CHALMERS
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Digital Transformation in Commercial Real Estate

A Case Study on Creating Digital Twins of Existing Buildings

Master's thesis in Design and Construction Project Management

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Abstract

Smart cities use information and communication technologies in response to urban challenges to ensure sustainable development. Such cities are networks of digital infrastructures which comprise multiple integrated and interactive components, where smart buildings are real estate components that adapt their operations in response to gathered data. Real estate has ample opportunities to contribute to smart cities by digitalizing their portfolios, however, the effort for existing buildings with limited digital infrastructure is unclear. This thesis aim was to research how existing buildings can be transformed into smart buildings using digital twins by studying a case where a commercial real estate portfolio is digitalized. To realize the aim, ten qualitative interviews were held and provided material was analyzed.

The results suggest that digital twins in real estate can be described as a digital ecosystem where data flows from existing facility systems to a data cloud that enables applications to access the data. This is an industrial approach where interoperability is solved using ontologies and real estate owners utilize its existing platforms rather than purchasing a packaged product that hampers interoperability further. Previous research identified the benefits of digital twins in operations and maintenance. However, real estate is undergoing a transformation from asset to service provision where emerging business models entail service packages of flexible nature. In those business models, data can play a significant role in analyzing how spaces are used, best utilized, and easily accessed. The modeling to support this does not require high fidelity and existing basis can be sufficient. The models are instead refined to higher fidelity levels as changes occur in facilities' life cycle and thus enable object-oriented benefits. Life cycle management, i.e., keeping information updated, is argued as the primary challenge. However, it appeared that it would be sufficient incentives for life cycle management if the business model is dependent on it. To succeed, strict guidelines are required in project commissioning and day-to-day information management. User provisioning is identified as an essential tool for operative real estate personnel to easily add or alter information.

Keywords: commercial real estate, digital transformation, digital twins, existing buildings, smart buildings.

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The idea of the topic has been developed by the authors with support from Fredrik Ahl at Sweco. We would like to thank him for his guidance, encouragement, and time spent discussing this interesting topic with us. Furthermore, we would like to thank all the interviewees who contributed with knowledge, reflections, and insights. Without them, this thesis would not have been possible to complete.

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List of Abbreviations

AI	Artificial Intelligence
BAS	Building Automation Systems
BEM	Built Environment Management Model
BIM	Building Information Model
ICT	Information and Communications Technology
IoT	Internet of Things
LOD	Level of Detail

1 Introduction

The first chapter gives an introduction of why digital twins are an important enabler of the pursuit for sustainable solutions in the real estate industry. It will also introduce the barrier for investing in digital twins which will form the foundation for the research questions which the thesis will examine. Lastly the chapter will present the limitations and outline of the thesis.

1.1 Background

The world faces issues of climate change, demographic change, and urbanization (Baum et al., 2019). These issues are pressuring cities to innovatively manage overcrowding, energy consumption, resource management, environmental protection, and assure a high quality of urban inhabitants' lives (Brutti et al., 2019). Smart cities is a concept where Information and Communication Technologies (ICT) are used in response to the urban challenges to ensure sustainable development (Brutti et al., 2019; Baum, 2017). Smart cities are networks of digital infrastructure networks which comprise multiple smart components which form the cities (Brutti et al., 2019). Smart buildings are real estate components using ICTs to adapt their operations and physical form in response to gathered data (Lecomte 2019).

Few real estate companies have approached smart buildings (Baum et al., 2019). Historically, the real estate sector has been able to stay profitable using traditional business models, but commercial real estate has experienced a shift in demands from tenants (Lequeux and Guiot, 2019; Starr et al., 2020). In combination with the pursuit of corporate sustainability, companies have started to reflect on their current business models (Lequeux and Guiot, 2019). Therefore, commercial real estate companies are starting to examine how an investment in digital innovations might affect their sustainability and competitive positioning (Baum et al., 2019).

Digital innovations have changed the structure of industries for many years. In the mid-twentieth century, it concerned incorporating digital computers and the advancement of information technologies. The fourth industrial revolution (industry 4.0), the digital transformation advanced to gaining knowledge from data analytics, cloud computing, and Internet of Things (Starr et al. 2020). Industry 4.0 emerged from the manufacturing industry but is now influencing real estate. Proptech is the real estate industry's response to industry 4.0, whereas one technology that has risen in interest is the digital twin (Adamenko et al., 2020; Starr et al., 2020).

A digital twin is a digital replica of physical assets, processes, and systems, that learn from multiple sources to predict current and future conditions (Lu et al., 2020-a). The technology is described as valuable for real estate owners to optimize development, operation, and service processes by analyzing the building lifecycle (Adamenk et al., 2020). It is also described as a tool for smart building management to minimize consumed energy and carbon emissions to enhance corporate sustainability (Baum et al., 2019; Lu et al., 2020-b). However, today, several challenges and barriers obstruct a company's willingness to invest in digital twins (Baum et al., 2019; Jones et al., 2020).

Foremost, there is no consolidated view in the real estate and construction industry regarding digital twins, resulting in confusion (Jones et al., 2020). Additionally, there are gaps in research regarding if the benefits will outweigh the effort of developing and integrating the digital twin for existing buildings in the real estate business and operation. The creation of digital twins is dependent on building information which, in many cases, is lacking for existing buildings (Lu et al., 2020-c). Few studies have been conducted on the creation and benefit of digital twins in the scope of existing buildings. However, some literature suggests that digital twins might be more profitable for newly built buildings where models developed during the design and construction stages already exist (Koch, 2018). Around 80 % of existing buildings are constructed before 1990 and consequently lack efficient digital information (Volk et al., 2014). At the same time, these buildings are the majority of real estate portfolios. Therefore, existing buildings are a great resource for commercial real estate to enable its business and sustainability objectives and realizing smart cities.

Smart cities are far from realization, and one obstacle is the inadequate digital infrastructure (Baum et al., 2019). The smart building components are, on the contrary, achievable to pursue by a digital twin aided the digital transformation of real estate companies. However, the barriers of digital twins in the real estate sector need to be addressed to attract early movers (Baum et al., 2019). To fill the knowledge gaps, this thesis will investigate a case composed of developing and implementing digital twins for existing commercial buildings. The case includes the consultancy firm Sweco's BIM-platform Twinfinity and SimpleBuilding concept, followed by a real estate company's approach to digital twins and intended use of Twinfinity.

1.2 Aim and Research Questions

This master thesis aims to contribute to the research of smart cities by investigating how existing buildings can be digitalized from a commercial real estate owner's perspective. This aim will be realized by examining the concept of digital twins and how one can be formed in a real estate context. Three research questions were stated to support the aim.

- **RQ1:** How can digital twins be described in a real estate context?
- **RQ2:** How can digital twins create benefits in commercial real estate considering existing buildings?
- **RQ3:** What are the prerequisites for real estate companies to enable and sustain the digital twins?

1.3 Limitations

This master thesis will conduct a single case study composing an ongoing collaboration between Sweco and the case company to answer the research questions. The case company is a commercial real estate owner, including offices and retail. Therefore, the thesis is limited to their reality and values. The empirical data is collected from this case study and is not compared to other empirical cases. The methodological choice is further motivated and evaluated in chapter 3 Method. The thesis will not study the development of smart cities but rather the smart building as an isolated component which, in the future, is an essential enabler of smart cities. Moreover, several ethical questions, e.g., privacy and security, arise from smart technologies. Such are excluded in the scope of this study. Last, the literature that constructs the theoretical framework was mainly collected from realities that resemble the Swedish's.

1.4 Outline of the Thesis

- **Chapter 1 - Introduction:** Introduces the thesis's background and problem formulation, followed by aim, research questions, and limitations.
- **Chapter 2 - Theoretical framework:** The theoretical key concepts used from previous research to analyze the empirical material are framed.
- **Chapter 3 - Method:** Describes the methodological strategy that was used to conduct the thesis. It includes research design, data collection from case study, critical evaluation, and an ethical statement.
- **Chapter 4 - Result: Case study** Provides the case background and an overview of the technologies.
- **Chapter 5 - Result: Case interviews:** Provides the case company's reflections on the topic, including digital transformation, usage areas, and challenges of digital twins.
- **Chapter 6 - Discussion:** Compares the theoretical framework to case results directly related to the research questions.
- **Chapter 7 - Conclusion:** Concludes the research questions, states the thesis contribution to academia and industry, and suggests future research.

2 | Theoretical Framework

The theoretical framework intends to create an understanding of key concepts that are used to investigate the research questions. Real estate and facilities management and the key processes areas it comprises be defined. This is followed by introducing information management in facilities. Then, digital twin and its related concepts will be explored, focusing on the building level. Lastly, theories in change management will be addressed to grasp the implementation of new technology in an organization.

2.1 Real Estate and Facilities Management

The core business of a real estate organization is to aggregate and exploit a portfolio of real estate assets (Glickman, 2013). The processes which this entails can jointly be summarized under the name real estate management. As Wirdzek (2010) states, the emerging integrated data models for the built environment need a clear classification of its processes. There are many attempts to complete such categorization, but many labels that are used fragmentize the real estate literature (Ebinger and Madritsch, 2011).

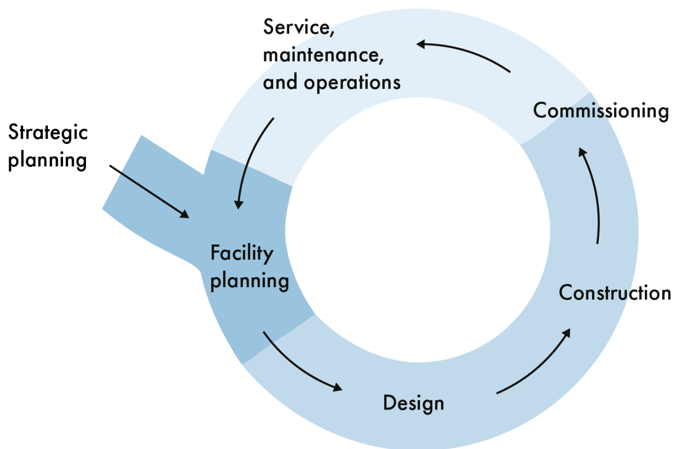

Figure 2.1: The "built environment" life cycle (based on Ebinger and Madritsch, 2011).

This thesis's notion of real estate management is derived from an industry-neutral classification framework in real estate literature, namely the built environment management model (BEM2) by Ebinger and Madritsch (2011) and Ebinger and Madritsch (2012). It is a comprehensive and process-based framework that compiles real estate and facilities management from a two-dimensional approach, comprising the built environment management functions and the value stream from strategic to portfolio and operational. The researchers recognized a cyclical pattern in the built environment management functions and arranged the functions accordingly (see Figure 2.1).

The life cycle of the built environment was further elaborated in an organizational environment. A series of sequential and interdependent key process areas (KPA) were then identified: KPA 1; strategic planning, KPA 2; facilities planning, KPA 3; project and transaction management and KPA 4; services, operations, and maintenance management. Similar to methodologies in project management, it is advocated that the processes occur in a hierarchical organizational structure. A tactical setting should support the operational project work to reach the organization's strategic aim (PMI, 2008). This resulted in the industry-neutral and process-based framework, as it is the foundation of all real estate organizations to plan, provide, service, and maintain their built environment (Ebinger and Madritsch, 2011) (Figure 2.2). Strategic planning, KPA 1, is an enterprise function that revolves around defining vision and mission, business strategies, and strategic objectives. An in-depth description of KPA 2 - 4 follows.

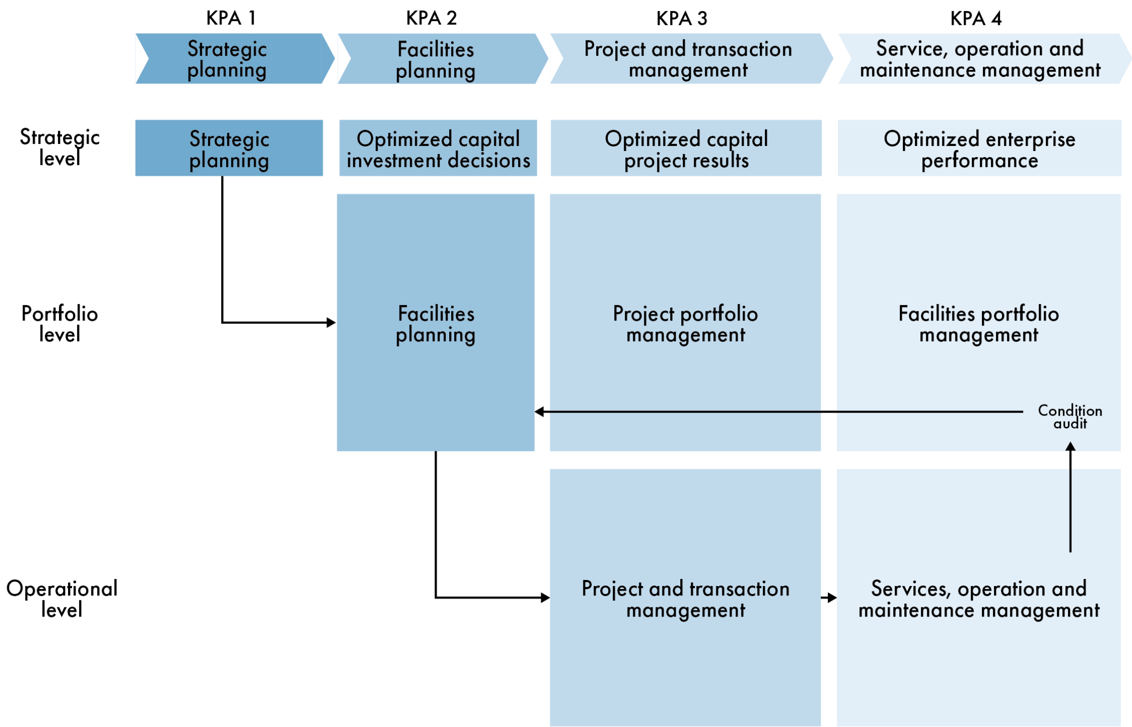

Figure 2.2: The Built Environment Management model BEM2 (based on Ebinger & Madtrisch, 2012).

2.1.1 Facilities Planning

The strategic objectives of KPA 1 are translated in facilities planning, KPA 2, with the aspiration to optimize capital investment decisions in the facilities portfolio. In a real estate portfolio, reinvestments for maintaining existing facilities compete with requirements for new facilities. The different categories of reinvestments and new requirements are balanced altogether, and approved projects are handed over to KPA 3, project management, and transaction (Ebinger and Madritsch, 2012).

2.1.2 Project and Transaction Management

KPA 3, project and transaction management, materializes the decisions in KPA 2 by performing a construction project or real estate transaction. The strategic goal of this key process area is to achieve optimal project performance with minimal disruption and where the project delivery satisfies the organization's requirements (Ebinger and Madritsch, 2012). According to the BEM2, the tactical level involves coordinating all capital projects and transactions that are planned in a real estate portfolio. The sub-processes are defined as: program management of resources and team members for effective operation, monitoring risk, meeting regulatory requirements, maintaining client relationships, and assessing performance measurement.

The operational level of project and transaction management revolves around implementing the capital projects or transactions established by facility planning. An operative real estate representative often manages the project, but other processes are outsourced to architects, engineers, construction managers, and contractors. A project is then divided into the sub-areas: planning, implementation and control, and commissioning. Project planning expands the project assumptions identified in KPA 2, facilities planning, with a detailed initial study of the project. Project plans and specifications are then developed for implementation. During implementation, the construction is controlled by the real estate representative. After construction competition, the project is commissioned to service, operations, and maintenance management, KPA 4, that manages the facility. The commission process includes handing over relevant building information, i.e., maintenance schedules, warranties, 2D/3D models, and as-built documents (Ebinger and Madritsch, 2012).

2.1.3 Service, Operations, and Maintenance

This operative key process area has the strategic goal to uphold the desired performance of existing facilities and provide an optimal environment for the organization leasing the premise (Ebinger and Madritsch, 2012). The tactical level is responsible for the operational function's delivery. Like project and transaction management, the tactical level includes managing resources, risks, client relationships, and performance. It also constitutes a constant reviewing of facilities condition and identification for renewals. The sub-areas of service, operations, and maintenance are described below.

Service management includes all the service processes supporting the facility's core business requirements and working environment. It includes a broad spectrum of operational services such as: office support, technical, janitorial, food, and lease and space management (Ebinger and Madritsch, 2012). Lease management concerns finding potential tenants that match the facilities' available spaces and continuous management of the tenant relationship (Ebinger and Madritsch, 2012; Glickman, 2013). Space management is a critical function in facilities management, including efficient and cost-effective use of space (Atkin and Brooks, 2015). This is done by incorporating flexible and adaptable features that support different activities of different tenants and systematically collecting information about space utilization to increase cost-efficiency (Atkin and Brooks, 2015).

Operations management entails performing and managing the processes that ensure the work environment facilitates an effective operation of core businesses in organizations (Ebinger and Madritsch, 2012). These processes include operating the facility systems (HVAC, Electrical, Plumbing) and the utility and energy management of these systems (Ebinger and Madritsch, 2012).

Maintenance management is responsible for the preventive and reactive maintenance of the existing asset portfolio. Preventive maintenance activities are either time-based or condition-based (Mangano and de Marco, 2014). Time-based maintenance is planned maintenance that is set to be completed in a specific interval based on manufacturing information of building components. Condition-based maintenance is based on consistent monitoring of building component's conditions and identification of abnormalities. The opposite to preventive maintenance is reactive, or corrective, maintenance. It is the maintenance of unplanned breakdowns where the action is only taken when a failure occurs (Mangano and de Marco, 2014). Errandonea et al. (2020) include additional categories for maintenance that rely on computer analytics, namely predictive and prescriptive maintenance. The former is based on statistical analytics of asset information to predict the remaining life. The latter is based on analytics of information of the condition monitoring to predict the current asset status.

2.2 Information Management

Information management processes generally include collecting, structuring, storing, analyzing, and updating information and data (Atkin and Brooks, 2015). Data is an objective fact, while information is processed data and is, therefore, the resource that is valuable in decision making-processes (Parsanezhad, 2015). This chapter will describe information management in facilities, followed by introducing Building Information Model.

2.2.1 Facility Information

Atkin and Brooks (2015) state that information is the "*lifeblood*" for efficient real estate and facilities management. The processes generate a large amount of data, and if it is captured, it can be used for efficient decision-making. In facilities, there are many tools and systems used to improve the processes, and those are filled with information. Various systems usually steer the processes in service, operations, and maintenance management. Building Automation Systems (BAS) is used to manage

HVAC, electrical, mechanical, and plumbing systems. Daily maintenance and other activities within service management are supported by Computer-Aided Facilities Management (CAFM).

The commissioning process from project finish to facilities management is too filled with facility information. Technical information concerning the facility's as-built information, including its design and construction, is suggested to be considered in the context of Building Information Models (BIM) (Atkin and Brooks, 2015). However, the exchange and re-usability of the data in these systems and the fragmented nature of the industry make the information transfer among stakeholders challenging (Yalcinkaya and Singh, 2014).

2.2.2 Building Information Model

Building information model (BIM) is growing in interest in the real estate sector due to its effective information management across the facilities' life cycle (Atkins and Brook, 2015). BIM can hold information about the physical attributes of a facility, i.e., geometry, components, systems, the spatial relationship, and attached non-geometric information (Atkins and Brook, 2015). Some common examples of physical attributes are floor plans, windows, structural information (e.g., columns and beams), and arrangement of the HVAC system (Klein et al., 2012; Lu et al., 2019). Besides geometric information, objects may also have non-geometric attributes, commonly in text format (Fitz and Saleeb, 2019). By adding such attributes, objects can hold information about, e.g., where its service zone is, how much energy is used and when it was last maintained (Becerik-Gerber, 2012). Industry Foundation Classes (IFC) is a format for BIM with standard specifications that makes it possible to hold and exchange information between various software applications (Atkins and Brook, 2015).

A common way of characterizing a BIM model is the level of detail (LOD) (Alshora and Ergen 2021, Bedrick, 2008). LOD is used to define the attributes of geometric and non-geometric data in the design of construction projects (Volk et al., 2014). Therefore it is not fully applicable in facilities management. There are five levels in the scale of LOD ranging from 100 to 500 explained below.

- **LOD 100 - Conceptual:** Non-geometric data or lines, areas, volumes zones.
- **LOD 200 - Approximate geometry:** Generic elements shown in 3D.
- **LOD 300 - Precise geometry:** Specific elements confirmed in 3D geometry.
- **LOD 400 - Fabrication:** Shop drawing or fabrication.
- **LOD 500 - As-build:** Representation of the component as it is built.

In a mature process-oriented industry, BIM is used during the whole life cycle (Thydell, 2017). The model is then categorized depending on when it was last configured. As-designed models emerge during the design phase and detailed planning. The as-designed model is updated after construction with observed differences to an as-built model. As-is models are modeled from existing in-use buildings where no previous reliable building document or representation exists (Becker et al., 2019). The benefits of BIM are well recognized in the design and construction phases (Becker et al., 2019). It is expected to be beneficial in facilities management as well. However, the adoption of existing facilities is less confident compared to the cost of creating the model initially (Atkins and Brook, 2015; Becker et al., 2019).

2.3 Digital Twin

The concept of digital twins has greatly increased in interest over the past couple of years, both by industries and as a research topic by academia (Jones et al., 2020; Lu et al., 2019). It was introduced in 2003 when Michael Grieves held a lecture in Product Lifecycle Management. It was then defined as "*a reengineering of structural life prediction and management*" (Boje et al., 2020). The concept was initially used within the aerospace field, later appeared increasingly in the manufacturing industry and more recently within the built environment and smart cities. Most research applications of digital twins are within maintenance because its significant impact on companies (Errandonea et al., 2020). However, the definition of a digital twin varies between literature and industries; hence there is no consolidated view of what it is (Errandonea et al., 2020; Jones et al., 2020).

The idea behind the digital twin is to deliver and receive product data that can be used to understand a physical product during its lifecycle (Errandonea et al., 2020). Several studies describe it as a virtual-physical integration. In other words, a combination of the physical component, its virtual counterpart, and the data which connects them (see Figure 2.3) (Boje et al., 2020; Errandonea et al., 2020; Jones et al., 2020). The physical component represents the real-world spaces and real-time data that the virtual component mirror (Al-Ali et al., 2020; Boje et al., 2020). The virtual model involves data aggregation of the collected data and the virtual modeling of the physical component (Al-Ali et al., 2020).

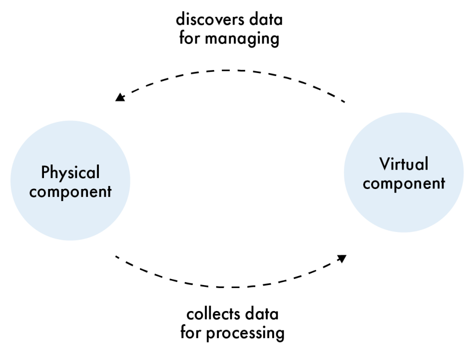

Figure 2.3: The structure of digital twin (based on Boje *et al.* 2020).

The term fidelity described the transferred data between the physical and virtual components. Fidelity is defined as "*The term fidelity describes the number of parameters, their accuracy, and level of abstraction that are transferred between the virtual and physical twin/environment*" (Jones et al., 2020, p.40). Jones et al. (2020) explain three levels: fully comprehensive, ultra-realistic, and high fidelity. In industry, other characterization methods have been identified. Arup (2019) uses five levels. The first level has low fidelity and is described as a conceptual model, and the fifth level has high fidelity and is described as a model with a high degree of accuracy. However, this method has not been acknowledged in the literature as an accepted categorization of a digital twin (Jones et al., 2020). Both Boje et al. (2020) and Jones et al. (2020) argue that high fidelity is an unachievable goal and that the level of precision instead should mirror what is required by the use case. Hossain and Yeoh (2018) conclude that the higher the fidelity, the higher the cost. The fidelity level should therefore be appropriate to maximize benefits while minimizing expenses and technical difficulty (Hossain and Yeoh, 2018; Jones et al., 2020)

The technical difficulty is determined by the different systems and components that construct the digital twin (Jones et al., 2020). To explain how a digital twin at a building level, a system architecture framework was constructed by Lu et al. (2019), Figure 2.4. The architecture is built on four layers where data flows from a data acquisition layer through a transmission layer into a data/model integration layer. The layers are complemented with a modeling and data complementary layer. The service layer is where applications are formed.

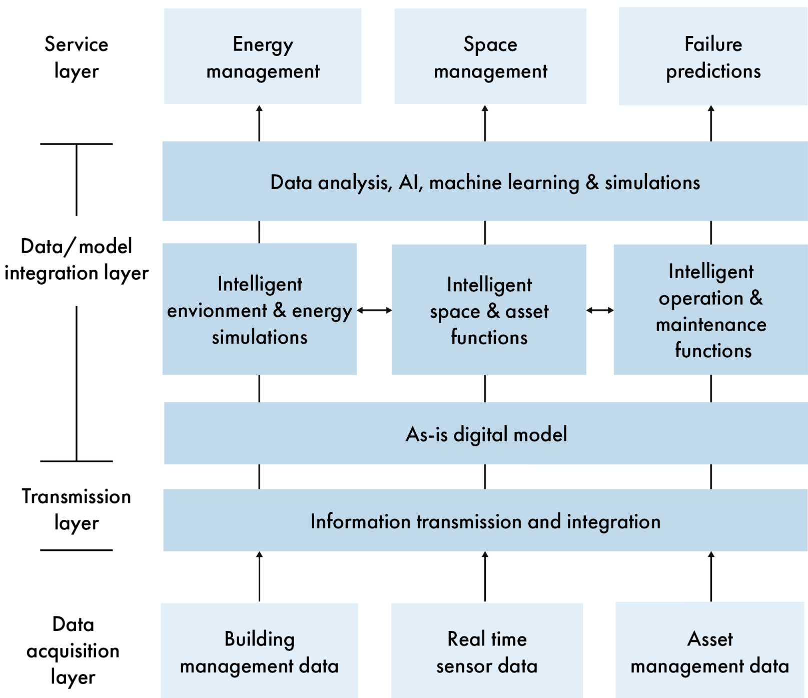

Figure 2.4: System architecture of a digital twin at building level (based on Lu *et al.*, 2019 and Lu *et al.*, 2020-a).

2.3.1 Data Acquisition Layer

Data is the foundation of the digital twin (Boje et al., 2020; Uhlenkamp et al., 2019; Lu et al., 2019). Data acquisition entails collecting data from the physical product and its environment. Errandonea et al. (2020) explained that a digital twin used for maintenance should contain building data along with operational, organizational, and technical data. Furthermore, some common data sources for digital twin at the building level addressed in literature are: building management data (e.g., BAS); asset management and space management data (e.g., CAFM); and real-time sensor data (Cheng et al., 2020; Fitz and Saleeb, 2019; Fukuda et al. 2014; Lu et al. 2019).

Sensing data is real-time data describing the operational data in the building and environment with physical sensors (Cheng et al., 2020). Internet of Things (IoT) network allows the transfer of data from the physical sensor device to the data/-model integration layer (Cheng et al., 2020; Jones et al., 2020). Lu et al. (2019) mentioned several types of data collected through IoT-enabled wireless sensing networks, among other sensors measuring indoor climates such as temperature, humidity, carbon monoxide, motion, vibration, and light detectors.

As data is acquired, the data is transferred to the data/model integration layer by the transmission layer, which composes the next step in the digital twin system architecture (Lu et al., 2019). Lu et al. (2019) explain that the main challenge of data integration is how to integrate various sources from various autonomous, disparate, and heterogeneous sources. Lack of data is not the main issue of existing digitalization approaches but instead the lack of structured data (Cajias, 2020; Lu et al., 2020-b). Unstructured data is data that lack the required organization for being able to be readable and analyzed by machines (Gandomi and Haider, 2015). Structured data is consequently digitally organized in the format required by the machines and, in this case, the analyzing functions of the digital twin.

Lu et al. (2019) add that another important aspect is data quality. This implies the data's ability to support the various applications by ensuring the quality meets its requirements. Lu et al. (2019) explain four main reasons why low data quality may occur. The first reason is simply that the quality of the original data source is low. Another reason could be that the extraction process is of low quality resulting in the degrading of data, or the integration process of data could result in quality loss. The last reason is that the process for acquiring and integrating the data is developed for supporting an application of lower data quality requirements than the intended application (Lu et al., 2019).

Cajias (2020) summarizes that defining the pipelines of collecting, cleaning, and organizing data is a challenging process that demands a substantial amount of human resources. Many actors struggle with this process. However, Lu et al. (2019) adds that the process has to be well designed to generate value (Caijas, 2020).

2.3.2 Digital Modeling Layer

The digital model is the geometric representation of the building components and systems (Boje et al., 2020). The most common modeling approach for the digital model in buildings is BIM (Lu et al., 2020-c). However, Boje et al. (2020) state that BIM is a static model, and it must be adapted to a semantic web paradigm to be used as a digital model. Otherwise, cyber-physical integration will be lost (Boje et al., 2020).

Some natural sources of collecting building geometry information are drawings, models, and other documents created during design and construction phases (Klein et al., 2012; Lu et al., 2020-c). Jones et al. (2020) note that this information needs to be updated to create value. This means that the as-designed should be updated to as-built representation and continuously updated throughout the life cycle when changes are made. However, Klein et al. (2012) address that commonly, the as-built drawings used within facility management are not updated into as-is documentation when changes are made. These documents and models representing the building geometry are usually not available for existing buildings (Klein et al., 2012).

Lu et al. (2020-c) stated that literature describing how digital modeling should be efficiently executed is limited, but there are established processes. If some materials, such as 2D drawings and hard-copy text documents, are available, one method is to model from the existing material and complement manual verification (Klein et al., 2012; Lu et al., 2020-c). This method has shown to be error-prone and time-consuming to achieve accurate measurements (Klein et al., 2012). Laser scanning and photogrammetry are two building data acquisition techniques that are commonly used to gather spatial information. Those are more accurate than manual field surveys (Klein et al., 2012). *Laser scanning* is a technology that calculates the distance to objects by emitting a laser, where the distances are later used to form a 3D point cloud. Digital software is then registering the images to create texture and 3D data. *Digital photogrammetry* relies on camera-captured images processed through digital software to create 3D geometric information (Hossain and Yeoh, 2018; Klein et al., 2012). These digital data acquisition technologies can either support the modeling and as-is verification of acquired drawings or be used to collect information when no previous building geometry information is available (Klein et al., 2012; Lu et al., 2020-c). However, laser scanning is time-consuming, relatively expensive, and inappropriate for regularly updating as-is models (Lu et al., 2020-c).

2.3.3 Data and Model Integration Layer

The data and model integration is the kernel layer where the data are combined (Lu et al., 2019). Processes included are storing, integrating, processing, and analyzing data and models (Lu et al., 2019).

Lu (et al. 2019) explains that Application Program Interface (API) enables the transfer and integration of data between the layers. API allows applications to easily communicate with one another (Mathijssen et al., 2020). However, to allow communication, the data needs to be structured as previously described. Gunes et al. (2014) declare that interoperability is a leading technical challenge with a physical to a digital communication network. The digital twin should be interoperable, which means that it has effective communication and can exchange information between systems. This often requires a common ontology (Gunes et al., 2014; Klein et al., 2019). An example of data and model integration is the combination of sensing data such as temperature with a modeled component representing the geometric positioning of that sensor (Stenberg, 2018).

Analytics is a part of the data/model integration layer, as stated in the system architecture. Jones et al. (2020) explain that analytics are virtual processes where software, algorithms, and other computational techniques are used. Klein et al. (2019) describe four levels of data analytics (see Figure 2.5). Descriptive analytics aims at describing what is and what has happened by visualizing the current and past performance, for example, in the form of visualizing sensing data. Diagnostic, predictive, and prescriptive analytics are described as advanced data analytics where prescriptive analytics represents the highest maturity level. These can be achieved through artificial intelligence and machine learning (Boje et al., 2020; Klein et al., 2019). However, data analytics also require a lot of data and high data quality for efficient analytics (Boje et al., 2020).

Diagnostics analytics answer why something happens by finding causes, reasons, and patterns in the descriptive data. The diagnostic analysis could be used to support condition maintenance (Errandonea et al., 2020). Furthermore, predictive analytics aims at describing what will happen based on statistics or machine learning. Prescriptive analytics aims to answer how the future performance can be improved by evaluating alternatives, using simulations and optimization processes to recommend action and support decision making (Klein et al., 2019). The analytics processes depend on the previous step's results from the previous steps. A higher analytics maturity level decreases human involvement decreases and increases the dependency on intelligence and learning ability. Nie et al. (2019) add that most buildings passively react to change, not yet using real-time strategies to describe status.

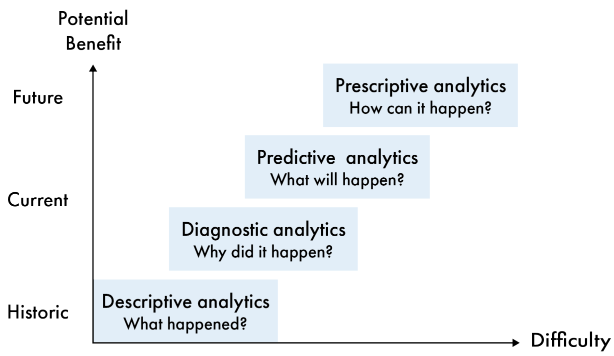

Figure 2.5: The four main analytic processes of information, structured from lowest to highest maturity level (based on Klein *et al.*, 2019.

2.3.4 Service Layer

All the processes composing the digital twin aim to facilitate smart construction services and applications (Boje et al., 2020). Lu et al. (2019) explain the application layer as the layer which "*interacts with the facility managers and provide services for users*" (Lu et al., 2019, p.70).

Each digital twin application requires its specific data and data quality (Lu et al., 2019). In Lu et al. (2019), the following applications were mentioned: security and health management, energy management, space management, as-is asset monitoring, and facilitation of preventive maintenance. Other expressed applications facilitate the design and construction of facilities and information management, including minimizing information loss and facilitating operational activities (Lu et al., 2020-c).

2.4 Implementing Technology in Organizations

To optimize processes and achieve organizational improvement, the PPT theory is a widely used approach which address that the focus for change should be on people, process and technology (Prodan et al. 2015). *Change management* is a management discipline that includes capabilities for managing individuals, organizations, and institutions through a change process and making the intended transition successful. There are several change management models and theories presented in the literature. This thesis will use the benefits management model by Love and Matthews (2019) to grasp implementing technology in an organizational context by addressing the drivers. Secondly, this chapter will cover an intention model, namely the Technology Acceptance Model by Davis (1989), for evaluating the user acceptance of information technology.

2.4.1 Benefits Management

The *"whys"* of implementing technologies are usually well understood and agreed upon. Though, the *"hows"* of realizing the *"whys"* are rarely documented. The expected benefits are often exaggerated and the management effort is often overlooked (Love and Matthews, 2019). A strategy for successful implementation and realization of digital technologies benefits is the benefits management strategy composed by Love and Matthews (2019). The strategy is described as a frame of reference for planning change management processes to ensure that the intended technology effectively generates value (Love and Matthews, 2019).

Before initiating the benefits management processes, Love and Matthews (2019) address that the organization needs to acknowledge the basic principles of implementation of digital technologies. These are: benefits only materialize from the technological use and when the technology enables people to do things differently. The organization should also remember that technology adoption is a cost, and not all use of technology produces benefits. An unsuccessful implementation might even affect the organization's competitive positioning negatively. The change process needs to be carefully planned and actively managed to obtain benefits from technology.

Furthermore, benefits management manages and aligns project outputs, results, benefits, and organizational strategy. Love and Matthews (2019) present a five-stage process that addresses this management and alignment. The first stage, *Identifying and structuring benefits*, entails understanding the business drivers for introducing the new technology and identifying the aspired benefit realization from the change. The second stage,*Planning benefits realization*, entails planning how the benefits will be achieved and the required changes necessary for these processes. The third stage,*Executing the benefits realization plan,*is where the designed change management program is being implemented. This execution is later evaluated in the fourth stage,*Evaluating and reviewing result*, which is continuously done during the whole system lifetime. The fifth and last stage,*Discovering the potential for further benefits*, is where the organization learns from the evaluation to identify additional opportunities. The stages continuously progress from each stage to the next in a circular manner and affect previous stages as results are evaluated (Love and Matthews, 2019).

Identifying and structuring benefits entail understanding the business context and identifying the fundamental drivers for the change. Since the benefit of implementing a technology only materialize from its use, it is essential that the motivation for implementation meets business and user demand rather than satisfy a trend within the industry. To develop a business case for investing in digital technology, Love and Matthews (2019) suggests that that the organization should answer the following questions:

- Why do we need to improve performance?
- What improvements do we want/could achieve?
- Where will improvements (benefits) occur?
  - How can we measure the benefits, quantitative (e.g., time, money) as well as qualitative (e.g., customer and employee satisfaction)?
  - Can a financial value for the realized benefits be determined?
- What changes are needed to ensure improvements materialize?
  - How can the changes be enabled and sustained?
- How can the changes be enabled and sustained?
- Who is responsible for making changes?
- Who will be affected by the change?
- How and when can changes be made?

These questions will support the mapping of the desired change. After a driver has been identified, the organization should work backward to recognize which business benefits support the driver. Then, how the technology can enable those benefits and which changes are needed to implement the technology. Related to the digital twin, Lu et al. (2019) suggest that the objectives and how the digital twin will create value should be clear before initiating the process of developing a digital twin. This includes what data the digital twin needs to fulfill this value creation and a well-designed process for collecting, updating, transferring, and integrating the data and the digital model throughout the whole building life cycle (Lu et al., 2019). To map required changes and activities to ensure expected benefits Love and Matthews (2019) used a mapping framework called the Benefits Dependency Network (BDN) developed by Peppard (2016), see Figure 2.6. The role of technology is the technology included in the change. Enabling changes are typically one-of and include both the prerequisites for creating the change and the prerequisites for bringing the new system to operate. Sustaining changes include the technology-enabled permanent changes of working practice, which assures the change's long-lasting operation and benefit realization. Business benefits are the aspired benefit that will satisfy the driver (Love and Matthews, 2019; Peppard, 2016).

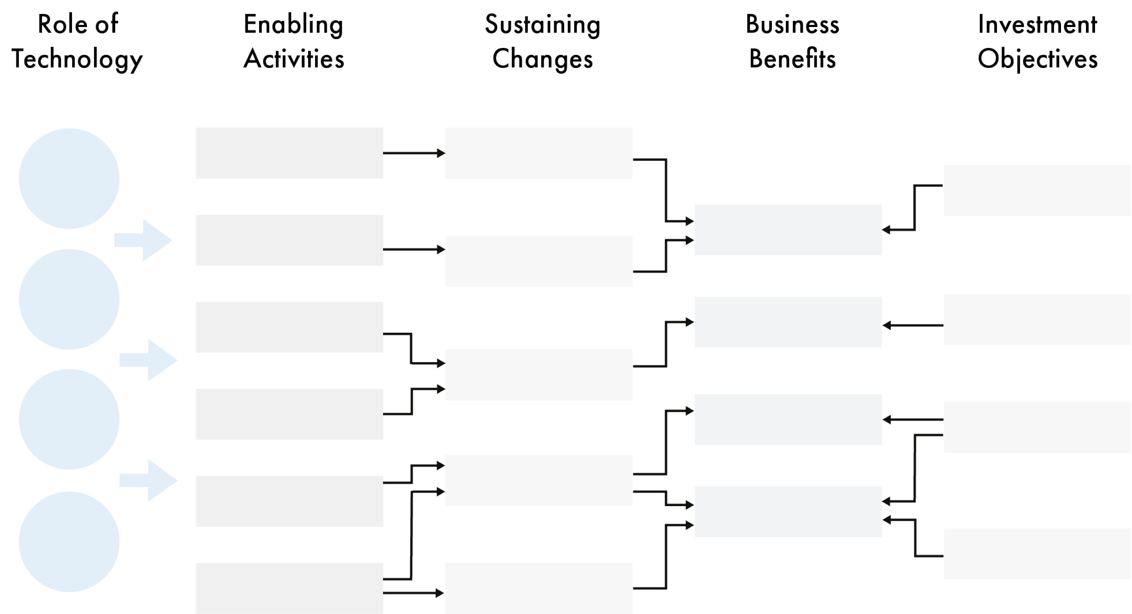

Figure 2.6: Benefits Dependency Network (based on Love and Matthews, 2019 and Peppard 2016).

2.4.2 User Acceptance

Another aspect of implementing technology in organizations is the behavioral response from users. This is relevant because no system can benefit organizations if they are not being used (Love and Matthews, 2019). Theories in this area of change management are built on behavioral science and understand how human behavior is associated with technology usage (Kukafka et al., 2003). These theories and models are intention models and explain the mechanisms of how technology is accepted by individuals and subsequently used.

Hilal et al. (2019) explain that the Technology Acceptance Model (TAM) is a widely used intention model. It was developed by Fred D. Davis in 1989 and later tested in a field study in 1993. TAM illustrates the relationship between system design features, perceived usefulness, perceived ease of use, attitude toward using, and actual usage behavior (Figure 2.7). The model is based on attitude psychology principles that divide behavior into four components: external stimulus, cognitive response, affective response, and behavioral response. The aim of TAM is not only to address why users may accept technologies or not but also aims to improve user acceptance through the design of the system features (Davis, 1993).

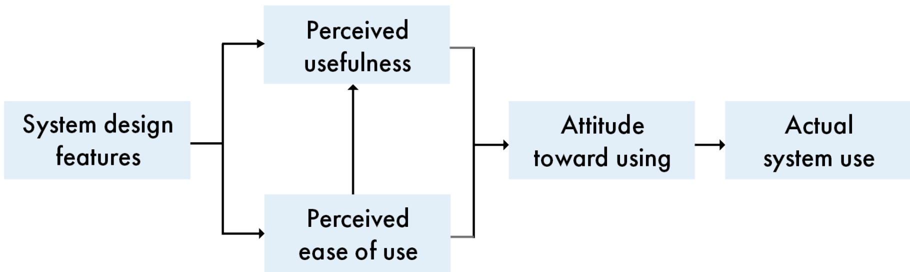

Figure 2.7: Technology Acceptance Model (based on Davis, 1993).

The model suggests that the attitude of a prospective user is the primary determinant of behavioral response and actual system use. The attitude toward using the technology is then dependent on two cognitive response variables: perceived usefulness and perceived ease of use. The two variables are affected by the system design features. Perceived usefulness is defined as "*the degree to which an individual believes that using a particular system would enhance his or her job performance*", where "*job performance*" concerns both process and outcome (Davis, 1993, p. 477). Perceived ease of use is defined as "*the degree to which an individual believes that using a particular system would be free of physical and mental effort*" (Davis, 1993, p. 477). Perceived ease of use has a direct effect on perceived usefulness, but not vice versa. A system can be perceived as more useful either by adding new functionalities or facilitating the functionalities that already exist (Davis, 1993). Mongogole and Jokonya (2018) argue that the attitude towards using is additionally affected by the organizational culture. Organizational culture is described as "*the morals, values, views, beliefs and unseen assumptions that staff publicly share in the organization.*" (Mongogole and Jokonya, 2018, p. 839).

3 | Method

This chapter aims to describe the research strategy. The main method to research the topic was a single case study encompassing a collaboration between technical consultancy company Sweco and a real estate company. First, an introduction to the chosen strategy will be presented. This section includes three subsections that describe how literature was reviewed, what the case study encompassed, and how data analysis was conducted. The last sections include a critical evaluation of the chosen method and an ethical statement.

3.1 Research Strategy

This thesis research strategy is based on a qualitative approach. It is an open process where the material collection and analysis are parallel procedures (Bell et al., 2019). It gives the research conditions to reach an in-depth understanding of the phenomena since the process becomes iterative and investigators can return to empirical material with new ideas. Moreover, qualitative research methods are preferable when conducting a case study since it allows unstructured interviewing which are helpful when examining a case (Bell et al., 2019).

The research began with performing an extensive literature review parallel to initial discussions with consultants at Sweco. The research questions were defined along with strategies for retrieving empirical data. The literature review research provided an understanding of the context by constructing a foundation from previous research. It created a theoretical framework that was used for analyzing the case study.

The case study included assessing material provided by Sweco and conducting ten qualitative interviews with relevant actors from both companies. The empirical data was later categorized and analyzed in relevance for its research question. The arrangement for the individual elements of the research will be further explained in forthcoming subchapters.

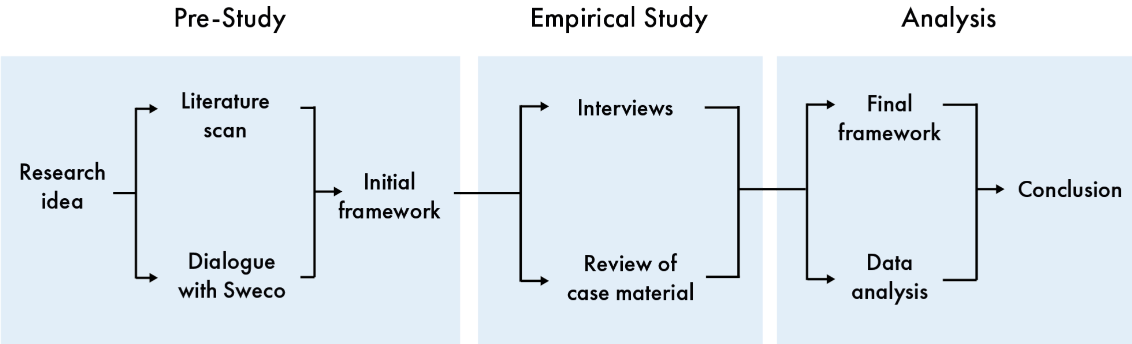

Figure 3.1: Research process (authors own figure).

3.1.1 Literature Research

A literature review is an essential element when conducting a research (Bell et al., 2019). It helps to identify what is already known about the research topic and previously applied theories. This literature review was conducted accordingly to the narrative approach. This approach focuses on quality rather than quantity by limiting the research to the most interesting contributions. The main focus is on the connections between found sources and research questions, allowing theories to emerge from the search and subsequently revise the research questions (Bell et al., 2019).

The collection of research was mainly done through the literature databases Chalmers Library, Google Scholar, and Scopus. Keywords such as digital twin, BIM, digital transformation, real estate, and facilities management were used in different combinations to collect relevant literature. Since digital twins within real estate still is a new topic with limited conducted research, the literature was combined with reports from companies developing digital twins.

Furthermore, an important realization was that the BIM concept had developed further than the static model. Many researchers use the concept synonymously to the ideas of the digital twin, e.g., "*BIM and IoT integration with real-time data*" (Cheng et al., 2020), which makes such, but not all, literature relevant for this thesis. This was a necessary realization to broaden the scope of relevant articles.

The literature research resulted in the theoretical framework that explains the key theoretical concepts in real estate and facilities management, information management, digital twins, and change management of technologies. The theoretical framework was used as a reference for evaluating the case and supported the analysis of the empirical data.

3.1.2 Case Study

The selection of case was made according to an intrinsic case study. In an intrinsic case study, the case is chosen based on interest by the researchers and conducted to achieve a better understanding of this particular case (Stake, 2000).

The case study consisted of two companies, one consultancy company Sweco, which served the role of product and service provider, and a real estate company. The real estate company is transforming its data infrastructure, and that is where digital twins have emerged. As a part of their IT strategy, Sweco has developed technologies called Twinfinity and SimpleBuilding to enable the digitalization of buildings. In 2020, Twinfinity was implemented as pilot projects in a few different facilities owned by the case company and situated in different geographical locations in Sweden. In 2021, the technology is planned to be implemented in 30-40% of the real estate portfolio.

The empirical data consisted of both materials describing the technologies used, and ten semi-structured interviews held online. The interviewees were employees involved in the case from both companies and with different professions. Semi-structured interviews were chosen as the method for conducting the interviews since it allows flexibility. It was beneficial as the interviewees had various insights into the case. Semi-structured interviews with open-ended questions are one of the main strengths of qualitative research (Mohajan, 2018). It creates the perquisites for obtaining new or unanticipated information (Mohajan, 2018).

The interview candidates were chosen in snowball sampling, where the researcher makes contact with a small group of people relevant to the research topic. This sampling helps to establish contact with other appropriate interviewees (Bell et al., 2019). In this case, the initial contact and interviewee was Consultant 1 (C1), who introduced relevant participants from both Sweco and the case company. Those participants aided in the further sampling of interviewees.

The ten chosen interviewees had various backgrounds and roles in the studied case. The interviews aimed to gain knowledge and opinions from employees within all the identified key process areas: facilities planning, project and transaction management, and service, operation, and maintenance management. Since the studied case was in the initiation phase, the number of people with knowledge was limited. However, the intended aspiration of interviewing employees within each of the key process areas was obtained by interviewing three employees who were not directly linked in the case but involved within the company. Two of these interviewees had prior knowledge of digital twins, but not precisely the solutions of this specific case. The interviewees and their role descriptions can be seen in Table 3.1. Henceforth their names will be shortened to C1 for Consultant 1 and R1 for Real estate representative 1. The three interviewees who were not directly involved in the case will be represented by a letter instead of a number, for example, CA.

Table 3.1: Overview of interviewees.

Interviewee	Short	Role Description
Consultant 1	C1	Service developer, involved in the case on several levels
Consultant 2	C2	System developer, involved in the case on several levels
Consultant 3	C3	Business developer, involved in the case on several levels
Consultant A	CA	BIM strategist, not involved in the case
Consultant B	CB	BIM strategist, not involved in the case but familiar with other cases of digital twins in real estate and FM
Real estate representative 1	R1	IT manager, strategically involved in the case
Real estate representative 2	R2	Facility development, projects, strategically involved in the case
Real estate representative 3	R3	Facility development, technical, tactically involved in the case
Real estate representative 4	R4	Research and development, strategically involved in the case
Real estate representative A	RA	Facility manager of several facilities, not involved in the case

3.1.3 Data Analysis

Qualitative content analysis was used to interpret meaning from the content of interview transcriptions. Such analysis is defined as *"Qualitative content analysis is defined as a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns."* (Hsieh and Shannon, 2005, pp. 1278). The process entails going through the text data and highlight words based on categories that organize the information in meaningful clusters (Hsieh and Shannon, 2005). This thesis used a conventional content analysis approach to determine the categories and subcategories for the coding process. With the conventional approach, the authors identify patterns and key concepts after collecting and getting a sense of all the data. Then forming categories based on the emerging themes (Hsieh and Shannon, 2005). By analyzing both the interviews and the provided materials, six categories emerged. The first three related to the technologies and methodologies of the case study. These formed the basis of chapter 4 case study. The latter three related to: digital transformation in real estate, usage areas of digital twins, and challenges of digital twins. These formed the chapter 5 interview study. Lastly, the conventional content analysis was used once more to divide the data into subcategories.

3.2 Critical Evaluation of Method

When conducting qualitative research, trustworthiness is an essential criterion for assessing the quality of the research (Bell et al., 2019). Trustworthiness can be divided into credibility, transferability, dependability, and confirmability. Credibility refers to how believable the findings are. Transferability address how well the findings can be applied to other contexts. Dependability tackle how well the findings can be applied later. Lastly, confirmability refers to whether the researcher's own beliefs and personal values have influenced the study (Bell et al., 2019).

To create credibility, this thesis used respondent validation by providing the research participants with the constructed result to gain confirmation and feedback of the conducted data interpretation (Bell et al., 2019). Moreover, to strengthen the conclusions, the results were compared to findings from the literature according to the triangulation methodology (Bell et al., 2019). Transferability is sometimes viewed as troublesome for a single case study. The concept of digital twins in real estate is an uncharted topic, and only a few companies use digital twins – as well, the approaches vary. This thesis, therefore, chose one case to answer the research questions and, therefore, provides perspectives from one approach. Another method would have been to examine a "cross-section" of the industry to display several approaches and perspectives. The consequences of this thesis method are that the results can be too one-sided to fit the whole industry.

Flyvbjerg (2006) however treat several misunderstanding concerning case studies in her research, among others the misunderstanding "*that one cannot generalize on the basis of a single case and that the case study cannot contribute to scientific development*" (Flyvbjerg, 2006, p. 12). Flyvbjerg (2006) emphasizes that one can often generalize the results gained from a single case study. However, one should not underestimate 'the force of example.' Even if the knowledge gained from the case might not be generalized, it can still contribute to the process of knowledge gathering in the specific field (Flyvbjerg, 2006). The following reflections regarding transferability can be made related to this thesis: The digital twin studied in this case might not symbolize all digital twins; however, the knowledge gained can contribute to the understanding of digital twins within real estate. Likewise, might the case not generalize a unified strategy regarding the implementation of digital twins in all real estate companies. However, the knowledge gained from the example can contribute to understanding of the implementation.

Moreover, Bell et al. (2019) argue that dependability can be gained by the auditing approach consisting of complete records of all phases of the research and peer review. This study conducted interview transcripts and provided documents and data analysis decisions but was not easily accessible and analyzed by the peer reviewer. Bell et al. (2019) identify that qualitative studies can generate a large amount of data that could affect the suitability of an auditing approach. This was relevant as the material was perceived as to extensive for a peer group to manage. However, to strengthen the dependability, the material and data analysis were discussed with peer reviewers during auditing of the draft result close to the end of the research. This auditing also helped to strengthen the confirmability. Discussion with both the peer review and examiner was held to evaluate the data analytics to ensure that open-minded analytics was conducted with minimal influence on the researchers' personal values.

3.3 Ethical Statement

When conducting a study within social science, the authors must be aware of the ethical principles involved to avoid harm to participants and unethical activities (Bell et al., 2019). According to Bell et al. (2019), ethical consideration should be a vital part of the research process and continuously revised through the study. The ethical consideration discussed in this section is based on the main ethical codes in business research stated by Bell et al. (2019).

This study included interviews with several participants from two different companies. The participation was voluntary to avoid harm to the participants and achieve consent. The participants received information about the study beforehand in order to make a well-informed decision relating to whether they wish to participate or not. Considering the interviews recorded, the authors asked for permission and consent beforehand. One representative from each company were presented with the result from the interviews to review before the study was published. This was done to avoid misrepresentation and harm or stress regarding accidentally omitting confidential information.

Moreover, the participants were anonymized, including only the professional title and name of the organization to protect privacy. Lastly, to prevent deception, one representative for the organizations was involved in the planning and execution of the research. There was a continuous dialogue between the authors and this representative when changes occurred in the research process.

A final statement of this thesis is that there is no intent to advertise any products but to reflect on the knowledge that practice possesses.

4 | Results: Case Study

The empirical result is derived from a case study where digital twins are developed in a commercial real estate company. The results are divided into chapters 4 and 5. This chapter presents the case background, followed by SimpleBuilding and Twinfinity that are the technologies used to digitalize buildings and last, the case company's approach to digital twins.

4.1 Background

The case was provided by Sweco, which is a leading technical consultancy company in Sweden within engineering and architecture (Sweco, 2021). The related department is Sweco Position which specializes in IT solutions within the built environment. The case study comprises Sweco and their partnership with the case company, which is one of the largest commercial real estate owners in Sweden.

Sweco and the case company have a far-reaching collaboration in developing the case company's digital information management. During their collaboration, they have long acted as partners and jointly developed solutions in line with their digital transformation. The collaboration initially concerned digital information management in projects but has in recent years approached facilities management. A few years ago, the product Twinfinity emerged. Simultaneously the collaboration changed to Sweco becoming a product owner, and the case company became a customer. However, there are still many consultants that work internally in the case company.

The case company is an active leader in digital innovation. In recent years, they have focused on contributing to an industry development that enables real estate owners to become more successful and benefit more from their platforms. In this way, they have been involved in developing RealEstateCore and ProptechOS. It is in that journey where the interest in digital twins has been established. They have chosen to collaborate with Sweco to create "collaborative digital twins" by using an "industrial approach". This is further explained in 4.4.

4.2 SimpleBuilding: Creating Spatial Models

To create digital representations of existing buildings, Sweco has developed a concept called SimpleBuilding. It is a methodology and technology for buildings that either lack or have poor basis. SimpleBuilding encompasses modeling in two Levels of Detail, named SimpleBuilding and SimpleBuildingPlus.

- SimpleBuilding: a space model with the simplest level of detail including only rooms.
- SimpleBuildingPlus: an extended space model with higher level of detail including objects, e.g. walls, floor, doors, windows, roof and staircases.

SimpleBuilding is the simple volume model for a building with a low level of detail, where the base only consists of the building's rooms (Figure 4.1). No other building envelope or installations are specified.

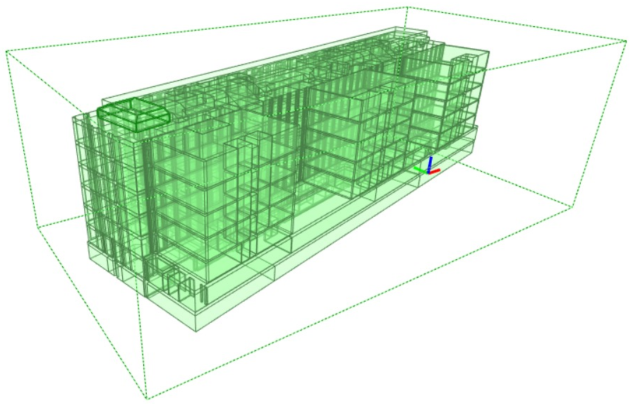

Figure 4.1: SimpleBuilding (by Sweco).

SimpleBuildingPlus is a simple architectural model that includes the building envelope, mezzanine floor, indoor walls, and doors (Figure 4.2). It extends the SimpleBuilding by including a larger part of the building and has a higher level of detail. The modeling method enables visualization opportunities and orientation inside the building. The SimpleBuildingPlus is a greater step towards realizing the digital twin as it allows more combinations of data.

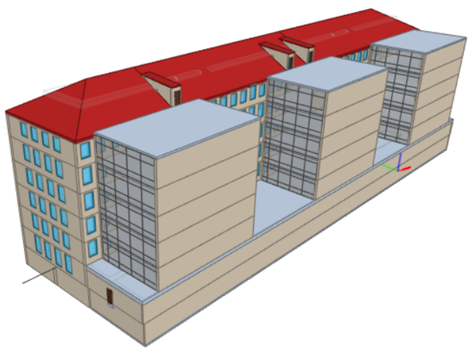

Figure 4.2: SimpleBuildingPlus (by Sweco).

The methodology of creating SimpleBuildings is seen in Figure 4.3. The process of constructing a model begins with performing an inventory analysis of existing material and data. Besides drawings, pdfs, and dwgs, other information of interest is, for example, room numbers and rental objects. Acquired 2D drawings are converted to a 3D model by an automized process. If no drawings exist or are of too poor quality, an inventory of the building is performed. This is either done with laser scanning, drone scanning, or manual measurement. Scanning generally creates a PointCloud in 3D. That is a geometrical and geographical correct representation of the as-is model. The spaces, i.e., those of interest of a real estate owner, are allocated. The result is a BIM model.

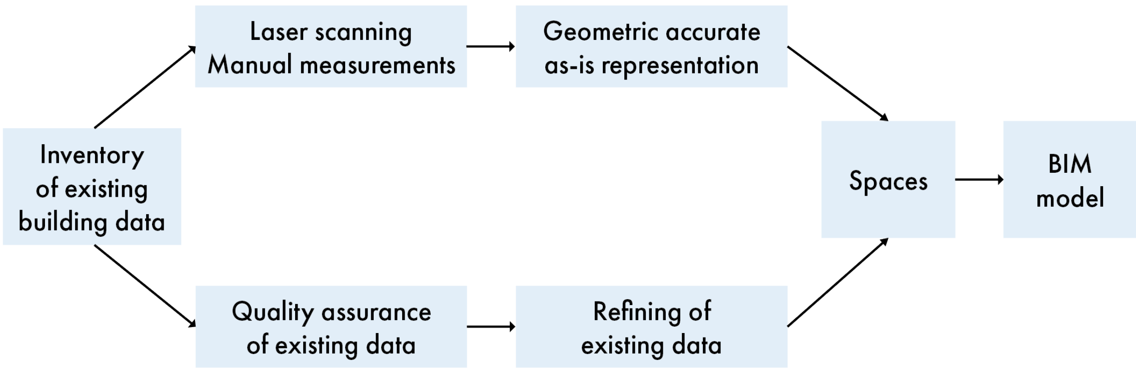

Figure 4.3: Sweco's process flow of creating SimpleBuildings (based on provided material from Sweco).

4.3 Twinfinity: Contextualizing Digital Twins

Twinfinity is a platform that includes processes for adding one aspect of the digital twin, the digital model. Hence, it is not a digital twin itself. It should rather be seen as an essential enabler of creating and contextualizing a digital twin. Twinfinity prepares building data to be integrated with other systems or applications. The aim of Twinfinity is to create value within the real estate and facilities management processes by combining several different data sources in building, business and operations. An overview of Twinfinity's processes is shown in Figure 4.4.

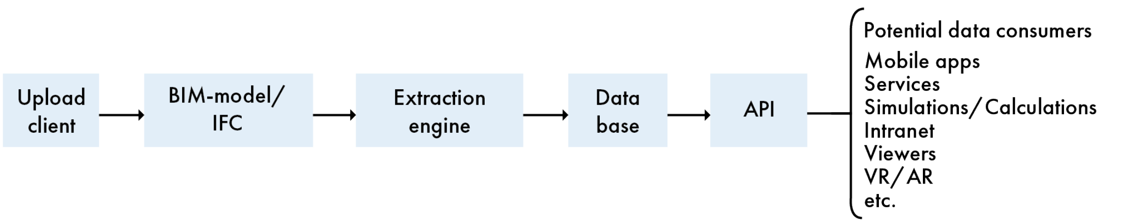

Figure 4.4: Twinfinity's extraction engine (based on provided material from Sweco).

The input data to Twinfinity are BIM-models, PointClouds, 360-photos, DWG, Raster, and/or PDF. Twinfinity has automized processes for transforming the formats into BIM models in IFC format. Areas that are of interest for real estate owners are allocated, such as LOA (premises area of facility), ATEMP (heated area), and BOA (area of household). The file, and the quality of the model, are validated in an automized process according to pre-set design guidelines to assure the model has the expected object properties. Twinfinity is then explained as an extraction engine that extracts the BIM model into objects organized by element type (see Figure 4.4). The element type can, for example, be walls, rooms, doors, windows, text information, toilets, and sinks. The objects are then stored within a database, and other systems can collect the data by Twinfinity's API.

Twinfinity has a tool for sending change requests to the IFC-file without going through a computer program. It is called provisioning and allows users to directly add or alter points of interest, e.g., assets, furniture, sensors, or spaces into the digital model. The users can add the points of interest while using the viewer function in a web browser or mobile devices.

Furthermore, Twinfinity includes an advanced 3D motor and viewer application that enables visualization of the spatial model and the linked data in webpages or mobile app (see Figure 4.5). This tool makes it possible for the user to digitally navigate in the digital building, click on spatial objects to visualize the linked information. It is also possible to apply a visualization setting, which determines what information should be visible and not. By using Twinfinity Embedded, it is possible to build Twinfinity's viewer into other systems and applications.

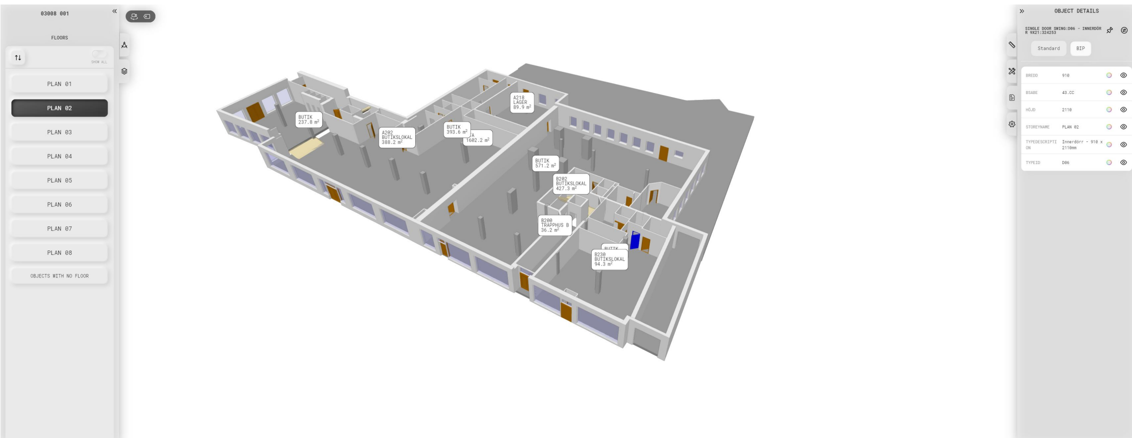

Figure 4.5: Twinfinity's viewer (by Sweco).

Twinfinity itself does not include any applications. Instead, applications are developed by the customer. By combining the building data with business and operational data, there are endless possibilities are to develop tailor-made services. Potential data consumers are, e.g., mobile apps, simulations, calculations, intranet, viewers, and virtual/augmented reality.

4.4 Collaborative Digital Twins: An Approach

This section describes how the case company is approaching digital twins. The first section presents their strategy of information technologies, and the second presents the digital aim of twinning their portfolio.

4.4.1 IT Strategy

The case company has not chosen to create digital twins directly but rather connect building, operational, and business data. The case company has described its approach as industrial, to create collaborative digital twins. It implies that they are not purchasing a packaged digital twin product but instead focus on benefit more from their existing systems and platforms.

A strategy has been developed on how to use information technologies. It consists of four steps where data flows from heterogeneous sources to the tenant, owner, or third party applications (see Figure 4.6). The steps are to (1) make data usable using RealEstateCore, (2) make data accessible using ProptechOS, (3) secure access to resources and data using Accessy, and (4) to create value for users using multiple applications, e.g., tmpl.

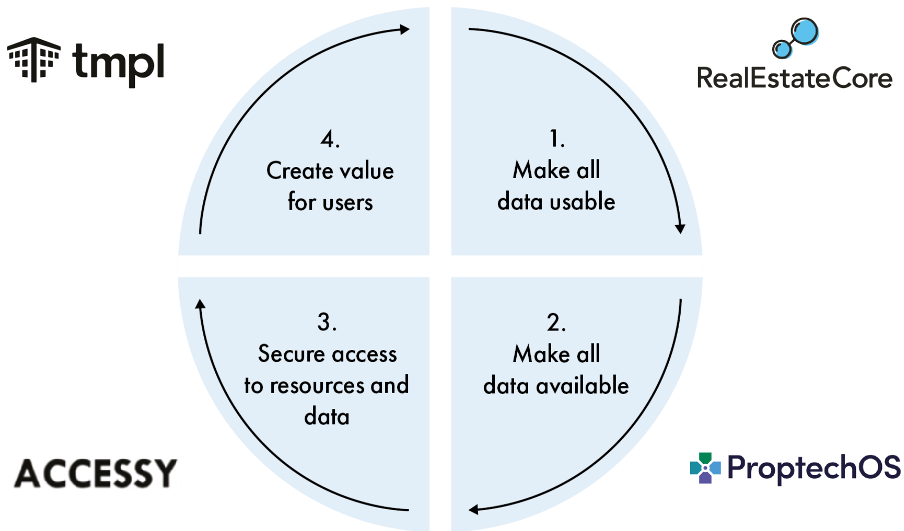

Figure 4.6: Case company's strategy of information technologies (based on provided material by the case company).

RealEstateCore is an ontology, i.e., language, to enable communication between various data sources in buildings. It is not a new standard but instead merges and bridges existing standards to find the common denominators. It is a prerequisite to enable data integration in smart buildings and prepare them to interact in smart cities. The ontology is the first of its kind developed by real estate companies for their needs (Hammar et al., 2019). It is modular, to avoid over-commitment and enable customization, covering building structures, ownership, inhabitants, technical systems, and sensors. Hammar et al. (2019) explains the three domains that are bridged in RealEstateCore:

- Digital representation of the building's and their constituent elements
- Control and operation of the building and its systems
- Emerging IoT technologies

Twinfinity uses the RealEstateCore standard to export the building elements according to the building's knowledge graph, i.e., the structure of how different building components relate to each other. RealEstateCore divides the building structure domain into components, for example, rooms and roofs, under the name BuildingStructureComponent. These components can then be joined under different premises. Premise is a collection of spaces and objects that are leased to a tenant. Devices within the real estate are linked to the BuildingStructrureComponent they belong to. Devices are defined as a piece of electronic equipment made for a particular purpose. Every device has one or more sensor(s) or actuator(s). Sensors are things that measures or detects, while actuators are components that controls or moves a system.

ProptechOS is a commercial product that is available on the market. It is a Building Operating System for importing and exporting data that is connected to buildings. It functions like a data lake, where all data is collected. It enables various data to integrate and applications to import information.

Accessy is a system to manage access to virtual and physical resources. As previously stated, data can be published to any stakeholder through APIs, internally with themselves or externally with the academy, colleagues in the industry, or customers. To enable or limit the sharing of data, the case company uses Accessy which manages access to resources in the digital or physical component. It can be used to manage which doors a person can access or access specific data.

Applications are systems that consume data to generate services. As mentioned in 4.3, combining the business, operation, and building data open several usage areas. The applications could be an interface for tenants, themselves, or third parties. Tmpl and Flowscape were two applications mentioned in the case study. Some examples are communication tools between tenants and owners to report problems, or interfaces for tenants to monitor their energy consumption or receive other relevant information, or used as a booking system (Tmpl Solutions AB, 2021; Flowscape Solutions, n.d.). Other applications could be analytical tools to optimize the actuators in systems or provide reports with results.

4.4.2 Digital Aim

The case company has an aim to digitalize its entire real estate portfolio. The purpose is to lift the entire existing portfolio to a connectable level that enables provisioning of, for example, sensors and objects, create facilities management benefits linked to the model and contribute to a smarter business. By the end of 2021, the ambition is that 30-40% of the portfolio is connected.

The SimpleBuilding methodology is used to create digital base models by relying on existing basis. However, the quality of the existing basis differs between facilities. The company has defined five levels that describe the model's trustworthiness and related capabilities. Each facility aims to be refined and climb upwards through its life cycle, regardless of what level it starts. By Level 1 the case company can linkage technical documentation to model objects and connect the model to ProptechOS. As ProptechOS require 3D models, the first level starts at SimpleBuildingPlus.

- **Level 1:** Spatial model without any significant evaluation based on its accuracy. Tenant divisions and floor plans are correct to the extent of number of rooms but not area.
- **Level 2:** Ensures the quality of the existing dimensions and provides more credible areas. However, the dimensions are not checked or inventoried with laser scanning or manual measurement.
- **Level 3:** Correct architectural model provided by laser scanning methods. Enables 360 photos and includes correct areas. This level enables energy declarations.
- **Level 4:** Provides a holistic view of the building. 3D models of installations and provisioned objects are quality ensured. The level enables tracing of systems and their service areas, as well a broader data supply to ProptechOS.
- **Level 5:** A full-scale BIM-models for every technical area. The level is assured by BIM-models provided from commissioning of new constructions or extensive reconstructions. The level completely enables model-based facilities management.

5 Results: Case Interviews

The following chapter presents the results from the interview study regarding the digital transformation in real estate, followed by usage areas and challenges of digital twins.

5.1 Digital Transformation in Real Estate

This first subchapter presents the result revolving drivers for the digital transformation and the current issues within digitalized information management. Last, the role of the digital twin within real estate digitalization will be presented.

5.1.1 Investment objectives

According to C2 and R1, a significant driving force for digitization in real estate is a transformation in business. The real estate business logic is changing from seeing leasing a facility as simply access to a physical space towards a packaged service with several offerings and flexible lease agreements. The previous long leases of three or even 15 years put much risk on the tenant. R1 describes that the customer demand for long lease agreements based on square meters is decreasing. Instead, the customers want flexibility and combine several different offers. Softer values such as productivity, health, and well-being are as well increasing in interest. However, C2 adds that expanded service business increases the importance of digital facility information.

> *"The customer would like to have the ability to expand and decrease [the lease], combine with different types of offers. Not a traditional office of ten thousand m2, maybe two to three thousand is enough combined with a "smart and ready" short leases and some subscriptions of co-working arena. The ability to have a hybrid solution. This demand would consequently in combination to our goal of delivering more services as an addition to our products, result in that we need to have greater control of our buildings, in a different way than before"*
>
> \- Real Estate Representative 1

R2 further explains that another focus area is making their business sustainable. R1 says that their goal is to be climate-neutral by 2030. Lowering the environmental impact and, in a way, "*save the world*," as described by R1, is an important driver, and it is everyone's responsibility to make their contribution. R3 says that they must find new ways to optimize their operations systems to save money and reduce the carbon dioxide load. The knowledge gained from effective data collection and analysis enables wise decisions on optimizing operations and reducing the environmental impact further.

Moreover, R1 explains that the transaction manager has mentioned that they are willing to pay more for a facility with a digital representation. Previously, the aspect of digitalization and digital information of a facility was not considered in transactions. R1 says that a digital representation and well-documented information will reduce uncertainties in transactions. Risk is costly, and as it is reduced by having a digital representation in place - the willingness-to-pay increases. In the same manner, this would increase the value of their facilities, R4 concludes.

Summarizing, R1 concluded that the case company's drivers for digitalization are quite simple - their goals are to achieve a high return to the funds that own the company. R4 adds that they would, of course, not start a project if they only saw it as cost-driving.

> *"For our part, when we invest in new systems, it must either: reduce our operating costs so that we get lower expenses or make the houses better so that we get higher rents and better income."*
>
> - Real Estate Representative 4

5.1.2 Current Issues in Facilities

When asked about the current issues faced in real estate and facilities management, the interviewees expressed a common theme that there is a significant need for a more efficient way of collecting, updating, organizing, and analyzing data. It is an essential part of decision-making processes and can optimize the processes and gain new insights, thereby reducing costs or increasing income. Moreover, C1 stated that the unstructured management of documents results in unnecessary re-work. R4 added that it is easy to see the cost of this digitalization change but that the monetary benefits are not always clear. However, C3 and CB stated that an investment in the organization of data would generate benefits.

> *"If we can help our customers [the case company] to have better organization and management as well as better control of their numbers, data, and business, then they will generate more money from this."*
>
> - Consultant 3

R4 elaborates by explaining how the case company is a matrix organization where they work much in downpipes, but they also collaborate cross-sectionally. Real estate and facilities management processes are highly dependent on information. Keeping this information up to date and relevant has for a long time been the biggest challenge in the whole real estate industry. R4 also said that they are affected by an increasingly extensive bureaucracy that demands authority controls and inspections. The inspections and regulatory controls a facility needs to fulfill put a high demand on organized facility information. He addresses that anyone in the company needs to find information quickly. It is then vital to store data in a way that makes it accessible for anyone.

> *"It is really important that we have systems as well as structure and processes that says; this is how we store data in [the case company]. Then you will know where to find it, for example, inspection material from an elevator, no matter where you work at [the case company]"*
>
> - Real Estate Representative 4

Two interviewees mentioned that collecting operational information has not been the problem. The operational systems in the buildings are today relatively highly automized, according to R4. The systems have for a long time been able to show temperatures, ventilation data, or provide an operations overview. Though, the technical development is still relatively static and traditional. The problem is that each system has its own fabricate, and those cannot communicate or coordinate with each other. As a result, building automation systems may regulate contra productively, e.g., ventilation and heating. Therefore, real estate owners struggle to overview and controlling their facilities' operations effectively.

Moreover, information such as drawings, tenant information, and operations data are organized and stored in different databases and systems. Historically, R3 explains that much information has been stored in physical office binders, and then the information and knowledge has been isolated in the related department. Even though the case company is not currently using physical binders anymore, the problem of isolated information remains. This has made it hard to share the information between different departments or concerned stakeholders. The interviewees also state that it is hard to keep the scattered information stored updated since locating and updating all the information is time-consuming and error-prone since it is easy to miss one file.

Lastly, two interviewees addressed that simply accessing the information is not enough to make well-informed decisions. Instead, the information needs to be presented in its context to enable a better understanding of the presented information. BIM plays a big part in contextualizing buildings' design and construction phase, but R4 explains that the concept is not used in the operational phase. Additionally, the current tools for conducting analyses are not optimal. Some employees have created excel matrixes to conduct relevant analyses, but it is not an ideal solution R4 concludes.

5.1.3 Role of Digital Twins

The majority of the interviewees stated that defining a digital twin is complex and that the definition varies a lot within industries. However, the interviewees' answers when asked to define a digital twin and its role in the digital transformation were quite similar.

> *"[...] it should be a digital representation of the facility or building you are taking care of and it should be detailed enough to fulfill your needs. I do not think it needs to be at the screw and nut level but [detailed] enough. There are different views on it, 'that you shall have all data'. I do not think so, but rather that you should be able to link it to other types of data - or visualize the data together, one might say."*
>
> - Consultant B

All but one of the interviewees stated, in different ways, that a 3D representation of a facility does not fulfill the characteristics of a digital twin. CA, who primarily works with models used for the design and construction process of buildings or project, describes a digital twin as a 3D BIM model which includes all information created during the construction phase in an easily accessible and structured way. The model should remove the need for separate systems and documents.

Moreover, several of the interviewees stated that to fulfill the status of a digital twin, it needs to be able to visualize a 3D representation of the building and integrate additional data to this representation. What this additional data needs to contain was described in different ways by the interviewees. However, all concluded that it should represent the reality, that the business and building should be visualized in its context. Five interviewees specifically concluded that the additional information should contain building, business, and real-time data collected from the facility. When that is realized, R1 thinks that they have come quite far towards a digital twin. However, R1 addresses that it is difficult to talk about a digital twin because it is very hyped and can mean different things to different people but realizes that their approach resembles a digital twin.

> *"The digital twin is a representation of all of the facility data, all the data flows within the facility. [...] Basically, everything that happens inside a facility that could be easily followed up trough data communication"*
>
> - Real Estate Representative 3

Four of the interviewees included statements of what role or purposes the digital twin needs to fulfill to be defined as a digital twin. One interviewee stated that it is not until the model is combined with relevant information to facilitate the intended purposes, it will fulfill the status of a digital twin. Two interviewees stated that the information provided by the digital twin needs to be able to facilitate analyses of the current state of the building and the fourth interviewee stated that the information provided by the digital twin should facilitate change processes.

> *"For us at [case company] it is when we connect the real time data from a facility along with the spatial information and the business information. When we connect these three parts and has a process where we can handle changes in a life-cycle perspective, then we have come a long way towards a digital twin in my point of view"*
>
> - Real Estate Representative 1

R2 adds that the data is the actual interesting aspect of the digital twin and that the base model is only one way to represent and visualize data. The digital twin should mirror the whole business. In some cases, a building model as a visualization tool is beneficial, but for complex analysis other methods or tools to visualize the data might be preferable.

> *"The basic models are in a way a bit fragmented since you look at building for building and room for room [...] but if you look at complex relations then maybe there are other types of analyzes you need to use, diagrams or other methods which may better represent data."*
>
> - Real Estate Representative 2

5.2 Usage Areas of Digital Twins in Real Estate

This chapter will describe intended usages and benefits the interviewees have described categorized under its key process areas. Some of the applications have been tested during pilot projects. However, since the digital twin is not fully incorporated in the organization yet, many of the discussions covered future usage of the digital twin.

5.2.1 Facilities Planning

R2 explains that the project and transaction department are working collaboratively in facilities planning. The transaction department conducts investment analysis for the real estate portfolio yearly. A process that includes examining each facility by considering its economic condition, potential, and future plans. Several interviewees stated that historical and real-time data of the business, building, and operation would help to make wise decisions regarding facilities planning. By accessing digital facility information, like historical data about reconstructions, they will have a greater basis for deciding on a facility's future. CB stated that having control over updated building information and the different capacities of the facility will make the company be able to make decisions regarding if it is worth initiating a reconstruction. For example, what is the facility's capacity at the moment, what is needed to increase that capacity, is there room to expand the electricity systems, or how costly would the tenant adjustment. In the project department, the facilities' capacity for new tenants is examined by considering construction, floor heights, ventilation, and other systems, maintenance status, and legal aspects in detail planning.

5.2.2 Project and Transaction Management

R1 and R4 stated that a facility with a digital twin could increase the value in transactions. First, a smart building itself is attractive. R1 mentioned that environmental certifications are getting more common and can potentially increase their buildings' value, a process the digital twin can facilitate. Moreover, R1 implied that he would not be surprised if smart building certifications arise in the near future and that these could increase the value of a building in transactions. However, many certifications put high demand on control of the indoor climate and knowledge of the facility, which continuously needs to be validated to keep the certification. Secondly, R1 explains that the transaction manager has mentioned that they are willing to pay more for a facility with a digital representation. Previously, the aspect of digitalization and digital information of a facility was not considered in transactions. R1 says that a digital representation and well-documented information will reduce uncertainties in transactions. Risk is costly, and as it is reduced by having a digital representation in place - the willingness-to-pay increases. In the same manner, this would increase the value of their facilities, R4 concludes. Having control of what a building contains is of great value while selling a building. During a single transaction, the real estate employees can use the information gained by the digital twin to communicate the value of a building – then the buyer knows what the price includes.

> *"In facility transactions, a building with bad digital representation and bad technology density will be valued less."*
>
> - Real Estate Representative 4

Regarding projects, several interviewees find many user perspectives. The model composing the digital twin can be used as a foundation to start a new project. R2 explains that the time schedules are short once a project start, and then an organized basis is crucial. CA explain that during the initiating design phase of reconstructions, the architects need access to correct volumes to start planning. They need to retrieve dimensions in a room, e.g., where the original and suspension ceiling is situated. For an extensive reconstruction, the contractors need millimeter accuracy of the building information. However, in minor reconstructions or changes in a facility, CA believes that it may be sufficient to revise the existing basis. Moreover, CA declares that creating a BIM model for reconstruction can be very difficult. Older facilities contain many surprises that are not documented. The contractors need millimeter accuracy on the model, and therefore a laser scanning is beneficial. However, laser scanning of facilities in use comes with several barriers. Suspension ceilings, for example, obstruct the ability to read hidden elements. Additional laser scanning can be necessary as the project progress to make up for initially hidden parts. During their last reconstruction project CA was involved in, the initiating process of scanning and completing a building model fit for facilitating the design phase took six months and half a million SEK to complete.

Furthermore, CA adds that 360 photos should not be underestimated; they have been valuable during project design. This information can be structured, saved, and provided by a digital twin platform. A digital Point Cloud with complementary 360 photos enables consultants to digitally inspect the building and consequently save time because they do not have to visit the site. RA says that 360 photos are also valuable in communication between his client role, the design consultant, and the contractor. In a small project where they installed ventilation units in the attic, thick electrical cables would be placed in the stairwell. The contractor showed a solution that RA did not like because it would destroy the stairs with a cultural value that he wanted to preserve, but RA had difficulty communicating it with a simple floor plan. With easily accessible 360 photos, he can communicate his interest in the building without being on-site.

To summarize, the interviewees see several advantages of having a sufficient model available at project start. C2 says that the time project teams usually spent searching and reviewing drawings could be spent on performing analyses. The digital twin provides prerequisites to move on faster and simulate energy calculations, calculate costs and test various solutions. C3, C2, and CA add that the models can retrieve the number of particular objects, e.g., number of windows or square meters of inner walls, estimate the cost of reconstruction projects, or even share materials between projects to favor circularity and re-use. CA adds that the same function can be used to procure contractors based on quantity and set a price per square meter for any changes. Previously, changes have been costly since contractors can claim that removing 100 square meters of floor space would only save the client a small amount of money, but adding the same amount of floor space to the design would be very costly. Having the opportunity to procure a project based on a quantity price would therefore save the client money.

However, R2 addresses that projects are temporary aspects in a facility's life cycle, where the BIM model is in focus and projects shape variously depending on contracts. Based on the contract, The case company may or may not be part of the later purchasing or procurements. Instead, C2 explains that their focus is on their demands for commissioning and hand-over so that the model can go back to facilities management. To state the right demands in their design guidelines to use the information during the facility management processes might be most important.

5.2.3 Service Management

CB said that for a commercial real estate company, keeping track of leases and tenant information is the most important application. Making sure that spaces are leased today and in the future is a fundamental part of commercial real estate. For example, a shopping center can have over 100 tenants and consequently have many leases that need to be managed. Visualization of leases in the context of a building in combination with additional analysis tools can provide a better understanding of the facility's letting. The ability to link documents to its related spaces and co-visualize which premises are empty, which will be vacant in 6 months and similar analyzes, are important functions according to C1. CB as well stated, that these functions will aid the process of re-negotiating leases in time, reducing the risk of vacant facilities due to lack of information. Lack of information can also result in leases being charged lower than what the facility is worth C1 adds. C3 says that facilities with a high circulation of tenants which is constantly renovated or adjusted for new tenant requests have a very different demand on data than, for example, a facility which the same client has leased for the last 25 years. R4 gives an example where many offices are constantly re-built due to new tenants. He summarizes that a digital twin might be most valuable to a facility that is constantly facing change but will benefit static facilities as well.

Several of the interviewees as well mentioned that the digital twin could increase communication with customers. For example, floor plans can be used to communicate and visualize the emergency route or directions to rooms and components. Furthermore, the structured management of information will serve as a basis for demonstrating a professional business RA stated. If the employees can retrieve the correct information prior to or during customer encounters, the employees will be perceived as well informed and increase the customer experience. R2 concludes that increasing customer experience is essential because that increases the customer's willingness to pay, resulting in higher incomes. RA informed that previously they have not always had sufficient drawings and materials describing the space outside the building, for example, parking space, courtyards, or roof terrace. Having an app where customers can make faulty reports by attaching the complaint to the related object within the digital model is one frequently mentioned communication application.

> *"With this change we can create new customer interface which makes that instead of 300 customers we get 300.000 customers since we will be able to reach our customers coworkers in a larger extent and create the opportunity for new businesses."*

- Real Estate Representative 1

Additionally, R1 said that the case company wants to use the building model and up-to-date facility information to communicate with service providers. RA, R1, and C2 add that the facility plans and drawings expressing the surrounding environment can be used as a basis to construct service contracts and leases. By tracking the real-time data, the company has a greater opportunity to set requirements for products and services. Cleaning contracts can be based on usage data and be delivered based on need instead of time. The leases can as well include components that are based on presence. R1 declares that if they effectively measure shops' presence and visitor rate, this could be added as a factor in the lease agreement. Furthermore, the interviewees also address that the digital twin can generate the prerequisites to create a short lease agreement or co-working office subscription. An essential part of enabling short leases is providing access to the facility. C1 explained that this could be made by attaching data to the virtual door in the digital twin, which is linked to the locking system of the physical door. In the same way, the digital twin can facilitate systems that manage the booking of rooms and other tailor-made services based on customer needs.

Some interviewees also address that new services could be constructed and offered by sharing the collected data. R3 mentioned that with the digital twin, they would be able to provide data regarding energy consumption and other usage data needed when customers create their sustainability reports. RA stated that one customer need that arose during the pandemic was finding information regarding how many people there are at the offices and determining if tenants want to work from home if the spaces are crowded. Moreover, R3 believes that in the future, they will be able to share data and aid other actors to improve business and eventually contribute to the smart city. This could be an important resource in the environmental sustainability journey, R3 adds.

Furthermore, the tracking and analysis of presence data could have serval benefits regarding space utilization. Four of the interviewed employees at the case company mentioned that they want to track presence at their facility, both to create new services and strengthen the customer relationship and making sure the spaces are efficiently used. According to R4 presence can be measured by sensors in different ways: detect when someone is sitting at a desk, measuring how many computers that are used, collecting video photoaged which are analyzed by AI or simply having a sensor which can detect when there is movement presence. By analyzing presence data, the case company will get to know the customer on a deeper level and find solutions on how the customer can use the facilities more efficiently and be more productive while using the offices. Analyze how and when conference rooms are used is one mentioned aspect of this service. R1 adds that a facility's need depends on location, as well. The rents in Stockholm city are expensive, increasing the awareness and desire to utilize every square meter. Services of measuring activities and aid with tenant space management are more desired in those cases. R1 mentioned that eventually, AI could be used to simulate workplace placements to optimize the use of space. R4 also says that they see great potential in measuring presence in shopping centers. For example, measure visitor movement and how many people move both inside and outside their stores. R4 says that the exact number is not the important thing when making analysis for visitor movement in retail, but that it is more about measuring movement as a percentage compared to other sensors in the same building or premises.

Last, the digital twin can be used to facilitate the marketing while finding new tenants. The 3D model, along with 360 photos, enables useful material in a sales and rental process. With 360 photos, the customer can walk around in virtual tours and understand the building. C1 says that such material can otherwise be expensive to produce, and historically the material has not been efficiently saved, resulting in that marketing material needs to be re-created for every new process. The structuring of information enabled by the digital twin could reduce the risk of unnecessary re-work.

In summary, C2 stated that the core of a real estate business is mainly about the customers and the business, not operation and maintenance in the first place. The core business is where the revenue of the company is generated and where investment can have the most significant positive effect. Furthermore, C2 believes that the closer the digital twin usage get to the business, the less details are required in the model.

5.2.4 Operations and Maintenance Management

When operating systems are open and can communicate to other systems, many new opportunities in operations are made possible. When different data types are combined, new insights can be gained about the building's system, such as water, heating, ventilation, electricity, and solar cells. R3 describes that they want to gather everything in a superior system where they get an overview of the real estate portfolio and compare facilities against each other.

One frequently described usage area was to be able to do digital maintenance. R3 says that they are in the process of 360 photographing their fan rooms, heating plants, and other systems. With these photos, they will be able to digitally visualize the systems and greatly simplify the everyday life of the operational staff. C1 adds that the digital twin can provide information regarding "*what is the number on that meter?*", "*What was the product we had there*?" or "*which rooms do that aggregate serve?*". R3 declares no need for a high level of detail on the modeling of systems in the digital twin. Simply accessing correct text information, for example, when the systems inspected the last time or object properties such as the color-code of the wall is a value according to R4 and C3. C1 states that having a simplified modeled box representing a system or component where linked pictures and other data are found could greatly value the operating staff. Access to the linked information will make the staff find the correct information faster and easier plan their maintenance prior to visiting their site. The result is both that they become more efficient, but also that they are perceived as more professional by the tenant. R3 adds that they have started to discuss if and how they can share this information with others, for example, building and presence data with emergency personnel in case of fire.

Moreover, one frequently described usage within operation and maintenance was tracking changes and the current state of buildings by sensors. Parameters such as temperature, humidity, airflow, carbon dioxide, TVOC level, vibration, and presence were mentioned. R2 and RA concluded that one very important aspect of real estate is keeping track of the indoor climate. It is an important customer experience factor, and it is an important parameter when it comes to customer complaints. All the interviewees at the case company stated that they want to use the digital twin to track the indoor climate. In that way RA stated that they could be proactive and correct the wrong temperature or other parameter values before a complaint has been made. This will both save time for operating staff and reduce the need of reparations. R3 adds that sensors measuring vibration could detect changes of, for example, a fan, and analyzes whether a system is starting to get worn out can be made. C2 declares that by having control of real-time sensing data, some irrelevant complaints can also be stopped if the sensing information shows approved levels.

Furthermore, when a complaint and faulty report is made, the digital twin can aid as communication, as explained in the previous subchapter. The digital twin can as well aid in the structuring of complaints thereby reducing the staff operating time. C3 stated that previously faulty report has been structured by tenant. This process was time-consuming since the staff first had to identify where the tenant was situated and then visit the sight to find out which object the complaint was based on. Now the complaints can be made on object level instead since the tenant can link the faulty report to the virtual counterpart of the faulty object. The staff will then find the linked object information at the same place as the faulty report which enables the staff to sufficiently prepare before the maintenance is conducted.

Moreover, the functions of linking information to digital objects and the provisioning functions can aid in administrative processes. C3 stated that previously when sensors have been installed, the staff had to take notes regarding sensor ID and its corresponding location and then, after all are installed, rewrite the names and locations and submit to the digital building management systems. With provisioning the staff can, at the same time as the sensor is being installed, add objects to the digital twin and attach name and location to that object. The digital twin then extracts the information in an appropriate format for the external building systems, hence saving time and money. R3 mentioned that the building automation systems the case company is using today to report energy data had automated the way of recertifying buildings based on the LEED requirements. C1 stated that getting a facility certified is an extensive project, and much data is needed. Thereby buildings with plans on being certified were prioritized by Vasakornan while initiating the process of creating digital twins of their facilities. R3 stated that a similar automated process for recertifying buildings is desired to automate mandatory inspections, which the digital twin can facilitate.

Furthermore, the digital twin can aid in the energy-saving processes. The energy issue is a huge component in operations and a core issue for the case company in sustainability purposes describes R4. R2 stated that the digital twin could aid in achieving their environmental sustainability goals by aid in smart assessments regarding how they could lower the energy consumption of the operational phases. Much of the operating data has already been collected for a long time, but the digital twin can merge all the data, allowing completely new analyses. R4 thinks that the new analyzes do not have to be a screw and nut level, but instead that they are about large and quick perceptions of what is happening in the facility to detect deviations. He concludes that it is the early and quick overviews that they will benefit greatly from. The next step can, according to R3, be to involve artificial intelligence. This will enable optimal operation based on the need of the facilities.

> *"If we look at energy savings, which we have had during many years, then you might have selected the low hanging fruits, now it is time to reach higher the reach the ones on the top. On that level I believe we will eventually see the beauty in AI, however the first priority is to be able to understand the data before the process can start. That is important."*
>
> - Real Estate Representative 3

5.3 Challenges of Digital Twins in Real Estate

The following section will describe the discussed short and long-term challenges of digital transformation. The challenges both include technical challenges with developing and implementing the digital twin into the organization and the challenges of organizational acceptance of the change.

5.3.1 Enabling Activities

R1 explained that their approach to digital twins is long-term and rely on integrating different facility systems rather than purchasing a packaged product. A challenge, however, is to make everybody on board with these decisions. C1 stated that the techniques for developing digital twins have been available for some time. The problem has been to make the technology as easy as possible to make the user understand and accept it. R1 addresses that establishing an open culture and the right competence are essential to grasp the change and make the change less dramatic. The benefits in implementing change are rarely linear in R1's experience; instead, the processes form a J-curve. Initially, things get worse before the benefits increase exponentially - that requires acceptance from the organization. R1 further explained that they have re-structured organizationally in their technical department and increased competence by replacing the old roles with new ones that require higher education.

C2 and C3 stated that clients have different experience and maturity levels within digital tools. The company first needs to understand the effort of fulfilling the prerequisites of starting the process. C2 stated that many companies do not understand the effort required to enable communication and integration between different systems. Companies can also be differently accepting of a change, and the desired speeds to reach the implementation and usage stage differ between organizations. C3 declared that regardless of the organization's maturity level, an IT strategy has to be developed efficiently. Otherwise, there is a considerable risk that the procurement of programs and applications is done without proper reflections.

When it comes to organizational change, RA said that implementing a digital twin within the organization of the case company was not perceived as very challenging. That it simply requires a new working method. However, both R1 and R2 stated that communicating the benefits and persuading everyone that this technology and the new working method it requires will create value is far from easy. Furthermore, R4 addressed that one challenge they face, which arises in all digitalization projects, is how do we measure benefits? The cost of creating new technology is easy to track and describe. Describing the benefits is, however, harder. C3 stated that there are methods of measuring the benefits of using digital twins in the construction phase. The usage within facility management is still very new, resulting in limited abilities to measure quantifiable benefits so far. C1 continued and stated that people need to see the personal benefit, and communicating these benefits is the most critical prerequisites and central challenge. If the employees do not see how the technology will aid in their everyday tasks, there will be resistance. The function of customizing the displayed information depending on the department or user is important according to RA. Too much information will make the user "*drown in data*" and consequently not see the personal benefits.

The case company and Sweco have, during 2020, worked with several pilot projects to receive fast feedback and iterate the process. C1 explains that they worked with minimum viable products. The first pilot project was very simple and resembled a space model of the rooms within the buildings, and there were no detailed objects, e.g., windows or doors. Those pilots were proof of concept to visualize sensor data, e.g., temperature, in the digital model. As well, spaces were connected to the business system to visualize rental objects. However, the real estate employees claimed that the space model was difficult to understand since they had trouble grasping where spaces were situated in the building, and navigation was impossible. Consequently, the next pilot project included simple modeling of the whole building, making the spaces viewable in their environmental setting. This pilot project gave rise to more services and benefits, which the first pilot project could not provide.

C1 states that the main challenge is to convince all the people inside the organization that the technology can benefit everyone. Their everyday tasks can be simplified by using the technology. Sweco's part within the communication mainly consisted of answering questions and finding new usage areas by dialogue with employees who know about the operating and maintenance activities. C1 states that the pilot projects aided with creating an acceptance for digitalization among the people inside the organization. Since employees were included in creating the applications, the insight of benefit and utility was formed, and the acceptance grew.

Furthermore, as the result previously has established, an updated building model is essential for realizing the digital twin and enabling the change. Information needed to construct these building models are often lacking for existing buildings. R3 explains that drawings that are describing installations, e.g., HVAC systems, are, for example, minimal when it comes to old buildings. R4 stated that it is easy to underestimate the effort of finding and collecting the necessary information. Obtaining this information might be one of the most significant challenges. Laser scanning can aid in obtaining the missing information, but the cost of these processes can quickly get too great if the number of facilities in need of scanning increases. C3 further points out that it is, above all, not cost-effective to put everything on the same level from the beginning when twinning a complete real estate portfolio. The digital aim explained in 4.5 was therefore constructed to provide guidance for cost-effective modeling.

5.3.2 Sustaining Changes

When asked what they perceive as the long-term challenges of the digital twin, many of the interviewees said the same; the continuous refinement and updating of information. Several interviewees stated that the digital twin and the data it entails must be up to date. It is essential that everyone follows the new method of saving information and that there should be no exceptions, RA stated. Furthermore, R3 added that it essential keep up with the latest technical development in the industry and be on the same page as other companies. Several interviewees acknowledged that they have had problems organizing and updating information in the past and that it is vital that they do not fall back into those patterns.

> *"That is probably my greatest fear, that you don't have the energy to maintain these models and that they get a reputation of that 'this is not correct, and the walls are wrong'. That it will be as it has always been previously in analog form, but the problems are the same now only in digital form."*
>
> \- Real Estate Representative 4

However, the interviewees also stated that they believe that the size of this project will force everyone to change and keep the information updated. The more the digital twins are integrated with other systems and used across different departments, the more it will damage the organization if the data are not correct. If many people depend on the data, then at least someone will question why the information is incorrect. This will as well be a driver for keeping it up to date.

> *"One of the biggest challenges is the life cycle management. To contin-*

> *uously refine and improve the quality of the twin so that projects achieve good change management. It has always been a big challenge for real estate companies to handle this. Now, it will be visible, and it will hurt if it is not correct"*
>
> - Real Estate Representative 1

CB explains that companies have to go back to check what data and information they need to manage the life cycle management. If they need this data, they must start demanding it in the renovation projects. CA adds that it is crucial that the process is sustained for future reconstructions and that the processes are the same, even in smaller projects. Both the interviewees agree that it is crucial to have good design and BIM guidelines and consultants that can manage the work. Commonly the project manager's primary focus is on time and money, not so much on the information required in facilities management. Project teams and contractors move on fast in between projects, and commissioning correct models to the facility managers must be added to the project's time plan CA addresses. Otherwise, the complementary work in the commission of models will be low prioritized, and the quality of the digital twin will fail over time. In small projects such as tenant adjustments, contractors have historically just sent in papers and sketches during commissioning, but sustaining the digital twin CA declares that someone needs to make sure that all changes generate an updated model.

6 | Discussion

This chapter will use the literature and result to discuss the new insights related to the research questions. The discussion will be divided in three parts were each research question will be elaborated separately.

- **Section 6.1:** How can digital twins be described in a real estate context?
- **Section 6.2:** How can digital twins create benefits in commercial real estate considering existing buildings?
- **Section 6.3:** What are the prerequisites for real estate companies to enable and sustain the digital twins?

6.1 Digital Ecosystem of Data, System and Service

It appears in both literature and practice that digital twin is a concept that several industries want to embrace. However, the digital twin is defined in various ways, and there is no consolidated view of what it is (Errandonea et al., 2020; Jones et al., 2020). It was stated in the literature that the processes and systems of the digital twin should support the intended usage (Lu et al., 2019). Since intended usage differs between industries, it is reasonable that the definitions also differ.

The majority of the interviewees described that a digital twin in real estate should mirror and provide insights into the whole business, i.e., building-, operational- and business data. Most definitions described in the interviews covered all key process areas described by Ebinger and Madritsch (2012). However, it was noticeable that employees in project management did not include real-time, operational, or business data in their definition of a digital twin. Instead, a digital twin was equalized to a high-detailed digital model, including all technical information describing the systems and objects in the buildings. This definition probably relates to the fact that BIM is an established concept in projects and is easily confused with a digital twin. It is essential to distinguish it from the digital twin to avoid misunderstandings.

The digital twin concept is derived from the manufacturing industry and is used to enhance decision-making during the life-cycle of a product, system, or process (Errandonea et al., 2020). The focus is on optimization, visualization, or simulation, using data analytics, as explained by Arup (2019), Boje et al. (2020), and Lu et al. (2020-b). For a digital twin at a building level, building data are used to contextualize the operational and business data, which describes the building's activity in real-time. In a mature process-oriented industry, the building data comes from the BIM model created in the design and construction phases (Thydell, 2017). The BIM model is a database for static information linked to the building objects, but it is not enough for extensive analytics. The primary focus of the digital twin is to manage data flows and analytics.

However, Boje et al. (2020) add that advanced analytics tools advocated in digital twins are highly dependent on large amounts of data. According to interviews, the amount of data needed for such analytics is not yet prepared in real estate. In contrast, the real estate company's status is yet to succeed in describing its existing data. According to Klein et al. (2019), the descriptive analysis is the initial step before diagnostic, predictive, or prescriptive analytics can be performed. Several issues with conducting descriptive analytics were identified in the interviews. Similarly as Cajias (2020) and Lu et al. (2020-b) identified, issues in digitalization are not the lack of data but instead the lack of structured data. As described by interviewees, the building automation systems and sensing devices in facilities are already capturing real-time data. In addition, there are several other automatic control systems filled with data, such as alarms, locks, and elevators. The systems are of various fabricates, located in silos, and are steered in separate applications, see Figure 6.1. The data cannot be transferred between systems or facilities in an interoperable manner. Lu et al. (2019) described the issue of interoperability as one of the primary technical challenges with digital twins.

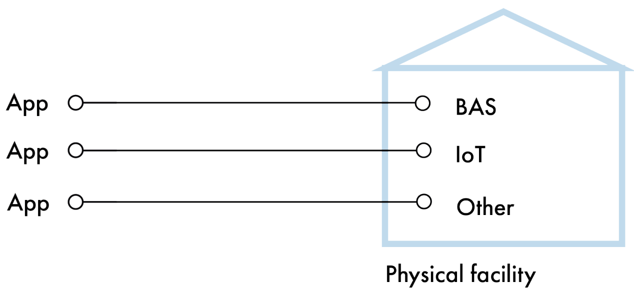

Figure 6.1: Current state where facility systems are placed in silos and managed in separate applications (authors own figure).

Two interviews describe the case company's approach to digital twins as an industrial approach. This approach means creating a foundation that transforms how data flows in the organization and enables the systems in facilities to communicate. An opposite approach is described as purchasing a ready-made platform, which is available on the market. Several interviewees argue that a complex structure is formed when new information models are added on top of each other. A ready-made platform hampers the interoperability as changes have to be resolved case-by-case, and real estate companies become dependent on further digitalization.

The industrial approach is comparable to the theoretical framework of a dynamic digital twin's system architecture at a building level, derived from Lu et al.'s (2019). This framework provides an understanding of the digital twin by compromising five layers: data acquisition layer, transmission layer, digital modeling and data complementary layer, data/model integration layer, and service layer.

To enable the entire system architecture in an industrial approach, RealEstateCore is the cornerstone for the studied case. It is the ontology that structures all facility data that is acquired according to the building's knowledge graph. In this case, the digital model layer has an important function. In addition to Twinfinity providing building data via its BIM API, it is also where a RealEstateCore export of the building data is performed and which produces the knowledge graph. The case company's approach illustrates the importance of a common ontology for data integration, not addressed by Lu et al. (2019) though by Klein et al. (2019). The use of RealEstateCore requires a data management system in the data/model integration layer. The case uses the operating system ProptechOS, which becomes the twin's hub, but could be another system. Importing data in the data acquisition layer is prepared by developing APIs for systems and platforms, enabling data sharing. From ProptechOS, data through the API can be further exported to applications in a service layer. For example, third-party applications that perform data analytics, send feedback to ProptechOS and regulate the systems. It can also be in-house applications to tenants, the owner, or service providers.

An essential aspect that the case highlights, but which was not addressed in the theoretical framework, is the importance of managing access to data as a resource. When the system architecture receives a data access layer, data can be shared or sold to third parties in a controlled manner. Together with the RealEstateCore ontology, the idea of an access layer is an essential part of realizing smart cities where data can be shared and sold to stakeholders in a structured way, as wished by Brutti (2019).

An interviewee describes this industrial approach to digital twins as a collaborative digital twin highlighting how existing systems are connected rather than adding new ones, see Figure 6.2. In this way, digital twins is not a system itself but rather an ecosystem where data from facility systems are communicated into a data cloud and made available for applications. The ecosystem describes the facility and its activities historically and as-is, enabling services to optimize, visualize and simulate the facility's usage. The possibilities with its ecosystem depend on the fidelity obtained, which is discussed further in 6.2.

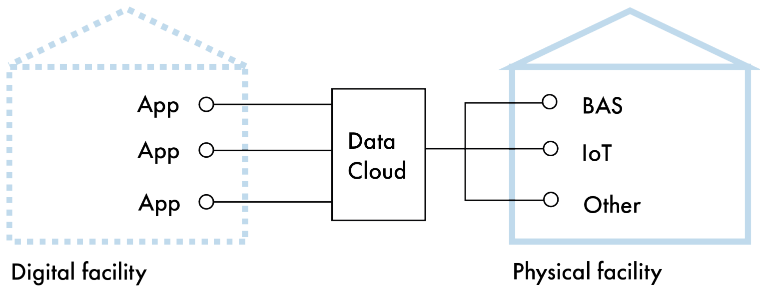

Figure 6.2: Digital twin as an ecosystem of data, system, and service (authors own figure).

6.2 Simple Modeling Enabling New Business Models

By using an industrial approach, the case company is transforming how data flows in the organization. This means that business and operational systems, which previously worked in silos, are made interoperable, and a large amount of data is made available for applications to utilize. As previously discussed in 6.1, the case company is creating spatial models of their existing facilities to fulfill this digital ecosystem. As stated by several researchers, it is unclear if the benefits of a digital twin in real estate and facilities management outweigh the effort of twinning existing facilities (Atkins and Brook, 2015; Becker et al., 2019; Koch, 2018). Jones et al. (2020) added that there is no unified level of fidelity that is appropriate for all cases, i.e., the number of parameters and their accuracy. That is because each usage area in a building's life cycle has various demands on data (Lu et al. 2020).

The case company aims for the entire portfolio to reach a connectable level, and when twinning an entire portfolio, there are some essential aspects to consider. First and foremost, the facilities have different needs and conditions. Some facilities undergo more frequent changes, while others are relatively static. Some facilities have structured information, while others require greater effort. It is reasonable to have a common aim for all facilities to avoid confusion about new ways of working. If the goal is set high and, e.g., involves laser scanning all facilities, it can be a costly process.

Laser scanning can however increase both fidelity and the model's trustworthiness. Trustworthiness for models is vital in projects where a higher level of detail is required. The model's measurements must be millimeter-accurate, and if the objects are accurate, it is possible to, e.g., make quantity withdrawals and plan for material reuse. Similar fidelity requirements seem to prevail in transaction management. There, a trustworthy model can be used as a basis to describe what the facilities contain. But, as R2 describes, these key process areas should be seen as temporary processes in a building's life cycle and should not set the requirements for the spatial model. However, both transaction and project hold essential functions. If digital data and technology density become a significant role in transactions, as R4 says, it can in itself be an argument for digitalizing existing facilities. Projects also have an essential role in maintaining the digital twin, which is discussed further in 6.3.

Since projects and transactions are temporary, real estate owners should pay more attention to service, operations, and maintenance management when creating spatial models. Previous research, such as Boje et al. (2020) and Lu et al. (2020-a) have argued cost savings due to optimization of operations and maintenance management as the main benefit of digital twins. This thesis argues that it is impossible to draw such conclusions without considering the type of real estate. For a commercial real estate owner that manages offices and retail, the primary return is derived from the business, i.e., service management, where leases, spaces, and tenant relationships are managed.

As the results present, the real estate industry is undergoing a significant transformation from asset provision to service provision (Lacomte, 2019). The emerging business models include service packages of flexible nature. Instead of offering square meters for some years, offers could, for example, gain access to a single workplace for a few hours or a lease where a base of 50 workplaces can expand periodically. It can be a tremendous competitive advantage for real estate owners to enable these business models to achieve high returns in the future. Such a business model has higher demands for data to understand how spaces are used, best utilized, and accessed. The most important aspect is that the floor plans and tenant divisions are correct. There, SimpleBuildingPlus as Level 1 of the digital aim is an example of a satisfactory solution for existing facilities to benefit from a digital twin. Therefore, the priority of a real estate company should be to develop a spatial model detailed enough to facilitate the new business models and postpone high fidelity modeling until a project phase is initiated.

When such a simple model is created, many opportunities for data analytics and information management are enabled. There, data can be linked to its spaces for further analysis by other applications. For service management, it is relevant to measure the presence and visualize it on spaces to analyze how they are used. There is great potential for intelligent applications to optimize spaces according to the tenants' needs in the future. By visualizing financial data, such as vacancy rates and rental levels, owners can avoid empty premises and significant financial losses. Information and documentation can also be linked to surfaces to facilitate information management. Consequently, a single point of truth where all information can be found, is created. According to the new business model, the digital ecosystem is essential for efficiently distributing access to space to tenants or service providers. The ecosystem can too facilitate the creation of sophisticated applications for tenants to improve their productivity, health, and well-being.

The same principles of data analytics and information management are useful in operation and maintenance management. Although these process areas advocate a higher fidelity and individual objects are included in the model, such as installation units or fixed furnishings, it is not the core in commercial real estate. Modeling entire systems such as ventilation and plumbing can be costly for existing buildings since drawings might be limited and existing building structures could hide the systems. This holistic representation of the building is declared as Level 4. However, it was explained that the need to visualize service areas of a system could be achieved by linking a component, for example, the ventilation unit inside the server room, to the spaces it serves and therefore remove the need of modeling the pipes between spaces. Likewise, technical information or faulty reports could be linked and accessed through the concerned spaces, removing the need for modeling some objects. There is a benefit in visualizing operational data, e.g., temperature or CO2, in spaces to gain new insights about energy use. If Level 3 of the digital aim is achieved, i.e., correct areas, it can be used for automized energy certifications. Some interviewees addressed that advanced analytics of data could aid energy optimization, which several authors expressed, and thereby perform at higher levels in certifications (Arup, 2019; Boje et al., 2020; Lu et al., 2020-b).

Although the ultimate goal of the digital twin may be to have all data gathered, it should initially be shaped according to the organization's need. Both Boje et al. (2020) and Jones et al. (2020) addressed that a high-fidelity digital twin might be an unachievable goal. By decreasing the fidelity and letting the needs steer, a digital twin does not have to be unattainable. Instead, it can be something that develops organically as the facility and its needs develop. Something that is predicted to be important in the future is efficiently refining the simple model with new information without going through a computer program. For example, to scan objects, rooms, or sensors via the mobile phone. Twinfinity offers a valuable provisioning tool to refine the model with points of interest. With these tools, operational staff can easily place objects, add service zone, maintenance data, and others, and enable object-oriented operations and maintenance management. Such solutions are essential to easily refine existing real estate models that initially are made very simple. The significance of the tools for managing changes through the facility lifecycle is further discussed in 6.3.

6.3 Enabling and Sustaining the Digital Ecosystem

To achieve the intended benefits from digital technologies investments, Love and Matthews (2019) presented a five-stage change process. The first step, identifying and structuring benefits, was discussed in the previous section. The following step was planning the benefits realization (Ebdinger and Madritsch, 2012). A concluding map of benefits network dependency is illustrated at the end of this section.

Lu et al. (2019) declared that a well-designed system architecture, including collecting, updating, transferring, and integrating data, was crucial to obtain value and long-term benefit realization from a digital twin. The case company addressed the importance of planning. They have been working with digital transformation for a long time and have now created an IT strategy that describes how data flows to achieve the benefits. The strategy is used to describe the components of the digital ecosystem and how it should be created.

First, the data acquisition layer needs to be defined (Lu et al., 2019). Finding and collecting information was described as challenging and time-consuming. Therefore, a strategy for collecting only the necessary information is beneficial. The result confirmed that the intended use should determine the fidelity and data quality. Then the heterogeneous data sources and the spatial model must be able to be integrated. Lu et al. (2019) identified API as a vital component to enable data transmission, and this was also recognized in the studied case. The data was then structured according to an ontology that enabled the interoperability of the system architecture. For the data to be integrated, an operating system for data is required that makes it available for applications that interact with the users. To exchange data as a resource to external stakeholders in the service layer, an access layer should be considered.

It emerged during the interviews that the approach in the strategy is a long-term solution and not a ready-made "digital twin platform." The advantages of the approach are discussed in previous sections, but the disadvantages are worth considering. It places higher demands on the acceptance of the organization, especially in the strategic processes areas. Davis (1989) pointed out that the organization's attitude towards the approach is influenced by the fact that the technology must have perceived usefulness. The interview established that communicating the benefits to establish the perceived usefulness has been a long and challenging process. With a ready-made platform where the applications are already available, it would be easier to visualize the benefits and thus create perceived usefulness. The industrial approach requires a higher understanding of the solution where the benefits cannot be shown but only explained. An interviewer explained it with the J-curve, where it initially gets worse and are only perceived as costs, but then the benefits grow exponentially. In this case, Mongogole and Jokonya (2018) point out that the organization's culture significantly impacts acceptance. It was also emphasized in the interviews, with the addition that competence and structure also impact. To enable the digital transformation, the company has undergone a major organizational change to increase the competence of technical personnel.

In the same way, perceived usefulness impacts how the ecosystem is used in the end, which Davis (1989) primarily refers to in his theory. Love and Matthews (2019) stated, no benefits from technology will be realized without being used. One method of achieving acceptance was to use pilot projects. The primary purpose was to create a proof of concept on the digital ecosystem. However, it was also used to include staff, which created acceptance when benefits could be visualized. The consultants described that the procedures or problems they face in their everyday lives were portrayed in meetings with the intended users. Davis (1989) also addresses the importance of perceived ease of use as an important factor for attitude and actual system use. Because the applications affect both operational staff and tenants, they must provide free of effort and not increase mental or physical effort (Davis, 1989). Several interviewees explained that the applications would probably be considered difficult to use if the users would "drown in data." Each application should have its interface with the appropriate data for its key process area is available.

However, according to interviews, the main challenge was to keep the information up to date. The interviews established that without the structured guidelines regarding "*this is how we store information at the company*", or if there are allowed exceptions, confusion might emerge. These confusions could be that the organization would fall back into old patterns and not update information sufficiently. This applies to all information connected to the system that does not flow automatically, where primarily technical documentation and building data seem to be critical.

An interview described it as life cycle management, which means that they then succeed in managing changes throughout the facility's entire life cycle, i.e., from planning, design, and construction to service, operations, and maintenance. The literature addressed that the commissioning process should include handing over relevant information from the projects and act as a natural source of acquiring information. However, this is not always done efficiently and in a proper format (Ebinger and Madritsch, 2012; Jones et al., 2020; Klein et al., 2012). Various changes are taking place in the facilities, from minor tenant adaptations to large reconstructions. To achieve life cycle management, the same work processes must apply to both small and large changes. The work process should include who should update and what should be updated. The case company has developed extensive design guidelines that describe how models should be delivered in project commission. There is also a decision made if the entire facility is to be remodeled, even if the reconstruction only concerns individual floors. It can be a risk factor if different floors are of different fidelity. Although it is advantageous if the complete facility achieves the new modeling, one should prioritize that the same tenant or type of spaces achieve the same fidelity. However, it is unclear how updating occurs regarding minor tenant adaptations, such as moving a single wall or an installation unit. As-built models are rarely used in this case, and involving BIM consultants to model every change would be a costly procedure. Then simpler tools, as mentioned in 6, can be helpful to update the building data easily. Then operational personnel should be able to easily change the model via mobile devices without going via computer programs.

Creating incentives to succeed with the life cycle management can be done in other ways than strict guidelines. Two interviewers point out that the more stakeholders depend on updated information, the more reasons will exist to keep it updated. In the same way, it can be critical to keep the digital twin updated if the business model is based on it; otherwise, it can pose a great risk to the company. It may also be worth noting that a more extensive ecosystem with much information requires more to maintain.

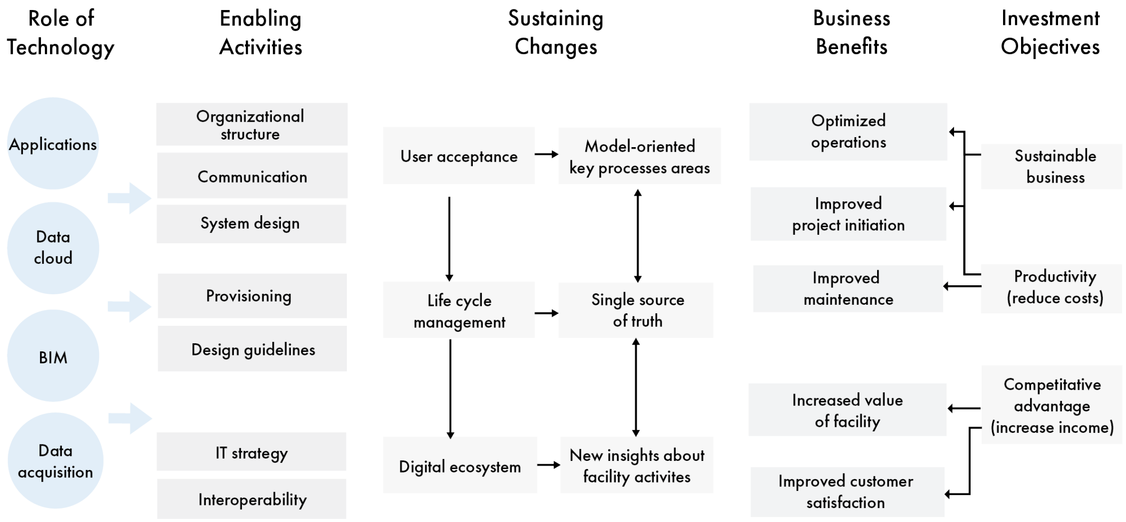

Figure 6.3: The Benefits Dependency Network of the studied case (authors mapping based on model by Love and Matthews, 2019 and Peppard, 2016).

7 | Conclusion

This thesis aimed at contributing to smart cities research by investigating how digital twins can realize smart buildings for existing buildings in a commercial real estate owner's perspective. In this chapter, the research questions related to the aim will be answered based on the findings from the study. Furthermore, the chapter will present the study's contributions to industry and academia and provide suggestion for future research.

7.1 Answering the Research Questions

How can digital twins be described in a real estate context?

The digital twin is a concept that analyzes a data flow to optimize, visualize or simulate a product, system, or process. In a real estate context, it means a combination of building, operational, and business data. Digital twins are often equated to BIM, but BIM resembles a static image of the facility. It does not enable the dynamic collection, integration, and analytics of data from heterogeneous sources. For real estate companies to avoid dependency on suppliers, a digital twin should not be a platform added on top of existing systems in facilities composing a complex structure. Ready-made platforms hamper interoperability as changes have to be resolved case-by-case. In facilities, automated building systems and sensors already capture data but are located in silos and cannot communicate. Digital twins are best seen as a digital ecosystem where data flows from existing systems and are accessible by applications through a data cloud. In smart cities, the data is exchanged with external stakeholders to enhance smarter services.

How can digital twins create benefits in commercial real estate considering existing buildings?

Existing buildings represent a significant resource in both cities and real estate portfolios but are often left outside the digitalization innovations due to its lacking digital material. In order to complete the digital ecosystem described in the previous section, it is required that the facilities receive a digital representation. In this context, fidelity often arises, which describes the number of parameters and their accuracy. The qualities that high fidelity entails are considered most important in projects and transaction management. However, these key process areas are seen as temporary processes and should not set requirements for the model. Instead, the focus should be on service, operation, and maintenance management. Previous research identified operations and maintenance, such as preventive maintenance and cost savings as main benefits. However, real estate is undergoing a significant transformation from asset provision to service provision where the emerging business models include service packages of flexible nature. Square meters in leases are replaced by hours, number of work stations, or other softer values such as productivity, health, and well-being. There, the digital data can play a significant role in analyzing how spaces are used, best utilized, and easily accessed, and thereby create higher returns. The modeling required to support this new business model can be very simple comprising correct floor plans and tenant divisions. Besides presence analytics, spaces enables data analytics in energy use for optimization. If areas are correct it is possible to complete automized environmental certifications and enhance corporate sustainability. Something that is predicted to be important in the future is to refine the simple model with tools in the mobile phone and thus enable object-oriented operations and maintenance management.

What are the prerequisites for real estate organizations to enable and sustain the digital twins?

To enable the digital ecosystem, some essential activities are required. Most of it relates to the organization accepting and succeeding in creating the system architecture for the industrial approach. It demands an organizational culture that enables attitudes and an organizational structure that ensures competence. If the organization does not experience the digital transformation objectives and understands how this specific approach achieves them, it is impossible to implement it. The biggest challenges, in general, turned out to be in life cycle management. There, information is updated throughout changes in the facilities' life cycle according to strict guidelines. The building data is critical and design guidelines should be developed to set requirements for project commissions. As mentioned in the previous answer, a mobile tool could be used to manage minor tenant adaptations or changes, to easily update information that is not covered by design guidelines. In addition to guidelines, there should be significant incentives to keep the information up to date if several stakeholders and the business model are dependent on it.

7.2 Industry and Academia Contribution

This thesis has established an urgency that the existing buildings are a significant resource in cities, and those must efficiently use space and energy for cities to achieve sustainable development. In smart cities, digital infrastructures are used to accomplish this, though, the existing buildings are currently left outside the digital transformation. By examining digital transformation in commercial real estate, an approach has been presented to how the buildings can be digitized in the form of digital twins. The thesis contributed by displaying that the facilities' existing systems should be integrated to collect data and support a business transformation from asset to service provision. The digital twins describe the digital ecosystem where data flows through a data cloud and makes data available for applications to perform analytics or create services. By using simple modeling, the existing facilities can support the applications and instead refine the digital models as changes occur. The thesis concluded that real estate owners contribute to smart cities by exchanging data from its ecosystem to external stakeholders and enhance smarter services. Finally, the thesis contributed by elaborating the activities and changes required to enable and sustain the digital twins from a life cycle perspective.

7.3 Future Research Suggestions

This study has identified a few suggestions for future research. The first reflection is related to the single case study as the choice of method. The case could be compared to other cases to broaden the understanding in academia and industry. Then various strategies, results, and challenges can be evaluated altogether. In addition, the case study was at an early stage, and only a few individual applications had been tested. It would be interesting to investigate a case where digital twins are used in day-to-day operations and thereby retrieve qualitative values of results, e.g., energy and space utilization or customer satisfaction index. In this way, investment costs can be compared with revenues or cost savings.

A challenge identified by the study was to refine the digital model as changes occur in the facility's life cycle. In addition to establishing design guidelines that set requirements in project commissions, it may be interesting to investigate simpler tools to add, remove or alter geometric or non-geometric information in the model. Where operational staff should efficiently perform such tasks through mobile devices and not a computer program.

The study also touched on how real estate owners can contribute to smart cities by sharing data produced by their smart buildings. Future research questions may concern what type of data would be valuable to share and to whom, and what this process would entail. Data should be shared without invading personal integrity or company competitiveness.

References

Adameko, D., Kunnen, S., and Nagarajah, A. (2020). Comparative Analysis of Platforms for Designing a Digital Twin. *3rd International Conference on Design, Simulation, Manufacturing: The Innovation Exchange, DSMIE 2020*, (pp. 3-12). Kharkiv. https://doi.org/10.1007/978-3-030-50794-7_1

Al-Ali, A., Gupta, R., Batool, T., Landolsi, T., Aloul, F., and Nabulsi, A. (2020). Digital twin conceptual model within the context of internet of things. *Future Internet*, 12(10), 1-15. https://doi.org/10.3390/fi12100163

Alshorafa, R., and Ergen, E. (2021). Identification of information requirements for implementing building information modeling based on model uses. *Journal of Information Technology in Construction*, 25, 561-574.https://doi.org/10.36680/J.ITCON.2020.032

Arup. (2019).*Digital twin: towards a meaningful framework*. Retrieved 2021-01-25, from https://www.arup.com/perspectives/publications/research/section/digital-twin-towards-a-meaningful-framework.

Atkin, B., and Brooks, A. (2015). *Total Facility Management*, 4th edition. Chichester, UK: Wiley-Blackwell. Retrieved 2021-03-15, from ProQuest Ebook Central: https://ebookcentral.proquest.com/lib/chalmers/reader.action?docID=1895527/&ppg=1

Baum, A. , Saull, A. and Braesemann, F. (2019). Proptech 2020: The Future of Real Estate. *Asset Magazine*, 1-111, University of Oxford Research

Baum, A. (2017). *PropTech 3.0: the future of real estate.* University of Oxford, 1-95. Retrieved from:
https://www.sbs.ox.ac.uk/research/oxford-future-real-estate

Becerik-Gerber, B., Jazizadeh, F., Li, N., and Calis, G. (2012). Application Areas and Data Requirements for BIM-Enabled Facilities Management, *Journal of Construction Engineering and Management*, 138(3), 431-442. https://doi.org/10.1061/(asce)co.1943-7862.0000433

Becker, R., Lublasser, E., Martens, J., Wolenberg, R., Zhang, H., Brell-Cokcan, S. and Blankenbach, J. (2019). Enabling BIM for property management of existing buildings based on automated As-IS capturing. *Proceedings of the 36th International Symposium on Automation and Robotics in Construction, ISARC 2019*, 201-208. https://doi.org/10.22260/isarc2019/0028

Bedrick, J. (2008).*Organizing the Development of a Building Information Model.*

AIA California Council's Integrated Project Delivery (IPD) Task Force. AECbytes.

Bell, E., Bryman, A., and Harley, B. (2019).*Business Research Methods* (5 ed.). Oxford, United Kingdom: Oxford University Press.

Boje, C., Guerriero, A., Kubicki, S., and Rezgui, Y. (2020). Towards a semantic Construction Digital Twin: Directions for future research. *Automation in Construction*, 114, 1-16.

Brutti, A., De Sabbata, P., Frascella, A., Gessa, N., Ianniello, R., Novelli, C., Pizzuti, S. and Ponti, G. (2019). Smart City Platform Specification: A Modular Approach to Achieve Interoperability in Smart Cities. In: Cicirelli F., Guerrieri A., Mastroianni C., Spezzano G., Vinci A. (eds) *The Internet of Things for Smart Urban Ecosystems. Internet of Things (Technology, Communications and Computing).* Springer, Cham. https://doi.org/10.1007/978-3-319-96550-5_2

Cajias, M. (2020). Artificial intelligence and real estate - not just an evolution, a real game changer!. *Journal of Property Investment and Finance*, 39(1), 15-18.

Cheng, J., Chen, W., Chen, K., and Wang, Q. (2020). Data-driven predictive maintenance planning framework for MEP components based on BIM and IoT using machine learning algorithms. *Automation in Construction*, 112, 1-21.

Davis, F. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319-340.

Davis, F. (1993). User acceptance of information technology: system characteristics, user perceptions and behavioral impacts. *International Journal of Man-Machine Studies*, 38(3), 475-487. DOI: https://doi.org/10.1006/imms.1993.1022

Ebinger, M., and Madritsch, T. (2011). Performance Measurement in Facility Management - The Environment Management Maturity Model BEM3. *Research Journal of Economic Business and ICT*, 2, 4-10.

Ebinger, M., and Madritsch, T. (2012). A classification framework for facilities and real estate management. *Facilities*, 30, 185-198

Errandonea, I., Beltrán, S., and Arrizabalga, S. (2020). Digital Twin for maintenance: A literature review. *Computers in Industry*, 123, 1-14.

Fitz, D., and Saleeb, N. (2019). Examining the quality and management of non-geometric building information modelling data at project hand-over. *Architectural Engineering and Design Management*, 15(4), 297-310.

Flowscape Solutions (n.d). Our Solutions Retrieved 2021-05-05, from: https://flowscapesolutions.com/

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, 12(2), 219-245.

Fukuda, S., Bernard, A., Gurumoorthy, B. and Bouras, A. (2014). Product Lifecycle Management for a Global Martket. *11th IFIP WG 5.1 International Conference, PLM 2014.* Yokohama, Japan, July 7-9. Retrieved 2021-04-02, from:

https://link.springer.com/book/10.1007%2F978-3-662-45937-9

Gandomi and Haider (2015). Beyond the hype: Big data concepts, methods, and analytics, *International Journal of Information Management*, 35(2), 137-144. https://doi.org/10.1016/j.ijinfomgt.2014.10.007

Glickman, E. (2013). *An Introduction to Real Estate Finance*. Retrieved 2021-03-16, from ProQuest Ebook Central: http://ebookcentral.proquest.com/lib/chalmers/detail.action?docID=5754441.

Gunes, V., Peter, S., Givargis, T., and Vahid, F. (2014). A survey on concepts, applications, and challenges in cyber-physical systems. *KSII Transactions on Internet and Information Systems*, 8(12), 4242-4268.

Hammar, K., Wallin, E., Karlberg, P. and Hälleberg, D (2019). *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 11779 LNCS, 130-145. https://doi.org/10.5281/zenodo.2628367

Hilal, M., Maqsood, T. and Abdekhodaee, A. (2019). A hybrid conceptual model for BIM in FM. *Construction Innovation*, 19(4), 531-549. https://doi.org/10.1108/CI-05-2018-0043

Hossain, M., and Yeoh, J. (2018). BIM for Existing Buildings: Potential Opportunities and Barriers. *IOP Conference Series: Materials Science and Engineering* (pp. 1-9). IOP Publishing.

Hsieh, H. and Shannon, S. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research*, 15(9), 1277-1288. https://doi.org/10.1177/1049732305276687

Jones, D., Snider, C., Nassehi, A., Yon, J., and Hicks, B. (2020). Characterising the Digital Twin: A systematic literature review. *CIRP Journal of Manufacturing Science and Technology*, 29, 36-52.

Klein, P., van der Vegte, W., Hribernik, K., and Klaus-Dieter, T. (2019). Towards an approach integrating various levels of data analytics to exploit product-usage information in product development. *Proceedings of the International Conference on Engineering Design*, ICED, (pp. 2627-2636). Delft, The Neatherlands.

Klein, L., Li, N., and Becerik-Gerber, B. (2012). Imaged-based verification of as-built documentation of operational buildings. *Automation in Construction*, 21(1), 161-171.

Koch, C., Hansen, G. and Jacobsen, K. (2019). Missed opportunities: two case studies of digitalization of FM in hospitals. *Facilities*, 37(7/8), 381-394. https://doi.org/10.1108/F-01-2018-0014

Kukafka,R., Johnson, S., Linfante, A., and Allegrante, J. (2003). Grounding a new information technology implementation framework in behavioral science: A systematic analysis of the literature on IT use. *Journal of Biomedical Informatics*, 36(3), 218-227. https://doi.org/10.1016/j.jbi.2003.09.002

Lecomte, P. (2019). What is smart? A real estate introduction to cities and buildings in the digital era. *Journal of General Management*, 44(3), 128-137. https://doi.org/10.1177/0306307018823108

Lequeux, J. and Guiot, F. (2019). *Building flexibility in real estate management Real Estate Predictions 2019*. Deloitte. Retrieved 2021-05-12, from: https://www2.deloitte.com/lu/en/pages/real-estate/articles/building-flexibility-real-estate-management.html

Love, P., and Matthews, J. (2019). The 'how' of benefits management for digital technology: From engineering to asset management. *Automation in Construction*, 107, 1-15.

Lu, Q., Parlikad, A., Woodlall, P., Ranasinghe, G., and Heaton, J. (2019). Developing a dynamic digital twin at a building level: Using Cambridge campus as case study. *International Conference on Smart Infrastructure and Construction 2019, ICSIC 2019: Driving Data-Informed Decision-Making*, 67-75. https://doi.org/10.1680/icsic.64669.067

Lu, Q., Parlikad, A., Woodall, P., Ranasinghe, G., Xie, X., Liang, Z., Konstantinou, E. Heaton, J. and Schooling, J. (2020-a). Developing a Digital Twin at Building and City Levels: Case Study of West Cambridge Campus. *Journal of Management in Engineering*, 36(1), 1-19. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000763

Lu, Q., Xie, X., Parlikad, K., Schooling, M., and Konstantinou, E. (2020-b). Moving from building information models to digital twins for operation and maintenance. *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction*, 1-9. https://doi.org/10.1680/jsmic.19.00011

Lu, Q., Chen, L., Li, S., and Pitt, M. (2020-c). Semi-automatic geometric digital twinning for existing buildings based on images and CAD drawings. *Automation in Construction*, 115 , 1-19. https://doi.org/10.1016/j.autcon.2020.103183

Mangano, G., and de Marco, A. (2014). The role of maintenance and facility management in logistics: A literature review. *Facilities*, 32(5), 241-255.

Mathijssen, M., Overeem, M., and Jansen, S. (2020). *Identification of Practices and Capabilities in API Management: A Systematic Literature Review.* Utrecht University, Department of Information Sciences. arXiv

Mohajan, H. (2018). Qualitative research methodology in social sciences and related subjects. *Journal of Economic Development, Environment and People*, 7(1), 23-48.

Mongogole, K. and Jokonya, O. (2018). A conceptual framework for implementing It change management in public sectors. *Procedia Computer Science*, 138, 835-842- https://doi.org10.1016/j.procs.2018.10.109

Nie, J., Xu, W., Cheng, D. and Yu Y. (2019). Digital Twin-based Smart Building Management and Control Framework. *International Conference on Artificial Intelligence and Computing Science (ICAICS 2019)*, 1-14. https://doi.org/10.1016/j.procs.2018.10.10910.12783/dtcse/icaic2019/29395

Parsanezhad, P. (2019). Towards a BIM-enabled. *Facility Management - Promises, Obstacles and Requirements* [Doctoral Thesis, KTH Stockholm Sweden] DIVA. http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1303895&dswid=-1531

Peppard, J. (2016). *A Tool to Map Your Next Digital Initiative.* Retrieved from Harvard Business Review: https://hbr.org/2016/06/a-tool-to-map-your-next-digital-initiative

PMI. (2008). *A Guide to the Project Management Body of Knowledge* (Vol. 4). Newton Square, PA: Project Management Institute.

Prodan, M., Prodan, A. and Purcarea, A. (2015). Three New Dimensions to People, Process, Technology Improvement Model. In: Rocha A., Correia A., Costanzo S., Reis L. (eds) *New Contributions in Information Systems and Technologies. Advances in Intelligent Systems and Computing*, vol 353. Springer, Cham. https://doi.org/10.1007/978-3-319-16486-1_47

Stake, R. (2000). Case Studies. In N. Denzin, and Y. Lincoln, *Handbook of qualitative research* (2 ed., pp. 435-442). Sage Publications

Starr, C., Saginor, J. and Worzala, E. (2020). The rise of PropTech: emerging industrial technologies and their impact on real estate. *FJournal of Property Investment and Finance*, 39(2), 157-169. https://doi.org/10.1108/JPIF-08-2020-0090

Stenberg, J. (2018). Facility Information modeling: fokus på energisparingar i fastighetsförvaltning. Smart Built Environment. https://smartbuilt.se/projekt/vardekedjor-och-affarsmodeller/facility/

Sweco. (2021). *The most approachable and committed partner with recognised expertise.* Retrieved 2021-03-22, from https://www.sweco.se/en/about-us/

Thydell, (2017). *BIM – digitalisering avbyggnadsinformation.* Sveriges Kommuner och Landsting, retrieved 2021-03-20 from: https://docplayer.se/44020206-Bim-digitalisering-av-byggnadsinformation-i-offentliga-fastighetsorganisationer.html

Tmpl Solutions AB (2021). *Open and adaptable – the complete platform.* Retrieved 2021-05-05, from https://www.tmpl.se/en/the-platform/

Uhlenkamp, J., Hribernik, K., Wellstandt, S., and Thoben, K. (2019). Digital Twin Applications: A first systemization of their dimensions. *IEEE International Conference on Engineering*, Technology and Innovation, ICE/ITMC 2019.

Volk, R., Stengel, J., and Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings - Literature review and future needs. *Automation in Construction*, 38, 109-127.

Wirdzeck, P. (2010). Transformin FM with BIM in complex facilities and laboratories. *International Facility Management Assicuation World Workplace Conference.* Atnanta, GA.

Yalcinkaya, M. and Singh, V (2014). Building information modeling (BIM) for facilities management– literature review and future need.*IFIP International*

Conference on Product Lifecycle Management. Springer, 1-10

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