy sensors, collect data at all times during a building's operations. Such IoT devices are embedded or installed into the “things”, which refers to the physical objects within which they exist. This allows them to collect data about the performance of an object, communicate among the network, and exchange

information with each other and any management applications. In order to communicate, such IoT devices connect to a network which allows them to exchange data and transmit data to storage or other locations for the purpose of data analytics (Atta and Talamo, 2020).

### **1.3.2: What is a Digital Twin (DT)?**

The concept of a DT was first formulated in 2002 at the University of Michigan by Dr. Michael Grieves in his work related to Product Lifecycle Management (PLM). In this early concept, the model developed by Dr. Grieves contained 3 main components which set the standard for DT: real space, virtual space, and a linking mechanism between the two for the bidirectional flow of data. This model was referred to as the “Mirrored Spaces Model” (Grieves and Vickers, 2017). However, in relation to the term “digital twin” itself, NASA was the first to coin the term and develop a definition. In a technology and processing roadmap in 2010, NASA defined a DT for the first time as “an integrated Multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin” (Shafto et al., 2010, pg. 18). Following 2010, this definition continued to be used by the NASA program and can be seen in future publications (Glaessgen and Stargel, NASA, 2012). Since the development of the DT definition by NASA, the DT concept has been applied to a variety of industries beyond space and aviation such as manufacturing and construction (Agrawal, Fischer and Singh, 2022). For example, in a review of how DTs are being applied in the manufacturing industry, Kritzing et al. (2018) identified five major application areas including layout planning, optimization of the product life cycle, production planning and control to improve and automate decision support, process redesign, and predicting and managing maintenance (Agrawal, Fischer and Singh, 2022).

Within the construction industry, DTs have been applied to a variety of contexts. In the design and engineering phases, Opoku et al. (2021) describe the possibility of combining BIM and wireless sensor networks (WSN) to establish a real-time active model to provide designers with “a complete digital footprint of the project” (pg. 7). This research team described the application of DT within the construction phase for structural system integrity, as well as helping in resource, materials, schedule, quality and sequence management. Researchers have also identified the growing application of DT into FM operations such as real-time data access for predictive maintenance, building performance management, and energy consumption optimization (Opoku et al., 2021). However the application of DT in the operations phase of the building lifecycle will be discussed in detail in Chapter 2.

Although the application of DT has grown dramatically in the past decade, which has led to a variety of definitions for the term, the main components that compose a DT have remained the same since its inception. These main components include:

1. Physical object/component (the physical object which is modeled)
2. The virtual model of the physical object/component
3. Bidirectional data flow from the physical object to the virtual one and vice versa.

In relation to the bidirectional flow of data, Agrawal, Fischer and Singh (2022) state that the data from the physical to the virtual component is “raw”, meaning it requires processing in order for it to be converted to helpful information that can be used for things such as decision-making. In relation to the data flow from the virtual component to the physical component, this data is

processed information that “can be used to manage the day-to-day usage of the physical entity” (pg. 5).

### **1.3.3: Relationship between Internet of Things (IoT) Devices and Digital Twins (DT)**

To provide context to this study, it is important to understand how the concepts of IoT and DT relate to each other. As stated by Jacoby and Uslander (2020), “the rise of digital twins coincides with the rise of the IoT” as “the vast amount of sensor data and device metadata from the IoT creates the requirement for organizing and managing all that information in an adequate way, which is realized by the concept of DTs” (pg. 2). The authors continue to describe that IoT connects devices to the internet and collects information from these devices which is then fed into DTs in order to manipulate the data to optimize or automate a process, facility, or machine. The important functionality that IoT devices bring to a DT, usually in the form of facility integrated sensors in relation to building operations, is by equipping the virtual model (twin) with real-time data. As stated by Al-Ali et al. (2020), DTs use IoT technologies, data analytics and artificial intelligence to understand product and system performance, make predictions about future scenarios, and detect potential failures before they become evident. Khajavi et al. (2019) break down the digital twin concept for its application to buildings by describing that a digital twin relies on a “wireless sensor network integration” (pg. 07), “data analytics” (pg. 07), and a visualization component that can come in the form of a “3D CAD model extracted from BIM or a custom 3D model of the building” (pg. 07). The sensor network data which comes from IoT devices is then used in the DT to create a “real-time view of the asset” (pg. 07), which allows for “real-time analytics, informed decision-making, building efficiency, and comfort enhancement” (pg. 07). In essence, a digital twin is capable of being connected to the real-time environment

through the integration of IoT devices and sensors into a facility which is then model integrated. The real-time data which is used to make decisions, predictions etc. about the performance of a building relies on the IoT devices which collect this real-time information.

#### **1.4: Overview of Study**

This research is in the form of two case studies which holistically aim to address Research Questions 1 and 2. The first of the two case studies was conducted in partnership with the University of Washington Facilities and investigated the shifts/changes to FM practices required for the integration of IoT devices and systems into existing FM operations. This case study was separated into two parts, one which analyzed the changes to FM practices from an organizational perspective, while the other outlines the changes to practice from a technological perspective (Research Questions 3 and 4). To add clarity, the first part of this case study analyzed topics such as shifts in practice around the breakdown of disciplinary silos, requirements around bridging the gap between technological skills and institutional knowledge, and the leadership efforts necessary to navigate the technological transformation. The second part of this case study analyzed new practices necessary for maintaining IoT systems technologically, such as establishing sensor configuration, establishing network connectivity, device lifecycle management and managing access control and security.

The second of the two case studies was done in partnership with the Dallas Fort Worth (DFW) International Airport in Texas and focused on their DT development and utilization efforts for operations management. The goal of this case study was to test/validate the findings from the first case and analyze any new findings around changes to practices when a DT is implemented and utilized as opposed to IoT systems (Research Question 5).

## **1.5: Summary of Chapters**

**Chapter 2** outlines the literature review conducted for this research. The literature review is separated into two parts, the first part is focused on the application opportunities and potential benefits of IoT and DT integration into FM practices. The second part of this chapter outlines the themes related to digitalization in design and construction phases and the current state of the operations phase in relation to each of these identified themes. Lastly, the points of departure for this research will be outlined.

**Chapter 3** details the method used for this research including the methodological approach, setting, data collection methods, data analysis methods, and reliability and validity.

**Chapter 4** outlines the findings from Case Study One, Part One (Research Question 3). This chapter outlines the results of the case study conducted at the University of Washington in partnership with Facilities, with a focus on the shifts and changes to facility management and maintenance practices from an organizational perspective.

**Chapter 5** outlines the findings from Case Study One, Part Two (Research Question 4). This chapter outlines the results of the case study conducted at the University of Washington in partnership with UW Facilities with a focus on the new practices necessary for FM teams in order to ensure the technological feasibility of integrated IoT systems.

**Chapter 6** outlines the findings of Case Study Two (Research Question 5), which was done with the DFW International Airport. This study focused on validating the findings from the UW IoT Case Study (Case Study One) and analyzing any new findings regarding changes to organizational practices when a DT is implemented and utilized as opposed to IoT systems.

**Chapter 7** discusses the greater paradigm shift in operations brought about by digitalization and how the theories of digitalization from design and construction studies apply to the building operations phase. This discussion aims to understand how the themes in changes to practice required for digitalization in design and construction phases apply to the operations phase and what new themes emerge around digitalization in operations which have resulted from this research study.

**Chapter 8** concludes this study, providing a research summary, detailing the contributions to knowledge, potential impacts on the industry, limitations and future studies/next steps.

## **Chapter 2: Literature Review**

This literature review chapter is separated into two parts. In Part 1 of Chapter 2, the application opportunities and benefits of IoT and DT implementation to FM operations will be discussed in detail. This will outline how using IoT systems and DTs can lead to positive benefits for the management of building operations, if organizational and technical practices shift to best accommodate the use of these digital tools. This type of analysis into digital adoption and implementation, focused on the required shifts in practice to accommodate digitalization, is less studied in the operations phase of the building lifecycle, which motivates the objective of Part 2 of the literature review. In Part 2 of this chapter, the points of departure for this study will be introduced through a discussion of the literature around themes related to digitalization in design and construction phases and the current state of the operations phase in relation to each of those identified themes. In the second part of the literature review, I will discuss what can be derived from digitalization in design and construction phases of the building lifecycle in order to inform the research targeted at understanding digitalization in operations.

### **2.1 Literature Review Part 1**

#### **2.1.1 Application Opportunities and Benefits of IoT and DT to FM**

In this section of the literature review, I will address the application opportunities for IoT and DTs in FM and highlight the benefits such applications can bring to a FM organization in the operations phase. Research shows that IoT devices and DTs can be applied to buildings to aid facility managers in increasing their visibility, access to data, general building awareness, and ability to make good decisions. Throughout the two case studies which are part of this research, the shifts in practice necessary to achieve the potential benefits of IoT and DT systems will be

outlined. However an overview of how and why these technologies can be used in the management of buildings to improve operations will be discussed in this section. The various application opportunities and benefits of IoT and DT systems to FM operations and management will be described in detail below.

### **2.1.2 Real-Time Data and Integration**

The most direct potential benefit of the integration of IoT devices and DTs to the FM discipline is the ability to work with real-time data. Using IoT devices, whether linked to a virtual model or not, enable facility managers to gain insights into the operational state of their facilities. As found in their research on digital transformation in FM focused on IoT and big data for service innovation, Atta and Talamo (2020) illustrate that IoT use in FM can increase the ability of facility managers to create updated knowledge repositories due to the availability of real-time sensor data which then allows them to store real-time data and process it when needed. As described by Sahara and Aamer (2021) in their case study on IoT integration into a smart warehouse, “IoT accommodates the digital connectivity of the physical and digital components to present real-time data storage and sharing” (pg. 2). In relation to the use of IoT to manage the warehouse facility, the authors highlight benefits from a “massive amount of data” (pg. 2), “continuous moving information” (pg. 2), “greater visibility” (pg. 2), “synchronized information” (pg. 2) and “real time monitoring” (pg. 2). The ability to use real-time data in building operations allows facility managers to make better decisions regarding the present state of a facility and increase the overall visibility of their buildings, which can allow them to move to more predictive maintenance strategies as more data is collected and processed.

### 2.1.3 Improved Information Management

Core to the idea of IoT and DT application to the built environment and the management of facilities using these technologies is the centralization of data, which in FM organizations is often scattered, non-standardized and siloed based on discipline (Becerik-Gerber et al., 2012). The use of these technologies helps organizations to remove all the silos in processes that “otherwise work in isolation within compartments and divisions in more traditional industrial structures” (Singh et al., 2021, pg. 5). This allows for centralization and a more simplified information management structure. In an analysis of the challenges and benefits of implementing DTs in the use phase of a building conducted by Elyasi et al. (2023), the authors conducted a series of interviews around DT for operations with both industry and academic personnel. The results of these interviews showed that most interviewees agreed that the “main benefit of implementing digital twins relates to information management” (pg. 8), and specifically “better knowledge and understanding of the building” (pg. 8). The interview results portrayed that the use of DT helped FM personnel improve the ways they share and update information. Additionally, centralizing information in a DT improved learning and understanding of both the building itself and the FM processes necessary to maintain it. In Singh et al. (2021) work outlining the DT concept, history, and future direction, the authors highlight the critical centralization of information necessary for the development and use of a DT stating, “to create a DT, it is important to synchronize data scattered across different software applications, databases, hard copies etc.” (pg. 7). This synchronization then “simplifies the process of accessing and maintaining the data in one place” (pg. 7), which helps create an organization-wide comprehension of the building system through the development of organized methods of documentation and communication. As described by Jiang et al. (2023) in an example of IoT

application to a nuclear power plant facility, the authors describe that the plant is “composed of multiple components with differentiated functions, technologies, and forms, which requires transdisciplinary stakeholders to process cross-domain knowledge in a multi-subproject condition” (pg. 3). This is meant to highlight the level of complexity around information management for such critical systems brought by the “number of items interconnected through the intricate dependencies and constraints” (pg. 3). With that, the authors propose the application of information technology such as IoT for the purpose of information management to help in the development of centralized information and visualization systems like DTs. Allowing organizations to better organize and manage their data increases visibility and improves the productivity of personnel and the quality of their work.

#### **2.1.4 Improved Energy Management and Sustainable Operations**

Energy use in non-residential buildings is expected to increase by 57% worldwide from 2018- 2050 (eia.gov, 2019). The International Energy Agency additionally identified buildings as the largest energy consuming sector in the world as they consume over one-third of the total final energy. Buildings are additionally significant contributors to carbon dioxide emissions into the atmosphere. Utilizing IoT technologies and DTs can help FM personnel improve visibility of their systems and can give them access to unprecedented amounts of data that can be used to improve energy performance. As described by Atta and Talamo (2020), IoT devices can transmit data to a central management platform where that data can then be processed to control major energy consuming building systems. In non-residential buildings, occupants are often less considerate of energy use when utilizing spaces due their disconnect with paying usage costs (Azizi et al., 2020), which makes managing occupant energy use throughout the building over

the span of its operations a fluid and difficult task. Occupancy and occupant behavior have a large impact on a buildings energy use which can be tracked and controlled with IoT and DT systems in order to account for the highest energy saving opportunities throughout buildings. Various studies have implemented IoT sensors in building systems to aid in predicting and reducing the impact of occupant energy use in buildings. For example, Haidar et al. (2019) developed a building occupancy prediction model using eight IoT sensors to collect data over time in order to reduce building energy consumption based on occupancy. Onile et al. (2021) highlight the opportunities for DTs to be used for building energy management by creating a real-time synced model of the energy system in a building with a virtual replica which is integrated with building energy and occupant data. Overall, gaining insights into the performance of building systems and the ability to automate DT and IoT technologies to achieve energy efficiency objectives can aid FM personnel in increasing overall building sustainability and saving energy.

### **2.1.5 Predictive and Scheduled Maintenance**

A bibliometric review of DT enabled smart facility management conducted by Hakimi et al. (2024) showed that based on a co-occurrence network of keywords related to DT in FM, one of the most prominent words included “predictive maintenance” (pg. 37). The authors continue to describe predictive maintenance as “a diagnostic strategy that continuously evaluates the condition of the asset through various sensors” (pg. 37) and “uses AI based algorithms to provide automatic feedback so that action can be taken when needed to avoid failure and unnecessary incurrence of costs” (pg. 37). The benefits of predictive maintenance in the management of building operations is outlined by Tahmasebinia et al. (2023) who state that it can help FM

personnel in predicting and addressing equipment problems in advance which avoids wasted energy and saves on costs. In a systematic literature review focused on predictive maintenance in the Industry 4.0 era, Zonta et al. (2020) state that data is the key to the “generation of information that can anticipate or collaborate in making predictive decisions” (pg. 1). As expressed by Zonta et al. when expanding on the benefits of predictive maintenance to avoid system failures, using a DT can increase productivity by reducing downtime within which operators are unaware of systems which need attention. This can allow FM personnel to move away from reactive equipment management processes which are common in traditional facility management organizations (Singh et al., 2021), and embrace a more predictive strategy which will ultimately save them money, time, stress, and energy. As further expressed by Singh et al., using a DT can predict anomalies and errors in the system ahead of time and therefore react by scheduling maintenance activities.

### **2.1.6 Data-Driven Decision Making**

The large amounts of data collected through IoT sensors and simulated in a DT enables facility managers to make informed decisions that are supported by evidence in the form of data. Using IoT systems or a DT can help predict potential problems in real-time by monitoring integrated systems and providing feedback at a continuous rate to personnel to aid in decision-making, which can help reduce costs and increase sustainability (Salem and Dragomir, 2022). In the management of individual building systems such as electricity, heating, air conditioning and lighting, which form a large portion of building energy use, the application of a DT allows operators to simulate performance and predict consumption to control and reduce energy usage, therefore improving decision-making around the energy management of buildings

(Tahmasebinia et al., 2023). Echoing these ideas, Madubuike et al. (2022) state that the synchronization of a building model (BIM, 3D model etc.), sensors, and data from AI or ML technology “enables smart building operators to have access, control, detect faults and make smart decisions over the various systems, workspaces, and their ensembles within an asset” (pg. 163). With the use of IoT and DT systems, decisions can be based on robust information and data, improving the operational efficiency of buildings and allowing personnel to take less risks in decision making.

### **2.1.7 Enhanced Safety and Security**

IoT sensors can be used to detect building hazards such as leaks, fires, or unauthorized access in real-time and inform the proper personnel before these hazards become major problems. By integrating IoT and DT, facility managers can simulate emergency scenarios, develop response plans, and increase safety and security measures in their facilities. Khanjavi et al. (2023) conducted a study on using DTs for safety and security in which two case studies were explored for fire and anomaly detection using IoT sensors in a DT model. In their study on fire safety improvements using a DT during the operational phase, the researchers utilized embedded sensors which continuously observed the simulated interior environment. Over time, the sensors were able to formulate a “normal operational signature” (NOS) (pg. 44) within the system, which portrayed the state of normalcy in the environment. This NOS was then used to detect anomalies in the space at any given time and, therefore, better inform FM personnel of safety issues. As stated by the researchers, “if temperatures outside of the NOS are detected, the digital twin can estimate the location of the anomaly in the 3D model, visualize it, and inform the operator. This can prevent fire events and mitigate damages that can cause long equipment downtime” (pg. 46).

Studies additionally exist that have focused on increasing security in buildings using IoT technologies and DTs. For example, Dutta et al. (2018) developed an “enhanced security system for smart buildings using IoT” (pg. 158) in which building access was controlled using IoT technologies. Their proposed system integrates two layer verification for building access using the building visitors’ smartphone and IoT devices, which allow or deny building access based on the person’s access allowances or restrictions. With increased building visibility and access to data, FM operators can make their facilities safer, more secure, and more likely to detect and avoid potentially critical hazards.

### **2.1.8 Space Optimization and Occupant Satisfaction**

IoT sensors and devices can track occupancy levels and usage patterns in spaces within facilities. By analyzing this data alongside building models in a DT, facility managers can optimize space utilization, improve workflows, and allocate resources more effectively. Studies have shown that “interior use of space” (pg. 127) and “physical conditions” (pg. 127) accounted for 43.5% and 43.3% of the variance in employees’ perceived productivity. “Interior use of space” on its own accounted for 43.1% of the variance in employees’ wellbeing (Agha-Hosseini et al., 2013). Occupants who are happy with their workplace’s environmental quality are generally assumed to report higher levels of productivity (Kim and Dear, 2012). In most buildings, standardized and fixed values of occupancy for spaces are used during design phases, these numbers drawn from maximum capacity regulations, like fire regulations, as stated in the findings of the researchers above. The reality of occupancy levels can be much different from those assumed and expected. IoT devices can measure occupancy levels and specific energy use in spaces in order to give FM personnel access to data on the actual usage of spaces and their

energy consumption. IoT systems and DTs can be used to optimize space use to improve occupant satisfaction as well as customize activities such as cleaning or maintenance in areas that require higher attention (Seghezzi et al., 2021). With real time data on occupancy and space utilization through sensors and other technologies, buildings can increase sustainability by controlling lighting and other space management functions and ensure that systems are not operating when they are not in use. In addition, spaces can be improved to increase occupant satisfaction. Planning can also improve around the utilization of spaces to optimize the use of the facility area. This can also aid in potentially managing unpredictable events like COVID-19 and aid in space management and responding to such public health problems (Hassony and Ahmed, 2024).

### **2.1.9 Literature Review Part 1 Conclusion**

The literature discussed above shows opportunities for IoT and DT integration into FM practice to optimize a plethora of FM operations. Application opportunities range from improved energy management to predictive and scheduled maintenance to space optimization and increased occupant satisfaction. However, simply investing in IoT or DT systems will not lead to FM teams being able to properly leverage these technologies for such outcomes such as the ones described above. This will likely require shifts in practice and changes to existing organizational norms and operations in order to reap the benefits of IoT and DT integration to their fullest, an area of study that has not been deeply investigated in the operations literature. Following Part 1 of the literature review, Part 2 will focus on the more studied design and construction phases to understand the required shifts to practice and tensions in digital adoption and how that can be applied to the operations phase. Within Part 2 of the literature review, the points of departure for

this study will be established through a discussion of the literature around themes related to digitalization in design and construction phases and the current state of the operations phase in relation to each of these identified themes.

## **2.2 Literature Review Part 2**

### **Themes Related to Digitalization in Design and Construction Phases and the Current State of Operations**

In this section, I will present the findings of Part 2 of my comprehensive literature review which encompasses two main components. Within each of the sections listed below, I will first present a discussion of the literature around the themes related to digitalization in design and construction phases and the current state of the operations phase in relation to each of these identified themes. Subsequently, I will describe my points of departure within each thematic category (below), framing and laying the groundwork for my study.

This section has been organized into four thematic categories:

1. Disciplinary Silos
2. Standardization in Technology Use and Data Management
3. Resistance to Change within Cultural Norms and Entrenched Organizational Practices
4. Leadership in Technological Transformation

### **Literature Review Part 2 Rationale**

Under each thematic category, the following review of literature is organized into three sections: first I introduce the theme focused on digitalization from the AEC literature which is primarily studies of digitalization from design and construction phases of project lifecycles. Then I present the literature from FM/operations related to this theme. Finally, in each theme I identify the points of departure for this study.

This part of my literature review is structured in this way for two main reasons. Firstly, the literature available around operations is not very extensive, in particular when analyzing the adoption of technologies into operations and the relationship between the operations phase and digitalization. For this reason, this literature review aimed to understand the challenges, adoption barriers, and relationship between earlier building life cycle phases and digital adoption in order to understand how digital technologies have been integrated into design and construction phases and what tensions have impeded or challenged that transformation. This helped serve as a point of departure to develop themes of investigation for this study and helped identify where tensions would likely exist and changes to existing practices may be necessary.

The review of literature related to digitalization in the design and construction phases then allows me to investigate as to whether the same challenges and adoption barriers are present in digitalization for operations and subsequently analyze whether any novel considerations exist in the realm of FM and the adoption of different technologies in the form of IoT and DT. This then helps contribute to knowledge in building operations studies and allows analogous themes to be drawn between the phases.

Second, many similarities exist in the design and construction and operations phases of the building lifecycle, which validate this analysis. This is likely a result of the direct transition between the two in the natural progression of a building's lifecycle, as a building is handed off to operations teams directly following its completion by design and construction teams. For example, in the construction phase of the building lifecycle, management is divided by discipline such as mechanical subcontractors who do their portion of work, electrical subcontractors, and plumbers who are all responsible for the duties within their disciplinary boundaries. In the operational phase, there is a progression of this management structure, as disciplinary entities

manage their portion of operations serving as an extension of the same expertise as what is present in the building phase. In addition, organizational and cultural trends in construction transcend lifecycle phases, such as the historically slow rate of innovation and low use of modern technologies, which generally reflect directly on the operations phase as well. The construction phase of a building's lifecycle lays the groundwork for how operations are to function, creating natural similarities between the phases. When analyzing technology adoption across the building lifecycle, there is an absence of study in technology applications in the operational part of the building lifecycle. However, the similarities in structure, culture, and practice connect these phases in many ways which validates this literature review.

### **Thematic Category 1: Disciplinary Silos**

#### **Disciplinary Silos Hinder Digitalization in the AEC Industry**

Studies in the literature focused on design and construction phases, particularly concerning the integration of new technologies into existing construction organizations, highlight the challenge posed by disciplinary silos within the AEC industry. These silos have been identified as a significant barrier to the digitalization of the construction sector. In a study observing MEP coordination for two large projects using BIM in order to analyze its effect on collaboration, Dossick, Neff and Homayouni (2012) aimed to understand what inhibits innovation and technological adoption in the construction industry when adopting digital tools such as BIM. The researchers found that organizational and cultural barriers inhibit collaboration and communication within AEC teams in particular when construction and design professionals continue to work within silos marked by formal lines of communication between them, even when using BIM. The researchers further stated that the divisions of labor in commercial

construction dictate and define distinct scopes of work that are difficult to dismantle through the use of a collaborative technology like BIM. Similar findings are echoed across the literature, such as the study conducted by Azouz et al. (2014) that found that the use of digital technologies like BIM can increase rather than decrease “the number of lines of communication and their ensuing complexity” (pg. 1) due to the fact that disciplinary units operate as silos when it comes to communicating with traditional methods. Another study conducted by Bonanomi et al. (2020) focused on the impact of digital transformation on formal and informal organizational structures in the AEC and highlights that key characteristics of the industry such as “silos” (pg. 4) and “individuality” (pg. 4) are clashing with the interconnectivity required to manage and utilize new digital technologies which are disruptively changing the ways professionals do their work, interact with each other, and set their working context. Similar findings are expressed by Neff, Fiore-Silvfast and Dossick (2010) on a study focused on understanding when digital artifacts such as BIM can serve to bridge knowledge barriers across epistemic communities. In this study the researchers found that IT tools designed to foster collaboration can instead “solidify and make explicit organizational and cultural differences between project participants” (pg. 556). This can be attributed to “deeply embedded disciplinary thinking”(pg. 556), which is “not easily overcome by digital representations of knowledge” (pg. 556).

### **Presence of Disciplinary Silos in FM**

The current state of FM practice and organizational structure contains disciplinary silos within its composition that are similar to design and construction phases. Although these silos do not come in the form of separate organizations such as design firms and general contracting entities, silos come in the form of compartmentalized or segregated functional areas or

departments within the organization. These silos are often based on discipline such as mechanical system management groups, energy engineers, electrical teams, plumbing, central utility plant operators, or contracted consulting firms which support specific FM functions. When characterizing the typical organizational structure of FM organizations, Atkins (2021) observed that public sector FM entities frequently adhere to a top-down functional line approach. The author describes this approach by stating, “what it lacks in flexibility, it can make up for in its adherence to defined processes and procedures, often rigidly so” (pg. 125). The author then states that this form of organizational structure within FM often has the “potential to encourage and reinforce siloed working” (pg. 126). Atkins continues in his discussion of this phenomenon describing that such siloed working tends to “weaken inter-departmental communication and collaboration, resulting in limited commitment to higher level goals and objectives by those on the lowest, operational level” (pg. 126). In their study on big data analytics and facilities management, Yang and Bayapu (2019) identify the existence of information silos between different units within FM organizations which limit the potential for implementing a data-driven decision-making system. In addition, Atta (2021) describes the potential for information and communications technologies to help organizations overcome information “silos” which inhibit participation, inclusion, and information sharing. The current literature on FM highlights the existence of disciplinary silos which inhibit centralized information management and storage throughout the organization.

### **Point of Departure**

Digitalization in the design and construction phases by integrating virtual tools like BIM requires a breakdown of disciplinary silos to support interdisciplinary collaboration, data sharing,

and communication. The literature poses that a more centralized organizational approach is critical to integrating digital tools like BIM. The existing literature on FM identifies the existence of disciplinary silos within FM organizations and practices. Consequently, this research takes up the question: as FM organizations integrate digital tools like IoT and DT, will a centralized approach that breaks down disciplinary silos and barriers be required?

Table 1 below summarizes what has been discussed above, identifying the inhibiting factor of disciplinary silos that hinder digitalization from the design and construction literature, the specific themes related to this, as well as the current state of FM operational practices in relation to this theme. Lastly, the table summarizes my point of departure drawn from Category 1 in this literature review.

**Table 1:** Disciplinary Silos in AEC and FM

Overarching Theme	Specific Themes Related to Inhibiting Factor	Current State of FM	Point of Departure
<b>Disciplinary Silos in the AEC Industry</b>	AEC professionals continue to work in silos marked by formal lines of communication when using digital tools (e.g. BIM) (Dossick et al., 2012)	Structure of public sector FM entities are often inflexible, adhere to defined processes and procedures and encourage/reinforce siloed working (Atkins, 2021)	Digitalization in the construction industry requires the breakdown of disciplinary silos. FM organizations are often marked by disciplinary silos. As IoT technologies become integrated into FM operations, will a breakdown of disciplinary silos be required?
	Use of digital tech. (e.g. BIM) can increase rather than decrease lines of communication and complexity due to communication silos (Azouz et al, 2014)	Siloed working in FM can weaken inter-departmental communication and collaboration, resulting in limited commitment to higher level goals by operational level employees (Atkins, 2021)	
	Industry characteristics such as "silos" and "individuality" clash with interconnectivity required for digital technology use ~ disruptive changes to industry norms (Bonanomi et al., 2020)	Existence of information silos between different units in FM organizations (Yang and Bayapu, 2019)	
	IT tools designed to foster collaboration can instead solidify cultural and organizational differences in teams (Neff et al., 2010)		

## **Thematic Category 2: Standardization in Technology Use and Data Management**

### **Digitalization in the AEC Requires Standards around Technology and Data Management**

Based on the design and construction phase literature, the adoption of digital technologies within the AEC industry requires the development of clear data and delivery standards and robust data management procedures to facilitate effective collaboration among the diverse project disciplines when using digital tools. The literature presents the development of organizational standards around digitalization as one of the major challenges to the adoption and use of digital tools to take the place of traditional methods and materials such as paper documents and established disciplinary communication routines. In Khanzode, Fischer and Reed's (2008) study on the benefits and lessons learned from implementing VDC technologies for the coordination of MEP systems, one of the major implementation challenges faced was how to address technical issues and share virtual models. In this study, they found that clear and coordinated data delivery standards were required for the use of VDC technologies as the variety of disciplines on the project created their models independently and therefore, had to agree upon rules and standards around the sharing of electronic 3D models in order to efficiently collaborate. In Harty and Whyte's (2010) study examining the practical and theoretical tensions between existing ways of working and the introduction of new digital coordination tools, part of their conclusions outlined that it is essential for digital coordination that a document management system was used to make sure that data was correctly produced, held in a central location, shared and regularly updated in order for project team members to utilize digital tools effectively. Similarly, in a study conducted by Leite et al. (2016) focused on identifying the grand challenges in the construction industry to adopting visualization, information modeling, and simulation (VIMS) tools, the researchers identified data formats and interoperability to enable data sharing

as a major challenge and further identified “output formats and mediums suited for construction” (pg. 2) as the biggest challenge to visualization from a survey of both academic and industry respondents. In relation to information modeling, “data format and interoperability” (pg. 2) was again ranked as the biggest challenge. This included issues such as non-industry standard formats for BIMs, “incompatible file types” (pg. 7), and “lost model data between software applications especially when using unstructured data formats” (pg. 7). In their study *Messy Talk and Clean Technology*, Dossick and Neff (2011) develop the concepts of “messy talk” and “clean technology” as necessary attributes to collaborating within the dynamic complexity of design and construction processes. They define the concept of “clean technology” as “explicit processes and standards required for sharing digital information” (pg. 85), which in combination with informal open-ended problem-solving conversations and collaborations, can lead to more effective use of virtual tools like BIM.

### **Unstandardized and Decentralized Data Management and Technology Use in FM**

Due to existing organizational structures, which often result from the prevalence of disciplinary silos, FM organizations are often disorganized in data collection, management, and storage and often do not follow a standard and centralized approach to managing facility data. In their study on implementing Construction Operations Building Information Exchange (COBie) into UW Facilities, Anderson et al. (2012) found that no consistent procedures for naming or storing building information were present, in addition to no centralized data storage location or procedures existing in the organization. In addition, the technologies that have been long used for the purpose of FM, including CMMS, CAFM, BAS, EMS, or EDMS, are useful tools in building management; however they are characterized by a lack of interoperability, which makes them

unable to communicate or exchange any form of information (Araszkiewicz, 2017). This makes data sharing difficult and can promote a lack of standardization in data form and type. This is further echoed by Mannino et al. (2021) who state that within “Computerized Maintenance Management Systems (CMMS), Energy Management Systems (EMS) and Building Automation Systems (BAS)... data are often fragmented and manually entered after the handover of the building” (pg. 2). Mannino et al. continue to point out that such fragmentation and “data poorness” (pg. 2) generate laborious and inefficient practices. When describing the way FM groups typically locate building data, Becerik-Gerber et al. (2012) stated that FM personnel need “access to vast amounts of information and log into multiple databases, sometimes toggle between them, locate the information needed, and print the information to perform a certain job” (pg. 435). The researchers further describe that FM personnel rely on paper-based documents or on their experience and intuition to locate building equipment and problem areas when maintenance is necessary. When such methods are utilized, very little important building data is centrally stored or inventoried for future reference and a standard around data type, form, and storage cannot be established holistically throughout the organization. This becomes more difficult when building information cannot be transferred or exchanged between various management systems. The lack of centralized data management often makes FM processes operate within a reactive system, meaning that they “are based on heuristic experience and worst case-scenarios” (Sing et al., 2021, pg. 6). In a case study conducted by Atkins (2021) with an operations organization for an aerospace corporation, managers at this facility shared their serious concerns about the level of reactive maintenance in the organization and the risk of equipment failures this brings about. In a similar study conducted by Mobley (2008) on the maintenance team of the Boeing Commercial Airplane Group, the researcher found that lower

level organization members are not receiving or do not have access to adequate data and the data that is available is not being used in meaningful ways by the organization. The author continued to state that data collection methods and plans must be established to improve maintenance activities. Authors studying paradigm shifts enabled by ICTs in FM describe the current FM practice as being characterized by statements such as “lack of information”, “poor quality information”, “not updated information” and “not-validated information” (Atta, 2021, pg. 37).

When describing the opportunities for FM organizations to improve data management and potentially move to a preventive or predictive maintenance strategy, Akcamente (2010) highlights the ineffectiveness involved in current FM practices around collecting and utilizing data for maintenance activities. The researcher states that inadequacies exist in the data handover procedure of building information and that FM teams must engage in a holistic and accurate transition of data and documents for all operational parts of the building in order to effectively perform their duties. Akcamente recommends that initial steps towards storing and maintaining facility information and capturing building behavioral information be taken, suggesting that a reliable maintenance database of building information, history of work and associated change information is necessary. This is further echoed by Sullivan et al (2010) who suggested inventorying operational history, recording failures, and analyzing data around failures as necessary to FM organizations to help standardize how data is used in organizations.

### **Point of Departure**

Efforts towards digitalization within design and construction phases suggest that organizations must establish comprehensive standards around the utilization of technologies, data protocols, exchange procedures, nomenclature conventions, and other important aspects to

ensure technology interoperability to best transition to the use of digital tools like BIM. The literature focused on the current state of FM practice suggests that many organizations lack structured information repositories and standards around data formats, and their building data remains decentralized, unstandardized, and often not interoperable. Consequently, in this research, I ask the question: with the integration of IoT technologies into FM operations, will FM organizations need to increase efforts toward standardized data management, standardized data form, type, exchange, and storage processes, and standardization of practice around how technology and the data it produces is used throughout the organization?

Table 2 below summarizes what has been discussed above, identifying the need for standardization in technology use and data management for digitalization from the design and construction literature, the specific themes related to this, as well as the current state of FM operational practices in relation to this theme. Lastly, the table summarizes my point of departure drawn from Category 2 in this literature review.

**Table 2: Standardization in Technology Use and Data Management**

Overarching Theme	Specific Themes Related to Inhibiting Factor	Current State of FM	Points of Departure
<b>Development of Standards Around Technology Use and Data Management</b>	Clear and coordinated data delivery and exchange standards are required for the use of VDC technologies (Khanzode et al., 2008)	Traditional FM management tools are not interoperable and unable to exchange or share information (Araszkievicz, 2017). Data within these tools is often fragmented and manually entered leading to "data poorness" (Mannino et al., 2021)	Digitalization in design and construction phases requires that organizations establish comprehensive standards governing the utilization of data and technology. FM organizations often lack structured information repositories, and their building data is often decentralized and unstandardized. With the integration of IoT technologies into FM operations, will standardization in data and technology use be required?
	A document management system is essential for digital coordination – data is correctly produced, centrally held, shared and updated (Harty and Whyte, 2010)	FM personnel often work within multiple databases, utilize paper based documents, and rely on tacit knowledge that is not documented (Becerik-Gerber et al., 2021)	
	Data format and interoperability to enable data sharing are major challenges to digitalization (Leite et al., 2016)	Lack of centralized data/data use standards etc. often create a reactive maintenance and management system (Atkins, 2021), (Mobley, 2008), (Singh et al., 2021)	
	Explicit processes and standards required for sharing digital information are necessary ~ clean technology (Dossick and Neff, 2011)	Inadequacies exist in data handover and collection procedures making collecting, inventorying, and utilizing data for maintenance activities difficult (Akcamente, 2010) (Sullivan et al., 2010)	

**Thematic Category 3: Resistance to Change within Cultural Norms and Entrenched**

Organizational Practices

**Existing Cultural and Organizational Norms make Digitalization Difficult in Design and Construction Phases**

In Dossick, Osburn, and Neff’s (2019) study focused on understanding how to make technologies based in visualization, virtual worlds and information exchange useful for design and construction operations, they found that tension in the use of these technologies exists with established norms of practice as well as social and organizational norms that “frame team members expectations about how they should engage with others on a project” (pg. 1). This study highlights that engineers, architects, and construction professionals are trained in different

methods of working, approaches and processes for problem-solving which can make the interaction among them with the use of digital tools fragmented and complex. According to the authors, successful technology adoption in the construction industry partially relies on people's attitudes toward the technology and their individual levels of resistance to change which can sprout from challenging their cultural and organizational norms of practice. A similar point is made by Harty and Whyte (2010) who found that "the delegation of IT-based tools might be resisted where such delegation significantly challenges existing ecologies of practices" (pg. 472) which are based in well-established professional and experiential factors. This study further found that even with the introduction of digital tools, the exchange of information between disciplines often resisted the use of these tools and continued to come in the form of paper-based documents even with a digital model. As founded by MacLoughlin and Hayes (2019), a significant barrier to the adoption of BIM in the construction industry is the aging demographic of the industry and enthusiasm to adopt new technologies. Other studies additionally highlight the criticality of overcoming resistance to change amongst the workforce and getting personnel to understand the potential value of new technologies to their day to day operations (Arayici et al., 2011). This is additionally highlighted by Ahmed (2018) who found that the top five crucial barriers to the implementation of BIM include "social and habitual resistance to change" (pg. 108), "traditional methods of contracting" (pg. 108) and "lack of awareness about BIM" (pg. 108). Studies done by Hartmann and Fischer (2009) recognize the resistance to change amongst AEC professionals with the introduction of new digital tools and methods of working and recommend that this resistance should be reconceptualized as a necessary and important part of a construction IT implementation. This frames resistance to change as a natural part of the organizational transformation process, straying away from the notion that such resistance to

change is negative and disruptive, but rather a productive and important aspect of organizational change. Overall, changing operations with the integration of digital tools calls for changes in the state of normalcy in terms of practice, culture, documentation, and overall methods of operation, and it is these changes that seem to often result in resistance and pushback as part of the digitalization process where staff negotiate new practices and processes.

### **Entrenched Organizational Practices and Cultural Norms in FM**

The current state of the FM industry paints a picture of a rather static discipline that has not drastically changed in organization and structure as technologies have emerged in the market. As a whole, analogue methods of operation, which are manual methods that do not use digital computers or technologies (Prayagi, 2015), persist in the FM industry, marked by the low use of modern technologies or digital systems and an aging workforce resistant to changing their methods of operation and outlook on the requirements of managing a facility. As described by Anderson et al. (2012) in a study focused on the implementation of COBie and BIM into the existing University of Washington FM organization, the researchers concluded that the majority of facility employees are “conservative with computing environments” (pg. 690) and prefer to leverage people or paper-based documents to exchange information even when digital alternatives were present. The researchers also discovered that the information structures within the FM division have evolved over time into trade-specific systems for gathering and handling data, incorporating both paper-based and digital formats within a rigid and inflexible system based on that discipline’s operating preferences. Continued reliance on paper-based information and tacit knowledge exchange are echoed in studies by Becerik-Gerber et al. (2011) analyzing the application areas and data requirements for BIM-enabled FM. The authors describe the

current state of FM information systems, highlighting the prevalence of “computerized maintenance management systems (CMMS), electronic document management systems (EDMS), energy management systems (EMS), and building automation systems (BAS)” (pg. 431), which support FM practices independently however create a fragmented non-interoperable data environment which is often based on manually entering data at the onset of a building’s operations and infrequently thereafter. In operations, organizational change can threaten an organization’s status-quo and create natural resistance among workers and managers (Franklin, 2008), likely due to habitual norms. Overall, the FM industry has been rather static in structure, technology, practice, and methods which may clash with the requirements of more advanced digital systems.

### **Point of Departure**

The existing design and construction literature shows that entrenched organizational practices and cultural norms inhibit digitalization in the industry and often lead to resistance to change due to habitual preferences. The FM sector is marked by entrenched organizational practices, is divided disciplinarily, and is limited in technology use and development. This makes it static in its habitual norms and processes in many ways. Consequently, in this research, I asked that given the existence of these factors in FM operations, will entrenched organizational practices and norms in FM challenge the adoption of IoT and DT technologies within FM organizations?

Table 3 below summarizes what has been discussed above, identifying the prevalence of cultural norms and entrenched organizational practices in the design and construction phases from the literature, the specific themes related to this, as well as the current state of FM

operational practices in relation to this theme. Lastly, the table summarizes my point of departure drawn from Category 3 in this literature review.

**Table 3: Resistance to Change through Cultural Norms and Entrenched Organizational Practices**

Overarching Theme	Specific Themes Related to Inhibiting Factor	Current State of FM	Points of Departure
<b>Resistance to Change through Cultural Norms and Entrenched Organizational Practices</b>	AEC professionals are trained in different methods, approaches, and processes which makes interaction with digital tools fragmented and complex. Successful adoption relies on individual levels of resistance to change from challenging cultural and organizational norms of practice (Dossick et al., 2019).	A majority of facility employees are “conservative with computing environments”, preferring to leverage people or paper based documents to exchange information (Anderson et al. 2012)	Digitalization in the AEC industry shows that resistance to change due to entrenched organizational practices and cultural norms inhibits the adoption of digital technologies. The FM sector is marked by entrenched organizational practices, disciplinarily groupings, and limited technologically due to habitual norms. Will entrenched organizational practices and norms in FM impede the adoption of IoT technologies within FM organizations?
	The delegation of IT-based tools might be resisted where such delegation significantly challenges existing ecologies of practices based in well-established professional and experiential factors (Harty and Whyte, 2010)	Information structures within the FM division have evolved over time into trade-specific systems for gathering and handling data, incorporating both paper-based and digital formats within a rigid and inflexible system (Anderson et al., 2012)	
	Social and habitual resistance to change, traditional methods of operation and a lack of awareness of the benefits of technology must be overcome (Ahmed, 2018) (Arayici et al., 2011)	FM information systems are interoperable and often create a fragmented data environment in which data is often manually entered (Becerik-Gerber et al., 2011)	

#### **Thematic Category 4: Critical Role of Leadership in Steering Organizational Change**

##### **Strong and Effective Leadership is Essential to Digitalization**

In a series of case studies on BIM adoption for precast concrete design by structural engineering firms, Kaner et al. (2008) identified the criticality of leadership by management in the early stages of technological transition, particularly when “human resource issues arise and frustrations may be felt” (pg. 322). A similar finding is made by Won et al. (2013) in their study on where to focus for the successful adoption of BIM with their finding that the “construction industry relies on individual leadership to overcome organizational and technical challenges”

(pg. 6). In Kunz and Fischer's (2012) study on the theory and methods of virtual design and construction (VDC), which includes detailed suggestions on how to implement VDC in practice, the authors highlight the important role of management in guiding the organizational vision, strategy, and operational plans. In Homayouni, Dossick, and Neff's (2014) study which analyzed the configurations of integration strategies used in over 30 high-performance projects, they found that the literature identifies four areas as effective in facilitating integrated practices, one being leadership. Their findings additionally showed that four elements create a sufficient recipe for achieving a high level of energy efficiency, including having committed and trustworthy team members and early and frequent involvement of the key team members to best facilitate integrated practices. The importance of leadership in adequately implementing BIM into existing organizations is further echoed by Azouz et al. (2014) who frame the BIM concept as an unbound innovation and state that "as the number of tools that support communication and information exchanges increases, so do users and managers need to develop their skills for the collective use of these tools" (pg. 5). Dossick and Neff (2009) state that "the industry is relying heavily on the individual leadership of particular people in the MEP coordination process to substitute for closer communication connections among trades and among construction divisions, a strategy that works only when strong, effective leadership is in place" (pg. 460). Additionally, in Hartmann et al. (2012) study on aligning BIM tools and construction management methods, they state multiple promoting factors for BIM-based tool implementations based on a number of studies. Some of these included "the availability of high quality support from IT departments and top management support" (pg. 606), "the existence of strong social networks to align goals and processes of an implementation" (pg. 606), and the personal motivation of implementing actors to use the tools. Resistance to change amongst organizational personnel is often additionally

addressed in the design and construction literature (Harty and Whyte, 2010, Arayici et al., 2011, Ahmed, 2018, Hartmann and Fischer, 2009), and managing this resistance to change is often under the responsibility of leadership. Lastly, in Bonanomi et al. (2019) study on the impact of digital transformation on formal and informal organizational structures of large architecture and engineering firms, they found that during technological transitions, formal reporting structures might not help in directly connecting employees to the right people. This often leads to the formation of “new informal leaders” (pg. 885) to help employees navigate the transition. This again highlights that leadership is a critical component of organizational digitalization and change, even if it is not coming through formal hierarchical communication lines.

### **Trends in Leadership in FM**

In Atkins (2014) literature, part of the author's work investigates the factors causing stress in facility management organizations. His findings included that tension exists within current FM organizations around “role ambiguity and inconsistency in management style” (pg. 94) and “senior managers who lack leadership skills and whose actions result in confusion and discord” (pg. 94). In Atkins work, he further discusses the implementation of Environmental Management Systems (EMS) in FM operations and states that implementation must be considered from three perspectives, one of those being leadership. The existence of disciplinary silos can additionally make centralized leadership more difficult in facility organizations. For example, In Anderson et al. (2012) case study with the facility division at the UW, the researchers found that “facilities operation and management is divided into geographic zones to better serve the university, and over the years many of the trades within each of the zones have developed and maintained their own system for collecting and managing data” (pg. 695). When

disciplines, zones, or trades operate as their own entities within a larger organization, the leadership necessary to incite change may be more difficult as groups have already cemented their own ways of working. In Sarpin et al. (2016) work to develop a people capability framework to promote sustainability in FM practices, the researchers found that “leadership skills and the necessity to develop good relationships with organization’s top management” (pg. 19) is an important aspect to promoting sustainability in the FM sector. Mobley (2008) identifies that one of the major challenges operations and maintenance organizations face in changing from a traditional to a highly collaborative environment is “fostering a culture of management support” (sec. 1.8), continuing to state that “a smooth transition depends heavily on securing management commitment, preferably early in the process” (sec. 1.35). The author expresses the importance of managers providing the “vision and leadership needed to spark change” (sec. 1.35) and just as critically, “the buy-in of middle managers” (sec. 1.35) to overcome the natural resistance to change.

### **Point of Departure**

Digitalization in design and construction relies on strong and effective leadership to guide organizational change. Similarly, the FM literature emphasizes the significance of leadership in driving transformation and shows that FM organizations are often marked by inconsistency in leadership and independently operating groups within organizations. Consequently, this research asks the question: as FM organizations adopt digital tools like IoT and DT for building operations and management, will the critical role of leadership remain important to the integration of these digital tools?

Table 4 below summarizes what has been discussed above, identifying the critical role of leadership in steering organizational change resulting from digitalization in the design and construction literature, the specific themes related to this, as well as the current state of FM operational practices in relation to this theme. Lastly, the table summarizes my point of departure drawn from Category 4 in this literature review.

**Table 4: Critical Role of Leadership in Steering Organizational Change**

Overarching Theme	Specific Themes Related to Inhibiting Factor	Current State of FM	Points of Departure
<b>Critical Role of Leadership in Steering Organizational Change</b>	Leadership by management is critical in the early stages of technological transition (Kaner et al., 2008)	Tension exists within current FM organizations around “role ambiguity and inconsistency in management style” and “senior managers who lack leadership skills and whose actions result in confusion and discord” which create stress in FM organizations (Atkins, 2014)	Digitalization in design and construction relies on the critical role of leadership in facilitating organizational change. Inconsistency is common in FM leadership and organizations often lack strong and central leadership. With the integration of IoT and DT technologies into FM operations, will strong and effective leadership remain indispensable for organizations integrating these digital tools?
	The construction industry relies on individual leadership to overcome organizational and technical challenges (Won et al., 2013)	One of the 3 main drivers in technological system implementation in FM organizations is leadership (Atkins, 2013)	
	To successfully implement new technologies, the availability of high quality support from IT departments and top management support, the existence of strong social networks to align goals and processes of an implementation, and the personal motivation of implementing actors to use the tools is necessary (Hartmann et al., 2012)	leadership skills and the necessity to develop good relationships with organization’s top management, vision and leadership in order to spark change, and the buy-in of middle managers are important attributes to organizational change (Saprin et al., 2016) (Mobley, 2008)	

## Literature Review Part 2 Conclusion

Having discussed the themes of digitalization in design and construction phases, as well as the literature around the current state of FM practice within those thematic categories, the points of departure for this research have been established with the goal of filling the gap in the literature around digitalization in operations. Part 1 of this literature review established the

benefits and application opportunities of IoT and DT to facility operations and management, while Part 2 aimed to draw from the more studied design and construction phases of the building lifecycle in order to understand what the requirements for digitalization are in that setting and how they might apply to the operations phase. This allowed me to understand how and why IoT and DT can benefit FM organizations, and then understand how those organizations will likely need to shift and adapt in order to leverage these digital tools. Following this, the next chapter will discuss the research methods used for this research.

## **Chapter 3: Research Method**

### **3.1: Methodological Approach - Qualitative Case Study Analysis**

The objective of this research was to identify and understand the changes to existing FM practices from both an organizational and technical perspective which are required for the management of buildings when FM organizations shift to the use of IoT systems and DTs for building management. With these objectives in mind, this research is intended to target people, their perspectives, and their lived experiences around using IoT systems and DTs within their facility organizations. This is done to gain a realistic and first-hand perspective into the tensions, challenges, and shifts that personnel are experiencing around the implementation of these systems and the changes that using such systems are bringing to their work, operational procedures, collaboration structures, and necessary skill requisites, to name a few. With these objectives in mind, qualitative research methods were chosen as the best fit to understand the relationship between facility personnel, their work, and the utilization of IoT systems and DTs. The goal of this research is to capture the experiences of people who are actively engaging in practices around the operations and maintenance of IoT and DT systems, which leads to a need to interface with facility personnel directly in order to understand their work, observe their routines, and understand the changes they are experiencing through within their individual perspectives. This goal makes quantitative study unfitting for the objectives of this study, which led me to pursue qualitative methods to address the research. Within the realm of qualitative research, the case study methodology was chosen as the best suited for this research.

Qualitative case study research allows for the exploration of a phenomenon within its naturally occurring context (Yin, 1993). In this research study, the phenomenon under investigation is the shifts and changes to practices that utilizing IoT and DT systems bring about

in an FM organization. In real-life environments, such as an active FM and operations organization, it is difficult to isolate variables and follow a traditional lab based quantitative experimental setting in the pursuit of valid conclusions. In a setting such as a facilities organization, the true “reality” of the research setting (context) is dynamic and ever changing, meaning that looking at it through a synthetic or static lens would only portray a single point in time within the active and complex environment. Within this research context, the study of the humans who produce the phenomenon under investigation is crucial as their opinions, thoughts, perceptions, and individually constructed realities are intricately interwoven with the outcomes of their actions that produce said phenomena. To understand the shifts in operations for facility personnel, we must speak directly to said personnel and explore their individual work processes and procedures around the technology to gain a realistic perspective as to how work is changing for FM employees with the use of IoT and DTs.

Within the umbrella of qualitative research methodology lie many different approaches such as case studies, ethnography, grounded theory, and narrative inquiry (Glesne, 2016). All of these methodologies share common characteristics in their pursuit of “discovery, insight, and understanding from the perspectives of those being studied” (Merriam and Tisdell, 2015, pg. 25). Foundational author in the establishment of case study research methodology, Robert Yin, defines a case study as “an empirical research activity that, by using versatile empirical material gathered in several different ways, examines a specific present-day event or action in a bounded environment.” (1994, pg. 18). Within the bounds of Yin’s definition, a case study “investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident” (pg. 13). The case study methodology and research methods within it complement this research study by allowing me to

gain first-hand perspectives from personnel within the bounds of the identified facility management organizations, which led to the utilization of the case study approach for this research.

### **3.2 Research Design + Strategy**

In this section, I will introduce my case study design, research setting, and population and sampling strategies for the two case studies that are included as part of this research. I will begin with case study one (UW) and follow it with case study two (Dallas Fort Worth Airport).

#### **3.2.1 Case Study One: University of Washington Facilities Case Study Design**

The first case study in this research focused on the University of Washington (UW) Facilities and investigated the shifts and changes to FM practices when using IoT systems for building operations, both organizationally and technologically. The UW had recently made an organization-wide transition to the implementation of IoT technologies in a plethora of buildings across campus, aiming to make a full transition to IoT based building operations in the near future (described in Chapter 4). This aligned nicely with this study's objectives as many facility personnel were present before and after this technological transition and the UW Facilities team actively sought to understand how to shift their organization and practices to accommodate the use of IoT technologies for their intended building management objectives.

In order to study the full range of changes to FM practices from both an organizational and technological perspective, Case Study One was split into two separate parts aimed at exploring the two interlinked phenomena. The first segment of the UW IoT Case Study (Chapter 4) targeted understanding the organizational shifts in practice brought on by the utilization of IoT

systems, while the second segment (Chapter 5) focused on the new practices necessary to ensure the technological feasibility of IoT systems.

### **Case Study One- Research Setting:**

The first case study for this research took place at the University of Washington within the bounds of the UW Facilities and those adjacent to its operations. This included a few interviews/collected materials from members outside of the direct UW Facilities stemming from UW Information Technology (IT), UW Sustainability, and closely related contractors from the McKinstry Building and Design Company (part of observation effort) and Casne Engineering (interview) who work with UW Facilities to maintain the energy meters on campus. Interviews and observations were mainly conducted on-site, within the UW Facilities main office on campus, with a few online interviews and observations when members were off-site or meetings included contracted parties outside of the UW organization. Document collection was based on directly provided documentation during interviews by FM personnel or FM organizational documents which were collected online and from within FM internal management portals which were holistically shared with me for this research study.

### **Case Study One- Participants and Sampling:**

In qualitative study, the “population”, as the term is used in quantitative study, is usually defined broadly to represent a large group or field, as opposed to quantitative study in which the population is defined more narrowly and contextually (Hurst, 2023). This is done in qualitative study to allow for exploration across a wide range of contexts and experiences within the targeted group, for example a disciplinary field. For this study, the case study bounds and

participants are looked at in terms of facility management organizations broadly, and the personnel that operate within these organizations. In qualitative study, the sample refers to the specific group of people that data is collected from (Hurst, 2023). Participants in this study were mainly part of UW Facilities, with 15 out of 20 conducted interviews being with direct members of the organization (see Table 5). The remaining 5 included an Energy and Sustainability specialist from UW Sustainability, two members from the UW IT Security and Cybersecurity Division, a member of the UW Project Delivery Group (PDG), and an external consultant who worked closely with UW Facilities from a technology infrastructure standpoint. The participants in this study are outlined in Table 5 below. In order to identify interview participants for this study, purposeful sampling was employed when selecting participants in initial stages (Patton, 2002). When identifying participants in the initial stages of this study, participants were recruited from UW Facilities directly. At this stage, the goal was to recruit a wide range of disciplinary professionals, ranging from facility managers and building coordinators to energy engineers and environmental controls technicians. After the initial recruitment period, the snowball sampling method was employed within the bounds of UW Facilities to identify new participants who could add to the value of the research. Using this sampling technique allowed me to pinpoint the most valuable participants for this study through the lens of other already interviewed participants. At the conclusion of each interview we (RA and myself) asked the participant(s) if they can recommend any facilities personnel which they deem would be able to contribute to the goals of this study. This allowed us to expand beyond our initially determined interview participants and focus on participants who can bring the highest value to our research investigation.

### **3.2.2. Case Study Two: DFW Airport Case Study Design**

The second case study that was conducted as part of this research was in partnership with the Dallas Fort Worth (DFW) International Airport in Texas, United States. The DFW Airport has recently developed and integrated multiple DTs for various aspects of airport operations. The goal of this case study was to validate our conclusions from the UW IoT Case Study by testing their validity in the airport operations setting. This was done to understand whether the same shifts to organizational practices are necessary with the use of DTs as IoT, as well as identify any new insights or differences that can be drawn to complement the findings from the UW IoT Case Study. Based on the findings of the UW IoT Case Study, I sought to determine whether similar conclusions hold true when an organization employs a comprehensive DT compared to an IoT-based management system and identify any additional changes in operational practices necessary when a DT is used for operations as opposed to an IoT-based system.

#### **Case Study Two- Research Setting:**

The DFW Airport served as the research setting for this case study. At the airport, DFW shared with me five DT-operated systems focused on achieving different objectives, at various levels of development. These include a DT-operated passenger boarding bridge initiative focused on optimizing gate utilization and availability, a DT of the central utility plant (CUP) which aims to increase the efficiency and optimize the use of their chillers, a customer experience DT which is focused on optimizing customer experience within the terminals by controlling things such as air quality, temperature, shading, and lighting, a traffic control and management DT, and a rental car fleet DT aimed at emissions optimization and decarbonization (expanded on in Chapter 6). Within these DT use cases, I looked at DT operations holistically to speak with industry

professionals working within the operations or development of any of the DT-operated systems at the airport. The variety of DTs at the airport with different objectives allowed me to understand the intricacies of development, deployment, and utilization at an early stage of DT adoption to get a holistic understanding of how organizations must shift organizationally to utilize DTs and how those shifts compare to the findings of the UW IoT Case Study.

### **Case Study Two- Participants and Sampling:**

The research participants for the case study included members of the DT development and management teams within the DFW airport, ranging from management strategists to data scientists. This was done to target those widely supporting the DT efforts within the airport in order to obtain a variety of personnel experiences and opinions throughout the multiple organizational levels that support DT development and use. Our initial research participants included mainly employees within the Environmental Department who led the DT initiative and served as the facilitating and central communication body for the effort. This was part of the purposeful sampling strategy used at the onset of this case study to begin the investigation within this large organization. Similarly to the UW IoT Case Study, the snowball sampling method was used to identify new participants who could add to the value of the research. Within this case study, the snowball sampling method proved crucial as the recommendations of already interviewed personnel allowed me to navigate the intricacies of the DFW organization as direct recruitment without employee introductions proved difficult.

### **3.3. Data Collection**

The data collection portion of this research was based on three major qualitative methods which were employed within each case study in various capacities. These methods included

primarily participant interviews and focus group interviews, but also document collection and naturalistic observations. In combination, these methods can produce holistic results on the social composition of an organization to understand why certain phenomena occur. When all three methods are utilized within a case study, it leads to the triangulation of data which aids in constructing internal validity, external validity, and reliability within a research study (Yin, 1993). The idea of data triangulation derives from geometric roots (Yin, 1993), however the concept describes that a finding may be reliable and validated if three or more sources lead to the same conclusion. The efficacy and reasoning behind the choice of these methods and an explanation of how they were used will be discussed in the sections below.

### **Data Collection Methods - Reasoning and Justification**

Below I will briefly describe the reasoning and justification behind the choice of data collection methods, including participant and focus group interviews, document collection and naturalistic observations. Following this, a description of how each was used in the context of Case Study One and Two will be presented.

### **Participant and Focus Group Interviews - Reasoning and Justification**

The benefit of participant and focus group interviews in case study research is in their ability to highlight and capture important data that cannot be observed or collected through non-human resources available on-site (Patton, 2014). Interviews allow researchers to get a glimpse into the emotions, history, and relevant social influences that affect the way individual decisions are made and the eventual actions of individuals that lead to observable outcomes. Interviews provide context to the case study under investigation and allow researchers to holistically

understand the thoughts and intentions behind observable behaviors and actions.. Principles from ethnography additionally support open-ended or semi-structured interview questions in which valuable data can be collected beyond the bounds of the interview protocol. This can further increase the value of the data and create new perspectives or avenues of investigation that had not previously been evident to the researcher (Merriam and Tisdell, 2015). In this research study, semi-structured interviews were used. Participant and focus group interviews composed the body of my research methodology and led to the most valuable data that was collected throughout this research study. Within each case study, interviews were conducted until the data reached a point of saturation.

### **Document Collection - Reasoning and Justification**

The second dimension of case study research centers on document collection and the analysis of archival data. The documents collected during this process are usually historical documents that existed prior to the case study investigation, aiding researchers in building out the context around the phenomenon (Yin, 1993). Existing documentation can contain information or insights relevant to the research question and can provide insights into communication patterns, data exchange processes, and the way information is shared and stored in an organization. Document collection can further shed light on the types of documents used within an organization, their format, and the typical structure upon which information is shared. The process of collecting documentation can additionally paint a picture of the history of an organization, how it has evolved, and what patterns exist in produced and shared documentation which may be relevant to the topic of research.

## **Naturalistic Observations - Reasoning and Justification**

Naturalistic observations take place in the natural environment of the phenomenon, giving researchers a glimpse into the day-to-day processes around the phenomenon that influence its place within the investigation. Interviews can give researchers perspective on the emotions, motivations, history etc. of individuals while observations complement this by allowing for a firsthand experience of the actions, interactions and observable results of the data gathered through interviews. Research observations include disciplined field note taking, robust and “thick” descriptions and scene setting, and systemic/disciplined attention to the predetermined factors that influence the phenomenon under investigation based on a robust literature review (Yin, 1984). Observations give researchers insights into the routines and actions of individuals that even they might not be aware of or bring to light in an interview. Observations can additionally provide context to interview data by allowing researchers to understand the relationships between individuals’ perceptions/emotions and their actions. In addition, observations allow researchers to use their own lived experiences and knowledge to analyze a case which reduces the necessity to solely rely on interview data to understand situations. Lastly, conducting observations can further validate or invalidate interview data as what is expressed by an interviewee will not always result in coinciding actions within the real life setting (Merriam and Tisdell, 2015). This further increases the reliability of the data.

### **3.3.1. Case Study One**

The ways that participant and focus group interviews, document collection, and naturalistic observations were used in Case Study One with UW Facilities will be described below.

## Case Study One - Participant and Focus Group Interviews

Within the UW IoT Case Study, a total of 20 interviews were conducted over a six-month span during the summer and autumn of 2023. Each interview lasted approximately 60 minutes and was recorded and professionally transcribed. Interview notes were also actively taken during the duration of each interview by both the interviewer and a supporting research assistant whose primary responsibility during the interview process was note taking. The interview protocol can be found in Appendix A for reference. At the conclusion of each interview, we additionally asked interviewees to draw out a map of their workflow in relation to IoT system management including communication flow, data flow, and teams interacted with. These flow maps will be discussed below as part of the document collection process. Table 5 below shows a breakdown of the interviews conducted as part of the UW IoT Case study by department, title, and number of interviews.

**Table 5:** Case Study One - Interviews Conducted

<b>Department</b>	<b>Title</b>	<b># of interviews</b>
<b>Campus Energy, Utilities and Operations</b>	Energy and Resource Conservation Assistant Director	2
	Energy and Resource Conservation Engineer	3
<b>Business Innovation and Technology</b>	Systems Engineer	2
	IT Building and Infrastructure Systems Manager	1
<b>Environmental Controls</b>	Environmental Controls Manager	1
	Electrical Utilities Manager	1
	Environmental Controls Shop Supervisor	1
	Controls Technician	2
<b>Facilities Operations</b>	Facility Manager	2
<b>Campus Sustainability</b>	Energy and Sustainability Specialist	1
<b>Security and Cybersecurity</b>	Cybersecurity Risk Advisor	1
	Director of IOT risk mitigations strategy	1
<b>UW Capital Projects Office (Project Delivery)</b>	Project Delivery Director	1
<b>External Consultants</b>	Technology Infrastructure Manager	1

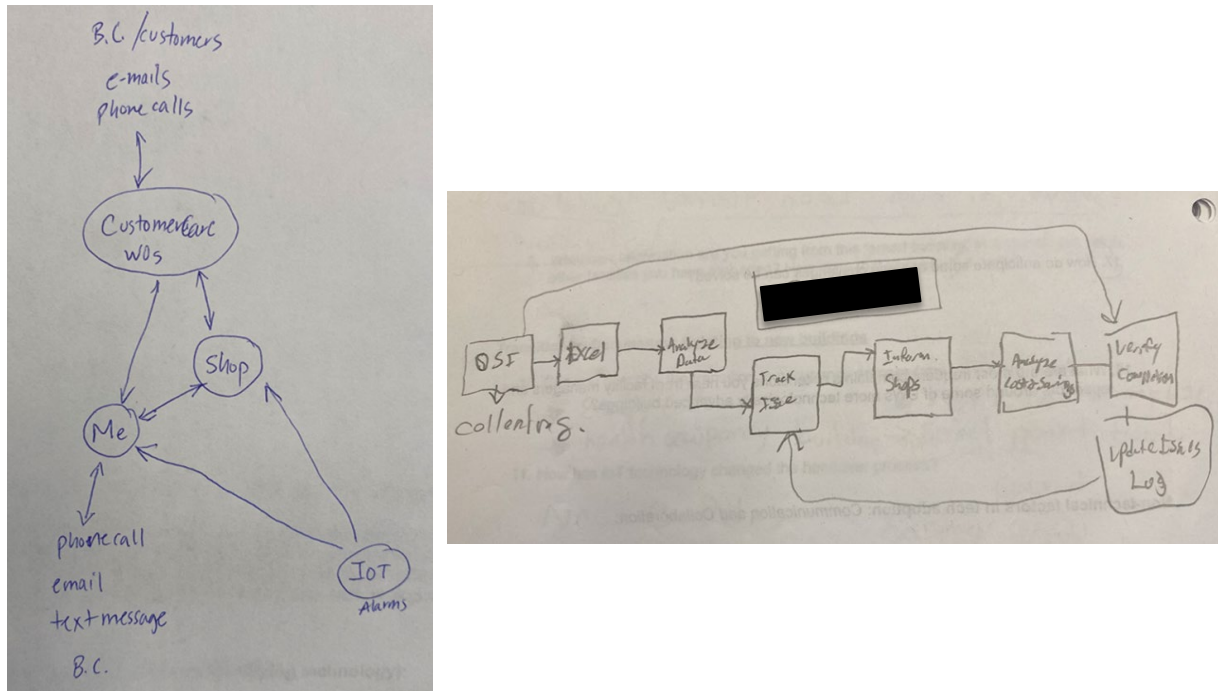
## **Case Study One - Document Collection**

For the UW IoT Case Study, the document collection process focused on standard documentation used by the FM division, facilities design guides, existing operation and maintenance manuals, building handover documents, energy strategy documentation, meeting notes, and the way information is shared and stored within the organization. Our research team was given access to the Facility Division SharePoint site, the web based collaborative platform within which all electronic documents were managed and stored which allowed me to access an array of FM documentation to aid this research. This gave us access to the above, including more specifically documents such as UW energy strategy status update documentation, IoT meter tracking sheets, metering databases, device lists, device consumption information, utility and connections flowcharts and in-depth access to the mentioned Facilities Design Guide which is an important aspect of guiding building operations within the organization. In addition, through the help of various research participants, we were able to explore the Computerized Maintenance Management System (CMMS) used for the control of various buildings throughout campus and were given information on how the facilities teams work within these systems currently.

In addition to the above, after each interview conducted, our research team asked the interviewees to draw out a map of their workflow in relation to IoT system management including communication flow, data flow, and teams interacted with. This exercise gave us insight into the way data flows through the organization when managing IoT systems and gave us a better understanding of how teams are collaborating around IoT data based on the experience of each interviewee. Analyzing these hand-drawn maps alongside the interview transcripts allowed us to better map the requirements of IoT system management and better

comprehend what was shared through the interviewee data. Examples of two of these hand drawn flowchart diagrams are provided below.

**Figure 1:** Example of Hand Drawn IoT Workflows from Interviewees



### Case Study One - Naturalistic Observations

Naturalistic observations took place in the UW IoT Case Study around biweekly coordination meetings between the UW Facilities team, specifically the Campus Energy, Utilities, and Operations Division, and external contractors who aided in the management of the digitally integrated energy meters on campus. These observations took place during the summer of 2023. These meetings discussed topics such as addressing action items for energy meter monitoring, infrastructure updates, building integration developments, overall campus health discussions around energy usage, new meter integration initiatives and other such topics. During these observations, robust notes were taken by both myself and our team RA and special

attention was paid to how the team collaborates, recurring points of contention in the management of IoT systems, the ways information was shared around IoT initiatives, and communication routines present in the teams.

### **3.3.2. Case Study Two**

The ways that participant and focus group interviews, document collection, and naturalistic observations were used in Case Study Two at the DFW Airport will be described below.

#### **Case Study Two - Participant and Focus Group Interviews**

Within Case Study Two at the DFW Airport, a total of 5 interviews were conducted with DFW personnel over a three month span during the winter of 2024. Similar to Case Study One, each interview lasted approximately 60 minutes and was recorded and transcribed. Interview notes were additionally actively taken during the duration of each interview. The interview protocol can be found in Appendix A for reference. Through the more data-backed interview questions in this case that were based on the findings of the UW IoT Case Study, the goal was to test the organizational findings of the UW IoT Case Study (Research Question 3) within an operations organization using DTs instead of IoT systems. Preliminary conversations with DFW DT Airport personnel who helped establish this research partnership helped verify the scope of our interview protocol and its relevancy to the DFW Airport Operations group. Table 6 below shows a breakdown of the interviews conducted as part of the DFW DT Case Study by department, title, and number of interviews.

**Table 6:** Case Study Two- Interviews Conducted

<b>Department</b>	<b>Title</b>	<b># of Interviews</b>
<b>DFW - Environmental Department</b>	Senior Environmental Planner	1
	Data Scientist - Passenger Loading Bridge DT, Customer Experience DT	2
<b>National Renewable Energy Laboratory (NREL) - DT Development at DFW</b>	Data Scientist - Traffic Control and Management DT, Rental Car Fleet DT	1
<b>Collaborators from Supporting Organizations</b>	Senior Commissioning Agent	1

### **Case Study Two – Document Collection**

The document collection process for the DFW DT Case Study was based on documents shared with us by the organization and interviewees as well as online documents from the airport. However, due to the existence of sensitive data and information that could not be shared with outside sources, I was not given access to the airport operations’ document management system like I was in the UW IoT Case Study. Collected documentation included strategy documentation around DT development at the airport, web based DT publications for individual development initiatives, DFW airport DT model walkthroughs, Video documentation on individual DT initiatives, interview transcripts from interviews with experts and technical leaders in the airport’s DT initiatives, and facility operations resiliency documentation. In addition, I was able to access DT specific information about airport initiatives through the National Renewable Energy Laboratory (NREL) website including video walkthroughs on the DT collaborations,

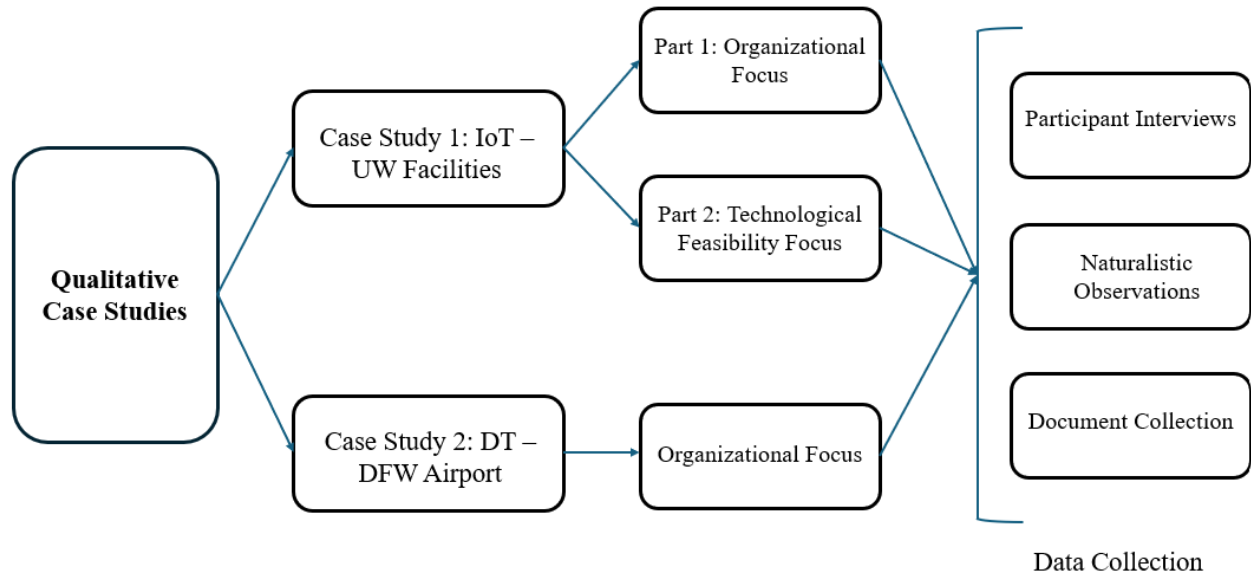
information on their initiatives with DFW and other supporting documents coming from outside of the DFW airport, highlighting the same projects through different perspectives.

### **Case Study Two – Naturalistic Observations**

For the DFW DT Case Study, we conducted naturalistic observation through a site visit to the DFW airport, where one of our research team members engaged in firsthand observation. This included a guided tour led by DFW DT leadership, providing insights into the DT operations on-site. This member of our research team met with various stakeholders in DT development at the airport and observed the Integrated Operations Center (IOC) to experience the intricacies of dashboard management and DT operations and collaboration at their central management location. This visit was complemented by observation notes which were shared with the team. This provided the research team with increased context into the operations of the facility around the DTs and aided in pinpointing critical personnel for research engagement. In addition, observations additionally occurred around two presentations about the airport's DT initiatives which provided context and allowed me to understand the current state of work, the organization's strategies around DT deployment, and their use cases at the airport.

Below is a graphic depiction of the case study structure and methodology including the data collection methods used in this research.

**Figure 2:** Case Study Methods Flowchart



### 3.4. Data Analysis

In order to analyze and process the collected data, qualitative coding strategies were used as the backbone of the data analysis effort. Coding is a qualitative data analysis technique wherein parts of the data are assigned “a descriptive label” which allows for the identification of similar and related content throughout the data and the identification of patterns in the collected data (University of Illinois, 2020). Chandra and Shang (2019) describe qualitative coding as assigning meaning to a small body of text using a label that best represents the text. In describing a small body of text they provide examples such as specific words, a sentence, a phrase, or a paragraph. When describing the label, they give examples such as “used\_digital\_technology” (pg. 91). The coding effort was based on both inductive and deductive strategies. The results of our literature review informed some of the codes I created as I looked for areas in the data which inform the predetermined tension points and areas of specialty attention from the literature

review. This led me to employ deductive strategies in analyzing the data wherein I tried to prove/disprove certain predetermined assumptions drawn from the literature review procedure which I believed to be important. However, I also did not want to limit the potential insights and conclusions which can be drawn from the data, therefore I also looked for new and unexpected patterns which can inform important conclusions that I did not account for in the literature review. This led me to employ an inductive data analysis strategy based on Glaser and Strauss's Grounded Theory Method (1967) concerned with the generation of theory from collected data. Through utilizing both these techniques, the data analysis for this research followed both a preliminary deductive approach followed by a more intensive inductive coding approach which will be discussed in the sections below.

The data coding procedure involved multiple iterations of coding which went from broad to specific as the data analysis effort progressed and more connections began to be drawn. I used a descriptive coding strategy which aimed to summarize sections of transcriptions by encapsulating the main idea of that portion of data. Once I assigned codes to categorize types of data, I used these codes to derive themes and patterns as part of the data analysis.

In the observation and document collection data, I similarly coded collected data for important themes and relevant information that support or contrast with our collected interview data. When analyzing collected documentation, I employed both descriptive coding strategies which focused on content as well as structural coding methods which helped form process flows and workflows that describe how responsibilities and tasks moved through the UW Facilities in relation to maintaining IoT systems. In this effort I focused on questions like "who", "what", "when", and "where" in order to code the many collected documents into a concise representation of how data and responsibilities currently flow through the many parties involved

in maintaining and operating these systems (Andrasik et al., 2014). The coding process for collected documents helped me understand the current form of documentation and device tracking and how these important duties were performed in the organization.

### **3.4.1. Data Analysis- Initial Deductive Coding Approach**

As the first step of my data coding procedure, I followed a deductive approach in order to organize my data for subsequent inductive analysis which embodied the larger portion of my analysis efforts. In my data analysis, the strength of deductive coding came from allowing me to perform the first round of coding by sorting my data into broad categories which embodied the overall takeaways and topics of specialty interest derived from my literature review. When approaching qualitative research through a deductive lens, the theoretical propositions extracted from the literature review serve as points of departure that inform how the data is collected and what data is extracted as part of the analysis (Pearse, 2019). The structure of my preliminary deductive coding approach followed the strategy performed by Bingham et al. (2018) in their study on *Implementation Challenges in Personalized Learning School Models* in which their first round of coding included a deductive macro-coding approach using a coding scheme developed by their research team that reflects broad areas of interest derived from their literature review. This includes using larger and existing predetermined categories to sort the data into broad categories. This then allows inductive codes to emerge as subcodes of the broad categorical deductive codes. This approach is modeled after the study by Crabtree and Miller (1999) in which they designed a template approach to deductive analysis where codes from a codebook of predetermined areas of interest are applied as the first round of coding in order to organize the data for later in-depth inductive analysis.

As mentioned, the broad categories that I used to structure this first round of deductive coding were derived from the literature review analysis. These topics were based on the synthesis of my review around the relationship between the AEC and FM industry and digital adoption and my review centered on defining the current state of FM and operations practice. The broad categories included codes such as “organizational barriers and groupings”, “siloes data management practices”, “technology skill-set”, “ineffective leadership”, “centralized data management”, and “knowledge management” to name a few dominant themes. These broad categories served to guide the rest of the analysis which followed an inductive approach based on grounded theory. The remainder of the data analysis effort focused on allowing codes, categories, patterns, and themes to emerge naturally from the data. My inductive coding approach will be described in detail below.

### **3.4.2. Data Analysis - Inductive Coding Approach**

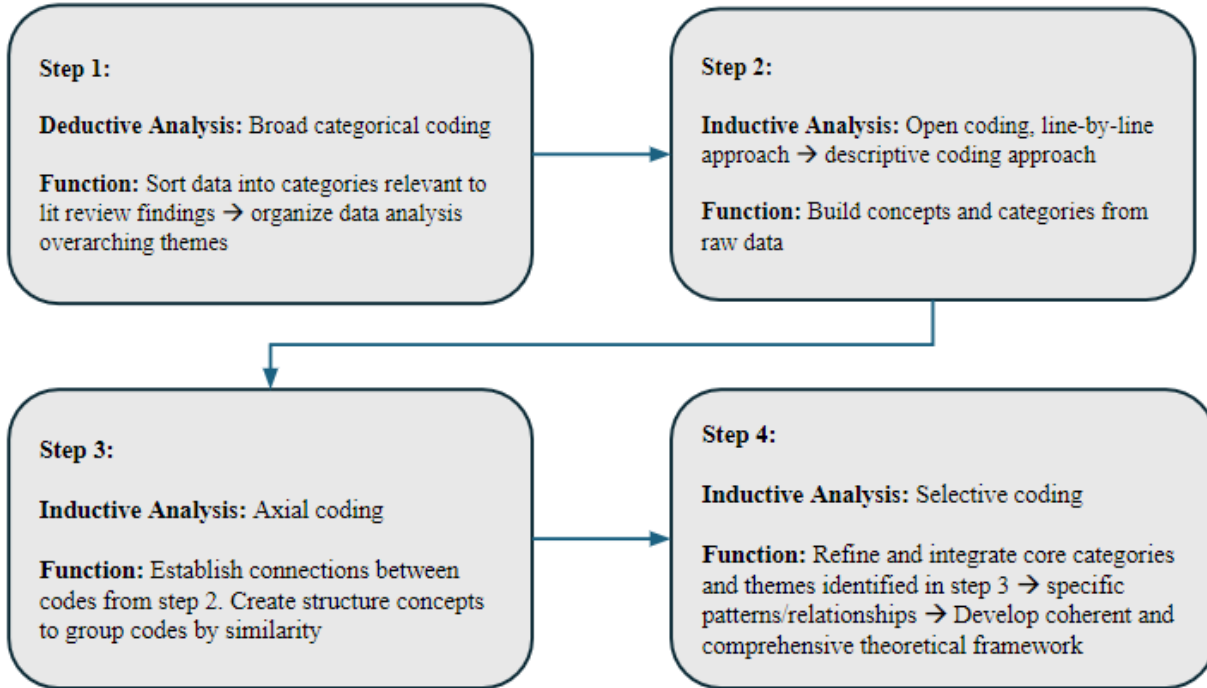
In this section I will describe how inductive based coding strategies were employed in my data analysis effort. Much of my data analysis was based on the principles of grounded theory developed by Glaser and Strauss. Grounded theory is based on discovering theory from data which has been systematically collected and analyzed. In grounded theory, pre-existing conceptualizations are not used in data analysis and the researcher formulates theory which is “grounded” in the collected data. The principles of grounded theory are naturally inductive as they aim to establish “clear links between the research objectives and the summary findings” (pg. 2) derived from “raw data” (pg. 2) in order to “develop a model or theory about the underlying structure of experiences or processes which are evident in the raw data” (Thomas, 2003, pg. 2). Grounded theory allows a researcher to pull out concepts and sort them in order to develop theory that is based directly on the data, requiring coding procedures “which are based on the

method of constant comparison” (Vollstedt and Rezat, 2019, pg. 83). The process of coding data is therefore critical to the development of theory through comparison between the various collected data sources. Coding in grounded theory methodology is “a process of conceptual abstraction by assigning general concepts (codes) to singular incidences in the data” (Vollstedt and Rezat, 2019, pg. 86). Strauss and Corbin (1990) describe three kinds of coding procedures in the pursuit of grounded theory including open, axial, and selective coding. These were the procedures I followed in the coding phase of my data analysis which led me to the development of theory. An example of my coding schema for the UW IoT Case Study which outlines the open codes, axial, and final selective codes can be seen in Appendix B.

In open coding, researchers start the coding process by thoroughly examining the data without preconceived notions or categories. This follows a line-by-line approach in order to begin to build concepts and categories. In this process, the concepts begin to emerge from the raw data in order to be later grouped into conceptual categories (Khandkar, 2009). In my open coding effort, I used a descriptive coding strategy which aimed to summarize sections of transcriptions by encapsulating the main idea of that portion of data. As an example that will be followed throughout, for Case Study One at UW (Research Question 3), the analyzed data sources (e.g. interviews) led to over 85 different descriptive codes in the open coding process. Open coding was done for each of the individual 20 collected interviews which I approached as independent data sources. This led me to the next step in Strauss and Corbin’s coding process which is axial coding. In axial coding, the focus shifts to establishing connections between the codes derived in the open coding procedure. In this process, I analyzed the relationships between different codes to identify broader themes or categories in data. Through axial coding, I categorized open codes into structured concepts to group codes based on similarity throughout

each of the 20 interviews, utilizing constant comparison. In Case Study One at UW, 50-60 axial codes were derived and sorted into about 20 categories from comparison in axial coding. These categories were based on an overview of the entirety of the data in which I looked for commonalities and similarities in codes in order to categorize them into a unified structure based on the variety of different codes in each document from open coding. The last coding procedure described by Corbin and Strauss is selective coding, which is the final stage of the coding process. In this stage, researchers refine and integrate the core categories identified through axial coding. The goal in this final stage is to develop a coherent and comprehensive theoretical framework that explains the underlying patterns and relationships derived from the data. Through selective coding, I was able to refine my findings and develop holistic overlying themes in the data that serve as the larger groups within which the categories from axial coding lie. Following the example with Case Study One, the selective coding procedures led me to create the 19 major themes that I was able to derive from the data. These themes encapsulated many of the axial codes which were grouped by similarity and thematic relevance to each other. This involved multiple iterations of coding and various attempts at structuring the categories and themes into different groupings until the final form was developed. Throughout the entirety of the coding process, many codes were excluded as they did not encapsulate holistic ideas and were independent to a small number of data sources. However, as the number of analyzed data sources increased, new conceptualizations and categories emerged which I had not previously considered or expected, encapsulating the core concepts behind grounded theory. My overall data analysis coding approach is depicted in the graphic below.

**Figure 3:** Coding Strategy/Procedure Diagram



### 3.5. Research Method Limitations and Reliability + Validity

#### Limitations to Qualitative Case Study Research

The use of qualitative research methods in technical disciplines has been scrutinized and criticized due to the existing patterns and themes associated with “proper” research within the scientific community, which usually takes the form of quantitative study. In this section the limitations to the qualitative case study method will be addressed and the ways those weaknesses were overcome in this study will be discussed.

The biggest criticism of qualitative research is that methods such as case studies do not provide a basis for scientific generalization (Yin, 1993). In other words, the results of a qualitative case study cannot be generalizable to populations or groups outside of the specific case. However, the goal of the qualitative case study is not to produce statistical generalization,

but rather to achieve analytical generalization. What is meant by this is that the goal of the case study is to expand on the theories related to the domain of study rather than be able to statistically reproduce results in the general population (Yin, 2013). A case study focuses on one specific phenomenon within its natural context, therefore striving for replicability within a general population that does not concern that specific phenomenon makes little sense. Additionally, the concept of data triangulation serves to further increase the validity of a case study as the same conclusions must be derived from three or more different methods to ensure the validity of one's findings. In this study, the goal was to produce analytical generalization and to build on existing knowledge around IoT and DT adoption and implementation, and the use of interview, observation, and data collection methods aimed to help ensure that the analytical generalizations made were valid through data triangulation.

A second common criticism to qualitative research and specifically case studies is the subjective nature of the research. Critics of the method emphasize that researcher bias plays a role in data collection, analysis, and interpretation (Stoecker, 1991). However, it is possible to avoid bias within case study research through multiple methods including data triangulation, the use of multiple researchers, and the development of a system of checks and balances with a trusted advisor or outside source (Glesne, 2016). Data triangulation ensures that the same conclusions can be drawn from multiple sources, while utilizing multiple researchers and having an outside resource for guidance statistically decreases the chance for bias in the formulation of conclusions. In this study, apart from employing diverse research methods for triangulation, the research team for Case Study One included a research assistant to help ensure bias was not being introduced into conclusions by providing a second opinion and perspective. In addition, throughout both case studies, a trusted advisor was kept informed and regularly was consulted to

provide an additional layer of validation and perspective. This reinforced the credibility of our findings and ensured our methods remained vigorous and meticulous.

Concerns around the rigor of case study design and the necessary length of research to make valuable conclusions within this method have additionally been criticized as pitfalls. The development of systemic procedures and a well-documented research plan can aid in improving the rigor of a case study (Yin, 1993). In addition, defining the unit of analysis within a case and properly bounding your study environment can help researchers avoid lengthy studies and add clear structure to their research design. This research developed a systemic research plan which framed the steps and boundaries of this study in order to portray a clear beginning and end to the research procedure to avoid such critiques. In addition, the unit of analysis was clearly defined and bounded at the onset of each study in order to ensure that the research scope was defined and study boundary set.

By understanding the common criticisms to qualitative research and case studies prior to beginning my investigation, I was able to design this study to avoid such criticisms and navigate the common pitfalls of these methods with careful consideration and methodological rigor. This study was able to avoid researcher bias by using data triangulation methods as well as multiple researchers and the oversight of a trusted advisor to ensure the rigor of the methodology and integrity of the research. In addition, the development of a systematic research plan and clear unit of analysis addressed concerns about study length and structure. With these common pitfalls addressed, the following chapters will describe the findings of my case study research.

## **Chapter 4: Case Study One, Part One**

### **Research Goal:**

In this chapter, I will present the findings of this research from Case Study One, Part One, which was focused on the UW Facilities and aimed to analyze the shifts in organizational practices for FM organizations to leverage IoT systems for building operations and management. Specifically, this section of Case Study One targeted answering the following research question:

What shifts in organizational practices are needed for facility management teams to leverage IoT technologies?

The findings of this case study are listed below in Table 7. The findings are organized by category to reflect the overarching theme that each individual finding represents, followed by the detailed requirements around shifts in organizational practices within each thematic area. This chapter will begin with some background information, briefly introducing the FM organization and its history around IoT implementation and then discuss each finding within each category in detail.

**Table 7: UW IoT Case Study, Part One - Findings**

Category:	Findings:
<b>1. Breakdown of Disciplinary Silos - Centralization and Democratization of Data</b>	1.1: Centralized Inventory Management
	1.2: Centralized Communication and Data Distribution
	1.3: Increased Need for Interdisciplinary Collaboration
	1.4: New Communication Necessities – Breaking Down Disciplinary Communication Barriers
	1.5 Vendor Management, Relationship Building, and Collaboration
<b>2. Bridging the Gap - Institutional Knowledge and "New" Knowledge</b>	2.1 Balancing “New” Knowledge with Institutional Knowledge
	2.2: New Technical Skill Set Requirements - Learning/Understanding Device Coding and Programming
	2.3: New Technical Skill Set Requirements - Learning/Understanding Network Connectivity, Data Flow, and IoT System Architecture
	2.4: Introduction of Data Analytics
	2.5: Advanced Device Troubleshooting
<b>3. Leadership Requirements</b>	3.1: Managing Personnel Resistance to Change
	3.2: Establishing Management Consistency
	3.3: Enhanced Training and Education Requirements
	3.4: Creation of New Roles - Operational Technology Manager
	3.5: Creation of New Roles - Building Handover Director
<b>4. Challenging Entrenched Organizational Practices, Standards and Norms</b>	4.1: Restructuring the Traditional Construction Decision-Making Hierarchy
	4.2: Restructuring Traditional Building Maintenance Handover Documentation
	4.3: Creating New Maintenance Cycles to Accommodate IoT
	4.4: Increasing the Frequency of Updating Standard and Shared Documentation

#### **4.1. Case Study Background:**

Over the past decade, the University of Washington (UW) has been increasing efforts to retrofit existing buildings and build new campus facilities to increase campus sustainability, increase the amount of data that FM teams can access, and increase visibility and control of their built environment systems. Many of these efforts are part of the university-wide “Sustainability Action Plan,” which aims to reduce the carbon footprint of the campus and institutionalize sustainability. UW Facilities plays an important role in this process as the central management entity to buildings at the University. UW Facilities is in stage one of its energy transformation process, which is focused mainly on making their buildings more efficient through “expanding metering,” “upgrading controls,” “establishing data analytics,” and “funding efficiency upgrades with utility savings.” According to collected document data, as of August 2023, 75% of the campus buildings have been equipped with full or partial direct digital control technologies, many of which are in the form of IoT technologies to tackle these objectives.

Many of buildings on campus prior to this transformative initiative relied on pneumatic control systems, and many buildings on campus are still actively being upgraded and retrofitted to move away from pneumatics. Such pneumatic building systems rely on pressurized or compressed air for building control, an outdated system that was established as far back as the 1950s in many campus buildings. Pneumatic controls operate by varying air pressure, which responds to changes in temperature or other set factors using thermostats, actuators, dampers, and valves. This gives FM personnel very little non-analog control (non-manual) over systems after they have been set and no real-time data portraying building performance, making it very difficult for the organization to achieve any type of predictive maintenance strategy.

However, due to the size and diversity of the campus, a smattering of control systems have been implemented throughout the various campus buildings based on funding and management entities over the years. Some of the newer buildings on campus had various forms of Building Automation Systems (BAS) or Computerized Management and Maintenance Systems (CMMS) for building control, which use digital and electronic control to manage systems like HVAC, lighting, and other building services. These systems allowed for higher precision, better system visibility, and automated response according to set thresholds. However, the application of these systems was not standardized throughout campus, and little collaboration existed between FM personnel in different zones or disciplinary buildings, making knowledge of control systems localized. In addition, these more “advanced” control systems were not interoperable, creating unique data management processes, storage, and collaboration routines depending on building. This led to the formation of an organization that possessed operational skills based on their individual zones and building responsibilities, which ranged dramatically based on building ages and integrated operating systems.

With a unified energy transformation initiative and objectives around upgrading controls and establishing data analytics, UW Facilities began an organization-wide building transformation and retrofit effort around the integration of IoT devices, DDC technologies and building management systems. These initiatives aimed to open the door to advanced troubleshooting, better system performance visibility, enhanced energy management, and data analytics to improve operations throughout the entire campus. However, due to the structure of the FM organization, the lack of holistic data management processes with prior non-interoperable or pneumatic systems, and the diverse range of building control and management skills throughout the organization, establishing IoT systems into the existing organization and

leveraging their capabilities proved to be a difficult task which involved many shifts in operational practices to manage IoT systems effectively. The required shifts in organizational processes to manage IoT systems in FM organizations was the topic of this case study, and this will be discussed in detail in the sections below.

## **4.2. Findings**

### **1. Breakdown of Disciplinary Silos - Centralization and Democratization of Data**

Similar to other AEC disciplines such as construction, disciplinary silos exist in FM organizations that inhibit the use of digital technologies like IoT systems. The findings of this case study suggest that an integrated and centralized approach to the management and maintenance of IoT systems is required to leverage their capabilities. This calls for centralizing and democratizing data from all disciplinary groups and an initiative to develop organization-wide processes and procedures around data standardization in type and form, distribution, and storage. This additionally calls for increased efforts around interorganizational communication and collaboration. The findings of this case study show that the following shifts in organizational operations are required for IoT system management within the larger thematic topic of disciplinary silos:

- 1.1: Centralized Inventory Management
- 1.2: Centralized Communication and Data Distribution
- 1.3: Increased Interdisciplinary Collaboration
- 1.4: Breakdown of Existing Communication Barriers
- 1.5: Vendor Management, Relationship Building, and Collaboration

In this section each one of these will be discussed in detail below.

### **1.1: Centralized Inventory Management**

Managing IoT systems is inefficient and difficult in a decentralized data environment. In a siloed organization, disparate data repositories make coordination, and the organization-wide understanding of what data exists, where it exists, and how to access and use it for improvements in building operations difficult. The FM division is still working on developing a centralized data environment which means that currently data is still somewhat siloed and hard to access by essential personnel outside of disciplinary units due to the unique data management methods and strategies which individual units have formed over time. Amid discussions concerning the challenges of decentralized data management in FM operations, one interviewee shared their frustrations by expressing: “instead of everybody having their own spreadsheet, which is what is going on right now– we need a master database.” This interviewee then went on to exclaim, “then once that master database becomes synced and complete, then we can slowly start peeling off everybody’s Excels.” This statement highlights the current issues in FM around siloed data management which limits the ability for organization-wide sharing of data and the development of general IoT awareness. This causes confusion and creates a non-holistic strategy towards the management of a technology that spans across disciplinary boundaries rather than within them. To illustrate this confusion regarding important shared data, another interviewee stated, “We really don’t even know how many devices we have out there or where they’re at. We just know we have a lot of them.” This highlights the growing importance of inventory management, and particularly the centralized management and tracking of devices, their specifications, locations, and other critical lifecycle management information. As stated by an energy manager at the UW when expressing the importance of uniting the organization-wide effort towards optimally

managing this abundance of new IoT systems, “we are bringing it all together into a central hub so that they can manage the whole 12 million square feet with a few people at a central location where we have human interfaces on all 120 buildings.” As the number of integrated IoT devices with unique management requirements grows, developing a centralized device inventory which contains important standardized information becomes critical. This will allow IoT devices to be properly tracked and make device information easily accessible to all FM disciplines regardless of which entity “owns” or manages the individual IoT system. This calls for a breakdown of disciplinary information silos and a more holistic data organization, sharing, and storage strategy. Centralized inventory management may create new practices for FM personnel in establishing a central inventory database, converting all existing data repositories onto the centralized platform, encouraging/enforcing the use of the centralized database, and maintaining and updating the inventory regularly.

## **1.2: Centralized Communication and Data Distribution**

Organization-wide communication and data distribution networks and procedures that establish clear standards on how to deliver data effectively are essential to managing technologies like IoT systems, which produce data at an unprecedented rate. Centralized data inventorying is only useful if FM personnel know how to access data repositories, know where to find data, and are aware of how to exchange IoT information with others. Currently, data exchange processes are not centralized at the University which causes issues in FM personnel receiving the data they need to manage IoT systems and knowing where to find IoT-related data after building handover processes. For example, a facilities employee describing the communication gap between project delivery groups and FM personnel after a building is handed

over to the FM division for operations stated, “the project folks, they just deliver all the stuff [building and device information] to records. What records does with it, they put it into our DocFinity system.” This interviewee then goes on to highlight the lack of communication present in this data exchange process stating “but does anybody convey that down to the shop folks? It could be all in the right places where you need to get to it, but this side of the group doesn’t know where it is. They just know that it’s someplace.” This statement shows clear inefficiencies in the document handover process between project delivery groups (constructors) and FM teams due to the lack of centralized communication and data distribution standards within the organization. When data exchange procedures are not standardized or distribution networks fail to reach all required parties, a disconnect is formed between critical parties in how to share and access important data. This forms a barrier between the data, where to access it, and the teams needing it for their day-to-day operations. This also can create discontent between FM employees and project delivery team members. Without centralized communication and data distribution protocols, information remains siloed which brings multiple consequences to the organization. Firstly, it reduces the efficiency of FM processes as staff don’t know of the resources available to them to make their work easier and more productive. Secondly, it discourages the use of a centralized data sharing platform, centralized communication, and holistic data sharing outside of disciplinary teams which aids in diminishing trust in centralized technologies like IoT. This can push employees to rely on tacit knowledge networks for information retrieval and reduce trust in data centralization efforts.

### **1.3: Increased Need for Interdisciplinary Collaboration**

IoT systems span across disciplinary boundaries, meaning that their management must also span across disciplinary boundaries. This means that to most optimally manage IoT systems, management groups must integrate a more diverse range of interdisciplinary professionals for device configuration, troubleshooting, and life-cycle management. Currently, interviewees express that the management of IoT devices and systems is usually defaulted to the facilities control shop, or the UW Operational Control Engineering Group. This is due to issues around establishing management responsibility and consistency over individual IoT systems during their initial deployment, which will be discussed in the leadership section below. However, the management of such systems requires the teamwork of a wider group of disciplinary professionals who can bring their unique skills to the table in solving problems around these complex technologies. To illustrate this point an interviewee stated, “we’re trying to establish, re-establish, build relationships between different groups that wouldn’t normally be working very closely together,” continuing on to share that these groups could be “anything from a subcontractor on a project to a trade, somebody in the trades to the IT Department to the Construction PMs and CMs, and everybody in between.” As expressed by another interviewee describing the dichotomy of managing integrated IoT systems compared to traditional pneumatic building control systems, “you’re adding more people involved to troubleshoot issues. 10 years ago, it was just one service technician that would go out to the field to fix that irrigation system. Now, you’re having to deal with three or four people to fix it.” To further illustrate the growing need for interdisciplinary collaboration around IoT management due to their technical requirements, an operational engineer stated when describing the work of updating the servers on which IoT data is stored, “we have to have UW IT involved, and there has to be multiple entities

within UW IT.” Expanding even further this interviewee shared that “then you have the server people, and then the other people we have locally [FM personnel]. Then, you usually will have the vendor involved because of the application software involved. So, you have to have multiple people on the same page at the same time.” Managing such interdisciplinary collaboration is complex and new efforts towards putting the right people in the same room at the correct time is necessary to not only maintain the infrastructure upon which IoT systems are built but also to solve complex problems when they arise in the field. This calls for a unified effort between not only FM disciplinary groups, but also IT professionals specializing in IoT integration, device vendors, and sometimes even project managers and engineers who were responsible for the construction of the building within which IoT systems exist. Enhanced collaboration for the management of these devices might call for the development of system-specific management groups, increased interdisciplinary meetings, and enhanced leadership to organize and enforce such collaborations.

#### **1.4: New Communication Necessities – Breaking Disciplinary Communication Barriers**

With the use of IoT systems comes the necessity for facility personnel to be able to communicate with a more diverse range of disciplinary professionals than ever before. As managing IoT technologies requires a more holistic organizational approach, so too does communication need to span across disciplinary boundaries which traditionally were not often crossed. For example, new work appears for facility managers, operators, engineers and technicians alike in being able to communicate with IT personnel which therefore calls for an understanding of technical terminologies and an ability to communicate efficiently with technical jargon. An interviewee explained that, “the soft skills are being able to communicate with an IT

person who has no concept of what an HVAC system is,” and continued to share that it’s a skill to be “able to take your technical knowledge of this building system and being able to communicate the issues with someone who’s in a cubicle somewhere saying, ‘I understand the network and data flows’.” An interviewee stated the importance of “being able to communicate with different levels of the organization” to portray the growing diversity of communication requirements when managing such IoT systems. This interviewee then goes on to specify, “being able to communicate with blue-collar workers, white-collar workers, and everything in between... being able to communicate with people in IT. All those groups have different generalized ways of communicating.” This interviewee then exclaims, “and that’s a skill.” With the use of an integrated technology comes the necessity for an integrated approach to teamwork and problem solving to manage these technologies. However, due to existing disciplinary silos it will take an enhanced effort for teams to break down their communication barriers and begin to meet and communicate regularly around the commissioning, maintenance, and repair of such IoT technologies. This will come with enhanced efforts in learning discipline specific terminologies such as “IT language” and finding ways to communicate effectively during this transition. New work may additionally appear in needing to meet with diverse groups more frequently and problem solve when IoT errors occur outside of one’s disciplinary specialty.

### **1.5. Vendor Management, Relationship Building, and Collaboration**

As the diversity of both types and applications of IoT systems continues to rise in the management of integrated facilities, so too does the need for growing communications and collaborations between facility managers and device vendors/manufacturers. Facility personnel rely on IoT vendors and manufacturers to provide the foundational information required for

device management and to be available to resolve vendor specific issues throughout the IoT lifecycle, particularly in the more turbulent initial deployment periods. This is stated by an interviewee who shared, “we have to ask them [vendors], if it’s outside of our scope or whatever, to come in and help us with certain things.” Thus, the establishment of strong vendor relationships and the careful selection of vendors during decision-making periods is becoming increasingly crucial for later operational success with the use of vendor provided technological systems. When asked about some of the biggest challenges encountered in the management of IoT systems, an interviewee shared their opinion on the criticality of selecting the strongest suited vendor from the onset. This interviewee shared that some of the biggest challenges include “devices installed by companies that go out of business and inadequate vendor support/troubleshooting for device issues.” Related to this, during an interview with a building manager they shared a story regarding the construction and management of a new IoT integrated greenhouse as part of the Life Sciences research building. This interviewee described that a small company from Europe who specialized in technologically integrated greenhouses was contracted to build and help manage the facility. However, just a few months after construction, the contractor went out of business leaving the facilities teams with little to no support and information on how to operate the greenhouse effectively. This led to lost time, lost money and high levels of frustration which eventually led the facilities team to manage the greenhouse using traditional methods, leading to major reductions in its functionalities. Another describes the difficulties they have encountered in collaboration when vendors are needed to help resolve device specific problems, stating “sometimes it gets difficult because they don't understand us, we don't understand them, and we're trying to solve the problem together.” In addition, holding vendors accountable for the feasibility of their systems and providing adequate support leads to

the necessity for higher levels of collaboration and relationship building. Frustrations around such accountability were expressed by a technician who shared “some of the more mature companies in that space have kind of stopped all of the hyperbolic promises and have come back to reality where really 90% of your energy savings is just making sure that broken stuff is fixed.” This forms new responsibilities for facility personnel in managing relationships with vendors/manufacturers, doing proper background research prior to contracting vendors, and increasing their contractual accountability with vendors to avoid frustrations and problems down the line.

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## **2. Bridging the Gap - Institutional Knowledge and "New" Knowledge**

Bridging the gap between institutional knowledge and "new" knowledge entails developing a balance between the essential skills required for IoT management and development, such as device coding, programming, and network communications expertise, and the indispensable institutional knowledge gained from hands-on experience and time. This institutional knowledge refers to things such as an understanding of existing legacy mechanical systems within buildings and how they operate, as well as an intimate familiarity with the unique attributes of buildings on campus. Achieving this balance is crucial for effectively operating IoT technologies while leveraging the invaluable insights derived from years of practical experience in FM. It is important for FM organizations to not move into the use of new digital systems without understanding the value of retaining knowledge in legacy systems, rather they must embrace the knowledge of veteran personnel and find ways to retain this knowledge while updating the technologies on campus. In this section, the work of bridging the gap between these different skill sets will be discussed in detail, including the following topics:

### **2.1: Balancing “New” Technical Knowledge with Existing Mechanical Expertise**

2.2: New Technical Skill Set Requirements - Learning and Understanding Device Coding and Programming

2.3: New Technical Skill Set Requirements - Learning and Understanding Network Connectivity, Data Flow, and IoT System Architecture

2.4: Introduction of Data Analytics

2.5: Advanced Device Troubleshooting

In this section each one of these will be discussed in detail below.

### **2.1: Balancing “New” Technical Knowledge with Existing Mechanical Expertise**

Although the transition to the use of IoT systems calls for an increased and rather critical understanding of technical details in the form of topics such as device programming and configuration, network connectivity, and system architecture, gathered interview data exposes that an understanding of existing mechanical systems and traditional building components is still critical to managing IoT integrated facilities. This is especially necessary within buildings that have been retrofitted with IoT upgrades rather than newly constructed facilities. Thus, it becomes important for FM teams to find ways to bridge the gap between the mechanical and technical realms, ensuring the optimal operation of buildings that exist within the intersection of both of these realms. In other words, FM teams need to find a way to balance both institutional knowledge of mechanical systems and how they historically operate within existing buildings and the new technical skills required to configure and manage the software elements of IoT devices. As stated by an engineering manager, “individuals now have to have an IT background of some sort to at least understand the basics of network communication. Something that staff

never needed.” This interviewee went on to state, “it’s someone who can understand both worlds, the trade side and the IT side, and be that kind of glue that holds things together.”

Another facility engineer shared that, “it’s incredibly important for our techs to understand how the mechanical side of things work, because it then just becomes clear how you need to control things, or how you can safely control things.” This engineer described the type of skill-set they are now looking for in FM employees following the IoT technical transformation stating, “we have to hire people that are comfortable with and have an understanding of mechanical equipment, and also have to understand and not be afraid of technology, working with computers, operating systems, and code, but also to know how a fan works.” With the integration of IoT systems, there’s a growing demand for professionals who can work within both worlds. Creating a team which can understand “both worlds” is a tall task that will require increased efforts from FM organizations to leverage the unique skills of individuals and find ways to train their teams to have both mechanical and technical system knowledge. Alternatively, FM teams have to find ways to integrate professionals with critical knowledge in either domain together to optimize the management of IoT systems within existing and unique buildings. The criticality of this is further echoed by an interviewee when asked about the necessary skills to manage IoT technologies, “I think it’s both knowing the digital technology and how the IT infrastructure works but also simultaneously knowing how the mechanical systems operate, knowing how electrical systems operate, knowing how plumbing systems operate.” This suggests that although technical skills such as programming and coding are important, it is also critical that employees still understand the principles of how traditional building systems operate within the existing unique buildings on campus in order to solve FM related problems most effectively. Finding new employees who have experience in both backgrounds, training the current workforce to be able

to “speak both languages”, or composing teams of mixed skill-set which cohesively work together is a new task for FM organizations with the regular use of IoT-based systems.

## **2.2: New Technical Skill Requirements- Learning/Understanding Device**

### **Coding/Programming**

As stated above, FM personnel are now facing the need to develop a set of IT skills to stay effective at doing their job. At the UW, like other state-funded organizations, IoT devices are acquired from a list of approved manufacturers and installers. Each device acquired from these manufacturers is uniquely configured for its purpose, and its programming requirements are unique to both the individual device, and more importantly, its manufacturer/vendor. This requires that facility personnel performing device configurations and maintenance familiarize themselves with a range of programming requirements essential for configuring devices and managing the critical software which allows data to become meaningful to decision-making down the line. They must also acquire the skills needed to adapt to evolving programming requirements and emerging IoT technologies as they become integrated into current systems due to the fast-evolving field of IoT development. To illustrate this point, an engineer describing the configuration of IoT devices from different manufacturers stated, “if you saw it, the programming language is completely different. The user interface is completely different... You can translate, if you really learn one of them well, some of that knowledge into the different products.” New work forms for FM personnel in learning the coding/programming requirements of individual IoT systems, and more importantly understanding them well enough to be able to translate these skills into programming requirements for other IoT devices as they are deployed and connected to existing systems. A facility manager voicing their frustrations on the intricacies

of device programming stated, “imagine every few months you have a new software that you have to learn. And you’re like, ‘But I don’t do this on a daily basis. I run cable. I run wire’.” The rate of deployment of IoT systems leads to a relatively rushed transition period in which FM employees must address this large learning curve to stay effective at doing their job. With mechanically dominant systems in the past, understanding the configuration of a building operating system was more tangible as FM employees could physically trace wires and identify mechanical components to better understand how systems are operating or what is malfunctioning. However, with digital controllers it is difficult to understand how a device operates or why connectivity errors are occurring just by visual inspection. This idea is embodied through the statement from the interviewee below:

“it can be harder to tell how a digital controller is necessarily configured just by looking at it. In the past maybe with pneumatic, you could at least trace the wires around and see this component. I know what that component is. So, even if I don’t have the diagram, I can at least see what it is. If I spend some time, I can figure it out, but with digital controllers you can’t really know how a computer is programmed just by staring at the hardware device.”

When IoT systems fail or malfunction, it is most often the result of a technical error rather than a physical one which can be fixed through manual interaction or human touch. To illustrate the growing complication of problem solving in relation to IoT systems, an interviewee stated when describing the troubleshooting process of a particularly intricate IoT device, “We didn’t know how the thing was configured. We didn’t know what to do with it. We had to start over, buy a new Raspberry Pi, plug it in, find the software, download it, configure it like we’d never done it before. Stupid.” The lack of knowledge around device programming and coding requirements was a common theme throughout our interview data, leading to major frustrations and complications for facility personnel in navigating this technological transition. Errors such as

the one described above around the team's lack of understanding of the programming requirements of a new IoT system lead to lost time, money, and growing frustration. To manage IoT systems, it becomes clear that FM personnel must become comfortable with the coding requirements necessary to both configure devices and respond to device malfunctions when they occur, changing the necessary skill composition of the FM employee.

### **2.3: New Technical Skill Requirements - Learning/Understanding Network Connectivity, Data Flow, and IoT System Architecture**

Skillset shifts additionally appear for FM personnel in the effort to raise the organizational awareness of advanced technology's data flow, network connectivity, and system architecture in relation to inter-connected IoT devices/systems. Based on the collected data, connectivity and communication errors are some of the most common issues which FM personnel face around device troubleshooting. This makes an understanding of these details critical to FM employees. When asked what skills they look for in their employees, an interviewee said, "a basis of networking communication for one. Understanding how data flows through a network. I would put that at the top. The ability to do basic troubleshooting of an IT device." The struggles the organization has faced around building a workforce that has these skills is described by an interviewee in a management position who stated, "a lot of people don't understand the technology. It's difficult for us to find qualified people that can come in and work on these systems without needing a lot of training. Years of training." Another manager describing the newfound difficulties that FM employees are facing with navigating complex technologies such as IoT devices stated, "I think when we first did it [integrated IoT devices], they [FM personnel] said, 'we don't have the information'. So then we gave them the information, and it was a little bit embarrassing for them to maybe say, 'We don't know what to

do with the information’.” Prior to the integration of IoT systems to manage UW facilities, an understanding of network connectivity and system architecture was a very specific skill that was not holistically required by FM teams. Such responsibilities around network connectivity were usually contained to an internal specialist and supporting IT groups. However, with the rising FM responsibilities around device configuration, which requires establishing network connection and communication, an understanding of such topics becomes important to all FM employees tasked with installing IoT devices or troubleshooting issues when device communications malfunction or connectivity errors occur. As the skills required to maintain the devices for building controls shift, the knowledge of personnel maintaining these systems must also shift. This emerges from the interviews as managers shift their preferred personnel knowledge requirements to understanding basic data flow, network connectivity, and IoT system architecture rather than mechanical and equipment specific knowledge which would be traditionally expected.

#### **2.4: Introduction of Data Analytics**

IoT system utilization opens the door to new work in the arena of making the unprecedented influx of data meaningful to the organization through the introduction of data analytics, meaning that the organization must hire personnel with analytics skills or train their current workforce in data science principles. As shared by an interviewee, “there's a big push on campus right now for analytics, so that we can determine what kind of adjustments we need to make to conserve energy.” To illustrate the new opportunities for data analytics around the plethora of new data producing devices, another interviewee stated, “we get a lot of data from chillers, VFDs, lighting, control systems, and even metering that now comes in. We now have

the ability to trend all that data. You can really look deeply into how the building's operating.” This push towards data analytics means that the organization must train their personnel or hire additional personnel who can effectively harness the data that devices produce to create actionable insights. This is largely outside of the traditional arsenal of responsibilities for facility personnel. For example, a technician sharing the different programming skills one needs to manipulate different device data for analytical purposes stated, “Alerton and Siemens give you a lot more access to their assembly code. And so, with that, you can get very, very technical with what you can control, if you have the knowledge.” This shift towards predictive maintenance is only possible if FM employees are educated or properly trained in the discipline of data analytics, leading to new skill requirements within FM teams that had never before been needed. If teams possess the proficiency and knowledge in these principles, they now must often perform analytical tasks involving organizing, filtering, trending, manipulating, and simulating data-driven scenarios to identify energy-saving opportunities. Data is not useful unless it is analyzed and manipulated towards an organizational purpose, creating a plethora of new responsibilities in the realm of data analytics with the use of IoT in FM. However, developing a workforce that is capable to perform such tasks is a new challenge for FM.

## **2.5: Advanced Device Troubleshooting**

The abundance of available IoT data also opens the door to advanced device/system troubleshooting for maintenance and more accurate problem prescription and corrective action. As described by an interviewee, “things we can analyze are: Are things operating according to schedule, or is the equipment turning off or modulating as we expect it? And we come up with corrective actions.” Another interviewee describing the new troubleshooting capabilities and

advanced visibility that this abundance of data presents stated, “it helps our efficiency in the sense that we can hit multiple problems much quicker than we used to be able to.” To illustrate the new abilities for advanced troubleshooting, an energy manager gave an example describing the intelligence of IoT based building control systems by stating, “You don’t need to go walk the entire building or wait for somebody to complain...it’s giving you a heads up that, ‘Hey, we’re starting to trend in the wrong direction. Some preventive maintenance here would get us back on track’.” With the ability to identify issues before they escalate and have a more data informed approach to system troubleshooting, facility teams can schedule maintenance tasks in advance of equipment issues, optimize energy usage, and preemptively address potential equipment breakdowns or inefficiencies. However, to leverage these benefits, FM personnel must be willing to commit more time to performing these tasks. Advanced troubleshooting abilities means more work develops for FM personnel in ensuring individual devices and whole systems are operating according to desired/set parameters, which can get increasingly more precise and time consuming as each managed IoT system must be monitored and addressed as notifications and alerts are continuously sent to system managers. This often leads to new practices in regularly checking control dashboards and applications, increasingly responding to alerts that did not exist with older control systems, and an overall more intensive troubleshooting approach to devices and monitoring their performance productivity such as the need to respond in off-work hours. This is elaborated on in detail in Chapter 5, Section 4.3 which highlights the new practices for FM personnel that go into troubleshooting, fault detection, and diagnostics.

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### **3. Leadership Requirements**

The findings of this case study show that enhanced leadership and management are needed in order to implement and utilize IoT systems on an organization-wide level. Strong and

effective leadership is essential to implementing new technologies into existing organizations and adequately navigating the organizational transition around their use. In this section, the leadership requirements around implementing and utilizing IoT systems within the FM organization at the UW includes the following topics:

3.1: Managing Personnel Resistance to Change

3.2: Establishing Management Consistency

3.3: Enhanced Training and Education Requirements

3.4: Introduction of New Roles: Operational Technology Manager

3.5: Introduction of New Roles: Building Handover Director

In this section each one of these will be discussed in detail below.

### **3.1: Managing Personnel Resistance to Change**

Resistance to change is a natural part of organizational transformation and can be viewed as a necessary attribute to organizational growth and technological transition. However, although it is expected, leadership needs to take action to address the needs of personnel that can spark resistance to new technological systems. New practices become evident for leadership in the form of responding to and managing personnel resistance to change. Interview data sheds light on the new work of managing the generational divide and finding the best ways to integrate technologies and change daily routines within teams composed of both young tech-savvy professionals and older personnel with high levels of mechanical knowledge but limited computer skills. Interviews with upper-level management showed that managing resistance to change is not an easy problem to overcome and must be considered important due to the holistic

approach that IoT systems necessitate and the importance of teamwork in ensuring their proper operations. As expressed by an interviewee discussing the work of properly navigating an organizational technical transition, “I mean, if anybody had the magic formula for doing that I think they would be a very rich person because I think it’s where most of the challenges lie right now.” Conversations with multiple higher-level managers led to the emergence of two major strategies that helped ease the tension of transition during turbulent times, and guided the managers' approach to work during the technological transition. The first of these strategies involved gradually introducing IoT technologies to increase employee buy-in. By implementing these technologies iteratively, employees could organically recognize the benefits they offer within their existing work processes. This approach aimed to maintain employees' sense of ownership over their work, ensuring smooth integration of technology into their daily routines without creating a disconnect. As stated by an interviewee, “there’s a point where you can win them over by making it their idea...Because a lot of the reluctance is because they’re embarrassed... Once they get ownership, boom, they turn to a whole new person.” Another manager similarly states, “they need kind of ownership over their work. And it’s been a real positive and productive way to retool our staff.” A third interviewee focused on the importance of an iterative transition in creating employee buy-in stated, “It’s how they [new technologies] come in is what really matters because if they come in and people understand what they are, and they come in over a time, and they start to get a little bit of buy-in, then you got a chance of them actually being followed.” Conversations such as these showed that managers have developed certain strategies to best navigate turbulent times, such as increasing employee buy-in through increasing their individual sense of ownership over the technology or process. However, this is

more difficult than it seems as it requires an incremental introduction to new methods and systems which leadership must find a way to properly navigate.

In addition to the above, focusing on the immediate benefit of the technology on the daily operations of individual employees also emerged as a dominant strategy for leadership in best managing employee resistance to change. As stated by an operational technology manager, “if you’re dictating down, ‘You will do this’, that’s never really going to be successful in any meaningful way.” This interviewee goes on to describe “so, working with people in the shop to say, ‘here’s this new thing. Yeah, there’s extra complexity, but here are these tools that might make your job easier’.” To further support this, an interviewee stated when expressing what is needed to best introduce new technologies into an existing organization, “demonstrating how it [the technology] makes their job easier because I think people often look at the negatives.” Shifting the focus away from the changes to work which IoT systems bring and rather focusing on the immediate benefits of new systems proved to be a successful method for leadership in this transitional period.

### **3.2: Establishing Management Consistency**

With the abundance of new opportunities for IoT integration, especially in a setting such as a university where customizable spaces are critical for creating precise research environments, the distribution of management responsibilities and creation of system-specific champions becomes increasingly important. With this, the new work of establishing management consistency over the lifecycle of IoT devices and systems is rising in importance and becoming a critical element to the success of systems when things such as unexpected breakdowns occur or device troubleshooting is necessary. As stated by a facility manager, “I think that consistency of

who's working on the system is important. Like I said, being familiar with it [the device/system] is half the battle." When describing the integration of a new IoT system put in place to measure vibrations caused by the underground rail system below the university campus an interviewee stated, "the University said, 'Yeah, we'll do this thing'. But they never said who is gonna be responsible for managing this system once it's installed... They're [the client] the ones that were requesting this, but they didn't want the management of it once it was in place." Statements such as these illustrate the lack of coordination around ensuring that all new IoT integrated systems are allocated to specific managers to ensure their successful operations. When specific IoT systems are implemented to solve unique problems but are not allocated to a specific system management group, it causes confusion, pullback, and disarray within FM groups. To further illustrate the importance of role distribution and establishing consistency in IoT lifecycle management, a third interviewee stated, "Lighting control is a great example because the electricians are distributed in different zones. There's not one person guiding that process. Things just kind of get dumped on them. Here you go. Here's this new system. Have fun." Then when asked how responsibilities are allocated by the team when this happens, the same interviewee stated, "We're just not gonna touch it, just ignore it." IoT systems are complicated and call for enhanced attention to detail and familiarity with the system to best be managed. Due to the relatively fast transition to the use of such integrated technologies, the FM group at the University has not yet optimally developed best practices around device management and responsibility allocation. This suggests that management consistency and the allocation of responsibility over the lifecycle of devices are necessary to address problems when they arise in the field so that they can be solved by professionals with system familiarity and an understanding of their unique configuration and requirements. Establishing system champions and management

consistency can also ease confusion around IoT device integration and increase personnel's sense of ownership over systems. This proved to be a major requirement in the introduction of IoT systems which created an abundance of new responsibilities which did not exist with prior building operation controls.

### **3.3: Enhanced Training and Education Requirements**

To bring personnel up to speed on the technical knowledge necessary to manage IoT systems and work with a diversity of disciplines on IoT-related problems, enhanced training and education opportunities must be provided by management. This could encompass internal training sessions covering aspects like IoT integration, network connectivity, and specific programming prerequisites. Alternatively, it could involve more extensive and detailed training sessions extending over longer periods, conducted in collaboration with IoT device vendors or manufacturers during building handover phases. For example, when asked how to best ensure a smooth transition to the use of IoT devices an interviewee responded, "My personal belief is that education and outreach continue to be a kind of top priority, especially education." To highlight the major problem with inadequate training, a manager shared, "what we found is, even after a year, our facilities staff is still somewhat drinking from a firehose. It's just a little bit too much, too quick, too soon." Another interviewee describing the current inefficiencies in training stated that there are "big retraining gaps in raising staff skill sets and modifying what their role is from being hands-on mechanics of mechanical devices to mechanics of digital devices. It is a very different skill set." Restructuring IoT training procedures and ensuring that adequate time is spent with personnel to ensure their proper understanding of system configuration and maintenance is proving critical. The prolonged learning curve of adapting to IoT system

integration and utilization must be addressed by FM leadership with longer and more intensive training periods and procedures, while continuing to provide expert support during initial adoption and transition periods.

### **3.4: Introduction of New Roles- Operational Technology Manager**

Interview data sheds light on the opportunity to develop a new facility role centered around the commissioning, operation, management, and maintenance of operational technologies such as IoT systems. This role can be called “Operational Technology Manager”, or OT manager, who’s responsibilities revolve around the management of IoT systems and serve to fill the gap between FM and IT necessities in the management of these technologies. As stated by a facility employee when describing the organization’s needs, “We don’t need IT support. We need OT support, operational technology support. It’s the world of physical to IT – when they meet.” Another interviewee describing the potential responsibilities of a new OT manager role stated, “their role now is to take all these technologies as they’re coming and figure out a way to have a communication channel to the folks that are gonna get the item ...I use the word 'liaison’ – can liaison between these different folks.” This OT manager role can fill multiple needed responsibilities such as championing incoming IoT systems, connecting and assigning the proper teams for device integration and issue resolution, assigning management roles for incoming devices, and managing the centralized data storage and distribution of IoT system data. To illustrate the frustrations that an OT manager may help alleviate in the management of IoT devices/systems, an interviewee in a current management position stated, “we haven't really figured out how we're going to make these systems work together because we have different shops that take care of the different systems. So for me to be responsible for all of them, it's hard

to direct other shops that I don't manage.” The OT role can help guide the centralized effort and serve to connect the proper teams together to work as a more integrated unit in addition to help steer the organizational shift towards full IoT building management transformation. As put by an interviewee above, the OT manager role can serve as a liaison between the FM and IT world, but additionally as the liaison between the many specialty specific shops within the FM discipline such as electrical, plumbing, HVAC etc.

### **3.5: Introduction of New Roles - Building Handover Director (Transition to Occupancy)**

Another potential opportunity for the creation of a new organizational position lies in the development of a “Building Handover Director”, or a “Transition to Occupancy Manager”. The main goal of this position would be to help facilitate the handover of important building information from project delivery groups, or the construction contractors, to the FM team. In addition to this, the introduction of this position could give the FM division representation throughout the project’s design and construction phases to help ensure compatible systems are being integrated into the existing IoT environment. Currently, the handover of building documents and information is the responsibility of the project delivery team which often struggles to juggle their construction responsibilities and simultaneously fulfill their handover obligations. During discussions about the absence of a centralized understanding among project delivery managers regarding the required building handover documentation during the handover phase, an interviewee remarked, “they diluted that by giving everybody who’s in the project delivery groups the transition to occupancy responsibilities. So, this project manager’s understanding is different from that one which is different from the third which is different from the fourth guy.” Furthermore, the support for a building handover director is echoed by an

employee who shared, “having somebody whose job is really that transition to occupancy, that – doing the finishing stages of construction and return of the building to UW I think would be very beneficial.” The interview data clearly indicates that numerous issues in IoT system configuration and maintenance arise due to the absence of comprehensive handover documentation and a general lack of familiarity with specific systems and devices when they are introduced to FM teams tasked with their integration and management. Creating a role to help facilitate the accurate and holistic handover of building information as well as serve as FM representation in decision-making around choosing IoT systems during design phases would help alleviate some of these tensions that operators are experiencing down the line.

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#### **4. Challenging Entrenched Organizational Practices, Standards and Norms**

This case study shows that in many instances, the existing organization practices, structures, and norms are not adequate in fulfilling the requirements of implementing and managing IoT systems effectively. Entrenched norms and practices must be challenged in order for an organization to use IoT systems and innovate beyond the use of existing technologies that are familiar and comfortable. To address this challenge, organizations must be willing to challenge and adapt entrenched practices, standards, and norms while finding ways to ensure that institutional knowledge is maintained within the organization. In this section, the following topics within this category will be addressed:

- 4.1: Restructuring the Traditional Construction Decision-Making Hierarchy
- 4.2: Restructuring the Traditional Building Maintenance Handover Documentation
- 4.3: Creating New Maintenance Cycles to Accommodate IoT Devices
- 4.4 Increasing the Frequency of Updating Standard and Shared Documentation

In this section each one of these will be discussed in detail below.

#### **4.1: Restructuring of the Traditional Construction Decision-Making Hierarchy**

The use of IoT technologies calls for a restructuring of the traditional construction decision-making hierarchy through the integration and early involvement of FM representatives within design meetings in the planning/construction phases of the building life-cycle. This becomes necessary to leverage invaluable FM knowledge around topics such as IoT device network connectivity, device compatibility, unique building intricacies, vendor specific knowledge, and other building information which can only be acquired through the experience that FM personnel have in daily building management. The collected data shows that the integration of FM personnel into decision-making procedures can help decrease tension and confusion after building handover, decrease design errors, increase device/system compatibility with existing systems, and decrease the need for rework or repair later down the line. When describing the current flow of communication within the organization during decision-making periods, an interviewee stated, “the project never thought to ask those that were gonna be actually doing it [managing IoT systems], because of this communication trail.” To highlight the inefficiency of the current methods of communication, this interviewee then sarcastically asked “why would these folks [decision-makers] be talking to our shop folks? They’re talking to our PDG (Project Delivery Group) folks. Our PDG folks should be talking to our engineers. Our engineers should be talking to folks down here.” This trail of communication creates communication gaps and is inefficient in ensuring that the best suited decisions are made around IoT integration when FM knowledge needs to be leveraged to inform such decisions. Breaking down the levels of communication to create a more straightforward connection between FM

personnel and decision-makers can help ensure that better IoT related decisions are made by the organization. Describing the current representation of FM within organizational decision-making, an interviewee described the FM group as “always playing second fiddle” during decision-making periods. FM involvement in decision-making can ensure that internal standards of quality are met, as described by an interviewee who stated, “when we do it ourselves, we know where everything is. We know how it works. We have our own internal standards of quality.” When describing the current procedures around decision-making for IoT integration, the same interviewee shared, “a lot of times the standards of quality really aren’t up to speed. Then there's the learning curve of how it was programmed, where they installed the field devices, because we don't know where they are at. We have to rely on the contractor to show us.” While FM representatives do not need to have exclusive decision-making authority, their expertise can only help make better decisions around building management and make maintenance activities more efficient when FM teams eventually assume sole responsibility for integrated IoT systems. Therefore, it is very important for FM personnel to participate in decision-making meetings and play more active roles in device commissioning processes to ensure that building management is effective, and systems do not eventually become abandoned due to ill-fated decisions that were not made by experienced decision-makers.

#### **4.2: Restructuring Traditional Building Maintenance Handover Documentation**

Traditional design documentation and building handover documents (Ex. O&M Manuals, as-built documentation, specifications, design guides) need to change in form to accommodate IoT devices/systems rather than the static building components which they traditionally represent. The traditional format of these documents does not fulfill their intended purpose when

managing IoT devices and systems, as they necessitate a different set of information to be included in critical handover documentation. To illustrate this, an interviewee stated when discussing IoT implementation, “it’s a very different sort of as-built for an O&M manual requirement,” continuing to state that the organization must “rethink the way that you write a specification for these kinds of [IoT] devices, and a new way of asking for the submittal for that kind of device, and a new way of requiring testing, commissioning, and documentation of that device.” To support this claim, another interviewee further states, “These devices need a very different sort of submittal and as-built and owner’s manual, with all sorts of very dynamic and specific information, like what version of the software actually got commissioned onto the devices. Something that no one would ever really think about.” The necessary form of data handover required for building maintenance and lifecycle management is changing with the integration of IoT systems, which is challenging habitual norms and document structures. With the use of IoT devices, data handover documents are no longer solely supporting static building elements, but more dynamic technological systems. In adjusting the form or type of data handover documentation around newly implemented IoT devices, our interview data shows that such documents must now consider information on things such as the interoperability of devices and the intricacies of network connection, device communication, configuration, compatibility, software update cycles, and software and hardware maintenance requirements to ensure that IoT systems are not “treated as if they’re a static component of the building, just like everything in construction used to be.” This creates new work for FM personnel in re-structuring their traditional building handover documentation around IoT devices in order to address all the necessary management attributes that must go into leveraging IoT technologies for effective outcomes. Beyond re-structuring their handover documentation, new work will additionally form

for FM teams in enforcing the new requirements with designers, managers, and manufacturers developing these handover documents and encouraging their use in initial turbulent transition periods.

### **4.3: Creating New Maintenance Cycles to Accommodate IoT Devices**

New practices around developing and maintaining IoT device maintenance and replacement cycles, as opposed to traditional static building component maintenance cycles, is becoming critical with the continuously growing use of IoT devices/systems. The maintenance, updating, repair, and decommissioning cycles of IoT technologies are not on the same timescale as static building components, requiring new work in restructuring the operational procedures and frequency of maintenance and decommissioning related work activities. As expressed by an interviewee, “older systems that are less IT-heavy, you can honestly let them run for 20 to 30 years with minimal input and time. But IT systems don't last as long.” Another interviewee describing the need to restructure maintenance cycles around IoT-specific technologies stated, “updating software patches is expected to be something you could do nightly or monthly. When you look at the building industry, our operators of digital systems, the presumption of how often you have to do that kind of work is more on the year scale.” Due to the connectivity and communication requirements of IoT systems, the frequency at which maintenance activities such as software updates need to occur rises dramatically compared to less IT-dependent building technologies that require less frequent attention. Due to this, new work forms for building operators to ensure that IoT systems are up-to-date while keeping in mind their reduced lifespan. This means that swaying away from norms around building maintenance must be embraced and

traditional maintenance methods must be adapted to sufficiently address IoT maintenance requirements.

#### **4.4: Increasing the Frequency of Updating Standard and Shared Documentation**

In relation to the necessity to restructure IoT device/system maintenance cycles, new work appears for FM personnel in the necessity to update shared organization-wide documentation on a more regular basis than was necessary before integrating IoT systems. To encourage personnel to maintain a device inventory and utilize shared documents such as the facility design guides, O&M manuals, and as-builts, these documents must stay updated, relevant, and critical to the work being performed daily by building operators. This means that increased efforts must be put into updating such documentation to encourage its continued use so that it does not become obsolete. Similarly to the above, the current update cycles for such organization-wide documentation are no longer compatible with the use of technologies like IoT systems which require a more integrated and frequent document updating approach. An interviewee expressing their frustrations around the new work of keeping standard maintenance documentation up to date as technology continues to be implemented stated that, “they said every two years they would look at the design guide and see if it matches the building code.” This interviewee then goes on to share “you would hear complaints from the engineers lately because the technology is causing the codes to be updated – where they would have to update it every five years, now they’re doing it almost yearly.” This shows that as the IoT technology continues to develop at a fast pace, FM personnel must be on top of updating documentation to keep them relevant and useful to building operators. As expressed by another interviewee describing the current updating cycles for documentation such as the facilities design guide, “I

think once a year, twice a year, maybe they update the design guide. And right now, governance over the design guide is sort of, I don't want to say it's ad hoc, but as operators, we feel that it's a bit ad hoc.” With the need to change device maintenance and replacement cycles, comes the need to additionally change document updating and tracking cycles to ensure the continual use of documentation and encourage its continual growth and development into important everyday documentation that can help make facility personnel’s daily operations easier and increase their system awareness.

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### **4.3 Conclusion/Case Study Overview**

Within the setting of the UW Facilities, this case study aimed to understand what shifts in organizational practices are needed for FM teams to leverage IoT technologies. Overall the findings of this case study fall into four major categories as seen in Table 7, including the following:

1. Breakdown of Disciplinary Silos - Centralization and Democratization of Data
2. Bridging the Gap - Institutional Knowledge and "New" Knowledge
3. Leadership Requirements
4. Challenging Entrenched Organizational Practices, Standards and Norms

Within Category 1, shifts in organizational practices around the centralization of data, centralized communication and data distribution, the increased need for interdisciplinary collaboration, and requirements around relationship building with IoT vendors were discussed. Within Category 2, requirements around bridging the gap between institutional knowledge and “new” knowledge, new technical skill set requirements, the introduction of data analytics, and advanced device troubleshooting were discussed in detail. In Category 3, leadership

requirements around managing personnel resistance to change, establishing management consistency, enhanced training requirements, and the creation of new roles and responsibilities were established. Lastly, within Category 4, requirements around restructuring entrenched decision-making hierarchies, restructuring traditional documentation structures and forms, and creating new maintenance cycles to accommodate IoT technologies were discussed in detail.

Chapter Four highlighted the key shifts to organizational practices necessary for IoT management in building operations. In Chapter Five, the new practices necessary to ensure the technological feasibility of integrated IoT systems will be discussed in detail.

## **Chapter 5: Case Study One, Part Two**

### **Research Goal**

In this chapter, I will present the findings of this research from Case Study One, Part Two, which was focused on the Facilities at the UW and aimed to understand what new practices emerge for FM teams in order to ensure the technological feasibility of integrated IoT systems. Specifically, this portion of case study one targeted answering the following research question:

What new practices are necessary for facility management teams to ensure the technological feasibility of IoT systems?

The findings of this case study are listed below in Table 8. These findings are organized by category and the individual findings within each category. Categories 1-3 represent the necessary practices that go into ensuring the initial operational feasibility of IoT systems including their configuration in the field, their connection to existing communication networks, and their ability to properly route, sort, and process data so that it can be used by the FM team for decision-making and other operational purposes. Category 4 represents the new practices that go into leveraging the capabilities of IoT systems for operational improvements, ranging from topics such as system performance monitoring to creating and maintaining data visualizations. Category 5 describes the processes necessary to maintain IoT systems over their lifespan, and lastly category 6 details the new practices around managing access control and security with the implementation of IoT systems. Overall, these findings compose the requirements for ensuring the technological feasibility of IoT systems and their operations over time and the new practices that must go into leveraging their capabilities for operational improvements.

**Table 8: UW IoT Case Study, Part Two - Findings**

<b>Category:</b>	<b>Findings:</b>
<b>1. Sensor Configuration</b>	1.1: Managing Diverse Vendor Specific Software Tools
	1.2: Programming/Coding Responsibilities in Device Configuration
<b>2. Establishing Network Communication</b>	2.1 Sensor Configuration - Creating Unique Identifier/Instance Numbers
	2.2: Communication Protocol Standardization for Device Connectivity
	2.3: Converting Existing Buildings to IoT Control – Network Wiring
	2.4: Third Party Device Integration and Ensuring Compatibility with Existing Systems
<b>3. Middleware/Supervisory Device Configuration</b>	3.1: Establishing and Implementing Logic in Supervisory Devices - Message Routing and Processing
<b>4. Leveraging the Capabilities of IoT Systems</b>	4.1: System Performance Monitoring
	4.2: Data Analytics
	4.3: Troubleshooting, Fault Detection, and Diagnostics
	4.4: Creating, Maintaining and Responding to Alerts and Notifications
	4.5: Managing and Navigating Diverse Vendor Specific User Interfaces and Applications
	4.6: Creating, Understanding, and Maintaining Data Visualizations
<b>5. IoT Device/System Lifecycle Management</b>	5.1: Updating Software and Servers
	5.2: Sensor Lifecycle Maintenance
<b>6. Managing IoT Access Control and Security</b>	6.1: Managing Access Control
	6.2: Maintaining Firewall and Intrusion Detection Systems for IoT Devices and Controls

## 5.1. Case Study Background: The IoT System Architecture

Before describing this case study's findings, it is important to briefly describe IoT system architecture to provide context to the findings and inform the structure of this chapter. The categories by which the findings are organized, as seen in Table 8 above, follow the IoT integration and management process in a sequential manner, starting with configuring field-level devices and controllers, then ensuring network connection for communication, and ending with managing the lifecycle of IoT technologies and ensuring their security requirements once implemented and regularly used. The findings were structured in this way to provide a holistic analysis of the new practices necessary to ensure the technological feasibility of IoT systems from initial implementation to lifecycle management and security. This structure mirrors that of the typical IoT system architecture and the practices necessary to fulfill the requirements of each layer of the system architecture. The precise composition of IoT system architecture is not standardized due to the relative novelty of this technology (Al-Qaseemi et al., 2016). However, a general system architectural framework/hierarchy has been established, which defines the operational system layers within IoT-enabled systems. Generally, IoT systems can be sorted into 3 broad layers, which can be subdivided further, including the perception layer (physical sensors/controllers), communication and network layer, and the application layer (Hakin, 2018) (Al-Qaseemi et al., 2016). Many studies break these layers down further to add precision to the technical requirements of each layer; however that is outside of the scope of this study. The basic IoT architecture layers will be briefly described below to provide context to the structure of the case study findings.

## **1. Perception/Physical Layer:**

This is the lowest layer in the IoT system architecture and involves the physical devices or sensors that collect data from the environment. These devices can include sensors, actuators, cameras, temperature sensors, and motion detectors. The devices collect data from the facility and send it to the network layer (Al-Qaseemi et al., 2016). The physical layer comprises all the “things” (Hakin, 2018) that are connected to the internet. Within the findings, the work of configuring sensors and devices (Category 1) lies within the perception layer of the IoT system architecture.

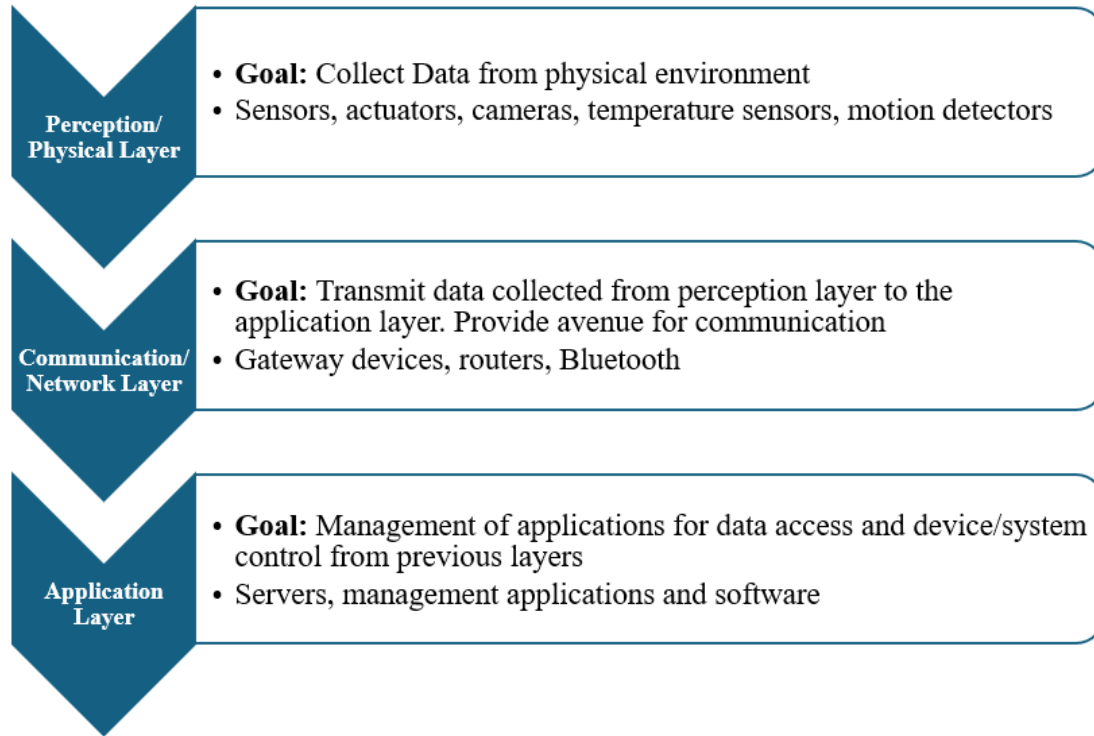
## **2. Communication/Network Layer:**

The network layer is responsible for transmitting the data collected by the sensors and end devices to the application layer. The network layer is essential to IoT system architecture as it provides a communication avenue for the array of individual IoT devices to exchange large amounts of data between the individual device and the necessary computing systems through the network (Verma et al., 2019). The network layer allows interconnected devices to “communicate” and provide the network connectivity to do so. A subset/addition of the network layer is the middleware layer (in many instances considered an individual layer), which enables the interaction of perception layer devices like sensors and applications used for management by transmitting information between the two through processes like message routing and sorting. Within our findings, establishing network communication and middleware/supervisory device configuration (Categories 2 and 3) fall within this broader layer of the IoT system architecture.

### **3. Application Layer:**

The application layer, which is sometimes referred to as the service layer, is the interface between the FM division (users of the system) and the IoT system (Lawal and Rafsanjani, 2022). This is where any management applications live, such as web or other applications that allow the users to view the processed data from the IoT technologies and potentially make decisions or manipulate systems accordingly. In the findings of this case study, leveraging the capabilities of IoT systems (Category 4) often happens at the application level for things such as data analytics, troubleshooting, performance monitoring, and data visualization. The work of updating software and servers additionally exists at this layer which is part of the IoT device/system lifecycle management category (Category 5). In addition, as the application layer allows users to access the IoT system and therefore share and view data, this is where security considerations often exist due to the vulnerability of the data at this point. Within the findings, managing IoT access control and security (Category 6) exist within this arena. Similarly to above, the security layer and others are often considered individual layers in IoT architecture, however for the purpose of this study they are grouped within this general thematic layer.

**Figure 4:** Basic IoT System Architecture



## 5.2. Findings:

### 1. Sensor Configuration

In this section, the new required practices for FM personnel around initial sensor configuration for IoT devices will be discussed in detail. IoT device configuration involves programming devices in the field for their intended functionality so that they collect the data needed by the FM group. The integrated IoT sensors can come from a variety of vendors and manufacturers which leads to a diversity of configuration requirements and specific software tools. In this section the following topics will be discussed:

1.1. Managing diverse vendor specific software tools

1.2. New Programming/Coding Responsibilities in Initial Device Configuration

## 1.1. Managing Diverse Vendor Specific Software Tools

As the first stage of configuring IoT devices, facility personnel must use the tools and software provided by the vendor or manufacturer of the IoT system to configure the devices onto the communication network and ensure that the IoT systems are capturing desired data. This process is made more difficult due to the variety of vendor-based IoT packages that all come with unique configuration requirements. As a controls technician at the University stated, “all the vendor does for us is provide us with a package. They say these are the software tools needed to install physical devices and put them on a network.” The facility teams are responsible for understanding the unique vendor and device-specific nuances required to correctly install the hardware and the software and ensure proper network communication as part of the configuration process. To illustrate the distribution of responsibilities between the vendor and the facility staff at this point in the configuration process, a technician shared, “for the most part, as long as we have the tools to set up these lease systems, it's ours from there on out.” The variety of control protocols that must be integrated based on manufacturer as part of this configuration process is described by an interviewee who shared, “every manufacturer of a piece of, per se, HVAC equipment has a proprietary control protocol...Carrier has CCN, Carrier Comfort Network. Mitsubishi has the M-NET. There's just a smattering of them across the industry.” When asked if the control protocol programming requirements differ between manufacturers, specifically the three main vendors employed on campus, a controls technician shared, “between all three companies, they all do it differently.” The intricacies of initial device configuration are contingent upon the package provided by the vendor in terms of hardware connection, software, and communication and control protocols. Once the package is delivered to the FM division from the vendor, the responsibility of configuration shifts to facility staff to understand the

unique nuances of configuration that each manufacturer provides. As a result, facility personnel must develop an in-depth understanding of the diverse software packages and control protocols associated with different manufacturers' devices. This creates new work in effectively learning the intricacies of installing, configuring, and maintaining vendor-specific IoT systems. As the diversity of devices increases, so must the proficiency and adaptability of facility staff in correctly configuring devices.

## **1.2. Programming/Coding Responsibilities in Initial Device Configuration**

As part of the above discussion on the diversity of vendor-provided devices that come with unique configuration requirements, new work appears for facility personnel in properly programming the devices during the configuration phase. This leads to facility technicians and personnel needing to learn and develop a diverse set of programming skills to effectively configure devices. As expressed by a controls technician describing the differences in programming requirements between various device manufacturers, "it's a process, all of them have similarities, but it's the way they execute because all of them have different code in the background." To then highlight the differences depending on the device manufacturer, this technician adds, "Johnson Controls uses a block-based, state-based programming, which is a totally different way of configuring these. And Alerton uses a similar block-based, but not state-based programming." This interviewee then goes on to describe the complications this brings, stating that "you have to be versed in each one of those specifically because there's a lot of detail and nuance that you have to know that only experience gives you to be able to configure them correctly to work right." As expressed by the interviewee above, each manufacturer's programming requirements differ significantly, demanding a nuanced understanding of various

programming languages and coding techniques. This highlights the shift in skill set for facility personnel necessary to properly manage IoT devices and the learning curve that emerges for new and existing personnel. As the vendor-based code updates and the complexity of IoT devices increases, it becomes important for the facility control group to acquire these programming skills. However, this is a difficult process that involves dedication; as one technician expressed, “when I first started learning building automation systems, like I said, every single one was different. Every building you went to had a different version of that same control system, and they all acted a little bit differently... it was just a disaster.” Although difficult, ensuring that facility staff have the necessary skills to manage the diversity of vendor requirements not only ensures the efficient operation of the facility but also future proofs the workforce against technological advancements in order to ensure that they can continue to operate within their duties as coding requirements continue to rise in complexity.

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## **2. Establishing Network Communication**

In this section, the new requirements around establishing IoT network connectivity will be discussed in detail. For IoT devices and sensors to communicate with each other and transmit data in real-time to management applications for analytical purposes or improvements in decision-making, establishing proper network communication between all devices and the network is crucial. In this section, the following topics will be discussed:

- 2.1. Sensor Configuration: Creating Unique Identifier/Instance Numbers
- 2.2. Communication Protocol Standardization for Device Connectivity
- 2.3. Converting Existing Buildings to IoT Control - Network Wiring
- 2.4. Third Party Device Integration

## **2.1. Sensor Configuration: Creating Unique Identifier/Instance Numbers**

To ensure effective communication between IoT devices on the network as well as ensure that devices can be properly tracked and inventoried, assigning unique identifiers or instance numbers to individual IoT devices is very important. When an interviewee in a management position was asked about the most critical improvements to their current IoT management strategy, they stated “implement a common naming standard in HVAC controls.” Device identifiers are specific and unique numbers for each sensor or integrated device which allows the device to be identified, communicated with, and tracked holistically throughout the entire IoT ecosystem. This makes assigning and tracking these numbers in a central database a new critical task for FM personnel. As stated by an interviewee discussing the importance of this task in ensuring communication, “you need the instance number, which is a unique identifier that each one of the devices have. And if two of them have the same, then you have a communication problem.” To effectively fulfill this new responsibility, an interviewee describes the strategy the team used to create a unique nomenclature for the continuously growing number of devices being integrated into the network by stating that their team developed “an architecture for device ID ranges. Siemens Insight was the first on campus so they got the one million device range. And then Alerton Compass got the two million, and then Johnson Controls got three million.” This interviewee then goes on to state, “we try to keep it the same across campus.” The necessity to develop these standards in device identifying nomenclatures exists on multiple levels within the organization, from ensuring device communication on the network, to ensuring proper device identification on management platforms like end user applications that control the systems within which these IoT devices are manipulated on a day-to-day basis. With the number of individual IoT devices growing throughout campus, the need to create and maintain an updated device

inventory to track the thousands of devices on campus and their unique nomenclatures becomes increasingly important. FM personnel must then assign management groups to maintain these inventories and update them regularly to keep the inventory up to date and useful in everyday operations.

## **2.2. Communication Protocol Standardization for Device Connectivity**

In the process of establishing network communication for IoT devices comes the need to ensure communication protocol standardization across communicating devices on campus. This is done so that devices from a diverse range of manufacturers can communicate with each other and relay data through a common communication network. At the UW, devices utilize the BACnet (Building Automation and Control Networks) communication protocol, which enables facility teams “to bring in all of these different vendors into a cohesive network.” Establishing BACnet communications requires facility personnel to first ensure that devices that are being purchased for integration support the BACnet protocol, which has recently become a more simple task due to the fact that “BACnet is kind of what most everybody uses now. And it's an ASHRAE standard.” Once the facility teams have ensured compatibility, personnel must configure the IoT devices to communicate using this protocol. This often involves properly setting the device’s network settings, such as IP addresses and communication ports to align with the BACnet network. At this phase, facility personnel must assign objects for communication which represent various parts of the device such as sensors, actuators, and controllers. This object assignment creates the base with which BACnet devices can communicate. Each IoT device on the BACnet network needs a unique address to facilitate communication, so facility personnel assign addresses to the devices and commission them on the network. Similar

processes exist for the integration and communication of devices that are not BACnet compatible, such as the campus utility meters, which track utility energy data throughout campus using the Modbus TCP (Transmission Control Protocol) communication protocol. Standardizing communication protocols is critical to device connectivity amongst the entire IoT ecosystem, leading to new required practices in this arena for FM personnel.

### **2.3. Converting Existing Buildings to IoT Control - Network Wiring**

The University of Washington campus contains over 500 buildings, making the transition to IoT building control a long and evolving process. However, as more buildings are converted from existing pneumatic control systems to IoT-based management systems, new work forms for facility personnel in establishing the communication infrastructure on which IoT systems rely to operate effectively. Establishing network communication involves installing the proper cabling onto the RS-485 network communication system used by the University Facilities. When describing the network infrastructure, a technician stated, “it's basically 100% wired” while another shared “we use copper wire. I’m a big believer in copper... The RS-485 network that we have is very reliable and it’s all standard BACnet protocol.” However, converting buildings from pneumatic control to IoT control often requires an entire restructuring of the building’s wired infrastructure that allows for network communication. This is exemplified by a technician who shared, “we're pulling all the pneumatics out and we're putting in brand new controls, it's almost like a brand new job to a certain degree.” Although this work is a collaborative process with university electricians, it still becomes a labor-intensive procedure for facility personnel. This has led to the establishment of a separate team within UW Facilities dedicated to managing such building transitions and retrofits. This is exemplified by an interviewee who stated, “we’ve kind

of separated into a smaller team solely focused on upgrading older analog buildings to digital controls, and with that, integration of BACnet or Modbus or LonWorks or whatever they have.” This team has formed due to the critical nature of ensuring that this work is done to a precise level of quality, an idea exemplified by an interviewee who shared, “Communication is always key. And with that comes the physical wiring standards.” As more buildings undergo conversion from pneumatic to IoT systems, establishing robust network communication infrastructure becomes critical and leads to new required practices for the FM division, which has called for the development of a team dedicated to building wiring conversions.

#### **2.4. Third Party Device Integration**

In some instances, devices produced by manufacturers outside of the typical state sponsored vendors at the University (Johnson, Allerton, Siemens) require integration into the existing IoT infrastructure. When devices outside of the typical vendors require integration, this process can be more of a laborious task for FM personnel. Devices must be securely connected in order to communicate with existing protocols even when they are outside of the typical arsenal. However, this process varies based on the device’s compatibility with existing communication protocols like BACnet. When asked how frequently third-party device integration is necessary on campus, an interviewee exclaimed, “that is absolutely the name of the game of what we do around here.” They then went on to provide an example stating that, “a big concern lately is wildfire smoke in this area... so management wanted a certain set of parameters to be monitored. So they bought a very specific piece of equipment.” When describing the process of configuration and integration of this device onto the existing network this interviewee explained, “luckily, because we live in the day of open protocol such as BACnet, the

manufacturer sends out a bib cut sheet for this. Basically, all the BACnet points that can be collected are already there and labeled...all you have to do is pull them into our system.” This example shows a case of third-party device integration for a BACnet native device, which is a more simple integration process due to compatibility. However, when third-party devices are not BACnet compatible, they require a more intricate and laborious procedure to allow for communication within the existing network. This is described by an interviewee who shared that “if a third-party system does not abide by the BACnet standard, you have to go through and find out what each point is physically relaying.” This interviewee further explained how this process can get even more complicated: “even worse, sometimes third-party devices are literally just hard outputs, dry outputs. And from there, you have to program our system to take it in, use it as needed, and then spit out a usable piece of information.” This shows that the procedure for third party device integration can vary drastically based on the device manufacturer and the device itself. Open communication protocols like BACnet allow for a less complicated integration process for compatible devices; however, others require more intricate and time-consuming procedures in order to ensure compatibility and communication on the existing network, as exemplified in the quote above. When noncompatible devices require configuration, FM personnel must develop the skills necessary to connect them to existing networks and maintain them over time as communication protocols update and new versions become available.

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### **3. Managing Middleware/Supervisory Devices**

In this section, the new requirements for managing middleware/supervisory devices will be discussed, specifically for establishing and implementing logic in supervisory devices. This is necessary to ensure that data is routed and processed properly. For data to get where it needs to go for analytics or storage, implementing logic in transitory devices in the form of middleware

within the IoT system architecture is a new practice required for FM personnel in IoT management.

### **3.1. Establishing and Implementing Logic in Supervisory Devices - Message Routing and Processing**

In IoT system architecture, the supervisory (or middleware) devices serve as the central hub for collecting data from various sensors and devices within the established network. For data to be properly processed so that important information can be collected and sent to the server level for historicization or later analytics, facility personnel have to implement logic within these devices for message routing and processing. Such logic includes the implementation of rule-based algorithms so that the supervisory devices can process incoming data, identify relevant data patterns, and use implemented logic to route the data accordingly. To illustrate the new work that comes out of this requirement, an interviewee stated, “there’s business logic in that you can choose to pull every piece of data from a device, but that’s a lot of data.” This interviewee then goes on to share how they limit data collection to only useful information: “we go through and write small pieces of code saying if parameters are between this and this, then report. If it goes through a change of value, then report. Sample times, buffer sizes etc.” Another interviewee described the new work of implementing logic into these supervisory devices: “say if it's a trend log, you say after 144 samples, then you send all of that information to the server and then it appends that SQL database with that little chunk of information, and then it starts over.” However, with the vast diversity of IoT devices implemented throughout campus comes the necessity to implement different and unique logic within supervisory devices to ensure that the desired information is collected and processed. For example, an interviewee describing the

utility metering configuration throughout campus stated, “some systems such as our utility metering platform has this sort of arrangement to apply data cleanup and business logic to the information before it is stored/presented,” while another describing HVAC device supervisory configuration stated that “some systems have software which generate alarm messages to users/groups when devices are not operating normally.” To holistically describe the purpose of implementing logic into supervisory devices, an interviewee expressed, “it really depends on what data we choose to capture. All we’re choosing to capture is pertinent information. So, sometimes, that’s temperatures, pressures, operating hours, kilowatts, and energy consumed.” It falls upon facility personnel to ensure that these devices are configured with appropriate rule-based commands to recognize data patterns and efficiently route data to where it needs to go. This new responsibility calls for attention to detail, particularly in configuring supervisory devices to meet specific system requirements across various buildings, which call for unique data capture.

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#### **4. The Work of Leveraging the Capabilities of IoT Systems**

In this section, the new requirements around leveraging the capabilities of IoT systems will be discussed. What is meant by this is how FM personnel can use implemented IoT devices and systems to improve building operations by leveraging their functional capabilities. Many of these new practices fall within the application layer of IoT system architecture. If IoT devices are implemented but are not leveraged properly, then their full potential cannot be reached. In this section, the following topics will be discussed:

##### **4.1. System Performance Monitoring**

##### **4.2. Data Analytics**

- 4.3. Troubleshooting, Fault Detection, and Diagnostics
- 4.4. Creating, Maintaining, and Responding to Alerts and Notifications
- 4.5. Managing and Navigating Diverse Vendor Specific User Interfaces and Applications
- 4.6. Creating, Understanding, and Maintaining Data Visualizations

#### **4.1. System Performance Monitoring**

IoT systems allow for much greater detail in system performance monitoring, which creates new work for facility personnel in maintaining procedures around daily/frequent monitoring. The much greater visibility that IoT systems present allows the organization to move away from reactive maintenance and into a more predictive maintenance strategy. With the use of IoT systems, FM personnel can continuously monitor systems and receive up-to-date information on how systems are performing based on various metrics such as temperature, energy consumption, and equipment status. As described by an interviewee, “device activity on the network is monitored, offline devices generate email alerts and other notifications. Devices are also monitored for unexpected data outputs or status updates to address issues within the built environment.” With more robust monitoring technologies like IoT, deviations from the expected norm can be detected automatically and a response can be sent out quickly before the issue turns into a larger problem. For example, an interviewee stated, “these systems monitor device activity over the network to let us know what has fallen offline and requires attention from maintenance staff. We also have systems that track asset information.” Furthermore, to maintain real-time data collection, “devices are pinged to check their status at regular intervals by the management applications.” However, this move from a reactive to a predictive maintenance approach means that facility operators must actively check dashboards and management applications and ensure

that systems operate within norms daily, which requires much more frequent attention than needed before. In addition, to receive notifications of anomalies or deviations from normal system performance, facility operators have to create rules for the system to follow in order for it to detect the anomaly and inform the proper personnel to respond accordingly.

The new abundance of data that systems can generate with the use of IoT devices additionally leads to new work in the realm of performance reporting to outside parties. To illustrate this point, an interviewee describes, “sometimes the engineering group will ask us to provide a week's worth of trend logs that will indicate how the equipment is working.” This interview then goes on to provide an example stating, “right now, specifically, the College of Engineering is asking for humidity levels in the rooms. Over the next two or three weeks to be able to establish whether that equipment is working properly or not.” FM personnel must now actively provide the desired metric reporting for many more stakeholders, such as what was described above, due to the new visibility that IoT devices provide through collecting data that can be used for space upgrades. This creates new work for FM personnel that was not present with the use of previous building management technologies in ensuring that all desired trends are monitored and accounted for based on the requests of stakeholders and independent building occupying parties who are requesting performance data.

#### **4.2. Data Analytics**

As discussed in Case Study One, the opportunity for data analytics is a major attribute of the use of IoT systems. This opportunity brings about organizational changes to operations in ensuring personnel have the skills to perform such tasks and new technical practices in performing analytical tasks that were not possible prior to IoT system integration. With IoT

devices deployed throughout buildings to collect building performance information in real-time, facility personnel now have access to an abundance of data across various metrics such as equipment status, temperature, humidity, energy consumption, and occupancy information. This enables the FM team to use data analytics techniques to drive better informed decision-making and allows systems to take autonomous action when performance sways outside of norms. Facility managers must now identify data patterns, trends, and anomalies within building operations, allowing for proactive interventions. This is illustrated by a technician highlighting the new level of data presented to facility operators, “we're able to query that data and we can filter it on multiple different levels, like a date range or a user. We can go down to, what did this user do on this day,” continuing to express the visibility this gives operators, “we can see that they overrode this, they adjusted this, they changed this and changed that. Or if we want to look at a window of a room six months ago...between 9:00 a.m. and 12:00 p.m., we can do that.” An interviewee describing the new work that goes into trending data which often includes layering different information on top of each other to understand holistic performance described, “we can look at trends from the last week, and we can layer trends on top of each other and kind of get a better picture of exactly what is happening. We can see when events happen, and how they coincided with other events.” However, the opportunity to trend data for actionable insights requires that it is properly organized and sorted and the correct data is extracted from the systems. First, this creates new requirements for organizing the new abundance of data in a meaningful way so that it can be used for analytical purposes. Then, once the data is properly organized and separated from the larger data pool, additional new work is needed to filter the vast amounts of data to extract meaningful information related to device performance or system health. Once the data is organized and filtered, it now becomes possible to begin trending data to

transition from a reactive maintenance system, such as what was present with the use of pneumatic control systems, to a more predictive maintenance system drawing from data trends, historical/archival data, and probabilistic scenarios. As described by an FM employee, “We are able to start gathering just even what might seem like arbitrary data to then feed into more predictive maintenance models.” This creates new work for facility and energy engineers in the manipulation of data for trending and predictive maintenance.

Our interviews additionally shed light on the future of the facility management field and its relationship with data analytics. Our interviewees expressed current issues that they believe will be solved with the implementation of AI or machine learning functionalities, which they will welcome with open arms in the near future. For example, the organization is struggling to accurately backfill missing data when devices go offline or errors occur. Interviewees express how they believe this can be solved with the implementation of AI through statements such as, “ideally, in the long run, we can use modeling or machine learning or things like that in order to more accurately back fill gaps in data if there are some. You could use all these factors to back fill and predict.” Another interviewee echoed this sentiment, describing AI's potential to help them make accurate predictions if the data collected and stored is multi-year reliable data that they can use to train models. This proves the importance of maintaining precise data sets to pave the way for future AI advancements. As shared by an interviewee, “I think someday we will be able to actually turn the AI monsters on the building operations and actually improve stuff...but that's really gonna be dependent on being able to provide those models with good, clean, reliable, multi-year data to build those models up so that they're actually useful.” This statement sheds light on the importance of identifying, collecting, and storing accurate data to advance the use of AI and machine learning and improve operations. This creates new work for facility

operators in identifying pertinent information and developing the proper storage infrastructure to advance to using tools such as AI.

### **4.3. Troubleshooting, Fault Detection, and Diagnostics**

The integration of IoT systems in FM is changing the nature of troubleshooting processes which of course leads to shifts in practices around this theme. Traditionally, facility managers relied heavily on reactive measures to address issues as they arose and mainly implemented physical maintenance measures to troubleshoot errors and address malfunctions once they have occurred and FM staff were notified. However, with the integration of IoT technology, troubleshooting has become increasingly proactive and data-driven compared to the reactive measures which existed prior. Many device and system troubleshooting processes are now largely driven by software and technical analysis of systems and their network connectivity. As found in this study, overall troubleshooting with IoT systems largely revolved around issues in network connectivity or device configuration, both being primarily technical problems. This has largely changed the order of operations in troubleshooting procedures. This change is portrayed through our interviews when we asked facility personnel to describe their device troubleshooting procedures when errors occur. One interviewee stated, “you start out at the server level typically and you see something is wrong where it's not reacting the way that you feel like it should be. Then you go down farther and then you directly plug in, figure out if there's something wrong with the configuration,” another states, “we’ll determine if maybe there’s an error in the settings of the system or something like that, something got changed. Maybe the IP address got changed.” However, this type of transition to more technical rather than physical troubleshooting does not eliminate the need for physical investigation and fieldwork as was prevalent prior, it

simply changes the order of operations and shifts physical on-site troubleshooting to a later point when technical troubleshooting measures have already been attempted. This shift in order of operations is expressed by an interviewee who stated, “we do the first pass at it up and down. Can we determine any kind of IT issue? Is it a meter issue? Then we will go to site to troubleshoot the meter.” This statement shows that physical troubleshooting and maintenance, like rewiring or replacing meters, is still important to the troubleshooting workflow, however prioritization has shifted, with physical troubleshooting becoming more of a fallback option rather than an initial course of action.

Related to the above, device and system troubleshooting is additionally shifting in form allowing for remote work and offsite response to issues when they occur in real-time due to the nature of typical errors with IoT devices. This shift is due to the technical nature of errors and the reduced need for on-site maintenance as described above. This requires facility personnel to have adequate knowledge in individual device control programs to be able to manipulate them effectively while remote and remain available for response in typical “off-work” hours. As stated by a facility employee, “now that we've automated things, we can be more responsive, that I could be right in front of my computer, and within two minutes, I will have changed whatever setting needs to be changed.” The need for facility staff to be more responsive during hours outside of typical business operations is portrayed by a controls technician who shared, “I can be at home on a Saturday afternoon and FOMS calls me and says they have a problem... I'm able to manipulate the equipment they're standing in front of and they're able to tell me what they're seeing.” This transformation, driven by the technical nature of errors and the diminishing requirement for on-site maintenance, allows facility personnel to address issues more efficiently as they arise. However, it additionally requires a deep understanding of individual device control

programs and a readiness to be available during non-traditional working hours. This highlights a growing improvement in troubleshooting and response which is helping bring the organization into a less reactive workflow as errors do not need to reach criticality before they are addressed, however it involves a more detail-oriented approach and higher levels of commitment and availability.

In addition, the implementation of rule-based algorithms during the configuration phase of IoT system deployment has led to automated fault detection which serves to notify facility personnel of device malfunctions without their direct involvement or attention. While this improves efficiency, it also results in a higher frequency of issues requiring attention from facility personnel, meaning that in a lot of ways FM teams have more daily “work” due to improved visibility and automation. This contrasts with pneumatic systems, where faults often went undetected until damage occurred and became visibly noticeable. The heightened level of automation gives FM employees much improved visibility of system performance, ultimately increasing the workload for facility personnel. This is illustrated by an interviewee describing the fault detection response procedure in place for critical spaces like labs on campus, “we have some labs out here that have critical equipment that serves it. And sometimes if that equipment goes down, then we could specifically send an email or a text message to somebody who would respond right away to it.” This is further echoed by another technician who shared, “we have notifications for any critical services, computer services that go offline. If any one of the hosts goes offline... we can alert. We can afterhours respond and get the system back and functioning again.” The higher level of information which systems can now provide means that facility personnel are leveraged more often to solve issues that were not before possible due to reduced

visibility. Although this is a major benefit to system performance, it creates new ways to increase the workload of facility operators.

#### **4.4. Creating, Maintaining, and Responding to Alerts and Notifications**

As described above, facility personnel have access to a new abundance of data which can be used to better respond to system faults and irregularities in real time with the use of IoT. Therefore, creating, maintaining, and responding to system alerts and notifications is becoming a critical aspect of FM practices when operating IoT integrated buildings. Creating alerts means that FM personnel must define conditions within the IoT system that dictate system responses to certain parameters. More specifically, this means that when a set parameter is met or exceeded, it automatically triggers alerts that inform facility personnel of the abnormality in the performance of that device or system. Once such alerts are created, maintaining them requires regular review and adjustment to ensure they remain relevant and effective in identifying potential issues or abnormalities as systems, their function, and the context changes. To illustrate how these alerts impact day-to-day operations a facility manager explained, “if it's critical enough, then you're going to set up an alarm that will alert somebody that there is a situation happening. Then I can immediately interface with that situation within five minutes.” Once the alert is generated and the facility team gets eyes on it, they can then either make whatever adjustments are necessary through the control dashboard/application or can inform “somebody who will respond right away to it” in the field. However, due to the size of the campus and the limited number of staff available at any given time to respond to system alerts, the facility team has to develop and establish protocols around promptly responding to these alerts through creating automated responses or establishing a priority hierarchy to deem the criticality of immediate response. This

process of prioritization is illustrated by a technician who shared “For high priority areas, we can set up alarms and then send those to alarm handlers which, from there, will be distributed and disseminated to recipients. For example, an animal testing area.” As stated in this quote, certain campus areas will require more immediate response or attention than others, illustrating the need to establish a hierarchical criticality of response protocol for areas like animal testing labs or medical spaces.

#### **4.5. Managing and Navigating Diverse Vendor Specific User Interfaces and Applications**

Each manufacturer of IoT devices develops their own control application/platform that is used for device control, manipulation, and data access. As more IoT devices are acquired from diverse vendors, the challenge of continually adding new control platforms to the existing IoT ecosystem means that FM personnel must continuously learn the nuances of specific applications and adapt to a plethora of diverse control systems. In addition, these individual platforms regularly update and change their software requirements and user interface based on manufacturer updates, which again requires FM staff to continuously evolve their skill sets within them. This is portrayed by an interviewee who stated, “there are multiple platforms for different devices,” and they continued on to share that control dashboards all “have a separate and specific software for the top layer... a separate software set of tools for the supervisory device and a separate set of tools for the field device.” Another interviewee expressing their struggles in navigating the fast-changing environment shared that “each HVAC control vendor has their own proprietary user interface,” which comes with complications as they continued to share, “every other Tuesday, they seem to have changed their entire system. And with that comes the growing pains of a new system.” This sentiment is further echoed by a technician describing

the changes they have encountered in managing control dashboards during the transition from one operating application to an updated version as they stated, “they changed the entire architecture of how the entire system worked. And so, doing something as simple as just adding an input, like a sensor input, to a field device now became a challenge, because the way you did it was entirely different.” Another interviewee describing a similar user interface transformation describes the experience by stating “it was painful.” As more IoT devices are adopted from various manufacturers it creates the challenge of adapting to a diverse set of control platforms specific to said manufacturers. In addition to this, each management application is often subject to regular updates and changes in software requirements and interfaces which calls for FM personnel to be able to adapt to new platforms and user interfaces regularly.

#### **4.6. Creating, Understanding, and Maintaining Data Visualizations**

To make collected IoT data easy to comprehend and distribute to stakeholders, facility teams need to create data visualizations to represent trends and performance in a way that is easy to digest and simpler to comprehend by non-directly involved parties. Creating visualizations to represent data can also make it easier to analyze and comprehend for internal facility members by creating things such as data graphs, tables, and 3D visualizations to represent the data or the building sections themselves. This introduces new responsibilities for facility personnel in using visualization software to represent collected IoT data. As an example of software tools used for data visualization purposes by the facility team an interviewee shared “we have tableau to create visual representations of the data,” while another shared “there are basically two sets of visualization tools, one for the UW customer – the kind of summary or final report views, and that’s in Tableau... and there is a web visualization tool called PI Vision that is accessible

directly.” When describing the functionality of these visualization tools and what they help the facility group create, interviewees stated that they assist them in creating “code-required reports,” “EUI for the buildings,” and “interactive dashboards” where an FM employee can “from scratch build your own dashboards or build and save dashboards for other people to see.” In relation to the creation of 3D visual representations of building spaces, the facility team integrated a professional with a graphic arts background to assist them in the process, showing the importance of having such a skill-set to manipulating IoT data. In describing this an interviewee stated “we have a guy that actually went to art school, and so he's able to take the AutoCAD drawings and he's able to use a tool that we bought...to raise up the floor plans and orient them and color them and everything.” Leveraging data visualization tools entails not only learning software like Tableau and PI Vision but also leveraging them to create different forms of visual representations like code-required reports or interactive dashboards and 3D models of building spaces to make the IoT data more comprehensible. This is important in sharing data with outside stakeholders and finding ways to make applications easier to use through interactive dashboards as described above.

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## **5. IoT Device/System Lifecycle Management**

In this section, the new requirements around IoT lifecycle management will be discussed in detail. This is an important attribute to ensuring the operational capabilities of IoT systems overtime, especially due to their contrasting maintenance requirements and reduced lifespan compared to traditional building elements which often require less attention and demand much less frequent maintenance, as discussed in Chapter 4. The following topics will be discussed in this section:

## 5.1. Updating Software and Servers

## 5.2. Sensor Lifecycle Maintenance

### **5.1. Updating Software and Servers**

As IoT systems evolve and manufacturers continuously release new versions of software, facility personnel must stay ahead of the curve on updating software and servers in addition to keeping track of the status of their systems to ensure continuous compatibility. The fast pace of upgrades becoming available is embodied through an interviewee who shared, “I’ve been through a couple of those life cycles... some of what we’re upgrading is like two to three life cycles ago that we’re taking all the way up to now. And some of it is the last lifecycle we’re bringing up.” Another interviewee expressing a similar sentiment on the process of upgrading software and servers stated “this [upgrading software] is a challenge both in terms of funding and staff availability. Historically devices have run to failure and software updates were, with some exceptions, only applied through an ad hoc process.” Such an “ad hoc” process is no longer viable with the use of IoT systems as they can quickly become outdated if the correct updates are not regularly performed, requiring an organized approach to managing system updates. Such an organized approach would include tracking and documenting the status of existing systems through inventory efforts. One interviewee shared the consequences of falling behind in software updates stating “you won’t know until you go to the device, and you try to use the contemporary tools on that piece of equipment, and it says ‘not compatible’.” Further complexity is added to this process because various integrated IoT technologies are updated on different cycles based on the release of new software versions from their coinciding vendors. This issue is embodied by an interviewee who stated, “that is a constant battle, is software updates...the IT world doesn't wait

for us. They keep moving forward...so we have to keep upgrading our stuff to keep up with them at times too, both with server and with the local interface.” The continuous release of new software versions requires increased attention to update requirements and an organized tracking effort from the FM side. Falling behind the curve with updates creates compatibility issues, which then have cascading effects as newer upgrades become available over time.

## **5.2. Sensor Lifecycle Maintenance**

Over the lifecycle of IoT devices and as system updates/upgrades become available, measures need to be taken by facility personnel to maintain the end device sensor hardware and device configuration to account for continual compatibility and effectiveness with system updates. Sometimes this involves performing hardware maintenance, changing configurations, rewiring devices, or replacing entire controllers when they are no longer compatible with systems. To illustrate some of the hardware maintenance procedures required by facility personnel around the management of IoT sensors an interviewee stated, “some of those meters are now 15 years old, and they’re starting to wear out and break,” continuing on to share, “So [facility manager] is needing to order spares and make sure that there’s parts stocked so that when meters die they could be replaced in a reasonable amount of time so you’re not losing all the data.” Another interviewee describing software updates leading to sensors becoming obsolete stated, “sometimes end devices that are not compatible have to be changed. The physical controller has to be changed.” In certain circumstances such as what was described above, changes to the system software and the rapid pace of technological development around IoT require the need for total device replacements when the hardware is no longer viable to support new software versions. This additionally can occur when communication protocols are changed

or updated, and the existing hardware no longer supports the ability to interchange data. This can require the rewiring of entire systems or in some scenarios the total replacement of the sensor or end device for it to maintain its communication abilities with the network and other devices. This is illustrated by a technician who shared “when you’re upgrading to BACnet... you have to change the controller. Sometimes you have to change the wire too... if you’re talking a big network, you’re talking a lot of wiring.” The fast-changing IoT landscape calls for timely replacement of end devices and enhanced attention to the lifecycle of IoT systems which is significantly reduced compared to static building elements which FM teams are used to maintaining, a topic discussed in case study one. To account for this, FM personnel must develop IoT specific maintenance cycles and ensure that replacements occur on an accurate cycle.

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## **6. Managing IoT Access Control and Security**

In this section, the new requirements around managing IoT access control and overall system security with the growing number of IoT implementations on campus will be discussed. As more unique devices get integrated on campus, more system vulnerabilities may present themselves and more precise access control to systems must be assigned. In this section the following topics will be discussed:

6.1. Managing Access Control

6.2 Maintaining Firewall and Intrusion Detection Systems for IoT Devices and Controls

### **6.1. Managing Access Control**

With the increasing adoption of IoT devices in building automation systems for controlling building parameters such as HVAC, lighting, and energy, it becomes critical to

implement security measures to protect against potential threats and unauthorized access. Therefore, the FM team needs to provide a diverse set of users with their appropriate level of system control and visibility. This creates new work for facility personnel in the arena of assigning access control permissions to users and controlling permission levels across the diverse university-wide organization. This is illustrated by an interviewee who stated, “we grant engineers, data analysts, even just building coordinators with various permissions, what they can't change or what they can see... you can grant access to a smattering of people all across campus.” This is further portrayed about a technician describing how permissions are assigned, “say if I wanna give a building coordinator some ability to make changes, I’m gonna limit his access to this toolset, both on the web UI and if he has access at all to the propriety toolset.” In an environment like an active research campus, assigning control permissions additionally goes beyond permission control for members of the facility division, but can also include individual researchers and academic professionals who want higher space customization or specificity in their workspaces. This is exemplified by a controls technician who described a story about a researcher using an MRI machine for their work in one of the campus facilities. This technician stated, “MRI machinery is very dependent on temperature and humidity. So, with that, the operator has to have full control over these points.” The technician then explained the permission control solution to this problem stating, “it’s the coolest thermostat I’ve ever seen...the operator of the MRI machinery can go in and both verify that conditions are within tolerance and change them as needed to become within that tolerance.” Granting such specific controls depending on system users is a new responsibility for facility personnel which is continually growing as the number of IoT integrated buildings on campus increases. The process of meticulously assigning proper access control to users is embodied by an interviewee who shared, “sometimes, we grant

facilities a lot of permissions. Sometimes, we restrict it. It's a very case-to-case basis.” The diversity in access control permissions reflects the complexity of this requirement, where permissions may range from basic monitoring capabilities to full control over system settings, depending on individual circumstances. Therefore, the assignment of access controls is becoming an important aspect of FM, requiring careful consideration to meet the evolving needs of building occupants as systems continually rise in complexity.

## **6.2 Maintaining Firewall and Intrusion Detection Systems for IoT Devices and Controls**

Maintaining security systems such as firewalls aids in protecting interconnected IoT devices from possible security threats. In IoT management, facility operators are tasked with working with IT professionals to monitor, manage, and update firewalls and intrusion detection systems to ensure that only authorized personnel and traffic can access device information. In this process, FM personnel work with IT groups to help establish permissions and rules to allow internal groups to bypass firewalls while blocking non-approved users. This is illustrated by an interviewee discussing this topic, “the university manages all of the security devices, the firewalls, right. So we work with them to maintain the firewall rules and ensure that we have kind of that least privilege, basically block any and only allow traffic that’s whitelisted.” To illustrate the importance of managing security and access, a controls technician describing the organizational growth and development around establishing and maintaining security measures such as firewalls stated, “even five years ago, it was just the Wild, Wild West out there. And then security has come front and center recently.” Although facility personnel are not the developers of security systems as that task lies within the responsibilities of the University IT department, they are still critical in the work of managing these systems and configuring their access rules

and regulations. This creates an important line of collaboration and communication between IT and FM, within which FM groups provide the logic behind the ways security systems operate and detect potential harm.

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### **5.3. Conclusion/Case Study Overview**

Within the setting of the UW Facilities, this case study aimed to understand what new practices are necessary for facility management teams to ensure the technological feasibility of IoT systems. Overall, the findings of this case study fall into six categories, as seen in Table 8, including the following:

1. Sensor Configuration
2. Establishing Network Communication
3. Middleware/Supervisory Device Configuration
4. Leveraging the Capabilities of IoT Systems
5. IoT Device/System Lifecycle Management
6. Managing IoT Access Control and Security

Within Category 1, new practices to ensure the technological feasibility of integrated IoT systems include managing diverse vendor specific software tools and programming/coding responsibilities in device configuration. In Category 2, new required practices include creating and maintaining unique identifier/instance numbers, standardizing communication protocols for device communication, converting existing buildings to IoT control, and integrating third party devices. Within Category 3, new practices include establishing and implementing logic in supervisory devices for message routing and processing. In Category 4, new practices include

system performance monitoring, responsibilities in data analytics, new work in troubleshooting and fault detection, creating and maintaining alerts and notifications, managing diverse vendor-specific user interfaces and applications, vendor management and collaboration, and creating and maintaining data visualizations. Within Category 5, new practices include updating software and sensor lifecycle management requirements. Lastly, in Category 6, new work forms in managing IoT access control and maintaining firewall and security for IoT devices and controls. These new practices as described in this case study serve as best practices to maintain the technological feasibility of integrated IoT systems.

In Chapters Four and Five, this study established the shifts in practice and new emerging responsibilities around IoT management for building operations from both an organizational and technological perspective. In Chapter Six, the focus switches gears to DT operations in a different operational setting to investigate how the organizational shifts in practice required for IoT integration translate to a DT operated facility.

## Chapter 6: Case Study Two

### Research Goal

This case study was conducted in partnership with the Dallas Fort Worth (DFW) International Airport and focused primarily on the airport's implemented DT initiatives. The aim of this case study was to explore whether analogous themes in changes to organizational practices, as identified in the IoT investigation, are present in the adoption and operation of a DT-integrated facility. More specifically, this case study sought to specifically answer the research question below:

Does the use of a digital twin require the same shifts in organizational practices as IoT, and are there additional changes or unique considerations that emerge when analyzing the use of digital twins in facility management practices?

In this study, the objective was to corroborate or challenge the thematic conclusions about the shifts to organizational practices drawn from the UW IoT Case Study, while also identifying any novel considerations that may be important when operating facilities with DTs instead of solely IoT systems. Overall, many of the prominent themes discovered in the IoT investigation with the Facilities at the UW were validated with this case study, and new findings were made. Table 9 below displays the findings of this case organized by thematic category, the analogous findings to the IoT investigation within each category, and the new findings resulting from this case study, which lie within each theme. The thematic categories listed in the first column are the same as those found in Chapter Four (the UW IoT Case Study - Organizational Shifts in Practice), with the exception of one, and the addition of another. The category called

“Challenging Entrenched Organizational Practices, Standards, and Norms” was not present in the DT case study due to its relevance to traditional FM organizational structures and documentation structures. The new thematic category, “Leveraging DT Visualization Capabilities”, describes the new required operational practices in the form of creating and maintaining data and simulation visualizations, a category that was touched on but not as impactful in the IoT investigation. These findings will be discussed in detail in the sections below, after a brief discussion of the current DT use at the DFW airport to build out the context of this case study and provide background to support the findings.

**Table 9: DFW DT Case Study Two Findings**

Category:	Corroborated Findings with IoT Case Study:	New Findings within Category:
<b>1. Breakdown of Disciplinary Silos - Centralization and Democratization of Data</b>	1.1. Centralized Data Management	1.5. Importance of Colocation
	1.2. Centralized Communication and Data Distribution	
	1.3. Increased Need for Interdisciplinary Collaboration	
	1.4. New Communication Necessities	
<b>2. Bridging the Gap - Institutional Knowledge and “New” Knowledge</b>	2.1. Balancing “New” Knowledge with Institutional Knowledge - New Finding: Institutional Knowledge Shift	2.1. Institutional Knowledge Shift
	2.2. New Technical Skill Set Requirements - Learning/Understanding DT Data, System Architecture, and Application Opportunities	
	2.3. New Technical Skill Set Requirements - Learning/Understanding Device Coding/Programming	
<b>3. Leadership Requirements</b>	3.1. Managing Personnel Resistance to Change	3.4. New Roles and Responsibilities- Integration of Data Scientists/Engineers
	3.2. Establishing Management Consistency	
	3.3. Necessity for Enhanced Training	
<b>4. New Theme - Leveraging DT Visualization Capabilities</b>		4.1. Creating and Maintaining Data and Simulation Visualizations

**6.1. Case Study Background: DT Use at the DFW Airport**

The DFW airport has been in operation since 1974 and has seen major growth and development in the past 50 years. The airport is a hub for international travel, serving over 73 million customers per year, making it “one of the most frequently visited superhub airports in the world” (dfwairport.com). The airport supports 193 domestic flights within the United States and

67 international destinations around the world. This is in addition to the 22 cargo airlines that pass through the airport regularly. The airport is over 17,207 acres (26.9 sq. mi.) in size, making it the largest airport in Texas and the third busiest airport in the world by aircraft movement. The airport is positioned between the cities of Dallas and Fort Worth and produces over \$37 billion in economic impact annually, making it a major economic generator in northern Texas, supporting over 634,000 diverse disciplinary employees. With its seven total runways, five terminals, and 171 gates, this airport is an extremely complex system that calls for high levels of organization and discipline in properly managing its operations. It is also identified by personnel as a “mission critical facility.” In attempts to both increase energy saving opportunities and optimize operations and customer experience/satisfaction, the DFW airport has implemented multiple technological initiatives to aid in this process, including Digital Twin (DT) technologies.

Based on document collection data as well as conversations with a range of personnel who have worked on the DT implementation efforts at the DFW airport, this study is focused on five major DT initiatives that the DFW airport team has been developing simultaneously. These different DTs, which have been deployed to solve unique problems, are noted and briefly described below as background information for this study. However, first, it is important to understand how the stakeholders in the DT efforts at the DFW airport define a DT. According to a lead environmental scientist and planner with a previous lead role in the airport’s Special Projects Program who has been important in helping guide the DT efforts at the DFW airport, DTs are defined as “virtual replicas of the physical world, including the operations and the transboundary flow of information within the airport system. They can integrate real-time and historical data and allow us to explore a wide range of ‘what-if’ scenarios to test policies and

interventions within a virtual environment before full-scale deployment.” The DTs that have been used at the airport, which will be referenced throughout this case study, include:

1. **Traffic Management DT** – The goal of this DT is to forecast traffic demand and creates high-fidelity simulations of traffic inside the airport for traffic predictions. The airport used this DT for traffic control strategy optimization, congestion relief, and energy efficiency. This DT was also used to optimize shuttle bus routes and parking choices to reduce energy use and operational costs while increasing transport efficiency.
2. **Rental Car Fleet/Zero Emissions Vehicles (ZEV) DT** – This DT aims to develop electrification pathways for the DFW airport, focusing on rental car fleets to accelerate the decarbonization of thousands of vehicles operating at the airport. Used to explore scenarios of widespread EV adoption by rental car companies at DFW.
3. **Passenger Boarding Bridge DT**- Part of the Terminal D energy enhancements and renovation project, the goal of this DT is to optimize gate utilization and availability in the terminal. The DT controls gate and bridge utilities such as electrification, air conditioning, lighting control, movement etc.
4. **Customer Experience DT (Smart IQ)** - Part of the Terminal D energy enhancements and renovation project, this DT aims to optimize customer experience in terminals by controlling factors such as air quality, temperature, the shade of windows, lighting, and other occupant experience-related metrics.
5. **Central Utility Plant (CUP) Digital Twin**- This DT is used to optimize and increase efficiency of chillers in the central utility plant of the airport.

## **6.2. Findings:**

The findings in this case study are organized based on thematic categories, as seen in Table 9, beginning with “the Breakdown of Disciplinary Silos- Centralization and Democratization of Data” and ending with “Leveraging DT Visualization Capabilities”. Each finding from within each category will be discussed in its corresponding section. The related findings to the IoT case study and the additional findings from this investigation will be elaborated on in each section.

### **1. Breakdown of Disciplinary Silos - Centralization and Democratization of Data**

Similar to the findings of the UW IoT Case Study in Chapter Four, disciplinary silos were present in the operations division at the DFW airport, which were inhibiting the use of DTs and making it harder for the organization to optimally manage digital systems. In this section, the analogous findings from the IoT case study related to the necessity to break down disciplinary silos will be outlined and the shifts in organizational practices at the airport will be discussed. In addition, a new finding resulting from this study will be introduced and discussed. The following topics will be outlined below:

1.1. Centralized Data Management

1.2. Centralized Communication and Data Distribution

1.3.,1.4. Increased Need for Interdisciplinary Collaboration + New Communication Necessities

1.5. New Finding - Importance of Colocation

## 1.1. Centralized Data Management

As founded in the UW IoT case study in Chapter Four, disciplinary silos were still present in the DFW airport within their operations, maintenance, and facilities teams. Similarly, such silos in the organization created siloed data management practices which made it more difficult to share information at the organizational level, which is where the DT's management and maintenance must occur. Based on our interview data, management seemed to be aware of this problem as they have instilled efforts aimed at breaking down silos to achieve a more centralized data repository and a more unified and democratized approach to data access and management. Interviewees embodied this sentiment by sharing statements such as "I think part of it is recognizing that the business-as-usual application to problems has not worked. We need to have that integrated approach to breaking down the silos. We need to have a mindset shift in how we think about even sharing information." Another interviewee discussing the benefits of democratizing data through dismantling silos: "It creates a sense of everyone understanding how they are collectively working towards a common vision and common goal," and continued on to share that, "I think that's where the strategy for hiring and developing the workforce should come from. It should come from that **shared vision** and **silo-bursting** perspective." However, although the team was aware of these issues and worked towards finding ways to dismantle such silos, they still encountered problems with data access which inhibited some of the DT's real-time data capabilities, as described below.

One of the principal developers of two of the DT models at the DFW airport shared an experience around their struggles with the lack of centralized data at the airport due to the presence of data silos during the initial development of the traffic management and rental car fleet DTs. This interviewee shared that the main issues that were experienced in developing these

DTs revolved around the lack of real-time data that they could access due to the various discipline-specific data sources that the DT had to pull from, which were held by different parties and not centrally managed. This interviewee expressed that “I think the data was at best a day old by the time I could get it, it limited its usefulness for sort of a real-time application.” In describing what the organization needs to do in order to develop DTs for different aspects of airport operations and use them in conjunction, this interviewee then continued to explain that “I think they will have to have access to these different data sources from a single interface, like an API. So that the tools they build can pull this data and use it in real-time.” In order to make data useful in real-time applications, this interviewee pointed to the necessity of creating a central location from where data can be extracted in order to make the process easier, more timely, and more efficient. When data is siloed based on discipline or organizational group’s individual information repositories, it is difficult to draw data from multiple sources, which creates a delay that affects the real-time capabilities of using a DT in the first place. This limits the ability of the DT to provide accurate data about the current state of the facility it represents, which can be used for predictive analytics or decision-making in more critical situations. This creates a need for timely data access, which can be achieved through the organization-wide centralization and democratizing of data.

## **1.2. Centralized Communication and Data Distribution**

Similar to the findings of the UW IoT Case Study, communication silos at the DFW airport led to issues in data and process consistency as well as timeliness in responding to DT insights. This creates the necessity for centralized and standardized communication pathways and information distribution throughout the organization to leverage DTs and manage their real-

time data capabilities. Collected data showed that the use of DTs requires organization-wide standard response protocols in order to maintain timeliness in critical response. An interviewee expressed their frustrations around the lack of communication standardization in managing the passenger boarding bridge DT at the airport by stating, “it's a lot of silos, and the sense of the way that the information is being shared right now is not consistent. It's also not as reliable. And it's not as timely.” In stating the above, this interviewee described the current inefficiencies in managing the passenger loading bridge DTs in the airport terminals. These inefficiencies largely revolve around the multiple airport personnel from different departments reporting problems at passenger loading gates through various communication pathways such as text, Microsoft Teams messages, phone calls, or emails. The process usually begins with airline personnel reporting an issue to the airport control center, which then notifies maintenance teams and reports to the customer experience department to address the issue. However, the timeliness of response initiatives is often sacrificed due to organizational members communicating problems in whatever form preferred by each individual group at each stage of this communication trail. Outside of timeliness, this additionally leads to a lack of communication consistency and reliability due to organizational silos, which use their unique and preferred methods of communication to inform the next group in line to address the problem. This echoes similar issues from the IoT investigation, reinforcing that clear communication and data distribution routines around managing and moving data are essential to navigating DTs, which allow for real-time data access. Without clear communication standards throughout the organization about how to share data and in what form this data should be shared, it can cause confusion, inefficiencies, and a lack of structure which does not encourage the effectiveness of both DTs and IoT systems, as seen throughout both case studies.

### **1.3, 1.4. Increased Need for Interdisciplinary Collaboration and New Communication Necessities**

When describing the network of stakeholders and individual teams involved in developing and managing the current DTs at the DFW airport, an interviewee explained the importance of connecting a very diverse group of professionals to ensure the DTs operations. This interviewee described that collaborative efforts must be made between the environmental department, who lead and facilitates the effort, the airport controls center team, various airport internal stakeholders, the commercial experience team, the airport's IT division, a contracted party helping in IT development for the DT, the Willow team (a Microsoft based DT development platform), and outside contractors who liaison data between Willow and the airport's operations teams. This interviewee then goes on to express the challenges that have been encountered in "balancing all the different stakeholder needs." Another interviewee described the collaborative process between all these unique teams that must be unified under a common vision: "you have different disciplines trying to collaborate, and you want them to be able to visualize the project, understand their part, but also understand their part in the context of the greater project." This has proved to be a difficult task due to availability and finding ways to express the vision and goals of creating DTs to teams that may not be intimately familiar with the concepts. However, to encourage such interdisciplinary collaboration, management has had to bring together a group of professionals with unique skills into a cohesive team to account for all the knowledge requirements of DT development and operations. This is articulated by an interviewee who shared that, "we realized that there were people who knew a lot about Lidar and scan-to-BIM models. There were people who knew a lot about building management systems and energy management, and then there were people who knew a lot about the digital platform

and digital twin technologies.” They continued on to pose the critical question they had to address, “so how do we bring everyone together, understanding that each of those pieces are important.” The team has found ways to leverage individual skills within a unified space by encouraging and developing real-time collaboration sessions where all team members were present and working together simultaneously in a digital real-time space. This is described by a manager who shared, “we’ll do blue beam sessions to share that information, have everyone commenting pretty much in real time, and updating parts so that we see how things are changing,” continuing to share that these collaborative work sessions are “a portion of what goes into the twin.” Beyond DT development, such diverse collaboration needs to continue in order to solve DT related problems which often require diversely skilled personnel to address such as device breakdowns, errors, or incorrect data. Additionally, maintaining the DT software and hardware over time as updates and bugs become more common will require such interdisciplinary collaborations. This validates the findings from the IoT study and solidifies that disciplinary collaboration silos cannot exist with the use of IoT and DTs.

### **1.5. New Finding - Importance of Colocation**

A notable discovery in this case study, setting it apart from the UW IoT Case Study, is the significance of physical colocation in managing a DT system. While both studies had similar findings regarding data centralization, centralized communication and data distribution, and enhanced interdisciplinary collaboration, the data gathered in this case study showed that with a DT, the physical proximity of teams is emphasized as important for effective management. This is embodied by an interviewee who shared, “The airport is a mission critical facility... I think that co-location is absolutely necessary,” going on to describe why they believe this by stating,

“because of the nuances to what someone is observing on their portion of the twin or on their dashboard. While I can observe it as an outsider, I won't get as much context by just looking at something.” At the DFW airport, operations are centralized in a control room called the Integrated Operations Center (IOC). Observational efforts by the UW research team as well as interview data explain that this is a big room equipped with a plethora of control dashboards controlled by the many different teams needed for airport operations within one unified space. In this control room is where all critical information to airport operations comes in and is processed in order for decisions to be made. In describing the IOC room an interviewee stated, “if they get an emergency call, it comes to this center. If a chiller shuts down, they get notified at the center...all the issues come to the center.” When describing the teams that operate in this space an interviewee shared, “they have various different stakeholders in that one room. And with it being customer experience, and baggage claim, and gate coordinators, and bridge managers, as well as executive representation there as well.” In describing the purpose of the dashboards in this centralized location, this interviewee stated, “all those screens are just to help have visibility of what’s happening in the various different sectors of the airport, and to facilitate aircraft operations being efficient and safe.” The data derived from this study shows that a co-located management team for DT operations is very beneficial to managing this technology. By bringing together specialists from various sectors of airport operations in one space, the team can leverage the collective expertise of its members without the need for elaborate communication networks and long wait times for responses to critical situations. The data showed that a co-located environment promoted open collaboration, allowing for the efficient exchange of ideas and development of solutions by cutting out the wait time required to reach other disciplinary professionals in a traditional environment. In addition, a co-located management team reduces

the risk which might come with making decisions that are not informed by specialists which may be made in a more traditionally divided management space. Without the need to search for disciplinary specialists and wait for responses to critical questions, a co-located team can improve the efficiency of decision-making and reduce the risk of making decisions that are not backed by adequate knowledge or data within a setting they describe as a “mission critical facility.”

In explaining the benefits of colocation to improving airport operations by having a diverse range of specialists housed in a centralized area, an interviewee shared an experience at the airport around de-icing operations on the runways after the airport receives rain. This interviewee shared that the airport has digitally integrated rain gauges that monitor rainfall to help inform decision-makers on how to proceed with maintaining the runways after a storm. However, this interviewee described a unique phenomenon at the airport where rainfall can vary significantly between different sectors of the airport, particularly between the east and west sections of the airport, which is not necessarily portrayed or made evident by the data from the rain gauges. Although this can be marked as a fault of the technology, which calls for further development, in the current state of airport operations, this discrepancy creates inefficient de-icing operations, as one side of the airport may receive heavy rainfall while the other side receives little to none. Without considering these nuances which the technology does not pick up on, relying solely on overall rainfall data can lead to misinterpretations and potentially incorrect decisions around addressing de-icing operations. In this situation, the colocation of specialists helped address such airport specific nuances effectively as both the DT operators and veteran airport employees who understand such nuances were working in a centralized location. This can lead to avoiding wasted resources, better informed decision-making, better collaboration, and the

identification of best practices which are optimized when a co-located team of experts is utilized in the management of a complex system such as a DT.

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## **2. Bridging the Gap - Institutional Knowledge and “New” Knowledge**

The necessity for organizations to bridge the gap between institutional knowledge and “new” knowledge remains a prevalent topic in the adoption and use of DTs, similar to the findings of the UW IoT Case Study. In this section, the analogous findings from the IoT investigation related to bridging the gap between institutional knowledge and “new” knowledge will be outlined and their impact on this case study will be discussed. In addition, a new finding resulting from this study will be introduced and discussed. The following topics will be outlined below:

### 2.1. Balancing “New” Knowledge with Institutional Knowledge

- New Finding: Institutional Knowledge Shift

### 2.2. New Technical Skill Set Requirements - Learning/Understanding DT Data, System Architecture, and Application Opportunities

### 2.3. New Technical Skill Set Requirements - Learning/Understanding Device Coding and Programming

#### **2.1. Balancing “New” Knowledge with Institutional Knowledge - New Finding: Institutional Knowledge Shift**

With the use of DTs, the need to bridge the gap between institutional knowledge and “new” knowledge in the form of DT-specific technical expertise remains an important theme similar to the findings of the UW IoT Case Study in Chapter Four. However, the type of institutional knowledge shifts slightly in this case study. The findings of the UW IoT Case Study

focused on the value of retaining mechanical and trade-specific expertise on the existing mechanical systems within university buildings, while this case study focuses more on a different kind of institutional knowledge, which was still present in the UW IoT Case Study, however less of a dominant theme. With the use of DTs, institutional knowledge in the form of an intimate understanding of the setting within which the DT is being implemented is emphasized. To elaborate further, the case study data showed that a deep understanding of the institutional context of the setting, such as the unique attributes of airport management or the DFW Airport's unique characteristics and operational nuances was deemed highly valuable. This study additionally highlights the importance of institutional knowledge in managing any DT building integration, with increased priority as the complexity of the building's purpose/function increases. To illustrate this, an interviewee in a management position shared an experience involving the implementation of sensors within the airport's baggage handling system to monitor and improve luggage flow management. Despite having access to the virtual control system, the interviewee admitted, "I don't truly understand how those function, so as long as the lines were green, I'm like we are moving. Things are moving. Everything is on time." However, this interviewee was not part of regular luggage management and operations, so they were not able to pick up on the nuances of what the model was showing due to a lack of institutional knowledge in that domain. The individuals who work with the baggage handling system on a day-to-day basis were able to interpret the sensor data more accurately by predicting potential slowdowns based on the total number of loaded bags and predicting delays due to their experience and understanding of the nuances of the way such scenarios have played out in the past. This interview then shared, "they can provide that nuance that you should probably slow down this part of what you are doing because it's going to cause an issue in say 3 minutes." This showed

that experience and a deep understanding of the intricacies of the setting within which a DT is deployed was deemed very important to interpreting sensor data and making the best decisions on how to manipulate the system.

To further illustrate the importance of institutional knowledge to DT development, an interviewee shared another example around the efforts to develop the Rental Car Fleet/Zero Emissions Vehicles (ZEV) DT to simulate and predict rental car usage, electric loads, and customer wait time. In this scenario, the importance of institutional knowledge of the rental car business was again deemed very important to develop an accurate model. This interviewee shared that “we understand electrification, we know how to charge batteries, and simulation, all that kind of stuff. But there’s subtleties for the rental car business that we need to understand.” This interview then gave examples of such subtleties stating “like what if a customer shows up and there's no cars,” or the criticality of knowing that rental agencies often keep their inventories very low because its expensive to keep cars sitting in the lot, “so they like to keep the utilization of a vehicle at 85%... that’s a good thing to know.” This interviewee described that it was critical that the DT development team found ways to understand the nuances specific to the rental car industry in order to create a useful and reliable DT of the system that they were modeling. Without this business-specific information, the usability of the DT is limited because it will not operate within realistic bounds and will not be as useful in its actual setting. Therefore, having internal members in the team who have this kind of very context specific information is very important to simulating real-world scenarios accurately.

A similar situation was encountered in the development of the traffic DT at the airport. In this situation, the team struggled to accurately model the volume of cars going into the airport in order to predict traffic patterns due to subtle DFW airport specific nuances which required

familiarity and experience to understand and integrate into the DT. When modeling airport traffic, the team initially was modeling vehicle travel to the airport using toll data from a highway that traveled directly to the airport as they assumed that cars paying the tolls were going to the airport for drop off or pick up. This was leading to inaccurate models and the team was challenged to understand why. It eventually became evident that not all vehicles traveling on this highway and therefore paying the toll were going to the airport, as this highway connected the north and south travel routes which ran above and below the airport location, making it the quickest way to connect between interstates. Having such airport specific familiarity or internal team members with knowledge of the area itself could have helped solve this issue quickly and efficiently, again demonstrating the value of institutional knowledge in DT development.

## **2.2. New Technical Skill Set Requirements - Learning/Understanding DT Data, System Architecture, and Application Opportunities**

Similar to the findings of the UW IoT Case Study, a learning curve existed in bringing personnel up to speed around learning and understanding the intricacies of the new technology being implemented, such as understanding DT data, system architecture, and its application opportunities. This takes increased efforts in bridging the gap between old systems and new, and efforts at aiding employees in truly understanding how new implemented technologies operate and what the data they produce means for it to be used effectively. For example, in discussions with higher level employees, an interviewee shared the necessity for increased training around DTs in topics as basic as just understanding what a DT is capable of and what their purpose is. This interviewee shared that new training opportunities must embody “how to use the twin, how to collaborate in that twin environment and what the twin is capable of, and how to even develop

a use case.” An interviewee described the struggles in understanding how to make data useful and knowing what the new abundance of data represents stating, “they [DT radar technologies] have over 400 potential variables to work with. So they have a lot of data, which is great, but then it's kind of understanding what each of those actually mean.” Another interviewee describes a similar sentiment in the challenge of understanding data and ensuring its accuracy for DT use stating, “it’s hard to know that you’re in the ballpark of what’s correct, and especially if you’re going to use that as a digital twin where you are predicting loads in the next day or something.” Raising the organizational awareness of how the DT system operates and how data is used to best manage the DT is a difficult task that will require gaining experience and opportunities to gain familiarity with the system and how it operates. Similar to the findings of the IoT study, challenges around skill set changes and ensuring data accuracy have changed management’s view on skill set requirements for team members within the organization. For example, in describing team composition and the most effective team members in interpreting digital data, a senior employee stated, “in terms of team composition, what I have found is that I am not going to ask an old engineer to do it [interpret digital data]. I will ask younger engineers how they would interpret certain things...I tend to focus my efforts on the younger engineers.” As found in case study one, as the skills required to maintain building controls shift, the knowledge of personnel maintaining these systems must also shift. This requires personnel working with the DT system to learn and become comfortable with how a DT operates, what it’s uses are, the relationship with data and other such important technicalities that come with adopting a novel system which is generally not yet defined or bound in the industry.

### **2.3. New Technical Skill Set Requirements - Learning/Understanding Device Coding and Programming**

In addition, airport operators will need new technical skills to interface with the DTs. For example, the organization will need to develop personnel with programming and coding abilities for tasks such as IoT device configuration, potential troubleshooting in device malfunctions and DT development as a whole. This transformation in skill sets required to leverage the capabilities of a DT for it to serve the operational needs of the organization is stated by an interviewee who shared, “organizations truly have to consider that transformation of skillset, or that change in skill set required to implement and deliver what they used to deliver before.” This makes more technical skill sets very valuable to organizations utilizing such advanced technologies.

However, in the UW IoT Case Study, much more emphasis was put on training the existing workforce on these technical skills, while in this case study, such skills seem to be largely leveraged through the hiring and integration of data scientists and engineers into the existing organization. This will be greatly elaborated on in section 3.4 which is focused on the new roles and responsibilities for DT management. However, the transition to the use of DTs certainly requires the transformation of organizational skills to technical domains such as data science and data engineering.

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### **3. Leadership Requirements**

The literature focused on design and construction phases in addition to the UW IoT Case Study emphasized the importance of strong and effective leadership to guide an organizational shift to digitalization in built environment organizations. This case study has validated this finding and shows that strong and effective leadership and management are important factors in the success of DT use within an organization. In this section, the analogous findings from the

UW IoT Case Study will be outlined and their impact on this case study will be discussed. In addition, a new finding resulting from this study will be introduced and discussed. The following topics will be outlined below:

- 3.1. Managing Personnel Resistance to Change
- 3.2. Establishing Management Consistency
- 3.3. Necessity for Enhanced Training
- 3.4. New Finding: New Roles and Responsibilities - Integration of Data Scientists/  
Engineers

### **3.1. Managing Resistance to Change**

The use of a DT shows the continued relevance and significance of addressing resistance to change within management and leadership practices, as seen in the previous case studies. To portray the resistance to change that management experiences within the organization with the introduction of digital systems, an employee shared, “what I have found is that getting older team members to accept computer generated results comes with a certain amount of skepticism and sometimes downright hostility.” Another interviewee describes that leadership is currently grappling with “the pushback from employees they are working with” in the introduction of new ways of working with the DT system. An employee attempting to describe the root of this resistance to change from personnel described that, “we think it's a fear of it [DT] affecting someone's job, or taking the place of their job... not trusting that the system is effective.” With similar trends in resistance to change being present, parallels can be drawn between the strategies observed in the IoT investigation and those deemed necessary for managing resistance to change in this case study. As seen in the IoT case study, the findings of this investigation show that

management must focus on creating ownership over technologies for their employees and focus on the immediate benefits of the technology on day-to-day operations in order to increase buy-in to manage resistance to change. An interviewee in a senior position expressed that it is necessary to create pathways for employees to “take ownership based on a balance of both competence and passion.” Another interviewee expressing the importance of focusing on the direct benefits of the technology in order to increase employee buy-in stated, “let’s go take a step back and try to better communicate how this could be useful and how this is to serve them and make their role easier, not necessarily replace them or dismiss their knowledge of the system.” This is echoed by an interviewee sharing the biggest challenges to DT integration into the existing organization, stating “I think a big part is just buy-in, and trust. Then kind of ensuring that it is more effective than what the current processes are.” According to the case study data, leadership can address resistance to change by creating ownership among employees and emphasizing the direct benefits of using DTs. This validates the findings from the IoT case study and proves to show that not only does resistance to change exist beyond the specific organization, facility, or company, but it can be addressed in similar ways by leadership to combat resistance and increase support of the technological transformation or transition.

### **3.2. Establishing System Champions/Management Consistency**

Similar to the findings of the UW IoT Case Study, this case study portrayed the necessity for leadership to find ways to establish management consistency over new operations that form as the result of integrating and using a DT. In the early stages of DT development at the DFW airport, interviewees described the challenge of understanding their roles and responsibilities in the process. An interviewee shared, “in the early stages, it has been kind of everyone figuring out

what their role is in facilitating the development of the DT,” and expressed that “I think it wasn’t clear cut of what each stakeholder and person involved’ role is. We’re kind of in the process of establishing that.” This unstructured approach to managing a technology as complex as a DT is likely natural in early stages of organizational transformation, however it can cause confusion, stress, and a lack of productivity among the team. This type of transitional tension can also create higher resistance to change in an organization. This led the organization to find ways to delineate responsibilities to certain personnel in the organization and organize the effort in a way that encourages ownership over systems while ensuring that the team is properly addressing the necessary responsibilities in the management of the DT. An interviewee shared their experience around responsibility allocation in operations, stating that within the organization “they identify champions. For example, for sustainability, they’ll identify your champion for finding innovative ways to manage waste or to implement zero waste initiatives.” In describing the benefits of this solution to developing management responsibilities around DT operations, an interviewee stated that identifying such system champions “creates ownership based on both a balance of competence and passion. then, having them own and educate and share information with their peers.” As the complexity of the building management systems grows, IoT and DT systems require that leadership establish system champions and ensure that each component of the system has a consistent managing entity. This combats ambiguity, creates ownership, ensures continued operations, and combats resistance to change, which develops because of confusion and role uncertainty.

### 3.3. Enhanced Training and Education Requirements

With the use of DT, similarly to IoT, training employees to be familiar enough with new technological systems to not only do their jobs but also innovate is a new task for leadership to address. In the case of DT deployment at the DFW Airport, interview data shows that much of the training requirements for new employees should address understanding how the DT operates and the details of the back-end system. For example, a newly hired data scientist, who was the first data scientist in the environmental department, shared the training they believed would benefit them and other new hires the most. This interviewee stated, “I haven’t really worked with a digital twin at all. So I think having more exposure to that would be helpful. Especially for down the line, if we’re doing more and more analysis, understanding the kind of back end of the system will be helpful.” This interviewee then went on to elaborate, “I’ve had a very high-level kind of exposure to it [DT], I see what it looks like and what they are for... I see what the physical representation can look like. But I’m not developing it.” Continuing on to express how more technical back-end exposure would help in their work, this interviewee stated, “I think that would be useful to then be able to be more effective in my data analysis and ask the right questions.” As highlighted by interview data, understanding the intricacies of the DT, such as the details of the back-end system, emerged as a significant training requirement for new hires who must regularly work with the DT data. The idea of giving the people who are actively working on aspects of the DT a deeper understanding of the DT itself and how to leverage it for organizational improvements is further echoed by an interviewee who shared, “I think there should be standardized protocols of SOPS on training people on how to use the twin, how to collaborate in that twin environment, and what that twin is capable of.” Given the novelty of this technology and its ability to redefine traditional notions of technical capabilities and how we can

use data, there is a growing need to increase the exposure of new and existing employees to the DT tool. Training initiatives should extend beyond usage instructions or generalized introductions to introduce the intricacies of the system so that people unfamiliar with the DT can realize its potential for innovation and then be able to innovate themselves. Due to this, organizations transitioning their operations to DT management should prioritize training their employees to develop a deep knowledge of what a DT is and what it can do, to increase their levels of comfort with the technology and their ability to use it optimally.

### **3.4. New Finding: New Roles and Responsibilities - Integration of In-House Data Scientists and Engineers**

In an organization utilizing DTs for airport operations, the role of data scientists and data engineers is very important to managing and leveraging the capabilities of a DT for several reasons. Firstly, data scientists have the skills to create actionable insights from the high volume of data generated by a DT, a skill that is often not generally possessed by FM personnel. Their training or experience in data science allows them to identify patterns, trends, and anomalies within the data, which can help decision-makers make choices backed by real data. Others who may be knowledgeable in airport operations and the goals of implementing the DT itself need the support of data scientists and engineers to interpret the unprecedented amount of “raw” data which must be translated into actionable information before it can be used by knowledgeable decision-makers. As stated by a senior environmental planner who worked intimately in the DT deployment at the DFW airport, “you have people who, for example myself, understand the system and can think at the system level. I can understand parts of how to make the system work, how the digital twin works. But I need the skill set of the data scientists to do the crunching, to

run the models, and then synthesize that information so that I can communicate to decision makers.” This shows that having in-house data scientists can aid decision-makers in confirming that their choices are backed by information, trends, and data-backed insights which would likely not be identified by operational personnel who lack a background in doing such tasks.

In addition to interpreting the “raw” data to create comprehensible information that can be relayed to decision-makers, data scientists and data engineers are needed to maintain the structure of the DT platform itself. As stated by a data scientist who was part of the development of the traffic and rental car fleet DTs at DFW, “they will need people capable of understanding how to ensure that inputs are consistent into the DT. If the machine learning models for some reason stop performing well, they will need to know how to retrain or debug those and get them back online.” However, this interviewee additionally shared the importance of having in-house personnel with data engineering backgrounds who can reliably manage the back-end DT systems in an active environment such as an airport. This interviewee further shared, “it’s also an engineering task. It’s not enough to have just machine learning scientists who can prototype and debug and try new things, you need to have data engineers that can keep these things running in production with some sort of reasonable frequency and reliability.” The collaboration between data scientists and engineers is essential for both interpreting data and maintaining the programming of the DT itself to ensure that it is reliable and effective to real-world situations.

Another interviewee highlights the importance of having personnel with a technical background in-house even if the organization chooses to outsource its DT development and maintenance responsibilities, which is often necessary for some of the back-end work as seen in the airport’s collaboration with Willow. This benefit comes in their ability to communicate with technical professionals who have been outsourced and be able to understand and collaborate

around the back-end technical details of DT infrastructure and systems. This interviewee shared, “I think part of the benefit of having someone with that technical background is that they can communicate both with Willow, who are going to be very technical, understand what their needs are and ask the right questions,” and went on to state that they will, “also be able to relay that to other groups and stakeholders who do not have that background.” As shared by this interviewee, in-house team members with technical backgrounds can liaise between DT developers and non-technologically experienced organizational leadership. These team members can comprehend the technical requirements of the DT and be able to ask the right questions, which might not be within the capabilities of organization members who struggle to understand the intricacies of data science. This can essentially fill any communication gaps present during such conversations and transactions.

Overall, similar to the findings of the UW IoT Case Study around the implementation of new roles and responsibilities, operating DT facilities will involve the integration of new roles into the existing organization. In the UW IoT Case Study, these roles were more pertinent to organizing operations and managing data collection, data integrity, and teaming efforts, while in the case of the DT, these new roles take the form of data scientists or engineers. Such skill requirements in data analysis are echoed in the UW IoT Case Study findings around the new responsibilities in data analytics that FM teams must either integrate into their organization or train their teams to be able to perform. This shows an overlap between the findings of the UW IoT Case Study and this case study focused on DTs.

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#### **4. Leveraging DT Visualization Capabilities**

A finding from this case study that identifies new organizational practices required for managing a DT involves leveraging DT visualization capabilities. This finding is touched upon

in the UW IoT Case Study in Chapter Five, around the new work of creating, understanding, and maintaining data visualizations. However, this requirement is much more prominent in the management of DTs due to the critical component of the virtual model in a DT, making leveraging visual simulations and visualizing data a critical component to the management of DTs. This goes beyond the visualization requirements of IoT, such as creating graphical data displays and finding ways to make data comprehensible to outside stakeholders. In this section, the following new finding will be discussed:

#### 4.1. New Finding: Creating and Maintaining Data and Simulation Visualizations

#### **4.1. New Finding: Creating and Maintaining Data and Simulation Visualizations**

As described in section 1.3.3 in the Introduction Chapter (Chapter 1), DTs are composed of a network of interconnected IoT devices and sensors that transmit real-time data about the performance of a facility and are connected to a virtual model that serves as a replica of the physical facility. Due to the virtual model element, which is critical to the composition of a DT, new management and maintenance practices form around creating, maintaining, and, most importantly, leveraging this virtual model for decision-making and building management. In interviews with members of the DFW DT development team, the requirement for creating and maintaining data and simulation visualizations emerged as a major theme in the work that goes into leveraging a DT system, a finding that was not as emphasized in the IoT investigation due to the reduced visualization capabilities in IoT building management systems compared to DT systems. As described by an interviewee detailing the benefits that this visualization component brings to operations, “it's just so much easier to see anomalies. It's easy to see trends or patterns

when you visualize code or visualize data versus just seeing it in a table.” However, in order to leverage the capabilities of DT visualizations, the team needs to actively develop visualization and simulation strategies, virtual models, and find ways to simulate environments to predict accurate outcomes. In describing one of the visualization efforts that the DFW team initiated with their Traffic Management DT, an interviewee shared that the team needed to find ways to understand where traffic congestion most likely occurs within the airport grounds in order to use the DT to find ways to relieve this congestion. The team strategized around this issue and struggled to interpret data in time series forms or data tables. Eventually, they developed a color coded model using green (fast moving vehicles), yellow (average moving vehicles), red (slow moving vehicles), and black (standstill vehicles) in order to “quickly see exactly where the congestion is going to happen and how long it's going to take to resolve itself.” This interviewee then remarked “that would be really difficult to see if you were to just look at a time series of each road segment.” Creating and maintaining data and simulation visualizations becomes increasingly important with the use of DTs and becomes a regular responsibility for teams leveraging the DT for decision-making and performance forecasting and predictions. This is a new responsibility which is not as relevant in the management of IoT systems due to the DT’s model simulation capabilities, however proves to be a critical component in the management of DT technologies.

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### **6.3. Conclusion/Case Study Overview**

Within the setting of the DFW airport, this case study aimed to understand whether the use of a DT requires the same shifts in organizational practices as the UW IoT Case Study, and if there are additional changes or unique considerations that emerge when analyzing the use of DTs in operational practices. Overall, the findings of this case study show many analogous themes in

the shifts in organizational practices exist in the management of IoT and DT technologies. However, this case study additionally led to the development of new organizational shifts in practice that had not been found in the UW IoT Case Study. The analogous shifts to practice included requirements around centralized data management, centralized communication and data distribution, increased needs for interdisciplinary collaboration, the need to balance “new” knowledge with institutional knowledge (shift in form of institutional knowledge type), new technical skill set requirements, managing personnel resistance to change, establishing management consistency, and the necessity for leadership to provide enhanced training opportunities. New findings as a result of this case study included the importance of colocation in DT management, a shift in the form of institutional knowledge required for DT management, requirements around the integration of data scientists/engineers into DT management teams, and the necessity to create, maintain and manage data and simulation visualizations with the use of a DT.

In the following Discussion Chapter, I will circle back to the broad questions asked in this study. I will reflect on the entirety of this research process to discuss the greater implications of digitalization to the FM profession and how the theories of digitalization from design and construction studies apply to the operations phase. This is done in order to reduce the gap between the greater AECO disciplines and draw connections that link the less studied operations phase to the greater disciplinary sector.

## **Chapter 7: Discussion**

In the introductory chapter, two broad questions were posed which this research aimed to address. Those questions included the following:

1. How do facility management organizations change/adapt their management and maintenance practices in order to leverage IoT systems and digital twins?
2. How do theories of digitalization from studies in the design and construction phases apply to the operations phase?

Throughout this Discussion Chapter, these broad level research questions and their larger implications will be discussed in sections 7.1 and 7.2 below.

### **7.1 Addressing Research Question One**

Through the UW IoT Case Study and the DFW DT Case study (Case Studies One and Two), the first question was addressed and answered. The case study research was targeted at understanding the organizational and technological shifts in practices/new practices required for IoT building operations and how those organizational shifts translate to a DT-operated facility. More specifically, this objective was achieved by answering research questions three to five, which were the target of Chapters Four, Five, and Six. Research Questions three to five are listed below for reference:

3. What shifts in organizational practices are needed for facility management teams to leverage IoT technologies?

4. What new practices are necessary for facility management teams to ensure the technological feasibility of IoT systems?
5. Does the use of a digital twin require the same shifts in organizational practices as IoT, and are there additional changes or unique considerations that emerge when analyzing the use of digital twins in facility management practices?

However, a larger question emerges of how these shifts in practice that are brought about by major organizational and technological shifts are altering the FM and Operations industry itself. The findings of this research, supported by literature, suggest that the digitalization of operations is aiding in the development of a paradigm shift in professionalizing the FM profession and changing the identity of the discipline and the organizations within it. This paradigm shift is discussed below.

### **7.1.1 Paradigm Shifts in FM with Digitalization**

Historically, the FM discipline has received low attention, recognition, and funding compared to other built environment disciplines like design and construction (Atkins and Brooks, 2021). In this research, a paradigm shift has emerged that suggests that the FM occupation will become more professionalized through digitalization with the implementation of IoT systems and DTs. This research found that the FM profession is becoming increasingly interdisciplinary and the use of IoT systems and DTs is requiring the need for higher levels of collaboration and communication with professionals from a wide variety of backgrounds (Findings 1.3-1.4 of Chapter 4 and Finding 1.3-1.4 of Chapter 6). This is bringing FM out of its traditionally isolated environment, and alongside increased studies highlighting the inefficiencies

of the operations phase of the building lifecycle, is leading the operations phase to grow in attention and recognition (Roper, 2017). In addition, the evolving skill set needed for FM personnel to effectively manage digitally integrated buildings with IoT systems and DTs necessitates the development of technical skills and data management capabilities, which often require higher levels of education or advanced/specialized training (Findings 2.2 – 2.4 and 3.3 of Chapter 4 and Findings 2.2, 2.3, 3.3, and 3.4 of Chapter 6). Based on the findings of this research and their impact on the FM profession, in addition to literature drawing similar conclusions (Roper, 2017), the digitalization of the operations industry is aiding in a paradigm shift in FM which is professionalizing the operations industry and changing the identity of the discipline.

The professional evolution of the FM industry is partially pushed by new requirements around the interconnectedness that IoT and DT technologies demand. The FM discipline is opening up and being forced to collaborate with a much larger diversity of professionals due to the integration of technologies like IoT and DT. This is forcing FM organizations to move from static and rather isolated operations marked by small internal disciplinary collaboration groups (Atkins, 2021) to a more dynamic approach where the wants and needs of a larger pool of stakeholders must be addressed (Findings 1.3 and 1.4 of Chapter 4). This is largely creating a more professional and interconnected culture within the practice, which demands that FM professionals break out of their isolated internal collaboration routines. As mentioned above, in Findings 1.3 and 1.4 of the UW IoT Case Study (Chapter 4), the management of IoT technologies required the FM division to regularly interface with a larger disciplinary pool within operations, a variety of device vendors/manufacturers and their representatives, other university divisions such as IT and sustainability, and a growing number of consultants and contractors brought on board to aid in the IoT management effort. This required them to learn

how to communicate effectively with diverse disciplines like IT and form new communication networks and routines which made interdisciplinary collaboration frequent and required (Finding 1.4 of Chapter 4), expanding their responsibilities, connections, and stakeholder networks. The stakeholder pool in DT management at the DFW airport was even larger than that of the UW IoT Case Study, as seen in Finding 1.3 of Chapter 6, requiring the growing integration of diverse stakeholders and a highly interconnected network of professionals from different backgrounds and organizations to successfully deploy and manage a DT.

The professional evolution in the FM industry is furthered by the application of advanced building control technologies in facilities that demand a deeper and stronger understanding of the technical requirements of newly integrated systems. This is making entering the operations industry more difficult than ever due to the skillset now required to be effective (Roper, 2017), (Findings 2.2-2.4 of Chapter 4 and Findings 2.2, 2.3 and 3.4 of Chapter 6). To provide background to the recently experienced rapid growth of the FM industry and its legitimization as a profession, Roper (2017) describes that the first FM centric academic journal “Facilities” did not appear until 1999, followed by a second a decade later, “The Journal of Facilities Management”. The emergence of these academic bodies aided in opening the door to the development of industry professional associations such as IFMA and the initiation of FM higher education into university programs in the past couple of decades. As expressed by Roper, “the need for qualified facilities professionals has driven the expansion of education, in addition to the professionalization of FM” (236). This evolving skillset requirement is changing the identity of the professionals within the industry, as the skillsets of careers within the field have evolved due to the new complexities of operations with advanced technologies. For example, entry level professions have seen an evolution from “technicians” to things like “building mechanics,

engineers, and supervisory service providers” (Roper, 2017, pg. 236). This type of transition is directly evident in the research findings in this dissertation through the recent integration of new FM roles and divisions at the UW such as “IT Building and Infrastructure Systems Engineer”, “Operational Technology Manager” and the recent development of the Business Innovation and Technology Division within FM.

Overall, there are benefits that arise from the professionalization of operations and the FM discipline. It is legitimizing the discipline and attracting FM personnel who are adaptable to technological development, innovations, and new methods, which is needed for industry growth (Roper, 2017). This is directly apparent in this research, as adaptability to new systems and the ability to overcome the large learning curve that IoT and DT technologies present emerged as critical factors to successful integration and use (Finding 2.2 of Chapter 4 and Finding 1.1 of Chapter 5). In addition, adopting technologies such as IoT and DT can aid in energy management and improved efficiency in operations (Atta and Talamo, 2020, Haidar et al., 2019, Onile et al., 2021), which leads me to theorize that the professionalization of the FM discipline may be a required consequence of sustainable growth and development in today’s interconnected world. In order to incite sustainable change, FM organizations must develop new technical skills and collaborate with a wide variety of professional experts, changing the traditional paradigm of the profession.

## **7.2 Addressing Research Question Two**

I used a thematic analysis approach to address question two above across all three cases. This required revisiting the literature and conducting a comprehensive analysis of the themes of digitalization that are already known in the literature from the design and construction phases

and how they have applied to this study. As explained in the rationale in Chapter Two, many similarities exist in structure, culture, and practice between the construction phase of the building lifecycle and the operations phase. In addition, there are not many studies that have focused on digitalization in building operations and management. To analyze digitalization in operations, I asked how the theories of digitalization from design and construction studies apply to the operations phase. This strengthens the qualitative findings from other studies through triangulating findings from across the project life cycle and confirms that certain assumptions can be drawn between the various specialties and disciplines within the built environment project process. Additionally, revisiting the literature review and the established points of departure allows for an evaluation of whether the assumptions made were confirmed or challenged by the outcomes of this research.

Most identified studies that analyze digitalization in design and construction phases focus on the adoption and implementation of new digital technologies such as BIM into existing organizations. In this analysis, I compare the adoption of BIM and similar VDC tools for design and construction with the adoption of IoT and DT for operations. These are analogous digitalization processes because researchers have identified both BIM and IoT/DTs as disruptive technologies in the built environment industries (Ingram, 2020, Sadri et al., 2023), and such disruptive technologies can impact a large array of factors in an organization such as social relations, institutions, foundational concepts, values, and experiences (Hopster, 2021). This section discusses the findings from the research that align with the theories of digitalization from existing studies in the AEC literature focused on the design and construction phases. This section additionally outlines the new findings resulting from the integration of IoT and DT in operations as new themes in digitalization to complement and add to the existing body of knowledge.

Part Two of the literature review on digitalization in design and construction phases was organized into 4 categories: Disciplinary Silos, Standardization in Technology Use and Data Management, Resistance to Change within Cultural Norms and Entrenched Organizational Practices, and the Critical Role of Leadership in Steering Organizational Change. These served as categorical themes derived from the literature around theories of digitalization from design and construction phases. In Table 10 below, the theories of digitalization derived from the literature review are listed. Table 10 additionally lists the new themes in digitalization resulting from the integration of IoT and DT in operations that resulted from the findings of this study.

**Table 10:** Analogous Themes from Theories of Digitalization in Literature and New Themes

<b>Category:</b>	<b>Themes of Theories of Digitalization from Literature:</b>	<b>New Themes:</b>
1. Disciplinary Silos	<p><b>Breakdown of Disciplinary Silos is Required</b></p> <ul style="list-style-type: none"> <li>- <b>Centralized data management and tech. use</b> (Azouz et al., 2014, Harty and Whyte, 2010), (1.1, Ch.4), (1.1, Ch.6)</li> <li>- <b>Increased interdisciplinary collaboration and communication</b> (Dossick et al., 2012), (1.2-1.4, Ch. 4), (1.2-1.4, Ch.6)</li> </ul>	<p><b>Importance of Colocation</b> (1.5, Ch.6)</p>
2. Standardization in Technology Use and Data Management	<p><b>Centralized and Standardized Approach to Data Management and Technology Use is Required</b></p> <ul style="list-style-type: none"> <li>- <b>Clear data standards</b> (Dossick and Neff, 2011), (1.2, Ch.6), (2.1, Ch.5)</li> <li>- <b>Data/communication exchange procedures and distribution pathways</b> (Khanzode et al., 2008, Dossick and Neff, 2011), (1.2, Ch.6), (1.2, Ch.4)</li> <li>- <b>Tech. + data interoperability</b> (Leite et al., 2016), (2.1-2.2, Ch.5)</li> </ul>	
3. Resistance to Change within Cultural Norms and Entrenched Organizational Practices	<p><b>Challenging Cultural Norms and Entrenched Organizational Practices</b></p> <ul style="list-style-type: none"> <li>- <b>Org norms define how teams work/collab</b> (Dossick et al., 2019) , (4.1-4.4, Ch.4)</li> <li>- <b>Traditional methods and social/habitual resistance</b> (Ahmed, 2018, Harty and Whyte, 2010), (4.1-4.4, Ch. 4)</li> <li>- <b>Democratize decision making (include experts at all levels of org)</b> (Dossick et al, 2012), (4.1, Ch.4)</li> </ul>	<p><b>Restructuring Existing Documentation Standards/ Structures</b> (4.2, Ch. 4)</p> <p><b>Adjusting Maintenance Norms to Accommodate Technologies</b> (4.3-4.4, Ch. 4)</p>
4. Critical Role of Leadership in Steering Organizational Change	<p><b>Strong and Effective Leadership to Guide the Organizational Transition</b></p> <ul style="list-style-type: none"> <li>- <b>Leadership in early stages of org. transition</b> (Kaner et al., 2008) (3.2, Ch. 6) (3.2, Ch. 4)</li> <li>- <b>Guide and maintain strategy</b> (Kunz and Fischer, 2012) (1.1, Ch.6)</li> <li>- <b>Combat resistance to change</b> (Dossick and Neff, 2009) (3.1, Ch.4), (3.1, Ch. 6)</li> <li>- <b>Provide increase training and support</b> (Harty and Whyte, 2010, Kaner et al., 2008) (3.3, Ch. 4), (3.3, Ch.6)</li> </ul>	<p><b>Establishing System Champions/ Establishing Management Consistency</b> (3.2, Ch.4) ,(3.2, Ch.6)</p> <p><b>Integration of New Roles and Responsibilities</b> (3.4-3.5, Ch.4), (3.4, Ch. 6)</p>
<p><b>5.NEW CATEGORY:</b> Bridging the Gap Between New Knowledge and Institutional Knowledge</p>		<p><b>The Value of Institutional Knowledge is Critical</b> (2.1, Ch.4) , (2.1, Ch. 6)</p> <p><b>New Technical Knowledge Requirements</b> (2.2-2.4, Ch.4) , (2.2-2.3, 3.4, Ch.6)</p> <p><b>Creating, Maintaining, and Managing Visual Components of Technology</b> (4.1, Ch. 6), (4.6, Ch. 5)</p>

## **7.2.1 Thematic Analysis of Digitalization in Design and Construction Phases and Operations Phase**

In this section, I address research question two above, asking how the theories of digitalization from design and construction phases apply to the operations phase. This is done by discussing the findings from my research that align with the theories of digitalization from existing studies in the AEC literature focused on the design and construction phases. This section additionally outlines the new findings resulting from the integration of IoT and DT in operations as new themes in digitalization to complement and add to the existing body of knowledge. This section is organized by the categories seen in the first column of Table 10 above that include:

1. Disciplinary Silos
2. Standardization in Technology Use and Data Management
3. Resistance to Change within Cultural Norms and Entrenched Organizational Practices
4. Critical Role of Leadership in Steering Organizational Change
5. New Category: Bridging the Gap Between New Knowledge and Institutional Knowledge

### **Category 1: Disciplinary Silos**

#### **Theme from Literature: Breakdown of Disciplinary Silos is Required**

As founded by many scholars in the literature focused on design and construction phases (Dossick et al., 2012, Azouz et al, 2014 , Bonanomi et al., 2020, Neff et al., 2010), the presence of disciplinary silos in the AEC industry hinders digitalization in design and construction phases

when adopting novel digital tools like BIM. The literature attributes this to multiple reasons that align with the findings of this study. These reasons include cultural barriers and norms within disciplinary silos that constrict collaboration (Dossick et al., 2012, Neff et al., 2010), as seen in Findings 1.3 and 1.4 of Chapter 4 of this research, which describes the need for FM teams to build relationships with groups that they traditionally do not work with and learn how to communicate effectively with a wider variety of professionals. For example, in Finding 1.4 of Chapter 4, the FM group needed to adapt to being able to effectively communicate with IT groups who use technical jargon outside of FM norms to manage IoT systems effectively. The literature additionally points to tensions around formal lines of communication within silos that dictate how collaboration can ensue (Azouz et al., 2014, Dossick et al., 2012). In this research study, this can be seen in Finding 1.2, 1.4, and 4.1 of Chapter 4, as the FM interviewees described the formal communication methods and routines that create communication gaps and inefficiencies in ensuring that all parties receive important IoT-related information on an organization-wide level. Furthermore, as seen in Finding 1.1 of Chapter 4, disciplinary information silos led to the existence of many decentralized information repositories which made it difficult for the organization to know how many IoT devices they have in their buildings and where they are located. This created a need for a centralized inventory and data storage strategy.

A similar theme was seen in the DFW DT Case Study, as disciplinary communication routines needed to be abandoned for an organization-wide approach to communication and data distribution. As seen in Finding 1.2 of Chapter 6, interviewees stated that the way information was being shared in the operations of the passenger boarding bridge DT was siloed and non-consistent which made it less reliable, timely, and effective. Existing communication routines needed to be abandoned for new communication networks that accommodated the use of DT

systems. Finding 1.3 of Chapter 6, echoing the findings of the UW IoT Case Study, showed that managing DTs effectively called for increased collaboration outside of disciplinary silos and an organization-wide mix of team members from a variety of disciplines to best manage and operate DT systems. The need to break down disciplinary silos in the adoption of digital technologies like IoT systems and DTs resonates with the findings of prior research conducted in design and construction phases (Dossick et al., 2012, Azouz et al, 2014 , Bonanomi et al., 2020, Neff et al., 2010). This reinforces the importance of centralization and an overall approach that abandons siloed work and data management, as established in the design and construction literature.

### **New Themes within Category 1:**

#### **Importance of Colocation**

An interesting finding of the DFW DT Case Study (Chapter 6) was the importance of colocation in the management of building operations with the use of DTs. This finding was not strongly present with IoT systems alone, however similar ideas around centralized teams and enhanced collaboration and coordination were founded. The literature focused on design and construction phases points to the benefits of colocation in the adoption and use of digital tools. For example, in Homayouni, Dossick and Neff's (2020) study which analyzed the configurations of integration strategies used in over 30 high performance projects, they found that in the case of information driven projects, colocation can benefit awareness and successful collaboration and decision-making. However, colocation has not been established as a necessary requirement to the management of BIM or other VDC tools in design and construction phases, but rather a positive attribute, if attainable. In this research, colocation was deemed important with specifically the use of DTs. As seen in Finding 1.5 of Chapter 6, management shared that they view colocation as “absolutely necessary” due to complexity of a facility like an airport in which a co-located

management team can help understand the nuances of data and the airport's unique characteristics, can help reduce wait-time in the case of questions by putting diverse disciplinary professionals in a central location, and therefore aid in reducing risk in decision-making around the DT. The benefit of centralizing disciplinary specialists and diverse professionals aided in better understanding DT data and making better decisions around airport operations. Although previous studies have touched upon the benefits of colocation, with this study it emerged as a relevant and important aspect to DT integration and use into the future, contributing to the existing knowledge in digitalization of the operations phase.

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## **Category 2:** Standardization in Technology Use and Data Management

### **Theme from Literature:** Centralized and Standardized Approach to Data Management and Technology Use is Required

The literature focused on design and construction phases emphasized that integrating digital technologies into the construction sector necessitates establishing clear data and delivery standards along with robust data management protocols that are holistically followed by the organization. This research similarly found a need for the FM organizations to establish clear standards around data and technology use. The literature shows that this can include efforts to address information centralization (Harty and Whyte, 2010), as seen in Finding 1.1 of Chapter 4 and Finding 1.1 of Chapter 6, data and technology interoperability (Leite et al., 2016), as seen in Findings 2.1 and 2.2 of Chapter 5, and explicit processes and standards around using, communicating, and sharing digital information (Dossick and Neff, 2011, Khanzode et al., 2008), as seen in Finding 1.2 of Chapter 6 and Finding 1.2 of Chapter 4. These measures are crucial for fostering efficient collaboration among the various project disciplines utilizing digital

tools. To expand on the findings mentioned above, as seen in Finding 1.1 of Chapter 6 at the DFW airport, the existence of disciplinary data repositories made it difficult for DTs to collect and process real time data, calling for the standardization of data within one management platform to ensure optimal DT operations and allow DTs to access data from a variety of disciplines seamlessly and efficiently. This was similarly experienced in The UW IoT Case study in Finding 1.1 of Chapter 4, which addressed the need to bring all data into a single platform to effectively manage the IoT system. As seen in Finding 2.1 of Chapter 5, a requirement emerged around creating a centralized nomenclature and format for data to organize IoT information coming from various disciplinary entities effectively and increase interoperability which was previously unattainable with the use of the old building management systems. Needs for data standardization additionally emerged in Finding 2.2 of Chapter 5, around the requirement to standardize communication protocols so devices could communicate effectively throughout the network. Finding 1.2 of Chapter 6 additionally shows that clear communication and data sharing standards are required to adequately manage DTs in a timely and effective manner. This was seen in the passenger boarding bridge anecdote which was shared by an interviewee, as non-standardized communication pathways and routines around information sharing and management led to inefficiencies and non-timely response to problems. In Finding 3.3 of Chapter 6, management additionally shared the need to develop standardized protocols and operating procedures on training people how to use a DT, collaborate within DT environment, and understand DT application opportunities. In Finding 4.3 of Chapter 4, requirements emerged around creating standardized maintenance and lifecycle management processes around IoT devices that had previously not needed as frequent attention due to reduced lifespans and increased updating requirements. Within both research cases, the development of centralized

databases, standardized storage procedures, and data sharing and formatting standards were critical, echoing the findings from prior research conducted in design and construction phases.

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**Category 3:** Resistance to Change within Cultural Norms and Entrenched Organizational Practices

**Theme from Literature:** Challenging Cultural Norms and Entrenched Organizational Practices

As found by scholars in the design and construction literature, tension in digitalization exists due to established norms of practice as well as social and organizational norms that define how teams work and collaborate (Dossick, Osburn, and Neff, 2019). In this research study, established norms and entrenched practices posed a challenge to the adoption of IoT technologies, in similar ways as in the design and construction literature. The literature shows that when new technologies challenge “existing ecologies of practices” (Harty and Whyte, 2010, pg. 472), the use of these technologies is often resisted. Such cultural norms often include “traditional methods of contracting” (pg. 108), “social and habitual resistance to change” (pg. 108), and a “lack of awareness” (pg. 108) about technologies (Ahmed, 2018), that make it difficult to implement tools that drastically change existing methods of practice and challenge existing disciplinary structures. As seen throughout Findings 4.1 – 4.4 of Chapter 4, traditional practices which have been established and habituated in the FM industry caused tension in IoT adoption such as the traditional decision-making hierarchy which did not include FM representation (Finding 4.1), attempts at fitting IoT management requirements into existing handover and maintenance documentation structures (Finding 4.2), and trying to fit IoT technologies that have their own unique maintenance requirements and timescales into existing maintenance cycles (Finding 4.3 and 4.4). However, although these findings resonate with the design and construction literature, such as the need for project participant’s expertise in decision

making throughout organizational levels (Dossick et al., 2012), the requirements to restructure traditional building maintenance handover documentation, create new maintenance cycles to accommodate IoT devices, and increase the frequency of updating standard documentation due to the fast pace of technological progress are unique findings within the overall theme of challenging entrenched organizational norms and practices and will be elaborated on below as contributions to digitalization in the operations phase.

### **New Themes within Category 3:**

#### **Restructuring Existing Documentation Standards/Structures and Adjusting Maintenance Norms to Accommodate Digital Technologies**

Although it falls into the larger theme of challenging cultural norms and entrenched organizational practices, findings of this research point at the requirement to restructure existing documentation standards/structures (Finding 4.2 of Chapter 4) and adjust existing maintenance cycles to accommodate IoT devices which require more frequent maintenance, updates, and overall a distinct maintenance cycle as opposed to more traditional static building elements (Findings 4.3 and 4.4 of Chapter 4). Recent studies targeting IoT technologies, such as Dossick, Snider, and Osburn (2023) study on time orientations and the challenges of implementing IoT have found that varying time orientations between construction and FM stakeholders leads to tensions in the integration of new technologies into existing systems and in keeping existing systems up and running for the longer timescales of campus and infrastructure life spans.

Building on these new findings, this study has found that attempting to fit the maintenance of IoT systems into existing maintenance cycles for static building elements does not accommodate IoT technologies as they require more frequent attention and have a reduced lifespan compared

to building elements traditionally maintained by FM teams. This calls for a reevaluation of maintenance cycles for IoT integrated facilities to accommodate the maintenance, update, repair, and decommissioning cycles of IoT devices as opposed to “older systems that are less IT-heavy”, as expressed by an interviewee. This requires challenging habitual preferences and norms.

In relation to the need to restructure building maintenance documents and handover information to accommodate IoT technologies (Finding 4.2 of Chapter 4), habitual practice in the FM organization led to attempts to fit unique and specific IoT information into traditional documentation structures. Such attempts created tension and a lack of important information being included in handover documents which led to frustration and resistance by FM personnel. This research found that integrating IoT devices calls for a different form of operations and maintenance manuals, as-built documentation, specifications, and design guides which account for “dynamic and specific information” like software versions, hardware and software maintenance information and other technically critical information which is not usually included in such documentation for static building elements. This additionally comes with new requirements around the frequency of updating standard and shared documentation (Finding 4.4 of Chapter 4) due to the fast-paced technological environment within which IoT and DT systems exist, which often require documentation updates in an increased frequency as compared to traditional building elements.

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#### **Category 4: Critical Role of Leadership in Steering Organizational Change**

##### **Theme from Literature: Strong and Effective Leadership to Guide the Organizational Transition**

The literature focused on design and construction phases emphasizes the need for strong and effective leadership to guide the organizational transition to the use of digital technologies, like BIM. The findings of this research align with the literature, emphasizing the criticality of leadership in digitalization for operations. This includes an emphasis on the importance of leadership in early stages of organizational transformation (Kaner et al., 2008), as seen in Finding 3.2 of Chapter 6, where interviewees described the confusion and lack of clarity during early stages of DT adoption at the airport which required the guidance and organization of management. In addition, the literature emphasizes the importance of leadership to guide and maintain the vision, strategy, and operational plans of an organization (Kunz and Fischer, 2012), as seen in Finding 1.1 of Chapter 6, where interviewees shared the importance of an organization-wide mindset shift in their approach to work and integration, sharing that the hiring and workforce development strategy should come from a “shared vision and silo bursting perspective”. The literature also stresses the need for leadership to address resistance to change which comes with organizational and technological transformation (Dossick and Neff, 2009, Hartmann and Fischer, 2009), as seen in Findings 3.1 of Chapter 4 and 3.1 of Chapter 6, where leadership was needed to manage resistance to change that emerged from discomfort with new technologies in both IoT and DT integration. Expanding on the theme of managing resistance to change, the strategies that FM leadership used in order to manage this resistance were similar to those expressed in the literature: focusing on the immediate benefits of the technology on day-to-day operations to create buy-in and ownership over new technological systems at the individual

level (Hartmann and Fischer, 2009, Dossick and Sakagami, 2008). This shows a direct correlation between the design and construction literature, the UW IoT Case Study, and DFW DT Case Study. In addition, the literature shows the need for leadership to provide training and readily available support to organizations as they adopt digital tools (Harty and Whyte, 2010, Kaner et al. 2008). This is similarly seen in Findings 3.3 of Chapter 4 and 3.3 of Chapter 6, which showed that FM leadership must increase training and education opportunities around new technologies to combat resistance to change and best navigate the early organizational turbulence in both the IoT and DT setting. This often required longer training sessions, the readily available support of experts, and more tailored and unique training opportunities towards IoT and DT use. The similarities between the literature focused on design and construction phases and the findings of this study reinforce the significance of leadership's role in digital adoption and underscores its relevance across various lifecycle phases.

#### **New Themes within Category 4:**

##### **Establishing System Champions/Establishing Management Consistency**

An interesting finding in both the UW IoT Case Study and the DFW DT Case Study was the importance of establishing system champions and management consistency over individual systems within the larger IoT or DT ecosystem (Finding 3.2 of Chapter 4 and Finding 3.2 of Chapter 6). Based on the literature review on design and construction phases, establishing management consistency over various parts of the digital system was not emphasized in the integration of BIM and other digital tools into existing design and construction organizations. This is likely due to differences in the technologies themselves, as IoT systems and DTs for building operations are composed of numerous individual components that collectively form the

entire IoT or DT ecosystem. As the use of IoT devices and DTs continues to grow, it becomes increasingly important to assign each individual system within the entirety of the IoT or DT ecosystem to a designated management group. This approach ensures efficient operation, leads to familiarity with the specific intricacies of each system, and creates a sense of ownership over its management. The data from this research shows that if management consistency isn't established over various individual parts of an IoT or DT system, it can create personnel frustration, certain groups may become overloaded with responsibilities, entire systems can go unmanaged, and resistance from the workforce can become strong. In the case of IoT integration, the FM division at the UW initially struggled with ensuring that all aspects of the IoT system were being adequately managed and maintained. This often led to a single group being overloaded with responsibilities which sometimes caused the abandonment of systems entirely such as what was seen in Finding 3.2 of Chapter 4. This created the requirement that as new IoT devices become integrated into the system, leadership ensures that the responsibility of their management is distributed to individuals or groups to form consistency, familiarity, and system ownership. In the DFW DT Case Study, similar conclusions can be made in Finding 3.2 of Chapter 6. At the DFW airport, system champions were established to manage certain aspects of operations in order to ensure that all stakeholders had a clear role based on both passion and competence in managing that system. The data additionally showed that establishing such champions led to ownership and pride in the work that employees were doing.

### **Integration of New Roles and Responsibilities**

The results of this research additionally point to the development of new organizational roles with unique responsibilities around the integration and management of IoT and DT systems

(Finding 3.4 and 3.5 of Chapter 4 and Finding 3.4 of Chapter 6). The findings from the UW IoT Case Study point to the development of a new role dedicated to operational technology management (Finding 3.4 of Chapter 4), aimed at bridging the gap between the essential requirements of FM and IT groups. Additionally, the UW IoT Case Study highlights the potential for incorporating a building handover director to manage the transition of critical building information from project delivery teams to FM groups (Finding 3.5 of Chapter 4), ensuring efficient data distribution and information management within IoT system administration. This role can additionally ensure that document structures are adequate for IoT implementation and maintenance, and serve as FM representation during the construction phase of the lifecycle when decisions around IoT integration are being made. Finding 3.4 of the DFW DT Case Study (Chapter 6) calls for a rather critical integration of data scientists and data engineers into DT management teams. Although this did not emerge as a new role specifically, the UW IoT Case Study additionally points to new required skills in FM teams around data analytics, programming, and other data science capabilities for leveraging the data that these systems produce. Such opportunities for the development of entirely new roles to manage IoT and DT systems and address their data requirements contributes to knowledge around digitalization in operations outside of what is available in the literature on design and construction phases.

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#### **New Category 5: Bridging the Gap Between New Knowledge and Institutional Knowledge**

Comparing the literature from design and construction phases and the findings of this research, bridging the gap between new knowledge and institutional knowledge emerges as a new theme in studying digitalization in operations outside of the theories of digitalization present in the design and construction phase literature. This thematic category revolved around the new knowledge requirements that IoT and DT systems necessitate and the value of retaining

institutional knowledge during and after digital adoption. The findings within this category will be discussed in detail below and include the following topics:

- The Value of Institutional Knowledge
- New Technical Skill/Knowledge Requirements
- Creating, Maintaining, and Managing Visual Components of Technology

### **The Value of Institutional Knowledge is Critical**

A unique insight from this research study is the need to balance “new” knowledge, such as technical skills around integrated digital systems (IoT and DT systems), with institutional knowledge, or intimate knowledge of the building, its operations, existing intricacies, and unique characteristics in the management of IoT and DT systems (Finding 2.1 of Chapter 4 and Finding 2.1 of Chapter 6). Across both case studies, the data consistently showed the value of institutional knowledge regarding the building and its unique characteristics in facilitating the operation of IoT or DT systems within the building. Within this theme, understanding the contextual nuances of where and what IoT devices are deployed, which usually comes from experience, emerged as a pivotal factor in decision-making processes and ensuring the performance of the digital systems. Finding 2.1 of the UW IoT Case Study (Chapter 4), showed that developing a workforce with both a deep understanding of mechanical systems and traditional building operations as well as IT skills was critical to managing buildings that are IoT equipped. In Finding 2.1 of the DFW DT Case Study (Chapter 6), having a team composed of both tech-savvy personnel who can manage the technical aspects of the DT and personnel who truly understand the nuances of airport operations and the unique characteristics of DFW proved essential. This can be seen in many instances throughout the research, such as the anecdote about

the baggage handling digital system in Finding 2.1 of Chapter 6, the digital rain gauges anecdote in Finding 1.4 of Chapter 6, or the criticality of understanding the car rental business in developing a rental car fleet DT as seen in Finding 2.1 of Chapter 6. This insight contributes to the existing knowledge around digitalization in operations and should be considered as an important factor to organizations looking to adopt IoT or DT technologies in the future.

### **New Technical Skill/Knowledge Requirements**

To complement the discussion above, Findings 2.2 – 2.4 of Chapter 4 and 2.2, 2.3 and 3.4 of Chapter 6 additionally point to the need for FM personnel to develop new technical skills in the management of digital technologies like IoT and DTs, a finding outside of the existing literature in the design and construction phases. Chapter 5 of this dissertation outlines many of the specific technical requirements needed in IoT management and maintenance. Developing such newly required technical skills may come in the form of training employees in data analytics and programming, or hiring new personnel with backgrounds in data science, data management, or higher-level computer skills into the existing organization. This finding is likely not prevalent in the existing design and construction phase discourse around digitalization because BIM models are usually managed by a group of professionals who have the required skills, such as VDC managers or BIM modelers, and the organization largely uses these models for collaboration and decision-making outside of the requirements to develop them individually. However, in the management of IoT and DT technologies, a larger portion of the organization needs to have the technical skills necessary to configure devices, manipulate software for configuration, and analyze the unprecedented amounts of data that result from IoT and DT devices and systems. This creates requirements around data analytics to make the new abundance

of data collected by integrated systems useful to the organization. As seen in Finding 2.2 of the UW IoT Case Study (Chapter 4), IoT devices are typically acquired from a diverse range of manufacturers and require unique configuration according to the device's purpose and programming requirements. This necessitates that facility personnel overseeing device configurations and maintenance familiarize themselves with a range of programming requirements essential for configuring devices. They must also acquire the skills needed to adapt to evolving programming requirements and emerging technologies as they become integrated into current systems due to the relatively rapidly changing pace of the technological environment. Beyond configuration, the opportunity for data analytics, as seen in Finding 2.4 of Chapter 4 and Findings 2.3 and 3.4 of Chapter 6, leads to new work in the arena of making this influx of data meaningful to the organization. This creates new practices for FM personnel in organizing, filtering, trending, manipulating, and simulating data-based scenarios in order to aid the organization in transitioning to a predictive maintenance strategy. As seen in Finding 3.4 of the DFW DT Case Study (Chapter 6), FM personnel needed to develop technical skills in interpreting the unprecedented amount of "raw" data which must be translated into actionable insights before it can be used by knowledgeable decision-makers to improve operations. The skills of data scientists and data engineers were essential for both interpreting data and maintaining the operational integrity of DT platforms as well as ensuring their effectiveness and reliability in real-world applications.

### **Creating, Maintaining, and Managing Visual Components of Technology**

The importance of developing the organization's ability to create and maintain the visual functionalities of DTs particularly, but also IoT systems, to manage and leverage these

technologies emerged as a new theme outside of the design and construction literature. This is seen in Finding 4.1 of Chapter 6 and Finding 4.6 of Chapter 5. As described in the Introduction (Chapter 1), DTs are composed of a network of interconnected IoT devices and sensors which transmit real time data about the performance of a facility and are connected to a virtual model which serves as a replica of the physical facility. Due to the virtual model element which is critical to the composition of a DT, maintaining data visualizations and simulations and overall leveraging DT visualization capabilities became a new challenge for FM teams adopting these technologies that they had to overcome. As described in Finding 4.1 of Chapter 6, finding ways to visualize data, such as in the traffic congestion example shared by one of the DT developers, was a major part of operating a DT effectively. Virtual simulations are a large benefit of using a DT, to help organizations transition to predictive maintenance strategies by testing scenarios and finding ways to predict potential issues before they occur in real life. In addition, virtual simulations helped solve complex problems when the data was so large that attempting to interpret it through data series tables and other non-visual methods became increasingly difficult. In IoT system management, as seen in Finding 4.6 of Chapter 5, the unprecedented amount of data collected by IoT devices required FM employees to find ways to visualize the data both for internal decision-making and external sharing of data in ways digestible to non-FM stakeholders. This created new requirements for FM teams adopting IoT and DT technologies in the form of finding ways to train their workforce to be able to create, maintain, and manage the visual component of these systems, or hiring new personnel with these skills to fully leverage the model-based capabilities of these technologies. This insight contributes to the existing knowledge around digitalization in operations and should be considered as an important factor to organizations looking to digitize with IoT or DT in the future.

### 7.3 Summary

The goal of this discussion chapter was to understand the broader questions asked in this research study and explore their wider implications. In addressing research question one, that asked how facility management organizations change/adapt their management and maintenance practices to leverage IoT systems and digital twins, the paradigm shift occurring in the FM profession as a result of the organizational and technological change that integrating advanced building technologies like IoT and DT is creating was discussed. In exploring the question of how theories of digitalization from design and construction studies apply to the operations phase, a thematic analysis was done which found that many of the theories of digitalization established in the existing design and construction literature apply to the operations phase. However, this study additionally contributes to knowledge by identifying new themes that contribute to the theories of digitalization for operations.

Overall, the themes in the AEC literature around digitalization that were confirmed by this study included requirements around the breakdown of disciplinary silos, the need for standards around data management and technology use, the need to challenge cultural norms, habitual practices/structures, and entrenched organizational practices, and the importance of strong and effective leadership to guide the organizational transition during digitalization periods. However, this research additionally led to the identification of new themes that contribute to the theories of digitalization for operations to complement the above. These included the importance of colocation in managing DTs, the need to establish management consistency over individual IoT and DT systems within the entire digital ecosystem, the value of retaining institutional knowledge after digital transformation, the need to restructure existing documentation structures and adjust maintenance cycles to accommodate IoT and DT

technologies, the integration of new roles to aid in both IoT and DT management, and the new technical skill requirements which FM personnel must develop in order to configure and operate IoT and DT systems effectively.

## **Chapter 8: Conclusion**

### **8.1. Research Summary**

This research study sought to answer the following research questions through two case studies that focus on the IoT system integration and operations within Facilities at the University of Washington and the digital twin integration and operations at the Dallas Fort Worth (DFW) airport:

1. How do facility management organizations change/adapt their management and maintenance practices in order to leverage IoT systems and digital twins?
2. How do theories of digitalization from studies in the design and construction phases apply to the operations phase?

These were the broad level research questions asked in the Introduction Chapter. As a part of answering these questions, this study sought to achieve three individual research objectives within them (Research Questions 3-5). The first objective (Research Question 3) was to understand the organizational shifts to practice required for FM teams in order to leverage IoT integrated building systems. The second objective (Research Question 4) was to understand the new practices required for FM teams in order to ensure the technological feasibility of said integrated IoT systems. Lastly, this research sought to understand whether the use of a DT requires the same shifts in organizational practices as IoT, in addition to identifying any novel changes or unique considerations that emerge when using a DT for building operations as opposed to IoT systems (Research Question 5). The results of the data analysis and major findings from these case studies are summarized as follows.

The organizational shifts to practice required for FM teams to leverage IoT technologies (Research Question 3) fall into 4 major thematic categories. These include the breakdown of disciplinary silos and centralization and democratization of data, which holistically addresses the need for a centralized approach to inventory management, communication, data distribution, interdisciplinary collaboration, and relationship building. In addition, the need to bridge the gap between institutional knowledge and new knowledge was found to be essential to leveraging IoT technologies effectively. This included the need to balance traditional trade specific knowledge with new technical knowledge such as programming and coding, and finding ways to increase the organization's understanding of the technical intricacies of IoT management and data analytics. The organizational shifts to practice additionally included the need for strong and effective leadership to manage resistance to change, delegate management responsibilities over IoT systems, provide opportunities for training and education, and develop new roles to accommodate IoT management. Lastly, a requirement emerged around challenging entrenched organizational practices, standards, and norms such as bringing FM representation into decision-making, restructuring traditional building handover documentation, and creating new maintenance cycles to accommodate IoT technologies.

The new practices required for FM teams to ensure the technological feasibility of IoT systems (Research Question 4) fell into six thematic categories. These categories included new required practices in configuring IoT field devices based on their unique programming requirements, new practices in establishing network communication between IoT devices and management applications, and implementing logic in supervisory devices to adequately route and process messages between the smattering of IoT systems and management applications across campus. Beyond these, leveraging IoT systems in order to maximize their potential benefit to the

organization led to new practices in system performance monitoring, data analytics, advanced troubleshooting, and managing the diverse user interfaces that produce alerts and notifications at an unprecedented rate and require new skills in data visualization. Lastly, ensuring the feasibility of IoT systems required new practices in IoT lifecycle management and security as more devices become integrated onto the network.

As stated above, the objective of Case Study Two was to understand whether the use of a DT requires the same shifts in organizational practices as IoT, and if there are additional changes or unique considerations that emerge when analyzing the use of DTs in building operations (Research Question 5). The results of this case study showed that many similar requirements around shifts to organizational practice were needed with the use of a DT when compared to IoT. However, the study additionally identified new practices necessary to support the use of DTs outside of the IoT findings. Shared themes included the need for centralized data management, communication, and data distribution in addition to increased levels of interdisciplinary communication and the dismantling of disciplinary information silos. The need to bridge the gap between institutional knowledge and new knowledge additionally reemerged as an important requirement in addition to the new technical skills required for DT management that the FM organization needed to learn and develop. Similarities in the importance of leadership additionally emerged, specifically around the needs to address resistance to change, establish management consistency over individual systems within the DT ecosystem, and provide increased opportunities for training and skill development.

The new findings which resulted from the DFW DT Case Study that were not holistically found in the UW IoT Case Study included the importance of colocation in DT operations and management, a shift in the type of institutional knowledge important for managing DT

technologies, the need to implement new roles such as data scientists and engineers who have technical skills outside of the traditional FM scope, and lastly new responsibilities around creating and maintaining data and simulation visualizations which the utilization of a DT allows for at higher levels than IoT systems.

## **8.2. Contributions to Knowledge**

The contributions to knowledge that have resulted from this study are multiple. Firstly, this research identifies the shifts in practice and new practices necessary for the integration of IoT and DT technologies into FM organizations and the operations phase of the building lifecycle. From an IoT perspective, this research did a holistic analysis of the technological transition, from both an organizational and technological perspective. Additionally, similarities were drawn in the required organizational shifts in practice required for IoT integration to that of an organization operating with DTs. This research additionally identified analogous themes in theories of digitalization from studies in design and construction phases to the operations phase, highlighting similarities in digital integration across the project lifecycle. This contributes to existing knowledge around digital adoption in the built environment and allows for connections to be drawn between digitalization in operations and design and construction phases. This strengthens the correlation between phases across the project lifecycle for further research. This study also identifies new themes that contribute to the theories of digitalization for operations, enhancing the overall body of knowledge.

The findings of this study that align with existing theories of digitalization from literature in the design and construction phases include the need to break down disciplinary silos to achieve a more centralized organizational approach to data management, exchange, and

collaboration. Additionally, this research, as well as the literature, highlight the importance of challenging cultural norms and entrenched organizational practices in the context of digitalization. For example, the findings of this research point at the need for organizations to rethink habitual notions of practice and collaboration that hinder change in order to embrace IoT and DT systems. Lastly, the need for strong and effective leadership resonates with this research study, as the role of leadership in guiding the organizational transition around the implementation of new digital technologies proved essential.

The contributions to knowledge in digitalization for operations that have resulted from new findings in this study include the importance of colocation to DT management (mentioned in the design and construction literature as beneficial, e.g. Homayouni et al., 2012, however, deemed a major contributor to success for DT operations in this study), and the need to restructure documentation standards to meet new technological requirements. This includes revising building handover documents like Facility Design Guides, specifications, and as-built documentation to accommodate for IoT specific information. This study also identifies the need to adjust maintenance norms for shorter technology life cycles, ensure consistent management of individual systems within the larger IoT/DT ecosystems, and integrate new roles like Operational Technology Managers, Building Handover Directors, and in-house Data Scientists/Engineers. The findings of this research additionally contribute to knowledge through identifying the need to balance institutional knowledge and “new” knowledge, such as programming and data analytics, to optimally manage IoT and DT systems. Lastly, this study identified the need for FM organizations to train or hire facility personnel with new skills required in creating, maintaining, and managing the visual components of DT technology such as simulations and virtual models.

### **8.3. Potential Impact on Industry**

As the adoption of digital technologies continues to rise in the FM sector, studying how FM organizations must shift their practices to accommodate the use of digital tools like IoT systems and DTs becomes imperative. IoT and DT technologies are still in their nascence in the building and operations industries, lacking a common definition, standard operating procedures, and application use cases which define how the technology is to be used and how organizations must approach integration and management. This makes it difficult for FM teams to understand how to best use new digital tools and what is required of their organization to accommodate real-time data centric technologies. These technologies often produce unprecedented amounts of data at rates never before experienced by the FM organizations. In addition, the large amount of research publications on IoT systems and DTs within technical domains that discuss their system architecture and technical intricacies are not matched with an equal number of studies analyzing the qualitative impact of the technology. In other words, there are few studies analyzing how organizations and the personnel within them can best manage and interact with such new systems that challenge existing operational standards and norms. This research does a detailed analysis into a real and active FM organization managing a large research campus (UW), analyzing the experiences, tensions, challenges, and shifts that over 20 diverse facility personnel have experienced in the management of IoT integrated building systems. Beyond IoT systems, this research additionally investigated how the necessary shifts in practice in IoT building management translate to a DT integrated facility at the of the Dallas Fort Worth (DFW) airport in Texas, USA. The findings of this research can be translated to other FM organizations to inform their approach to integrating IoT and DT technologies into their unique organizations, giving

them a real-world perspective on how to manage this organizational and technological transformation.

As stated by one of our interviewees in the DFW DT Case Study describing the atmosphere around DTs, which encapsulated a common theme throughout this research, “everyone is kind of shooting in the dark” in terms of best practices with the use of these novel systems. Continuing this sentiment this interviewee shared, “It will take adjusting and learning from other organizations, borrowing from those people who are further in the journey”. This research can serve as a point of departure for other organizations beginning the digitalization journey by informing organizations currently navigating the transition to the use of IoT or DT technologies through both an organizational and technical lens. Organizations can draw on the findings of this study to realize the importance of dismantling disciplinary silos, approaching IoT and DT management through a centralized data and communications approach, the value of institutional knowledge in bridging the gap, and the new knowledge requirements of managing IoT and DT systems. In addition, organizations can draw on the importance of leadership in guiding the process and establishing management consistency over systems, the new role opportunities that IoT and DT systems create, the required changes to existing document and decision-making structures to better suit the management of fast changing technologies, and the importance of colocation in managing DTs. Providing an organizational and technical analysis in this research can serve as a baseline framework/guide for other organizations adopting these tools and can help ease the tension of transition when future FM organizations decide to innovate with the integration of IoT systems or DTs for building operations and management.

## 8.4. Limitations

In this section I will acknowledge the potential weaknesses and constraints that may have impacted my research.

**Scope and Generalizability Limitations:** This study took place in two specific settings, a University Campus and an international airport. The UW Facilities group provided a very thorough and holistic setting for an IoT integration analysis, however managing over 500 campus buildings may result in different requirements as opposed to a facilities group that manages one office facility or a smaller geographic campus area. In similar sentiment, a large international airport has very specific management requirements and objectives, which is reflected through their DT initiatives. For example, the passenger boarding bridge DT discussed in Finding 1.2 of Chapter 6, or their rental car fleet DT discussed in Finding 2.1 of Chapter 6. Although the airport did implement a DT to manage more general facility requirements, like the customer experience DT which managed general building parameters, a DT for a more traditionally occupied facility setting such as an office may result in slightly different shifts to practice due to the reduced scale, criticality of operations, and nature of function. Testing the findings of this research in other building and operational settings may further increase the validity and generalizability of the findings. This study was limited by the availability of potential industry partners for this research project that have operational DTs and could be contacted and interested in this research. Due to the early stage of DT development and implementation in the operations industry, this study was limited to organizations using operational DTs that were willing to participate. Consequently, the DFW Airport was identified as the research target.

**Methodological and Data Limitations:** Although the relationship with the DFW Airport is ongoing for future work, the sample size for interviews in case study two was limited due to

limitations in the amount of DFW employees who could be interviewed within time constraints. At the time of this research, the DFW DT efforts were still in their early stages, which made it difficult to connect with qualified interviewees who felt suited to participate in this research study, and more importantly, had the availability to meet. In addition, many potentially valuable contributors to this case study were contracted from outside of the DFW organization to aid in DT development, making connecting with them a more difficult task. Although my research objectives were met, having a larger sample size could lead to additional findings or further help with data saturation for reliability. However, within the UW IoT Case Study, connecting with qualified interviewees was a simpler task and a point of data saturation was achieved at a desirable level.

In addition, due to the limitations described above in participant availability as well as differences in the technical infrastructure of DT operations compared to IoT, I was not able to study the new practices that go into ensuring the technological feasibility of DT systems, such as what was done in the IoT investigation (Research Question 4). This is discussed below in the future studies/next steps section as a potential future avenue for this research.

The limitations and validity of the research methodology and data collection methods employed for this research as well as the steps taken at ensuring reliability were addressed in chapter 3. In the Research Methods Chapter, I also discussed how subjectivity and bias were avoided within my qualitative research.

## **8.5 Future Studies/Next Steps**

Future studies and next steps based on this research study are numerous. These future studies/next steps will be outlined individually below.

### **1. Test Theory in Different Settings**

As described in the limitations above, two case studies were conducted as part of this study within specific case boundaries, a University Campus and an international airport.

Acknowledging these specific case study boundaries, it would be valuable to do future research testing the theory developed in this study in other operational contexts to explore themes widely and understand whether studying other types of operational organizations will lead to the same results or garner new insights.

### **2. Expand digital twin investigation to include technical analysis**

Due to the differences between the settings of the two case studies and the differences in system architecture between IoT systems and DTs, it was not as viable to test the findings of chapter 5 to the DFW DT Case Study. Chapter 5 looked at the new practices necessary to ensure the technological feasibility of the integrated IoT systems. In addition, limitations around sample size also made this analysis difficult within time constraints. To complement the findings around the shifts in organizational practices required for DT use, it would be important to additionally conduct a study asking the following research question targeted at an organization using DT technologies:

What new practices are necessary for facility management/building operations teams to ensure the technological feasibility of digital twin systems?

### **3. Identify other DT operational facilities to test findings against**

Taking what was found to be analogous shifts in operational practices between IoT and DT operated buildings, it would be important to further test these findings in other DT operated facilities more holistically. This may be difficult in the current technological atmosphere around DT adoption and integration, which may make this a more long-term objective as the technology is still generally in its nascent state. However, such an investigation may give rise to other important considerations or findings which were not discovered in this analysis. In addition, doing such a study would only serve to further validate or invalidate the conclusions made between the analogous shifts in operational practices in IoT and DT systems.

### **4. Applying IoT findings to an organization beginning the process of IoT integration to test efficacy**

It would be interesting and useful to test the validity and efficacy of the UW IoT Case Study findings to an organization who has not yet begun the IoT transformation process and may be able to apply the findings of this research to their initial efforts as integration “best practices”. This may show whether the findings of this research will lead to a successful and fruitful integration process which may allow for the development of an IoT integration framework for organizations beginning the transformative journey.

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## **APPENDIX A Interview Protocols**

### **UW IoT Case Study Organizational Focus - Interview Protocol:**

**Target:** Key personnel who have designed, installed, or regularly interface with IoT systems

- Campus Energy, Utilities and Ops Personnel
- Sustainability groups
- Zone Managers
- Environmental Controls Personnel
- Business Innovation and Tech. Personnel
- Etc.

#### **Topics Covered:**

- Background
- Decision-Making
- Transition to Occupancy with IoT (T2O)
- Impact on Facilities and Ops
- Non-technical Factors in tech adoption

#### **Protocol:**

**Hello, it is great to meet you, is it still a good time for an interview?**

**[elevator pitch]** We are studying how people are using new digital tools (IoT devices and systems) to manage building systems. We would like to talk to you today about your experiences in building system management both prior to and after adopting digital tools for building system management. With these tools we are mostly looking to understand how practices have changed or need to change around the use of IoT devices.

#### **Background (setting the scene and identifying technology):**

1. What are your current roles and responsibilities in your job?
2. Can you tell us what your professional experience has been in the industry?  
(follow up) How long have you been in your current position? (if needed)
3. What work do you do around managing IoT technology at your job?
4. How has work changed since you added IoT systems?

### **Decision-Making:** (present and past)

1. Who decides and how is it decided which technologies will be adopted in buildings at the UW?
2. What kind of information do you need when making decisions about installing IoT?
3. Are there any challenging contract or bureaucratic barriers in the technology adoption process?  
Alternative: how do contracts and project delivery methods impact the technology adoption process?
4. Can you talk about a time from your experience when a technology adoption initiative was challenging and why?
5. What new information are you getting from this “smart building” that you did not get in other facilities you have managed? How does that change your work?

### **Transition to Occupancy: Existing to new buildings.**

1. Can you describe the transition to occupancy process from your experience?
2. How has IoT technology changed the handover process?
3. When and how are facilities involved during the building handover procedure?
4. How are facilities trained to operate new systems during the building handover procedure?
5. What challenges, if any, have you experienced during building handover in terms of IoT implementation?
6. From your experience, how do you think the transition to occupancy process can be improved?

### **Impact on Facilities and Ops:**

1. From your experience, what do you see as the biggest challenges for facility managers, operators, and shop personnel when managing and working with new IoT devices?
2. How do anticipate some of these challenges can be solved?

3. What are the most frequent complaints or tensions you hear from facility managers and operators around some of UWs more technologically advanced buildings?

**Non-technical factors in tech adoption-** Communication and Collaboration:

1. From your experience, are there any non-technical barriers to the adoption and use of new technologies in facility management on campus?
2. Are there any “soft skills” which may be improved in order to better adopt modern technologies, collaborate around them, and utilize them properly?
3. What is the reluctance in implementing these technologies, if there is any?
4. Can you describe the culture of facility management at UW?
5. Could you describe the process in a graphic how the IOT devices are implemented in the UW facilities?

## UW IoT Case Study Technical Focus - Interview Protocol:

<b>Technical Interview Protocol</b>	
<b>Name and definition of the layer</b>	<b>Questions related to the layer.</b>
<p><b>Background:</b></p>	<ol style="list-style-type: none"> <li>1. What are your current role and responsibilities within the UW FM organization?</li> <li>2. Can you tell us about your background in the industry, including the duration of your current position?</li> <li>3. Which building systems and zones(buildings) do you oversee/ manage data for within the organization? Can you provide a list of these systems or a list of the buildings that you help to control?</li> </ol>
<p><b>Perception Layer:</b></p> <p>This is the lowest layer and involves the physical devices or sensors that collect data from the environment. These devices can include sensors, actuators, cameras, temperature sensors, motion detectors, and more. They capture real-world data and convert it into a digital format that can be processed and transmitted</p>	<ol style="list-style-type: none"> <li>1. Could you provide a list of the most frequently utilized IoT device types within the buildings you manage?</li> <li>2. What kinds of data do these IoT devices produce?</li> </ol>
<p><b>Network Layer:</b></p> <p>The network layer is responsible for transmitting the data collected by the sensors to the cloud or other computing systems. It includes various communication technologies such as Wi-Fi, cellular networks, Bluetooth, Zigbee, LoRaWAN, and more. The choice of network technology depends on factors like range, data rate, power consumption, and coverage.</p>	<ol style="list-style-type: none"> <li>1. What type of network are you using to interconnect the IoT devices? Ex. Wi-fi, cellular, Zigbee, long range...</li> <li>2. Do you have a dedicated data network specifically for IoT devices and their communication? (for collecting/gathering incoming data)</li> <li>3. Do you practice network segregation based on specific types of IoT devices?</li> <li>4. Is there a distinct network established solely for the management of IoT devices? (a separate management network from the IoT data network)</li> <li>5. How are those networks secured and isolated from other networks?</li> <li>6. Are there specific data protocols that you employ to transmit information? For instance, do you use standardized protocols to package and transmit data?</li> </ol>
<p><b>Middleware Layer:</b></p> <p>The middleware layer provides the necessary infrastructure to manage communication between devices and the cloud. It includes protocols, APIs, and software libraries that enable seamless data exchange, device discovery, security, and authentication.</p>	<ol style="list-style-type: none"> <li>1. Are you using any middleware software in your IoT system architecture to interface the communication between IoT devices and the backend systems? (ex. for data filtering, data integration, implementation of business logic)</li> <li>2. Are you using middleware to route messages to particular receiving systems?</li> </ol>

	<ol style="list-style-type: none"> <li>3. Are you doing any form of message (data) transformation between IoT devices and the receiving device?</li> <li>4. Have you implemented any particular business logic in your middleware and why?</li> <li>5. Is the middleware a third-party platform, or is it an in-house developed solution? If third-party, who is responsible for its management, and which platform are you utilizing?</li> </ol>
<p><b>Application Layer:</b></p> <p>The application layer is where the collected data is processed, analyzed, and turned into actionable insights. This layer can involve complex data analytics, machine learning, and AI algorithms to make sense of the data. It also includes user interfaces and dashboards through which users can interact with and control the IoT devices.</p>	<ol style="list-style-type: none"> <li>1. What applications/dashboards do you use to manage your IoT devices? Are they developed in house or by a third party such as a device vendor?</li> <li>2. Could you elaborate on the functionalities and capabilities offered by these applications in terms of managing your IoT devices?</li> <li>3. How is the data collected from IoT devices processed to populate the dashboards or management applications you use?</li> <li>4. From your perspective, do you see any room for improvement in these applications to enhance your management of IoT devices?</li> </ol>
<p><b>Security Layer:</b></p> <p>This layer includes authentication, encryption, access control, and data integrity mechanisms to protect both data in transit and data at rest. IoT devices are often vulnerable to cyberattacks, so robust security measures are essential.</p>	<ol style="list-style-type: none"> <li>1. Do you implement end-to-end encryption for data in transit? Is encryption employed at any stage of communication with devices to ensure data remains inaccessible to unauthorized parties?</li> <li>2. Are you using encryption in rest? (when you save your data on a storage platform are you encrypting the information)</li> <li>3. What measures do you have in place to safeguard your devices against potential cyber-attacks? Do you have established security response procedures to swiftly detect and respond to such attacks?</li> <li>4. Among the various IoT device connections, what are the most prominent security concerns that you encounter?</li> <li>5. Are regular security audits conducted on your configuration? How do you address and rectify security vulnerabilities identified through these audits?</li> </ol>

<p><b>Management Layer:</b></p> <p>This layer involves managing the lifecycle of IoT devices, including device provisioning, updates, maintenance, and monitoring. It ensures that devices are functioning correctly and that any issues are addressed promptly.</p> <p>Management layer – connected to the network, management and data layer</p> <p>Where you have administrative applications to manage the whole IoT ecosystem</p> <p>Whole process of updating, decommissioning etc. of the IoT devices.</p>	<ol style="list-style-type: none"> <li>1. How do you monitor your IoT devices? What type of alerts do you have set up/normally receive and how do you address these alerts?</li> <li>2. How do you manage the lifecycle of the IoT devices? (process of updating software, initial configuration, decommissioning etc.)</li> <li>3. How do you update systems so that all software is up to date and functioning properly? Is this a UW responsibility or the responsibility of the 3<sup>rd</sup> party vendors of the IoT device?</li> <li>4. Do you have a central platform (or single pane of glass) where you can see and manage all your IoT devices or are there different platforms based on the manufacturer of the device?</li> <li>5. What challenges do you normally have with managing the IoT devices?</li> </ol>
<p><b>Integration Layer:</b></p> <p>IoT systems often need to integrate with existing enterprise systems, databases, and third-party services. The integration layer facilitates interoperability between different systems and ensures smooth data flow between them.</p>	<ol style="list-style-type: none"> <li>1. Do you have a use case where you have to integrate with other 3<sup>rd</sup> party systems?</li> <li>2. How is this implemented?</li> <li>3. Can you describe how you integrate IoT devices to existing enterprise systems to ensure smooth data flow between them?</li> </ol>
<p><b>Data Storage Layer:</b></p> <p>IoT systems generate vast amounts of data. This layer includes databases and storage solutions that store and manage the collected data. The data can be structured or unstructured and can be used for historical analysis, real-time monitoring, and predictive modeling.</p> <p>Common data environment – storage of data</p>	<ol style="list-style-type: none"> <li>1. When IoT devices collect information, where is this data stored?</li> <li>2. Do you collect and archive existing IoT data?</li> <li>3. Are you using cloud storage?</li> <li>4. Can you describe your data storage infrastructure?</li> <li>5. Do you backup your data and how often?</li> </ol>
<p><b>User Interface Layer:</b></p> <p>This layer provides interfaces for end-users to interact with the IoT system, monitor device status, control devices, set preferences, and access data insights. User interfaces can range from web-based dashboards to mobile applications.</p>	<ol style="list-style-type: none"> <li>1. Which IoT devices do users have direct control over?</li> <li>2. How do you monitor and control who is using devices?</li> <li>3. Does the process complicate when users also have control over IoT devices on a strictly functional level?</li> </ol>

## **DFW DT Case Study - Interview Protocol:**

### **TOPICS COVERED:**

Testing Findings from UW IoT Case Study, pt. 1:

- Background
- Organization – breakdown of disciplinary silos
- Technology housekeeping- technical skill sets and management responsibilities
- The Work of Making it Meaningful- leveraging digital twins for better performing built environments
- Bridging the Gap – managing the transition where modern technology meets traditional building systems
- Rethinking building maintenance workflows, cycles, documentation, and decision making
- Introduction of new roles, responsibilities, or positions

### **Protocol:**

**Hello, it is great to meet you, is it still a good time for an interview?**

**[elevator pitch]** We are studying how people are using new digital tools such as digital twins and IoT systems to manage buildings and facilities. We would like to talk to you today about your experiences in building/facility system management with the use of a digital twin. With these questions we are looking to understand how practices have changed/need to change and what new practices appear for facility personnel/building operators around the use of digital twins for building management and operations.

### **Background (setting the scene and identifying technology):**

1. What are your current roles and responsibilities in your job?  
(follow up) How long have you been in your current position? (if needed)
2. How does your organization use digital twins and what is their purpose/what goals would your organization like to achieve with the use of a digital twin?
3. What work do you do around managing digital twin technologies at your job? How does your role interface with digital twins?

### **Organization – Disciplinary Silos**

1. Thinking about disciplinary silos, how does using a digital twin change your organization's approach to data management and storage?

(follow up) Is the utilization of digital twins creating any new organizational communication requirements?

2. Could you describe how communication and information distribution are managed within your organization and how you perceive this approach is influenced by the utilization of digital twins for facility management?
3. How are roles and responsibilities typically delineated in your organization with regards to managing digital twins?
4. How does your organization interact with other disciplinary groups such as IT, engineering services, trades etc. around the management of a digital twin?

### **Technology housekeeping- Technical skill sets and management responsibilities**

1. What skills related to the hardware and software of digital twins have you and your team members needed to develop in order to operate digital twins?
2. How does your organization manage device lifecycle information, software updates, and maintenance requirements? Are there specific tools or systems in place to facilitate this process?  
(follow up -if needed) Can you describe the process of updating digital twin device software and servers? How frequently do you have to update device software and what does that process look like?
3. Can you describe the work that goes into establishing and maintaining proper network communications in order for the digital twin to operate in real-time?

### **The Work of Making it Meaningful - Leveraging digital twins for better performing built environments**

1. Please describe any software used for various aspects of digital twin operations.
2. Please describe your organization's processes around using DT control dashboards. Please provide insights into the tasks and processes involved in managing these dashboards on a regular basis.
3. If any, can you describe what alarms, alerts, or notifications you have put in place to inform you on the status of various building components with the use of a DT? How does your organization manage this and respond to such alerts?
4. Can you describe how system troubleshooting works with the use of a DT?  
(follow up) Has the nature of building troubleshooting changed with the adoption of DT?

5. How do you perceive the impact of DT on the maintenance approach within your organization?
6. How does your organization make collected building data useful?
7. Please describe the work that goes into data analytics with the use of a DT?

### **Bridging the Gap – Managing the transition where modern technology meets traditional building systems**

1. In light of digital twin technologies, has using the technology changed the skillsets you look for in a technician, operator, new hire? How so?
2. Have you felt any resistance to change with operators and technicians when digital twins were integrated to manage facility operations? Please describe.
3. If any, please describe the process of training and educating new and existing facility personnel in relation to using a DT for building operations.

### **Rethinking building maintenance workflows, cycles, documentation, and decision-making**

1. Please describe the typical maintenance, repair, replacement, and decommissioning process for digital twin integrated devices (or IoT devices) within your organization? Have device maintenance procedures changed?
2. If any, please provide insights into any standard documentation available to guide operators and personnel in operating and maintaining digital twin technologies within your organization.
3. What do you see as the biggest challenges to managing a digital twin and how does your organization address these challenges?
4. What unique insights or information are you gaining from this 'smart building' that differ from your experiences managing other facilities?  
(follow up) If at all, how do these insights impact your approach to your work?

### **Introduction of new roles, responsibilities, or positions:**

1. Do you see an opportunity for the creation of any new organizational roles with the use of a DT to help optimally maintain its functionalities? If so, what responsibilities would that role entail?
2. How does the potential for data analytics through the use of a DT influence considerations around integrating new roles within your organization?

## APPENDIX B: Example Coding Schema/Procedure

### UW IoT Case Study 1, Part 1 – Example of codes used

OPEN CODING		AXIAL CODING	SELECTIVE CODING
reverse engineering thinking	training reqs	centralized data management	Centralized inventory Management
knowing programming languages	develop standard handover procedure	inventory management	
adaptability with programming	data and procedure transparency	centralized effort	
understanding of network	ensure everyone knows of resources	advanced device inventory	
understanding of data flow	ensure everyone knows of goals	centralized communication	Centralized Communication and Data Distribution
awareness of system architecture	focus on immediate benefit of tech	Centralized information sharing	
detail oriented thinking	increase sense of ownership for buy in	awareness of resources	
knowing mechanical systems still integral	managing generational divide	data and process transparency	
liason IT and FM	employee adaptability	liason IT and FM	Increased need for Interdisciplinary collaboration
centralized data storage	shrinking and aging workforce	increased collaboration complexity	
centralized data management	education and training	interdisciplinary collaboration	
inventory management		disciplinary silos	New Communication Needs
centralized communication		speak IT language	
role distribution		collaboration with IT	
centralized information sharing		Learn Disciplinary Lingo	Vendor Management
awareness of resources		vendor research prior to selection	
Speak IT language		vendor device compatibility	
breaking down disciplinary silos		vendor transition to occupancy	
inventorying devices		bridging the gap	Balancing New Knowledge with Institutional Knowledge
standard log information		tech. and mech. collaboration in problem solving	
information distribution		employee adaptability	Device Coding and Programming
easy accessibility		programming adaptability	
defining parameters, roles, responsibilities		new software- writing code	
updating docs regularly		unique devices/unique requirements	
establishing leadership roles		awareness of advanced technology	Network Connectivity, Data Flow, System arch.
rethinking traditional design docs (O&M, as-built..)		detail oriented thinking	
establishing standard of quality		understand network arch.	
enhanced device management		establishing network communication	Data Analytics
establishing FM decision makers		making data useful for decision-making	
establishing management consistency		data analysis and projections	
emphasis on building codes in decision making		work of data analytics	
bringing FM into decision making		advanced troubleshooting	Advanced Device Troubleshooting
forward thinking		digital fault detection	
vendor devices for compatibility		responding to increased requests	
advanced device inventory		increased alarm response	Managing Personnel Resistance to Change
device replacement cycles		tech. transition strategies - immediate benefit	
updating standard documentation regularly		tech. transition strategies - ownership	
updating device softwares and servers		managing generational divide	
increased collaboration with trades		shrinking and aging workforce	Establishing Management Consistency
new collab reqs in problem solving		Role distribution	
centralized storage and management		defining parameters, roles, responsibilities	
increased collab with IT dept.		Establishing management consistency	
adhering to unique client requests in design		forward thinking- responsibility allocation	Enhanced Training and Education
respond to increased customer service requests		increased training requirements	
configuring devices for space customization		education and training	
increased alarm response		large learning curve	
rethinking traditional decision making heirarchy		leadership roles	New Roles- OT Manager
FM involvement in design meetings		enhanced device management	
research tech options before decisions - vendor		standards of quality	
new position- coordination and FM rep		liason IT and FM	New Roles- Building Handover Director
understanding network arch		leadership roles	
establishing network comms		new position- FM handover	
programming devices for their function		new position- FM handover	
plethora of new software controls		T2O director position	Restructuring Decision Making Heirarchy
writing code		FM involvement in design meetings	
unique devices with unique reqs		FM involvement in design meetings	
increased collaboration - increased complexity		FM into decision-making	Restructuring Handover Documentation
maintaining and updating inventory info		decision-making hierarchy	
making data useful for decisions		standard building handover information	
introducing data analytics		re-thinking traditional documentation	New Maintenance Cycles for IoT
advanced troubleshooting		defining standard of quality	
digital fault detection		updating documents	
configuring buildings - data and projections		updating software and servers	
introducing T2O person		device replacement	Increasing Frequency of updating standard documentation
increased device/building complexity		updating standard documentation	
increased handover reqs		building codes in decision-making	

## APPENDIX C: Supporting Case Study Data from Coding Process

Case Study One, Part One	
Findings:	Data:
<p><b>1.1: Centralized Inventory Management</b></p>	<p>“Instead of everybody having their own spreadsheet, which is what is going on right now– we need a master database.”            “Then once that master database becomes synced and complete, then we can slowly start peeling off everybody’s Excels.”            “We really don’t even know how many devices we have out there or where they’re at. We just know we have a lot of them.”            “We are bringing it all together into a central hub so that they can manage the whole 12 million square feet with a few people at a central location where we have human interfaces on all 120 buildings.”</p>
<p><b>1.2: Centralized Communication and Data Distribution</b></p>	<p>“The project folks, they just deliver all the stuff [building and device information] to records. What records does with it, they put it into our DocFinity system. But does anybody convey that down to the shop folks? It could be all in the right places where you need to get to it, but this side of the group doesn’t know where it is. They just know that it’s someplace.”</p>
<p><b>1.3: Increased Need for Interdisciplinary Collaboration</b></p>	<p>“We’re trying to establish, re-establish, build relationships between different groups that wouldn’t normally be working very closely together, anything from a subcontractor on a project to a trade, somebody in the trades to the IT Department to the Construction PMs and CMs, and everybody in between.”            “You’re adding more people involved to troubleshoot issues. 10 years ago, it was just one service technician that would go out to the field to fix that irrigation system. Now, you’re having to deal with three or four people to fix it.”            “We have to have UW IT involved, and there has to be multiple entities within UW IT. then you have the server people, and then the other people we have locally [FM personnel]. Then, you usually will have the vendor involved because of the application software involved. So, you have to have multiple people on the same page at the same time.”</p>
<p><b>1.4: New Communication Necessities – Breaking Down Disciplinary Communication Barriers</b></p>	<p>“The soft skills are being able to communicate with an IT person who has no concept of what an HVAC system is”            “Being able to take your technical knowledge of this building system and being able to communicate the issues with someone who’s in a cubicle somewhere saying, ‘I understand the network and data flows’.”            “Being able to communicate with different levels of the organization”            “Being able to communicate with blue-collar workers, white-collar workers, and everything in between... being able to communicate with people in IT. All those groups have different generalized ways of communicating.”            “IT language”</p>
<p><b>1.5 Vendor Management, Relationship Building, and Collaboration</b></p>	<p>“We have to ask them [vendors], if it’s outside of our scope or whatever, to come in and help us with certain things.”            “Devices installed by companies that go out of business and inadequate vendor support/troubleshooting for device issues.”            “Sometimes it gets difficult because they don’t understand us, we don’t understand them, and we’re trying to solve the problem together.”            “Some of the more mature companies in that space have kind of stopped all of the hyperbolic promises and have come back to reality where really 90% of your energy savings is just making sure that broken stuff is fixed.”</p>
<p><b>2.1 Balancing “New” Knowledge with Institutional Knowledge</b></p>	<p>“Individuals now have to have an IT background of some sort to at least understand the basics of network communication. Something that staff never needed.”            “It’s someone who can understand both worlds, the trade side and the IT side, and be that kind of glue that holds things together.”            “It’s incredibly important for our techs to understand how the mechanical side of things work, because it then just becomes clear how you need to control things, or how you can safely control things.”            “We have to hire people that are comfortable with and have an understanding of mechanical equipment, and also have to understand and not be afraid of technology, working with computers, operating systems, and code, but also to know how a fan works.”            “I think it’s both knowing the digital technology and how the IT infrastructure works but also simultaneously knowing how the mechanical systems operate, knowing how electrical systems operate, knowing how plumbing systems operate.”            “Speak both languages”</p>

<p><b>2.2: New Technical Skill Set Requirements - Learning/Understanding Device Coding and Programming</b></p>	<p>“If you saw it, the programming language is completely different. The user interface is completely different...You can translate, if you really learn one of them well, some of that knowledge into the different products.”</p> <p>“Imagine every few months you have a new software that you have to learn. And you’re like, ‘But I don’t do this on a daily basis. I run cable. I run wire’.”</p> <p>“We didn’t know how the thing was configured. We didn’t know what to do with it. We had to start over, buy a new Raspberry Pi, plug it in, find the software, download it, configure it like we’d never done it before. Stupid.”</p> <p>“It can be harder to tell how a digital controller is necessarily configured just by looking at it. In the past maybe with pneumatic, you could at least trace the wires around and see this component. I know what that component is. So, even if I don’t have the diagram, I can at least see what it is. If I spend some time, I can figure it out, but with digital controllers you can’t really know how a computer is programmed just by staring at the hardware device.”</p>
<p><b>2.3: New Technical Skill Set Requirements - Learning/Understanding Network Connectivity, Data Flow, and IoT System Architecture</b></p>	<p>“A basis of networking communication for one. Understanding how data flows through a network. I would put that at the top. The ability to do basic troubleshooting of an IT device.”</p> <p>“A lot of people don’t understand the technology. It’s difficult for us to find qualified people that can come in and work on these systems without needing a lot of training. Years of training.”</p> <p>“I think when we first did it [integrated IoT devices], they [FM personnel] said, ‘we don’t have the information’. So then we gave them the information, and it was a little bit embarrassing for them to maybe say, ‘We don’t know what to do with the information’.”</p>
<p><b>2.4: Introduction of Data Analytics</b></p>	<p>“There’s a big push on campus right now for analytics, so that we can determine what kind of adjustments we need to make to conserve energy.”</p> <p>“We get a lot of data from chillers, VFDs, lighting, control systems, and even metering that now comes in. We now have the ability to trend all that data. You can really look deeply into how the building’s operating.”</p> <p>“Alerton and Siemens give you a lot more access to their assembly code. And so, with that, you can get very, very technical with what you can control, if you have the knowledge.”</p>
<p><b>2.5: Advanced Device Troubleshooting</b></p>	<p>“Things we can analyze are: Are things operating according to schedule, or is the equipment turning off or modulating as we expect it? And we come up with corrective actions.”</p> <p>“It helps our efficiency in the sense that we can hit multiple problems much quicker than we used to be able to.”</p> <p>“You don’t need to go walk the entire building or wait for somebody to complain...it’s giving you a heads up that, ‘Hey, we’re starting to trend in the wrong direction. Some preventive maintenance here would get us back on track’.”</p>
<p><b>3.1: Managing Personnel Resistance to Change</b></p>	<p>“I mean, if anybody had the magic formula for doing that I think they would be a very rich person because I think it’s where most of the challenges lie right now.”</p> <p>“There’s a point where you can win them over by making it their idea...Because a lot of the reluctance is because they’re embarrassed... Once they get ownership, boom, they turn to a whole new person.”</p> <p>“They need kind of ownership over their work. And it’s been a real positive and productive way to retool our staff.”</p> <p>“It’s how they [new technologies] come in is what really matters because if they come in and people understand what they are, and they come in over a time, and they start to get a little bit of buy-in, then you got a chance of them actually being followed.”</p> <p>“If you’re dictating down, ‘You will do this’, that’s never really going to be successful in any meaningful way.”</p> <p>“So, working with people in the shop to say, ‘here’s this new thing. Yeah, there’s extra complexity, but here are these tools that might make your job easier’.”</p> <p>“Demonstrating how it [the technology] makes their job easier because I think people often look at the negatives.”</p>
<p><b>3.2: Establishing Management Consistency</b></p>	<p>“I think that consistency of who’s working on the system is important. Like I said, being familiar with it [the device/system] is half the battle.”</p> <p>“The University said, ‘Yeah, we’ll do this thing’. But they never said who is gonna be responsible for managing this system once it’s installed...They’re [the client] the ones that were requesting this, but they didn’t want the management of it once it was in place.”</p> <p>“Lighting control is a great example because the electricians are distributed in different zones. There’s not one person guiding that process. Things just kind of get dumped on them. Here you go. Here’s this new system. Have fun.”</p> <p>“We’re just not gonna touch it, just ignore it.”</p>

<p><b>3.3: Enhanced Training and Education Requirements</b></p>	<p>“My personal belief is that education and outreach continue to be a kind of top priority, especially education.”  “What we found is, even after a year, our facilities staff is still somewhat drinking from a firehose. It's just a little bit too much, too quick, too soon.”  “There are big retraining gaps in raising staff skill sets and modifying what their role is from being hands-on mechanics of mechanical devices to mechanics of digital devices. It is a very different skill set.”</p>
<p><b>3.4: Creation of New Roles - Operational Technology Manager</b></p>	<p>“Operational Technology Manager”  “We don't need IT support. We need OT support, operational technology support. It's the world of physical to IT – when they meet.”  “Their role now is to take all these technologies as they're coming and figure out a way to have a communication channel to the folks that are gonna get the item ...I use the word 'liaison' – can liaison between these different folks.”  “We haven't really figured out how we're going to make these systems work together because we have different shops that take care of the different systems. So for me to be responsible for all of them, it's hard to direct other shops that I don't manage.”</p>
<p><b>3.5: Creation of New Roles - Building Handover Director</b></p>	<p>“Building Handover Director”, or a “Transition to Occupancy Manager”  “they diluted that by giving everybody who's in the project delivery groups the transition to occupancy responsibilities. So, this project manager's understanding is different from that one which is different from the third which is different from the fourth guy.”  “Having somebody whose job is really that transition to occupancy, that – doing the finishing stages of construction and return of the building to UW I think would be very beneficial.”</p>
<p><b>4.1: Restructuring the Traditional Construction Decision-Making Hierarchy</b></p>	<p>“The project never thought to ask those that were gonna be actually doing it [managing IoT systems], because of this communication trail. why would these folks [decision-makers] be talking to our shop folks? They're talking to our PDG (Project Delivery Group) folks. Our PDG folks should be talking to our engineers. Our engineers should be talking to folks down here.”  “Always playing second fiddle”  “When we do it ourselves, we know where everything is. We know how it works. We have our own internal standards of quality.”  “A lot of times the standards of quality really aren't up to speed. Then there's the learning curve of how it was programmed, where they installed the field devices, because we don't know where they are at. We have to rely on the contractor to show us.”</p>
<p><b>4.2: Restructuring Traditional Building Maintenance Handover Documentation</b></p>	<p>“It's a very different sort of as-built for an O&amp;M manual requirement, you have to rethink the way that you write a specification for these kinds of [IoT] devices, and a new way of asking for the submittal for that kind of device, and a new way of requiring testing, commissioning, and documentation of that device.”  “These devices need a very different sort of submittal and as-built and owner's manual, with all sorts of very dynamic and specific information, like what version of the software actually got commissioned onto the devices. Something that no one would ever really think about.”  “They shouldn't be treated as if they're a static component of the building, just like everything in construction used to be.”</p>
<p><b>4.3: Creating New Maintenance Cycles to Accommodate IoT</b></p>	<p>“Older systems that are less IT-heavy, you can honestly let them run for 20 to 30 years with minimal input and time. But IT systems don't last as long.”  “Updating software patches is expected to be something you could do nightly or monthly. When you look at the building industry, our operators of digital systems, the presumption of how often you have to do that kind of work is more on the year scale.”</p>
<p><b>4.4: Increasing the Frequency of Updating Standard and Shared Documentation</b></p>	<p>“They said every two years they would look at the design guide and see if it matches the building code.”  “You would hear complaints from the engineers lately because the technology is causing the codes to be updated – where they would have to update it every five years, now they're doing it almost yearly.”  “I think once a year, twice a year, maybe they update the design guide. And right now, governance over the design guide is sort of, I don't want to say it's ad hoc, but as operators, we feel that it's a bit ad hoc.”</p>

Case Study One, Part Two	
Findings:	Data:
<b>1.1: Managing Diverse Vendor Specific Software Tools</b>	<p>“All the vendor does for us is provide us with a package. They say these are the software tools needed to install physical devices and put them on a network.”</p> <p>“For the most part, as long as we have the tools to set up these lease systems, it's ours from there on out.”</p> <p>“Every manufacturer of a piece of, per se, HVAC equipment has a proprietary control protocol...Carrier has CCN, Carrier Comfort Network. Mitsubishi has the M-NET. There's just a smattering of them across the industry.”</p> <p>“Between all three companies, they all do it differently.”</p>
<b>1.2: Programming/Coding Responsibilities in Device Configuration</b>	<p>“It's a process, all of them have similarities, but it's the way they execute because all of them have different code in the background.”</p> <p>“Johnson Controls uses a block-based, state-based programming, which is a totally different way of configuring these. And Alerton uses a similar block-based, but not state-based programming.”</p> <p>“You have to be versed in each one of those specifically because there's a lot of detail and nuance that you have to know that only experience gives you to be able to configure them correctly to work right.”</p> <p>“When I first started learning building automation systems, like I said, every single one was different. Every building you went to had a different version of that same control system, and they all acted a little bit differently... it was just a disaster.”</p>
<b>2.1 Sensor Configuration - Creating Unique Identifier/Instance Numbers</b>	<p>“Implement a common naming standard in HVAC controls.”</p> <p>“You need the instance number, which is a unique identifier that each one of the devices have. And if two of them have the same, then you have a communication problem.”</p> <p>“An architecture for device ID ranges. Siemens Insight was the first on campus so they got the one million device range. And then Alerton Compass got the two million, and then Johnson Controls got three million.”</p> <p>“We try to keep it the same across campus.”</p>
<b>2.2: Communication Protocol Standardization for Device Connectivity</b>	<p>“To bring in all of these different vendors into a cohesive network.”</p> <p>“BACnet is kind of what most everybody uses now. And it's an ASHRAE standard.”</p>
<b>2.3: Converting Existing Buildings to IoT Control – Network Wiring</b>	<p>“It's basically 100% wired”</p> <p>“We use copper wire. I'm a big believer in copper... The RS-485 network that we have is very reliable and it's all standard BACnet protocol.”</p> <p>“We're pulling all the pneumatics out and we're putting in brand new controls, it's almost like a brand new job to a certain degree.”</p> <p>“We've kind of separated into a smaller team solely focused on upgrading older analog buildings to digital controls, and with that, integration of BACnet or Modbus or LonWorks or whatever they have.”</p> <p>“Communication is always key. And with that comes the physical wiring standards.”</p>
<b>2.4: Third Party Device Integration and Ensuring Compatibility with Existing Systems</b>	<p>“That is absolutely the name of the game of what we do around here.”</p> <p>“A big concern lately is wildfire smoke in this area... so management wanted a certain set of parameters to be monitored. So they bought a very specific piece of equipment.”</p> <p>“Luckily, because we live in the day of open protocol such as BACnet, the manufacturer sends out a bib cut sheet for this. Basically, all the BACnet points that can be collected are already there and labeled...all you have to do is pull them into our system.”</p> <p>“If a third-party system does not abide by the BACnet standard, you have to go through and find out what each point is physically relaying.”</p> <p>“Even worse, sometimes third-party devices are literally just hard outputs, dry outputs. And from there, you have to program our system to take it in, use it as needed, and then spit out a usable piece of information.”</p>
<b>3.1: Establishing and Implementing Logic in Supervisory Devices - Message Routing and Processing</b>	<p>“There's business logic in that you can choose to pull every piece of data from a device, but that's a lot of data.”</p> <p>“We go through and write small pieces of code saying if parameters are between this and this, then report. If it goes through a change of value, then report. Sample times, buffer sizes etc.”</p> <p>“Say if it's a trend log, you say after 144 samples, then you send all of that information to the server and then it appends that SQL database with that little chunk of information, and then it starts over.”</p> <p>“Some systems such as our utility metering platform has this sort of arrangement to apply data cleanup and business logic to the information before it is stored/presented,”</p> <p>“Some systems have software which generate alarm messages to users/groups when devices are not operating normally.”</p> <p>“It really depends on what data we choose to capture. All we're choosing to capture is pertinent information. So, sometimes, that's temperatures, pressures, operating hours, kilowatts, and energy consumed.”</p>

<p><b>4.1: System Performance Monitoring</b></p>	<p>“Device activity on the network is monitored, offline devices generate email alerts and other notifications. Devices are also monitored for unexpected data outputs or status updates to address issues within the built environment.”</p> <p>“These systems monitor device activity over the network to let us know what has fallen offline and requires attention from maintenance staff. We also have systems that track asset information.”</p> <p>“Devices are pinged to check their status at regular intervals by the management applications.”</p> <p>“Sometimes the engineering group will ask us to provide a week's worth of trend logs that will indicate how the equipment is working.”</p> <p>“Right now, specifically, the College of Engineering is asking for humidity levels in the rooms. Over the next two or three weeks to be able to establish whether that equipment is working properly or not.”</p>
<p><b>4.2: Data Analytics</b></p>	<p>“We're able to query that data and we can filter it on multiple different levels, like a date range or a user. We can go down to, what did this user do on this day, we can see that they overrode this, they adjusted this, they changed this and changed that. Or if we want to look at a window of a room six months ago...between 9:00 a.m. and 12:00 p.m., we can do that.”</p> <p>“We can look at trends from the last week, and we can layer trends on top of each other and kind of get a better picture of exactly what is happening. We can see when events happen, and how they coincided with other events.”</p> <p>“We are able to start gathering just even what might seem like arbitrary data to then feed into more predictive maintenance models.”</p> <p>“Ideally, in the long run, we can use modeling or machine learning or things like that in order to more accurately back fill gaps in data if there are some. You could use all these factors to back fill and predict.”</p> <p>“I think someday we will be able to actually turn the AI monsters on the building operations and actually improve stuff...but that's really gonna be dependent on being able to provide those models with good, clean, reliable, multi-year data to build those models up so that they're actually useful.”</p>
<p><b>4.3: Troubleshooting, Fault Detection, and Diagnostics</b></p>	<p>“You start out at the server level typically and you see something is wrong where it's not reacting the way that you feel like it should be. Then you go down farther and then you directly plug in, figure out if there's something wrong with the configuration”</p> <p>“We'll determine if maybe there's an error in the settings of the system or something like that, something got changed. Maybe the IP address got changed.”</p> <p>“We do the first pass at it up and down. Can we determine any kind of IT issue? Is it a meter issue? Then we will go to site to troubleshoot the meter.”</p> <p>“Now that we've automated things, we can be more responsive, that I could be right in front of my computer, and within two minutes, I will have changed whatever setting needs to be changed.”</p> <p>“I can be at home on a Saturday afternoon and FOMS calls me and says they have a problem... I'm able to manipulate the equipment they're standing in front of and they're able to tell me what they're seeing.”</p> <p>“We have some labs out here that have critical equipment that serves it. And sometimes if that equipment goes down, then we could specifically send an email or a text message to somebody who would respond right away to it.”</p> <p>“We have notifications for any critical services, computer services that go offline. If any one of the hosts goes offline... we can alert. We can afterhours respond and get the system back and functioning again.”</p>
<p><b>4.4: Creating, Maintaining and Responding to Alerts and Notifications</b></p>	<p>“If it's critical enough, then you're going to set up an alarm that will alert somebody that there is a situation happening. Then I can immediately interface with that situation within five minutes.”</p> <p>“Somebody who will respond right away to it”</p> <p>“For high priority areas, we can set up alarms and then send those to alarm handlers which, from there, will be distributed and disseminated to recipients. For example, an animal testing area.”</p>
<p><b>4.5: Managing and Navigating Diverse Vendor Specific User Interfaces and Applications</b></p>	<p>“There are multiple platforms for different devices, and they all have a separate and specific software for the top layer... a separate software set of tools for the supervisory device and a separate set of tools for the field device.”</p> <p>“Each HVAC control vendor has their own proprietary user interface and every other Tuesday, they seem to have changed their entire system. And with that comes the growing pains of a new system.”</p> <p>“They changed the entire architecture of how the entire system worked. And so, doing something as simple as just adding an input, like a sensor input, to a field device now became a challenge, because the way you did it was entirely different.”</p> <p>“It was painful.”</p>
<p><b>4.6: Creating, Understanding, and Maintaining Data Visualizations</b></p>	<p>“We have tableau to create visual representations of the data”</p> <p>“There are basically two sets of visualization tools, one for the UW customer – the kind of summary or final report views, and that's in Tableau... and there is a web visualization tool called PI Vision that is accessible directly.”</p> <p>“Code-required reports,” “EUI for the buildings,” and “interactive dashboards”</p> <p>“From scratch you can build your own dashboards or build and save dashboards for other people to see.”</p> <p>“We have a guy that actually went to art school, and so he's able to take the AutoCAD drawings and he's able to use a tool that we bought...to raise up the floor plans and orient them and color them and everything.”</p>

<p><b>5.1: Updating Software and Servers</b></p>	<p>“I’ve been through a couple of those life cycles... some of what we’re upgrading is like two to three life cycles ago that we’re taking all the way up to now. And some of it is the last lifecycle we’re bringing up.”</p> <p>“This [upgrading software] is a challenge both in terms of funding and staff availability. Historically devices have run to failure and software updates were, with some exceptions, only applied through an ad hoc process.”</p> <p>“You won’t know until you go to the device, and you try to use the contemporary tools on that piece of equipment, and it says ‘not compatible’.”</p> <p>“That is a constant battle, is software updates...the IT world doesn’t wait for us. They keep moving forward...so we have to keep upgrading our stuff to keep up with them at times too, both with server and with the local interface.”</p>
<p><b>5.2: Sensor Lifecycle Maintenance</b></p>	<p>“Some of those meters are now 15 years old, and they’re starting to wear out and break, so [facility manager] is needing to order spares and make sure that there’s parts stocked so that when meters die they could be replaced in a reasonable amount of time so you’re not losing all the data.”</p> <p>“Sometimes end devices that are not compatible have to be changed. The physical controller has to be changed.”</p> <p>“When you’re upgrading to BACnet... you have to change the controller. Sometimes you have to change the wire too... if you’re talking a big network, you’re talking a lot of wiring.”</p>
<p><b>6.1: Managing Access Control</b></p>	<p>“We grant engineers, data analysts, even just building coordinators with various permissions, what they can’t change or what they can see... you can grant access to a smattering of people all across campus.”</p> <p>“Say if I wanna give a building coordinator some ability to make changes, I’m gonna limit his access to this toolset, both on the web UI and if he has access at all to the propriety toolset.”</p> <p>“MRI machinery is very dependent on temperature and humidity. So, with that, the operator has to have full control over these points...it’s the coolest thermostat I’ve ever seen...the operator of the MRI machinery can go in and both verify that conditions are within tolerance and change them as needed to become within that tolerance.”</p> <p>“Sometimes, we grant facilities a lot of permissions. Sometimes, we restrict it. It’s a very case-to-case basis.”</p>
<p><b>6.2: Maintaining Firewall and Intrusion Detection Systems for IoT Devices and Controls</b></p>	<p>“The university manages all of the security devices, the firewalls, right. So we work with them to maintain the firewall rules and ensure that we have kind of that least privilege, basically block any and only allow traffic that’s whitelisted.”</p> <p>“Even five years ago, it was just the Wild, Wild West out there. And then security has come front and center recently.”</p>

Case Study Two	
Findings:	Data:
<b>1.1. Centralized Data Management</b>	<p>"I think part of it is recognizing that the business-as-usual application to problems has not worked. We need to have that integrated approach to breaking down the silos. We need to have a mindset shift in how we think about even sharing information."</p> <p>"It creates a sense of everyone understanding how they are collectively working towards a common vision and common goal, I think that's where the strategy for hiring and developing the workforce should come from. It should come from that shared vision and silo-bursting perspective."</p> <p>"I think the data was at best a day old by the time I could get it, it limited its usefulness for sort of a real-time application."</p> <p>"I think they will have to have access to these different data sources from a single interface, like an API. So that the tools they build can pull this data and use it in real-time."</p>
<b>1.2. Centralized Communication and Data Distribution</b>	<p>"It's a lot of silos, and the sense of the way that the information is being shared right now is not consistent. It's also not as reliable. And it's not as timely."</p>
<b>1.3. Increased Need for Interdisciplinary Collaboration</b> <b>1.4. New Communication Necessities</b>	<p>"Balancing all the different stakeholder needs."</p> <p>"You have different disciplines trying to collaborate, and you want them to be able to visualize the project, understand their part, but also understand their part in the context of the greater project."</p> <p>"We realized that there were people who knew a lot about Lidar and scan-to-BIM models. There were people who knew a lot about building management systems and energy management, and then there were people who knew a lot about the digital platform and digital twin technologies."</p> <p>"So how do we bring everyone together, understanding that each of those pieces are important."</p> <p>"We'll do blue beam sessions to share that information, have everyone commenting pretty much in real time, and updating parts so that we see how things are changing, this is a portion that goes into the twin"</p>
<b>1.5. Importance of Colocation</b>	<p>"The airport is a mission critical facility... I think that co-location is absolutely necessary, because of the nuances to what someone is observing on their portion of the twin or on their dashboard. While I can observe it as an outsider, I won't get as much context by just looking at something."</p> <p>"If they get an emergency call, it comes to this center. If a chiller shuts down, they get notified at the center... all the issues come to the center."</p> <p>"They have various different stakeholders in that one room. And with it being customer experience, and baggage claim, and gate coordinators, and bridge managers, as well as executive representation there as well."</p> <p>"All those screens are just to help have visibility of what's happening in the various different sectors of the airport, and to facilitate aircraft operations being efficient and safe."</p> <p>"Mission critical facility."</p>
<b>2.1. Balancing "New" Knowledge with Institutional Knowledge - New Finding: Institutional Knowledge Shift</b>	<p>"I don't truly understand how those function, so as long as the lines were green, I'm like we are moving. Things are moving. Everything is on time."</p> <p>"They can provide that nuance that you should probably slow down this part of what you are doing because it's going to cause an issue in say 3 minutes."</p> <p>"We understand electrification, we know how to charge batteries, and simulation, all that kind of stuff. But there's subtleties for the rental car business that we need to understand."</p> <p>"They like to keep the utilization of a vehicle at 85%... that's a good thing to know."</p>
<b>2.2. New Technical Skill Set Requirements - Learning/Understanding DT Data, System Architecture, and Application Opportunities</b>	<p>"Training should include how to use the twin, how to collaborate in that twin environment and what the twin is capable of, and how to even develop a use case."</p> <p>"They [DT radar technologies] have over 400 potential variables to work with. So they have a lot of data, which is great, but then it's kind of understanding what each of those actually mean."</p> <p>"It's hard to know that you're in the ballpark of what's correct, and especially if you're going to use that as a digital twin where you are predicting loads in the next day or something."</p> <p>"In terms of team composition, what I have found is that I am not going to ask an old engineer to do it [interpret digital data]. I will ask younger engineers how they would interpret certain things...I tend to focus my efforts on the younger engineers."</p>
<b>3.1. Managing Personnel Resistance to Change</b>	<p>"What I have found is that getting older team members to accept computer generated results comes with a certain amount of skepticism and sometimes downright hostility."</p> <p>"The pushback from employees they are working with"</p> <p>"We think it's a fear of it [DT] affecting someone's job, or taking the place of their job... not trusting that the system is effective."</p> <p>"Take ownership based on a balance of both competence and passion."</p> <p>"Let's go take a step back and try to better communicate how this could be useful and how this is to serve them and make their role easier, not necessarily replace them or dismiss their knowledge of the system."</p> <p>"I think a big part is just buy-in, and trust. Then kind of ensuring that it is more effective than what the current processes are."</p>

<p><b>3.2. Establishing Management Consistency</b></p>	<p>“In the early stages, it has been kind of everyone figuring out what their role is in facilitating the development of the DT, I think it wasn’t clear cut of what each stakeholder and person involved’ role is. We’re kind of in the process of establishing that.”          “They identify champions. For example, for sustainability, they’ll identify your champion for finding innovative ways to manage waste or to implement zero waste initiatives.”          “It creates ownership based on both a balance of competence and passion. then, having them own and educate and share information with their peers.”</p>
<p><b>3.3. Necessity for Enhanced Training</b></p>	<p>“I haven’t really worked with a digital twin at all. So I think having more exposure to that would be helpful. Especially for down the line, if we’re doing more and more analysis, understanding the kind of back end of the system will be helpful.”          “I’ve had a very high-level kind of exposure to it [DT], I see what it looks like and what they are for... I see what the physical representation can look like. But I’m not developing it.”          “I think that would be useful [technical back-end exposure] to then be able to be more effective in my data analysis and ask the right questions.”          “I think there should be standardized protocols of SOPS on training people on how to use the twin, how to collaborate in that twin environment, and what that twin is capable of.”</p>
<p><b>3.4. New Roles and Responsibilities- Integration of Data Scientists/Engineers</b></p>	<p>“You have people who, for example myself, understand the system and can think at the system level. I can understand parts of how to make the system work, how the digital twin works. But I need the skill set of the data scientists to do the crunching, to run the models, and then synthesize that information so that I can communicate to decision makers.”          “They will need people capable of understanding how to ensure that inputs are consistent into the DT. If the machine learning models for some reason stop performing well, they will need to know how to retrain or debug those and get them back online.”          “It’s also an engineering task. It’s not enough to have just machine learning scientists who can prototype and debug and try new things, you need to have data engineers that can keep these things running in production with some sort of reasonable frequency and reliability.”          “I think part of the benefit of having someone with that technical background is that they can communicate both with Willow, who are going to be very technical, understand what their needs are and ask the right questions, also be able to relay that to other groups and stakeholders who do not have that background.”</p>
<p><b>4.1. Creating and Maintaining Data and Simulation Visualizations</b></p>	<p>“It’s just so much easier to see anomalies. It’s easy to see trends or patterns when you visualize code or visualize data versus just seeing it in a table.”          “[Models and visualizations help with ] quickly see exactly where the congestion is going to happen and how long it’s going to take to resolve itself. that would be really difficult to see if you were to just look at a time series of each road segment.”</p>