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The concept of digital twins in the manufacturing industry

A study untangling the digital twin concept to utilize its benefits

Master's thesis in Production Engineering

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Gothenburg, Sweden 2020

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Master's Thesis 2020
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Typeset in LaTeX
Gothenburg, Sweden 2020

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Abstract

The manufacturing industry of today is challenged by highly competitive and dynamic markets, changed customer behavior and new technologies applied in manufacturing industry seeking to improve productivity and efficiency. The concept of digital twins has entered the manufacturing scene as an important part of this technology development and Industry 4.0. The concept has attained large interest in academia in the recent years but the diffuseness of the concept still remains. This thesis explores the concept of digital twins in the manufacturing industry. Through a literature review and an interview study with representatives from the industry, the definition of the concept of digital twins has been explored further and a remarkable diversity in the view of the concept of digital twins has been found both in academia and industry. In this thesis two different types of digital twins have been identified: a product digital twin and a factory digital twin. These digital twins enable, among other things, improved productivity and efficiency in the manufacturing industry. When implementing digital twins in the manufacturing industries change management, clear communication, compatible systems and clearly stated use cases regarding the digital twin need to be established. Moreover, the concept of digital twins is still in its infancy and because of its diffuseness, further research could therefore focus on how the the evolution of the definition of digital twins can merge to a common understanding.

Keywords: digital twin, definition, Industry 4.0, manufacturing, smart manufacturing, interview study, benefit.

Acknowledgements

Firstly, we would like to thank our supervisor at Chalmers, Daniel Nåfors, for his unfailing support and encouragement during this thesis work. His guidance and great generosity with his time and thoughts throughout this project have been invaluable for us. We would also like to thank our examiner Björn Johansson for valuable input and making this thesis possible. We would also like to give a big thanks to Virtual Manufacturing for the warm welcome and for letting us perform this project. In particular, we want to thank Johanna Sigvardsson, our supervisor at Virtual Manufacturing, for providing feedback, contact information, and for answering our company-specific questions. We would also like to thank everybody who we met and got the opportunity to interview in this study for their willingness to share their thoughts and experiences.

Jenny Hultgren & Klara Lundström, Gothenburg, June 2020

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Acronyms

3D Three-dimentional. 33, 34, 39, 48, 49

AGV Automated Guided Vehicle. 36
AI Artificial Intelligence. 1, *Glossary:* AI

CAD Computer-Aided Design. 7, 34, 49
CPS Cyber-Physical System. 1, 5–7, 11, *Glossary:* CPS

ERP Enterprise Resource Planning. 6, 37, *Glossary:* ERP

IoT Internet of Things. 1, 6, 11, *Glossary:* IoT
ISO International Organization for Standardization. 8, 37, 51

MRP Material Resource Planning. 7, 37, *Glossary:* MRP

PLM Product Lifecycle Management. 5, 7, 12, 13, 49, *Glossary:* PLM

Glossary

AI - The technique for teaching computer programs or robots to take intelligent actions. 1

big data - A term that refers to a large amount of data and how to manage and analyze it. 1, 7

cloud computing - Cloud computing is a term for providing services over the internet such as storage, databases, software, networking, and analytics. 1

code or **coding** - is a way to label, compile, separate and organize data, from e.g. interview transcripts, which enables further data analysis. 14, 15, 22, 23, 45

CPS - The technologies that manage interconnected transformation between physical assets and its virtual representation. 1, 7, 8, 33, 36

deductive - A deductive study aims for testing theory and thus finding observations and data that support the hypothesis. 13

ERP - Unifies information from an organization's different departments, department functions, and business processes into one integrated system. 6

Grounded theory - A way to build up theory in a study. 5, 13–15, 17, 22

inductive - In an inductive study is the theory the outcome of the study, observations, and findings will result in a theory. 13, 17

Industry 4.0 - The fourth industrial revolution. Industry 4.0 includes high data volumes, multilateral communication, and interconnectedness between CPS and people. 1, 2, 5–7, 18, 37, 47, 51, 53

IoT - A core element within Industry 4.0 with embedded sensors, software, electronics, and network connectivity into devices. 1

Made-in-China 2025 - A strategic plan for transforming and improving China's industrial capabilities, through strengthening and securing China's position relative to global leaders. 1, 6

MRP - An information system supporting manufacturing business processes including planning and control, scheduling and other manufacturing activities. 7

PLM - PLM is a concept of seamless, streamlined integration of information from a product, generated through all phases of its entire life-cycle including information from related processes. 5

qualitative - In a qualitative study, the collected data refers to words and opinions rather than numbers. 13, 15, 17, 19, 21

quantitative - A quantitative study is a data-gathering method used for systematic collection of empirical, structured and statistical data. 13, 15

receiving companies - Manufacturing companies that are either using digital twins today or are identified as companies that could implement a digital twin. 19, 22, 23, 25, 29, 38

semi-structured interview - A flexible way to gather data by asking predetermined questions and unscripted follow-up questions. 15, 18

Smart Manufacturing - Smart Manufacturing is the term for a collaborative, integrated and real-time responding manufacturing system which utilizes big data, AI, IoT and cloud computing. 1, 2

structured interview - A way to gather data through a standardized process using a formal interview schedule to achieve as little variation between interviews as possible. 15

supplying companies - Companies claiming to deliver digital twins, or something that is generally classified as a digital twin, to the market. 19, 23, 25, 29, 31, 32, 36

1
Introduction

This chapter introduces the background of the thesis and why the subject is relevant. The chapter further describes the focus of the thesis presenting the thesis' purpose, aim and the research questions central in the project, followed by delimitations.

1.1 Background

The manufacturing industry of today is formed by highly competitive (Kritzinger, Karner, Traar, Henjes, and Sihn, 2018) and increasingly dynamic markets (Rosen, Von Wichert, Lo, and Bettenhausen, 2015). New ways of product consumption where customers request highly customized products (Schuh, Anderl, Gausemeier, Ten Hompel, and Wahlster, 2017) and short time to market (Schleich, Anwer, Mathieu, and Wartzack, 2017) challenge the manufacturing industry to adapt to fast changes in demand and to produce product mixes rapidly. The changed customer behavior together with recent technology development have pushed companies towards digitalization introducing new technologies to achieve higher productivity and efficiency (Kritzinger et al., 2018; Lee, Bagheri, and Kao, 2015). Companies see the productivity potential that the new production technologies, the connection of systems and digitalization, bring to the market which in turn allows for more efficient and sustainable use of resources and new business models (Schuh et al., 2017). At the same time, the virtual world is gaining increased importance in manufacturing (Tao, Zhang, and Nee, 2019). The interconnections between the physical and the virtual world and the fusion and seamless integration between them are seen as an increasingly important trend enabling technologies to improve the development of products and manufacturing (Tao, Zhang, and Nee, 2019).

Some of the technologies that have been used to overcome the challenges of connecting the physical and the virtual world other Smart Manufacturing, including big data, Artificial Intelligence (AI), Internet of Things (IoT), and cloud computing (Tao, Zhang, Liu, and Nee, 2019). These technologies have entered the scene of manufacturing during recent years. At the same time, manufacturing development strategies and campaigns have been initiated around the globe as the next step revolutionizing the manufacturing industry, such as Made-in-China 2025 and Industry 4.0 (Tao, Zhang, and Nee, 2019). Industry 4.0, which is a German initiative and refers to connectivity and Cyber-Physical Systems (CPS) (Xu, Xu, and Li, 2018), has eventually become prevalent and attained huge interest from research and industry (Culot, Nassimbeni, Orzes, and Sartor, 2020). Industry 4.0 has brought high expectations on the manufacturing scene to increase the level of automation, use resources more efficiently and increase the productivity of the production systems (Shao et al., 2019).

As an important part of Industry 4.0, and as a driver of Smart Manufacturing (Tao, Zhang, Liu, and Nee, 2019), the concept of digital twins has been widely mentioned in publications during the last years (Lu, Liu, Wang, Huang, and Xu, 2020). Digital twins have not only attracted academia but the industry as well, the concept is still in its infancy (Fuller, Fan, Day, and Barlow, 2019; Kritzinger et al., 2018; Lu et al., 2020) and there is a belief that the increasing interest in digital twins has only just begun (Lu et al., 2020). However, even though the interest of the topic is substantial, there is no clear definition of what the concept of digital twins entails (Shao et al., 2019; Tao and Qi, 2019). It is unclear what a digital twin is, what it should include and where it should be implemented (Shao et al., 2019). Despite this, the digital twin, which is characterized by its integration of physical and cyber systems (Tao, Zhang, Liu, and Nee, 2019), is seen as one of the technologies likely to enable Industry 4.0 and Smart Manufacturing (Tao, Zhang, Liu, and Nee, 2019). Today, due to the confusion of the concept, researchers as well as companies using the concept have their own definition of it (Wagg, Gardner, Barthorpe, and Worden, 2020). Consequently, the benefits of having a digital twin are diffuse, and the lack of consensus of the digital twin concept also contributes to manufacturers not embracing and introducing the concept of digital twins as quickly as expected (Shao et al., 2019). Due to the diffuseness of the concept, the application areas and desired features of the concept vary. Besides, many companies lack resources and expertise to examine and understand the concept (Shao et al., 2019). Hence, in order for the concept to be attractive and established on the market for manufacturing companies, the prerequisites for a digital twin need to be clarified and mapped.

1.2 Purpose and aim

The purpose of this master thesis is to investigate how the manufacturing industry could benefit from the concept of digital twins. Due to this, the aim of the project is to untangle the concept of digital twins and also investigate in how the industry perceives and uses the concept today. Based on this, this thesis will examine how manufacturing companies could gain benefit from digital twins and what prerequisites that need to be satisfied before a digital twin can be implemented. The aim is to define what problems that may occur during the implementation phase of a digital twin and how they could be solved.

1.2.1 Research questions

The following three research questions will be examined in order to gain insights in the stated purpose and aims of this thesis:

- **RQ1** - How could the concept of digital twins be defined?
- **RQ2** - What are the main uses and benefits of the digital twin concept in the manufacturing industry?
- **RQ3** - Which factors are important for a successful implementation of a digital twin in manufacturing industry?

1.3 Delimitations

During the project work, interviews were conducted with representatives from different companies. In the selection process companies positioned in Sweden were chosen, mainly in and close to the Gothenburg region in order to easier facilitate face to face interviews. Moreover, no physical tests or implementations of the findings were done, hence, the results are hypothetical.

2
Theory

This chapter presents the frame of theory related to the thesis. In the first part of this chapter, relevant technical theory is presented and explained. In this section, Industry 4.0 is central and therefore presented first. Related concepts to Industry 4.0, such as IT-programs and CPS, are then presented. Thereafter another concept related to Industry 4.0 is presented, namely the concept of digital twins which is central in this thesis and has therefore been given substantial focus in this chapter. Related to the concept of digital twins is Product Lifecycle Management (PLM) which is presented in the paragraph following Digital twin. The second part of this chapter contains study related theory. Here the concept of Grounded theory is presented along with two ways of gathering data, through a literature study and an interview study. An overview of how the chapter is build up is presented in Figure 2.1.

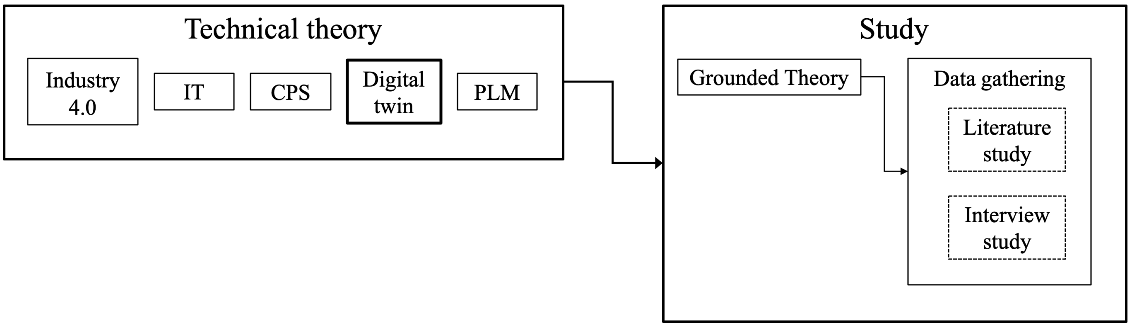

Figure 2.1: A summary and connections of the theoretical background of this study.

2.1 Technical theory

In this section, technical theory related to the thesis will be presented. Theory on Industry 4.0 is followed by IT, CPS, Digital twin and lastly PLM.

2.1.1 Industry 4.0

Throughout history, four industrial revolutions have occurred and each of them has substantially changed the prevailing manufacturing conditions. The first industrial revolution included the development of mechanical production facilities with the help of steam and water power (Xu et al., 2018). During the second industrial revolution, electrical energy was introduced which realized mass production (Xu et al., 2018). In the third revolution electronic and information technologies were introduced which enabled production automation. Industry 4.0 symbolizes the beginning of a fourth industrial revolution, which is currently evolving the industry (Xu et al., 2018). There is no clear definition of this fourth revolution (Culot et al., 2020). However, the Industry 4.0 concept can be defined as *"real-time, high data volume, multilateral communication, and interconnectedness between Cyber-Physical Systems and people"* (Schuh et al., 2017). Industry 4.0, with its huge amount of real-time data and information to affordable prizes, makes it possible for companies to make accurate and fast decisions (Schuh et al., 2017). This enables companies to react faster to rapidly changing customer demand (Schuh et al., 2017).

Industry 4.0 was first introduced in the year of 2011 during the Hannover Fair (Xu et al., 2018). In 2013 it was officially announced as a German strategy towards being a leader of the integrated industry (Xu et al., 2018). Similar initiatives to Industry 4.0 has been initiated at other places around the globe, in China for instance. In 2014, a strategy was revealed by China that aims to transform the country from being the world's workshop to being a world manufacturing power (Xu et al., 2018). The strategy is called Made-in-China 2025 and has a lot of similar newly developed technologies like Industry 4.0 (Xu et al., 2018). These technologies originate from disciplines such as IoT and CPS which are integrating the physical world with the virtual.

2.1.2 IT

IT is an essential part of Industry 4.0 and digital twins. In this section will notable IT-concepts within manufacturing, Industry 4.0 and digital twins be presented.

IoT

IoT is a core element in Industry 4.0 with embedded sensors, software, electronics, and network connectivity into devices (Negri, Fumagalli, and Macchi, 2017). This allows connection and interchange of data between devices with the help of internet (Negri et al., 2017). It also allows remote control of machines and resources which in turn enables a more direct integration between the physical world and the virtual world (Negri et al., 2017).

Data systems

ERP - Enterprise Resource Planning (ERP) unifies information from an organization's different departments, department functions and business processes into one integrated system (Ganesh, Mohapatra, Anbuudayasankar, and Sivakumar, 2014). The ERP system consists of various modules, normally one for managing each function in the company, such as HR, finance, production, quality, maintenance and sales, and distribution (Ganesh et al., 2014). The ERP system is built up by different hardware and software handling the different business processes (Ganesh et al., 2014).

MRP - Material Resource Planning (MRP) is a system that supports manufacturing business processes (Ganesh et al., 2014). The system integrates information and allows planning and control of materials, products and inventories as well as scheduling of manufacturing and purchasing activities (Ganesh et al., 2014).

2.1.3 CPS

CPS is defined as the technologies that manage interconnected transformation between physical assets and its virtual representations (Lee et al., 2015). Furthermore, has CPS been proposed as a smart, embedded and networking system that operates on both a physical and virtual level (Negri et al., 2017). CPS is interacting with and controls physical devices (Negri et al., 2017). CPS is feasible due to sensors and networked machines, which connect the physical assets within the factory (Lee et al., 2015). The sensors and networked machines contribute to large amounts of gathered data, so-called big data. If big data is managed properly the goal of an intelligent, resilient and self-adaptive industry can be reached (Lee et al., 2015).

2.1.4 Digital twin

A concept widely mentioned as an important part of Industry 4.0 is that of digital twins (Fuller et al., 2019; Negri et al., 2017; Tao, Zhang, Liu, and Nee, 2019). The digital twin concept first appeared in a presentation on PLM at the University of Michigan held by Grieves in 2002 (Grieves and Vickers, 2016). Over time the concept has been referred to as *mirrored spaces model*, *information mirroring model* and later, from 2011 and onward, *digital twin*. Various interpretations have encountered since the concept emerged, and neither academia nor industry agree upon what the concept entails (Tao and Qi, 2019). The digital twin is characterized by the integration of physical and cyber systems (Tao, Zhang, Liu, and Nee, 2019), and as the most basic description of a digital twin, many authors agree that it contains a physical part, a virtual part and a connection between them (Fuller et al., 2019; Tao and Zhang, 2017; Zheng, Lin, Chen, and Xu, 2018). However, the digital twin concept working as merely a descriptive Computer-Aided Design (CAD)-model in the early 2000s is now actionable (Grieves and Vickers, 2016) and the definitions are spread. People tend to classify simulation models as the same as digital twins, however, a digital twin might as well be a simulation model, but a simulation model may not for that matter be a digital twin (Shao et al., 2019). A digital twin may look like a simulation but is in fact much more (Lu et al., 2020). A simulation model may reflect real-world phenomenon but does not by definition show actions or happenings in real-time which digital twins do (Shao et al., 2019).

The first definition of the digital twin was given by NASA in 2010 for their air vehicles as *"A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin"* (Negri et al., 2017). Later, definitions of digital twins concerning other areas than aerospace appeared, covering more general products and production resources

(Negri et al., 2017). For instance, digital twins are used for planning (Kritzinger et al., 2018; Shao et al., 2019), monitoring, decision support, production optimization (Shao et al., 2019; Tao, Zhang, Liu, and Nee, 2019), testing, controlling states of products or processes (Shao et al., 2019), and for prediction of real-time behavior (Haag and Anderl, 2018; Shao et al., 2019). The motivation for using a digital twin is to achieve higher efficiency, economical benefits (Kritzinger et al., 2018), operation safety, improved product quality and higher productivity (Shao et al., 2019). The diversity of application areas has made the definition of digital twins scattered, but not only the fuzziness of the concept as such composes an obstacle for the implementation of digital twins. The collection and managing of huge data amounts, predictions related to complex systems, and low synchronization feasibility between the physical and digital world constitute other implementation problems (Schleich et al., 2017). International Organization for Standardization (ISO) standardization efforts of digital twins in manufacturing are currently being made (Shao et al., 2019), and the spread perception of the subject has paved the way for clarification and categorization of the digital twin concept. In the coming sections, three modern concepts within the digital twin area from the academic literature will be presented.

Digital twin - Level of data integration

Different definitions and sources use various terms describing the twinning concept. Apart from digital twin, terms such as digital model or digital shadow are used equivalently (Kritzinger et al., 2018). However, these terms can be distinguished from each other and classified from a data integration level point of view between the physical and virtual parts (Fuller et al., 2019; Kritzinger et al., 2018; Shao et al., 2019). In this classification, the digital model is ranged with the lowest level of data integration, the digital shadow comes next with a higher data integration level and the digital twin is classified as the term with the highest level of data integration of the three.

Digital model
A digital model is referred to as a digital representation of either a planned or an existing object, where no automated data exchange between the physical and the virtual counterpart exists (Kritzinger et al., 2018). It is described that the data exchange between the objects is managed manually, as visualized in Figure 2.2. The digital copy will not be affected by changes made on the physical object or vice versa (Kritzinger et al., 2018). An example of a digital model is today's offline simulation models (Shao et al., 2019).

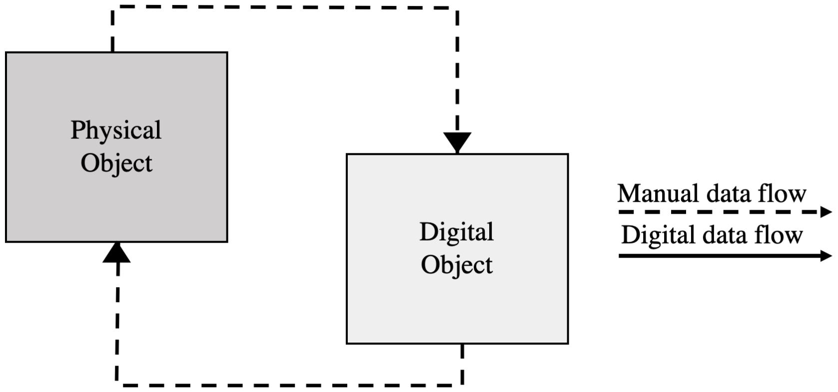

Figure 2.2: The data flow in a digital model is managed manually between the physical and virtual counterpart. Picture adapted from Kritzinger et al. (2018).

Digital shadow
The term digital shadow, having a higher level of data integration between the physical and virtual object, is built on the premises of the digital model with the addition that there is an automatic one-directional data flow from the physical object to the digital counterpart (Kritzinger et al., 2018), while the data flow from the digital part to the physical part is managed manually. As visualized in Figure 2.3, a change in the physical object implies a change in the digital copy, but not the other way around (Kritzinger et al., 2018). A digital shadow can be exemplified by a simulation model fed with real-time input data from sensors (Shao et al., 2019).

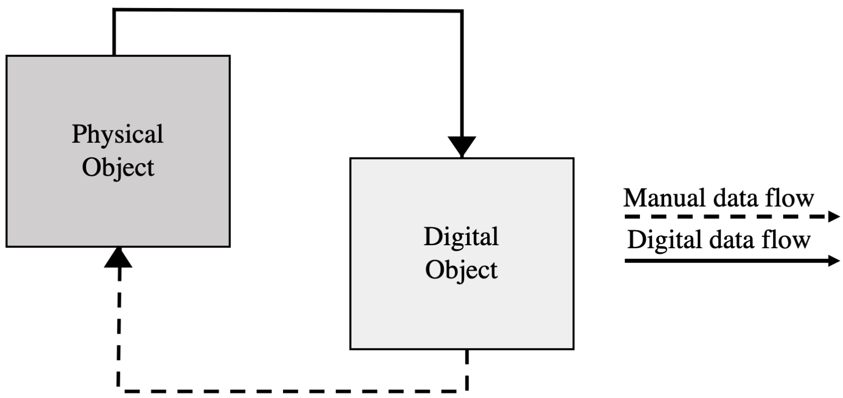

Figure 2.3: The data in a digital shadow is automatically transferred from the physical part to the digital part but managed manually in the opposite direction. Picture adapted from Kritzinger et al. (2018).

Digital twin

Expanding the level of data integration further, a digital twin can be achieved if the data exchange is digital and bidirectional between the existing, physical object and the digital object (Kritzinger et al., 2018). This completely integrated data exchange, as visualized in Figure 2.4, results in that changes made to the physical object also change the digital counterpart and vice versa (Kritzinger et al., 2018). A digital twin in this context could be a simulation model fed with real-time input data from sensors, which also updates process parameters or parameters of equipment in manufacturing for instance (Shao et al., 2019).

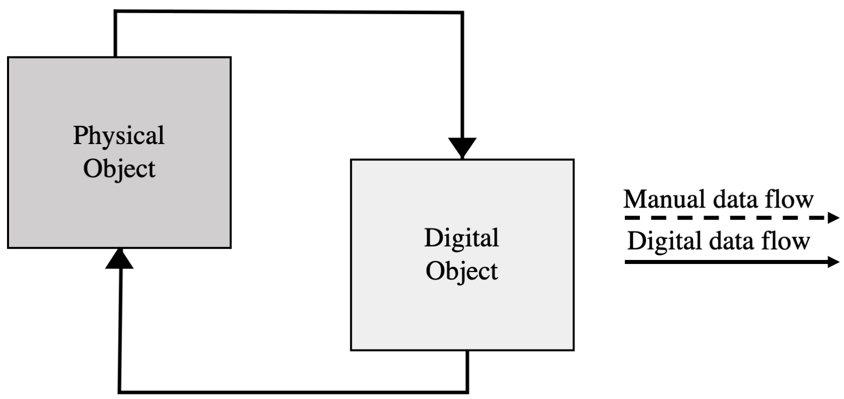

Figure 2.4: The data in a digital twin is automatically transferred from the physical object to the digital object and vice versa. Picture adapted from Kritzinger et al. (2018).

Digital twin - Maturity Levels

Another digital twin concept presented in literature is that of maturity or sophistication levels (Madni, Madni, and Lucero, 2019). The authors behind this classification use four levels for distinguishing between different levels of digital twins, ranging from low maturity to high maturity as presented in Figure 2.5. The model on the first level is called *pre-digital twin*, at the second level is the *digital twin*, followed by *adaptive digital twin* and *intelligent digital twin* (Madni et al., 2019).

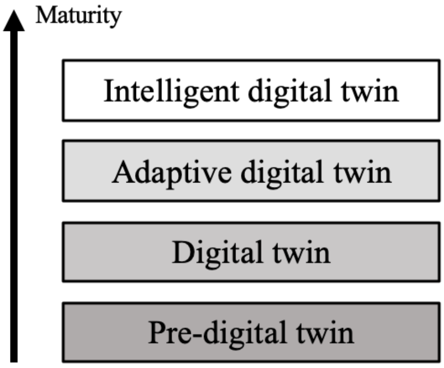

Figure 2.5: Digital twins divided into four levels based on maturity levels ranging from low to high maturity.

The *pre-digital twin* is described as a virtual prototype without a physical counterpart, which could be used for decision support and risk mitigation early in design phases (Madni et al., 2019). Moving on to the higher sophisticated *digital twin*, it has a physical counterpart (Madni et al., 2019). Further, it can batch-wise, integrate data concerning operations, maintenance and health status from the physical counterpart. The data exchange is bidirectional and this kind of twin can be used for improving operations of the physical object and investigate what-if scenarios (Madni et al., 2019).

The *adaptive digital twin* also has a physical counterpart, but data is transferred continually in real-time or in batches (Madni et al., 2019). The adaptive twin stretches into the "smart world" since it can adapt the user interface for various users and learn individual users' preferences with the aid of supervised machine learning (Madni et al., 2019). The highest maturity level twin incorporates all capabilities of the adaptive digital twin plus unsupervised machine learning (Madni et al., 2019). This *intelligent digital twin* is claimed to have a high degree of autonomy (Madni et al., 2019).

Digital twin - relation to IoT and CPS

In a paper by Lu et al. (2020) the different concepts of IoT, CPS and digital twins are explained and the interactions between them are presented in Figure 2.6. According to this model a digital twin is limited to the digital representation of a physical object and is a high-fidelity, living model that updates continuously when its physical counterpart changes. All digital twins exist in the cyber world but a digital twin can not exist without its physical copy. The paper also defines CPS as a digital twin with its physical asset together, thus connecting the physical and the cyber world through an object. Moving on to IoT, IoT is the connection of physical assets in the physical world and as illustrated in Figure 2.6, several physical assets in a facility can be connected through IoT (Lu et al., 2020).

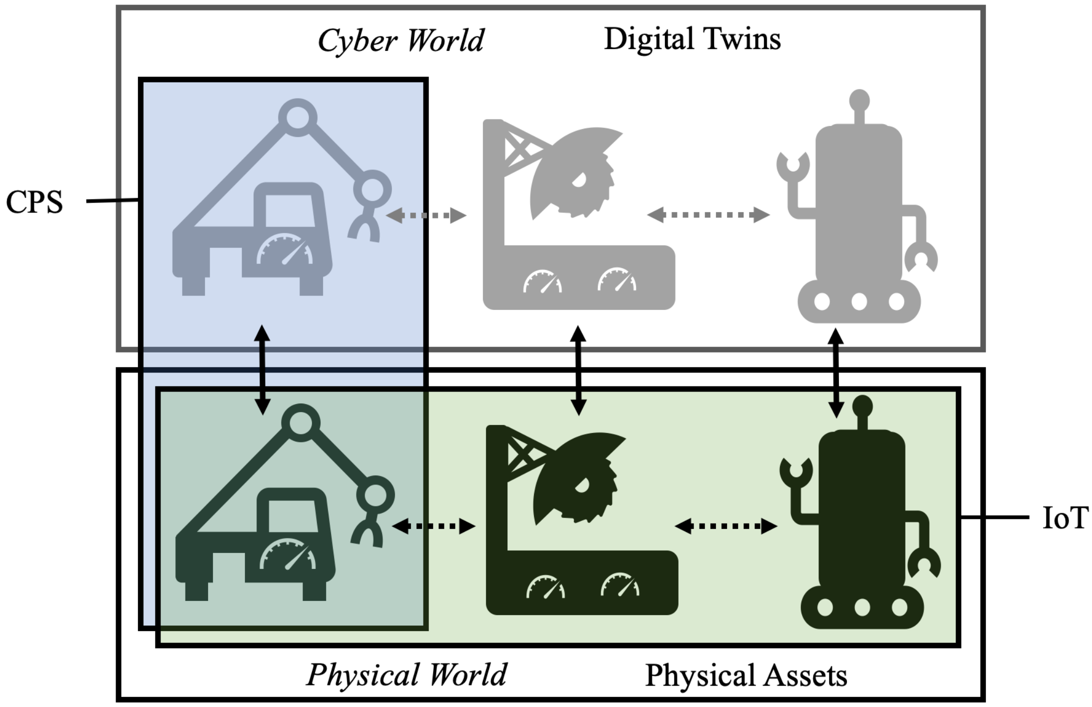

Figure 2.6: Relations of CPS, IoT and digital twins in the physical world and the cyber world. A digital twin is a digital representation of a physical object, CPS refers both to the digital twin and its physical counterpart, and IoT is the connection between physical assets in the physical world. Picture adapted from Lu et al. (2020).

2.1.5 PLM

PLM is a concept for seamless, streamlined integration of information from a product, generated through all phases of its entire life-cycle including information from related processes (Ameri and Dutta, 2005; Sudarsan, Fenves, Sriram, and Wang, 2005). The objective of the concept is not only to have information accessible in the right place at the right time (Ameri and Dutta, 2005), but also to make it available to everyone in an organization and other stakeholders, such as customers and key suppliers (Sudarsan et al., 2005). PLM is described as a strategy for businesses to create an environment where the product is central (Ameri and Dutta, 2005). Furthermore, it is used for knowledge management, it is a way to acquire, represent, regenerate and reuse knowledge of products in an effective manner (Ameri and Dutta, 2005). The essence of PLM is to through integration of information create a so-called body of knowledge (Ameri and Dutta, 2005) and to ensure traceability (Sudarsan et al., 2005).

PLM is often seen as a large set of complex IT tools and applications since the knowledge management, the core of the concept, is enabled by technology (Ameri and Dutta, 2005). The technology and IT infrastructure including software, hardware and internet technologies facilitate creation, transformation and sharing of knowledge along with the product's life-cycle phases (Ameri and Dutta, 2005; Sudarsan et al., 2005).

The PLM concept is seen as a necessity for successful business on the competitive, global market and is used for improving business through reduced time to market, improved innovation processes and reduced errors (Sudarsan et al., 2005).

2.2 Study

The nature of the link between theory and the performed research needs to be characterized (Bryman and Bell, 2011). While characterizing this link several issues affect the outcome. One of these issues is if data is used either to build or test theories. The relation between theory and research can either have an inductive or deductive approach (Bryman and Bell, 2011). A deductive study aims for testing theory and thus finding observations and data that support the hypothesis. With inductive studies, the theory is the outcome of a study, where observations and findings will result in the theory, this is visualized in Figure 2.7. Hence, general conclusions can be drawn from the collection of individual observations (Hammond and Wellington, 2012).

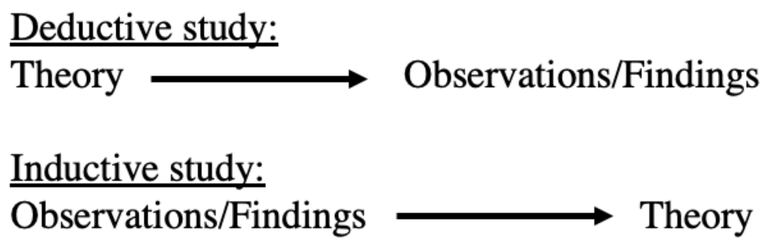

Figure 2.7: In deductive studies, theory is tested and the outcome is findings and observations supporting the theory hypothesis. In inductive studies, theory is built through observations and findings. Picture adapted from Bryman and Bell (2011).

Two types of research strategies are quantitative and qualitative studies (Bryman and Bell, 2011). Quantitative research entails a deductive approach to the relationship between research and theory. It also emphasizes quantification when collecting and analyzing data. Qualitative research emphasizes words rather than numbers when collecting and analyzing data. Qualitative research has also a more inductive approach to the relationship between theory and research.

2.2.1 Grounded theory

Grounded theory is a well-known and often used strategy when it comes to qualitative data analysis (Bryman and Bell, 2011) and inductive research methods (Hammond and Wellington, 2012). Furthermore, it has been used for quantitative researches as well (Walsh et al., 2015). Grounded theory was developed by Glaser and

Strauss in 1967 but since then have different paths of it been developed (Bryman and Bell, 2011). It has been applied in many fields of research and has, therefore, different meanings for different people (Walsh et al., 2015). There are, however, some core tools that Grounded theory entails (Bryman and Bell, 2011; Reilly, Paper, and Marx, 2012). These are *Theoretical coding, Constant comparison, Theoretical sampling* and *Theoretical saturation.*

Theoretical coding is the core process of Grounded theory (Bryman and Bell, 2011). Gathered data is decomposed into different parts that are labeled with a category (Reilly et al., 2012). These categories can have different levels. The purpose of doing this is to find patterns in the data and to organize it for further analysis (Saldana, 2011). *Constant comparison* means that the researcher should have a close and constant comparison between coding categories and found theory (Bryman and Bell, 2011). Data should be analyzed and coded simultaneously (Reilly et al., 2012). This means that all new data should iteratively be compared to old data to enable adjustments of theoretical categories based on the ongoing analysis. The process of data collection for generating theory is called *Theoretical sampling* (Bryman and Bell, 2011). Data should be collected systematically and logically based on previously collected data (Reilly et al., 2012). *Theoretical saturation* is about finding everything that can be found in a coded category (Reilly et al., 2012). When newly collected data is not giving new information or redefines coding categories then the category can be considered saturated.

In addition to these four tools a fifth one can be added, called *Theoretical sensitivity* (Reilly et al., 2012). Theoretical sensitivity is about the researchers' ability to discover and interpret which data that is meaningful to the theory that is about to be built up (Reilly et al., 2012). The first step to achieve this is to begin the coding with as few preconceptions as possible, this to be able to understand what is really happening during the work.

2.2.2 Data gathering

In research, data collection often plays an essential role. There are many different ways in which data can be gathered. In the below two sections, data collection by means of a literature review and an interview study are described.

Literature study

In the early phase of a study, prior presented knowledge within the field of interest should be investigated, for this, a literature study is proposed (Saldana, 2011). Studying literature on the topic gives an understanding of that is already known (Bryman and Bell, 2011), as well as a firm knowledge ground that enables new findings and contributions from one's own work to the field (Saldana, 2011).

Interview study

There are several different types of research interviews, of which the aim of them is to extract information from respondents (Bryman and Bell, 2011). Two common interview types are structured interviews and semi-structured interviews. The value of interviews is that the researcher can investigate feelings, thoughts, values, events and more general perspectives of the interview object (Hammond and Wellington, 2012).

The goal of the structured interviews, being the most commonly used type in survey research, is to gather data through a standardized process, using a formal interview schedule, with as little variation as possible, minimizing differences between the interviews (Bryman and Bell, 2011). When questions are asked in the exact same way and the same order for all interviews, results can easily be aggregated and the method is generally appropriate for quantitative studies (Bryman and Bell, 2011).

In contrast to the structured interview, the semi-structured interview refers to an interview where the interviewer often has a list of specific topics, or general questions, to be covered, an interview guide, but where the interviewer can vary the exact asked questions (Bryman and Bell, 2011). In a semi-structured interview the interviewer also has the opportunity to ask additional, non-predetermined, questions based on the interviewees' answers. The asked questions do not need to follow the outline of topics in the guide (Bryman and Bell, 2011). This enables flexibility in the interview and gives leeway for the interviewee to answer in his or hers desired way (Bryman and Bell, 2011). The important aspect is that all topics and general questions in the guide are covered by the end of the interview (Bryman and Bell, 2011). This interview type is associated with qualitative studies (Bryman and Bell, 2011).

One of the biggest challenges in qualitative studies is to transform huge amount of notes and data into a final report and a result (Chandra and Shang, 2019). To do this coding can be used. Coding is a key concept in Grounded theory (Bryman and Bell, 2011). Coding interviews entail reviewing interview transcripts or notes to find important parts to label with specific words (Bryman and Bell, 2011). One usually chooses to code words and phrases that stand out or summarize the interview (Saldana, 2011). Similar words can then be combined into categories or split up to further subcategories. Coding is a way to label, compile, separate and organize data in that way that enables further analysis of the data (Bryman and Bell, 2011).

3
Methodology

In this chapter, the methodology used in the study is described. The study, and hence the chapter, is divided into five main areas with corresponding subareas. The five areas are: Planning phase, Literature study, Interview study, Analysis and lastly Data compiling. The methodology used is illustrated in Figure 3.1, and it has been a parallel and an iterative process collecting and analyzing data from both the literature study and the interview study. Each main area and subarea in the figure is explained more thoroughly further in the subsections of this chapter.

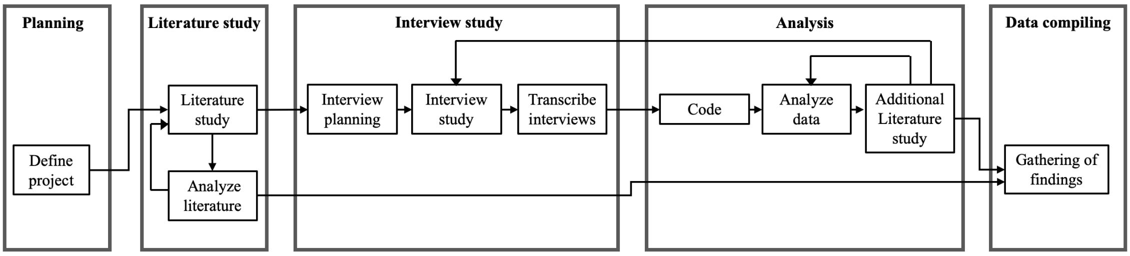

Figure 3.1: A summary of the methodology used in this thesis and their chronological order.

For this study, an inductive, qualitative research method was chosen since the emphasis is put on words, values, and interpretations of people rather than numbers and absolute figures. In this study, several sources have been used to gather qualitative data and build theory. The quality of a qualitative study depends on both the gathered data and how it has been analytically utilized (Saldana, 2011). Data has been collected through a literature study and an interview study. The philosophy of Grounded theory has been central throughout the project to iteratively collect data, analyze it and build the theory of the digital twin concept.

3.1 Project planning

The first phase of the project was a planning phase. To achieve an initial overview of the subject and to be able to establish research questions an initial literature study was conducted. For the same reason, a researcher within the field of digital twins was contacted for a meeting in the early phase of the project. A time plan illustrated by a Gantt-chart was also created and sub-deadlines were established to ensure that the work would meet the final deadline.

3.2 Literature study

An initial literature study was performed, as proposed by Saldana (2011). For the purpose of finding trustworthy sources of information Scopus database was used in the search for relevant literature. The document search was utilized for finding papers using the keywords *digital twin*, *digital twin AND definition*, *digital twin AND concept*, *digital twin AND digital shadow*, *digital twin AND challenges*, *digital twin AND production*, and *Industry 4.0*. In addition, associated and cited sources to papers already found have also been followed up. In the screening process, the number of citations and the year of publication was taken into consideration. Papers with the above-mentioned search words were sorted by the highest cited papers first. This was done to ensure that papers with high citation, and high fidelity content, would not be missed out in the study. As the development within the fields of digital twins and Industry 4.0 has gone extremely fast, the year of publication was noted and taken into consideration while reading the papers. Furthermore, the literature study contributed to the selection of a preferable methodology to use in the project, from which an appropriate interview method suitable for the project was chosen.

3.2.1 Analysis of literature - Definition of digital twin

To establish a definition for the concept of digital twins within this thesis, all relevant papers found in the literature study regarding digital twins were analyzed further. Firstly, common notions, definitions and descriptions from the literature regarded as important of what a digital twins should entail were identified and included as definition categories in an Excel sheet. The created categories were frequently mentioned in the studied papers as something the digital twin needed to fulfill to be regarded as a digital twin. The process of identifying definition categories in the literature's definitions of digital twins was iterative. As more papers were analyzed, new categories were added and old ones were altered.

Secondly, all explicitly written definitions of digital twins found in the studied papers were gathered in a list in the Excel sheet. Important to note is that only descriptions of digital twins clearly stated as definitions in the text were gathered. In several papers, similar content to the above-mentioned definition categories were presented or discussed, but not clearly specified as the definition of a digital twin, these were therefore not added to the Excel sheet. Thirdly, the list of definitions were then compared to each created definition category and if the definition fulfilled a category this was noted. In cases where it was difficult to, with absolute certainty, state that a definition fulfilled a category, this was also noted.

3.3 Interview study

For the interview study, a semi-structured interview approach was chosen. The rationale behind this decision was the apparent ambiguity and elusiveness of the concept of digital twins that have been addressed in the literature. Thus a flexible, semi-structured interview gave the opportunity to better meet interviewees with different conceptions and interpretations of the subject. This interview format also delivered qualitative, rich results and gave an indication of what aspects of the concept that the interviewees perceived as important.

3.3.1 Interview planning

The target companies in the focus of the interview study can be divided into two different groups. The first group constitutes of companies claiming to deliver digital twins, or something that is generally classified as a digital twin, to the market. These are from here on referred to as supplying companies. The other group comprises companies, in the manufacturing sector, that are either using digital twins today or are identified as companies that could implement a digital twin. The latter group will onward be referred to as receiving companies.

For each of the two interview groups, a suitable interview guide was developed in order to respectively get an insight into how the industry view the digital twin concept, what is offered on the market, and what features are desirable. To get guidance and tips in the process of creating the interview guides, a knowledgeable researcher with substantial experience in conducting interview studies was contacted for a meeting prior designing the guides. The researcher also contributed with information on what to consider when transcribing and coding interviews. These valuable words of advice was used when conducting the interview stud2y.

Since the formation of interview guides are rather unrestricted, the interview guides were designed with the research questions in mind as suggested by Bryman and Bell (2011). In other words, information that was wished to be attained from the interview study to facilitate answering the thesis's research questions were considered while designing the interview guides. The content of the two guides were also built on findings of what proved to be important aspects of digital twins in the literature study. The questions in the two guides differs a bit to fit the two company groups. Each of the guides are built around four to five sections. The interview guide for the supplying companies contains five sections: *Information & General Information*, *Map company context*, *General digital twin definition*, *Company specific digital twin* and *Sum-up*. The interview guide for the receiving companies holds four sections: *Introduction & General Information*, *Map company*, *Knowledge and usability of digital twins* and *Sum-up*. The different sections not only give the guide structure and a natural flow but are also a way to make sure that all sections get covered in all interviews so that no sections are missed. In Table 3.1 and Table 3.2 the motivation of the section's content for the supplying company guide and the receiving company guide are presented respectively. Further, guidelines given by Bryman and Bell (2011) regarding recording and ethical considerations while conducting interviews were followed in the planning phase. More specifically, the interview guides were designed to include introductory information of the interview, recording options, and the possibility to participate anonymously.

Table 3.1: Sections and content of the interview guide for supplying companies.

Section	**Content**
Introduction & General Information	The sections cover practical information to the interviewee regarding the interview session and how the collected information will be used. The goal of this section is to inform the interviewee about the background, scope and aim of the project so that the context of the interviewee's participation is clear. Moreover, it is an introduction of the interviewee and the interviewee's role in the company.
Map company context	This section is for achieving an initial understanding of the company, in what context they operate and how long they have been involved with the digital twin concept.
General digital twin definition	The goal of this section is to retrieve the interviewee's general perception and understanding of the digital twin concept (in order to compare this with common notions in literature).
Company-specific digital twin	The goal of this section is to comprehend the company-specific digital twin. What kind of digital twin the company offers, how it works, and the benefits of using it.
Sum-up	This section is to get feedback on the conducted interview and to verify that the interviewee understands how the information will be used.

Table 3.2: Sections and content of the interview guide for receiving companies.

Section	Content
Introduction & General Information	The sections cover practical information to the interviewee regarding the interview session and how the collected information will be used. The goal of this section is to inform the interviewee about the background, scope and aim of the project so that the context of the interviewee's participation is clear. Moreover, it is an introduction of the interviewee and the interviewee's role in the company.
Map company	The goal of this section is to understand the company and how they work with digitalization. It is also for assessment of the interviewee's knowledge about digitalization, and the concepts of Industry 4.0 and digital twins.
Knowledge and usability of digital twins	This section divides the interview into one out of two tracks dependent on whether the interviewee is familiar with the digital twin concept or not. Regardless of the track chosen, the questions are similar but adapted to fit the context. The goal is to identify wanted functions, when, how and by whom the digital twin can be used, what benefits can be drawn from it, strengths, weaknesses and potential implementation obstacles.
Sum-up	This section is to get feedback on the conducted interview and to verify that the interviewee understands how the information will be used.

To ensure that the questions developed in the interview guide would enable the collection of appropriate qualitative data leading the project closer to answering the research questions, the questions were developed in multiple iterations and a pilot test of the interview guide and its questions were made, as suggested by Bryman and Bell (2011). The pilot interview was conducted with a person active within the field of the study and not only provided experience of conducting interviews but was also an opportunity to judge how well the interview questions fit for their purpose (Bryman and Bell, 2011). Hence, it was an opportunity to identify and avoid misconceptions for the qualitative data gathering. Feedback from the pilot test was then used for modification of the interview guides.

3.3.2 Interviews

When searching for appropriate interview candidates various approaches were used and contact information was gathered from several different sources with the aim to attain different perspectives on the digital twin subject. Searching the web and using the research team's personal network were the two approaches used to find companies dealing with digital twins. In order get a broader, more nuanced picture of the industry's perception of the digital twin concept, the aim was not only to perform interviews with different companies but, to the extent possible, perform several interviews at the same company to identify inter-company discrepancy. For around a third of the interviewed companies more than one interview was conducted. Many of the interviewees were managers and had engineering background. For the receiving company group, several of the interviewees had work titles connected to manufacturing, production and layout.

To establish a more natural conversation and to avoid miss interpretations the intention was to conduct the interviews face to face with the interviewees. The majority of the interviews were performed accordingly, however, approximately half of the interviews were conducted digitally due to either long distances but also because of meeting restrictions due to the Covid-19 virus spreading at the same time the project was conducted. The interviews were around 1 h each and performed during five weeks. The interviews were conducted in the native language of the research team. The interview guides were developed in Swedish and later translated to English.

To get a view of what was offered on the market and ideas on how an actual digital twin could function and look like, the supplier companies were the first ones to be interviewed, followed by the receiving companies.

3.3.3 Transcription of interviews

The conducted interviews were transcribed in order to enable further analysis of them. To get the transcriptions as accurate as possible while having the interviews and observations fresh in mind, the interviews were transcribed as soon as possible after each conducted interview session, as suggested by Bryman and Bell (2011). This proceeding also enabled parallel data collection and analysis which is central in Grounded theory (Bryman and Bell, 2011).

3.4 Analysis

The information gathered in the interview sessions were analyzed by coding the transcripts. The interview coding was conducted systematically and the gathered information was categorized in a way that matched the topics in the interview guides so that the findings were structured appropriately. The coded information was then analyzed further and compared to the earlier performed, and an additional, literature study.

3.4.1 Coding of interviews

The transcripts were coded using the software nVivo. In the software, it is possible to mark and correlate parts of the text to one so-called node which is also given a heading. Each node then represents a category and it is possible to arrange nodes into sub-nodes to show relationships between the nodes. The software also enables collaboration on the same project. Since the interviews with the supplying and receiving companies were conducted based on two different interview guides leading to discussions on separate subjects, two separate coding files were constructed in nVivo, one for transcripts of supplying companies and one for receiving companies. To focus the coding and facilitate finding information that would lead the project work closer to its target, the research questions were kept in mind during the whole coding process.

3.4.2 Analyze collected data from interviews

Subsequent to the coding of interview transcripts in the nVivo software, the coded texts were analyzed further. In this process, the interviews were compiled and headings, categories, and node relationships in nVivo were used to draw parallels and conclusions between the different interviews. Specifically, this was done to compare interviews with each other, in order to investigate and identify patterns, connections, similarities and dissimilarities between them. In addition, this analysis also facilitated the structuring of findings in screening out what findings were new, what was already known and what information brought the project work closer to answering the research questions.

3.4.3 Additional literature study

An additional literature study was performed subsequent to the performed interview study alongside the analysis of the collected data. This second literature review aimed to get a greater understanding of topics brought up during the interviews, but it was also a way to further address commonly appearing matters and concepts from the interviews in the project work.

3.5 Data compiling

Compilation of all the relevant gathered data constituted the last part of the working process. In this step, all information gathered during the study, both from the literature review and the interviews, was compiled. For enabling identification of differences, similarities and knowledge gaps in the conception of the digital twin concept between academia and industry, findings from both the literature study and the interview study were compared to each other and conclusions were drawn for each of the project's three research questions.

4

Results

This chapter presents the results from the project. The chapter is divided into three separate main parts, each focusing on one of the research questions. This classification is shown in Figure 4.1 below. After each section a short summary of the research question in focus is presented.

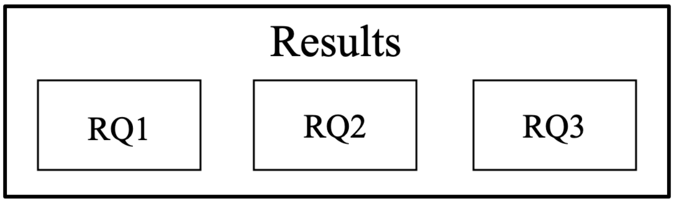

Figure 4.1: An illustration of how the chapter is structured. Starting from the left with research question number one and then the chapter will examine each research question stated in the thesis.

In this study, 26 people within the field of manufacturing and/or digital twins from 19 companies were interviewed. Out of these, 15 people from 11 companies were interviewed from supplying companies. The corresponding numbers for the receiving companies of digital twins were 11 people from 8 companies. The interview guides used in the interviews are available in Appendix A.

4.1 RQ1 - Definition of digital twins

In this section findings from both the literature and the interview study answering research question number one will be presented. The research question is: *How could the concept of digital twins be defined?*

4.1.1 Analysis of literature data

When reviewing literature regarding digital twins it is obvious that there is an ambiguity in the area, that different authors argue for different definitions and various aspects are considered as being the most important. In the screening process of the literature, 23 papers including 59 different definitions were chosen and considered. While identifying important and frequently occurring definitions in the compilation of definitions from the papers, seven definition categories of what a digital twin should include in order to be classified as a digital twin were developed. These categories are:

- A digital/virtual representation of a physical item
- Three parts: physical, digital and a connection between them
- Reflect real-time
- Continually updated
- Bidirectional information flow
- Represent the whole life cycle
- No clear definition

These definition categories are presented further in Table 4.1 together with a description of each category and references supporting the categories. The order in which the categories occur in the list is insignificant of their importance. Note that the categories are not mutually exclusive and that several categories can be fulfilled by the same definition.

Table 4.1: Definition categories of digital twins created from the definition analysis from the literature review, descriptions of the categories and papers supporting the categories.

No.	Category	Description	References
1	A digital/virtual representation of a physical item	A digital twin should contain two parts	(Borth, Verriet, and Muller, 2019) (Boschert, Heinrich, and Rosen, 2018) (Fuller, Fan, Day, and Barlow, 2019) (Haag and Anderl, 2018) (Kobryn, 2019) (Kritzinger, Karner, Traar, Henjes, and Sihn, 2018) (Lu, Liu, Wang, Huang, and Xu, 2020) (Madni, Madni, and Lucero, 2019) (Miller, Alvarez, and Hartman, 2018) (Negri, Fumagalli, and Macchi, 2017) (Rasheed, San, and Kvamsdal, 2019) (Rosen, Fischer, and Boschert, 2019) (Rosen, Von Wichert, Lo, and Bettenhausen, 2015) (Saracco, 2019) (Schleich, Anwer, Mathieu, and Wartzack, 2017) (Tao and Qi, 2019) (Tao and Zhang, 2017) (Wagner et al., 2017) (Zhang, Zhang, and Yan, 2019) (Zheng, Lin, Chen, and Xu, 2018)

No.	Category	Description	References
2	Three parts: physical, digital and a connection between them	A digital twin should contain three parts	(Borth, Verriet, and Muller, 2019) (Kritzinger, Karner, Traar, Henjes, and Sihn, 2018) (Negri, Fumagalli, and Macchi, 2017) (Rasheed, San, and Kvamsdal, 2019) (Rosen, Von Wichert, Lo, and Bettenhausen, 2015) (Tao and Zhang, 2017) (Zhang, Zhang, and Yan, 2019)
3	Reflect real-time	A digital twin should reflect what is happening right now	(Fuller, Fan, Day, and Barlow, 2019) (Kritzinger, Karner, Traar, Henjes, and Sihn, 2018) (Negri, Fumagalli, and Macchi, 2017) (Rasheed, San, and Kvamsdal, 2019) (Rosen, Von Wichert, Lo, and Bettenhausen, 2015) (Stecken, Ebel, Bartelt, Poeppelbuss, and Kuhlenkötter, 2019) (Tao and Qi, 2019) (Tao and Zhang, 2017) (Zhang, Zhang, and Yan, 2019)
4	Continually updated	A digital twin should update non-real-time data frequently but intermittent	(Fuller, Fan, Day, and Barlow, 2019) (Kobryn, 2019) (Madni, Madni, and Lucero, 2019) (Negri, Fumagalli, and Macchi, 2017) (Rosen, Fischer, and Boschert, 2019) (Zhang, Zhang, and Yan, 2019)
5	Bidirectional information flow	Information flows between the digital and physical parts should go in both directions	(Fuller, Fan, Day, and Barlow, 2019)

No.	Category	Description	References
6	Represent the whole life cycle	A digital twin should consider PLM aspects	(Borth, Verriet, and Muller, 2019) (Fuller, Fan, Day, and Barlow, 2019) (Haag and Anderl, 2018) (Lu, Liu, Wang, Huang, and Xu, 2020) (Madni, Madni, and Lucero, 2019) (Negri, Fumagalli, and Macchi, 2017) (Rasheed, San, and Kvamsdal, 2019) (Rosen, Fischer, and Boschert, 2019) (Rosen, Von Wichert, Lo, and Bettenhausen, 2015) (Schleich, Anwer, Mathieu, and Wartzack, 2017) (Tao and Zhang, 2017) (Tao, Zhang, Liu, and Nee, 2019) (Zhang, Zhang, and Yan, 2019) (Zheng, Lin, Chen, and Xu, 2018)
7	No clear definition	Definitions supporting ambiguity or fuzziness of the digital twin concept	(Negri, Fumagalli, and Macchi, 2017) (Wagg, Gardner, Barthorpe, and Worden, 2020)

When comparing all explicitly stated definitions in papers with the created definition categories, 54% of the definitions corresponded with category number 1, in Table 4.1, saying that a digital twin has a digital or virtual part, and a corresponding physical part. Thus, this category was the most occurring of the seven. In Table 4.2 the categories from Table 4.1 are sorted in descending order after how frequently they occurred in the 59 investigated literature definitions. Two of the categories occurred the same amount of times, these are marked with stars and placed in the table without putting further thoughts to the internal order.

Table 4.2: The definition categories sorted in descending order according to how frequently they occurred in the 59 literature definitions.

No	Most frequently occurring categories in the top	Frequency
1	A digital/virtual representation of a physical item	32/59=54%
6	Represent the whole life cycle	18/59=31%
3	Reflect real-time	12/59=20%
2	Three parts: physical, digital and a connection between them ⋆	6/59=10%
4	Continually updated ⋆	6/59=10%
7	No clear definition	3/59=5%
5	Bidirectional information flow	2/59=3%

As the second most occurring definition category, 31% of the investigated categories corresponded to category 6 referring to the representation of the whole life-cycle of the object or process that the digital twin is representing. The third highest noted category was number 3, which referred to the real-time update of the digital twin. This definition category occurred in 20% of the definitions in the investigated papers. The three categories, 1, 6 and 3, occurred more frequently in the papers' literature definitions than the other categories. Category 2 and 4 were noted considerably fewer times occurring in 10% of the 59 investigated definitions. As for category 7 and 5, these were noted fewest times explicitly in literature definitions, 5% and 3% respectively, but they still got included on the list since they were perceived as important when reading the papers.

If a definition of a digital twin would be based on this analysis, a digital twin should: have both a digital part and a physical part, be able to represent the whole life cycle of its physical counterpart and be updated in real-time. However, it may be important to consider other aspects when defining a digital twin. As mentioned earlier, the papers discuss more on digital twins and describe other important aspects than what is clearly stated in their definitions of digital twins. One such discussed category is number 2, in Table 4.1, describing the digital twin as three parts: a digital part, a physical part and a connection between them. Besides enabling communication between the digital and physical parts, the connection described in category 2, facilitates several of the other categories in the table, such as continually updated and bidirectional information flow. Therefore definition number 2, with a physical and digital or virtual part and a connection between them, is considered as key in a definition of digital twins. A basic definition of digital twins has been established in this thesis based on the analysis of the definitions found in the literature. *A digital twin has a digital or virtual part, a physical part and a connection between them.*

4.1.2 Analysis of interview data

The interviews indicate that the indistinctness of the concept of digital twins is not only common in literature but in the industry as well. The interpretations of the definition of a digital twin and what a digital twin is, is even broader in the industry than in the literature. Generally, the supplying companies are better informed and well-grounded in the concept, and have a closer view of the concept to those presented in literature than the receiving companies. The digital twin concept is referred to as an elusive buzzword reoccurring at conferences, seminars, exhibitions and in sale situations. Some of the interviewees tend to intentionally avoid the word digital twin in order to avoid misunderstandings. Moreover, many of the interviewees see the digital twin concept as nothing new, but rather as a new name on an old concept that entered the industry context about 5-6 years ago. Hence, there is a lag in the embracing of the digital twin concept in industry compared to academia.

Many of the interviewees describe a digital twin as a digital or virtual reflection of something physical, and that a digital twin should contain data. For both interview groups, it is common that merely simulations are considered as digital twins, and that they see the digital twin as something that is used for understanding and predictions. The literature, on the other hand, does not equalize simulations with digital twins in the same manner. Common industry notions of what a digital twin is, are presented in a word cloud in Figure 4.2, where the most frequently used ones are *Digital reflection*, *Data* and *Simulation*. The larger the font size the more frequently the words occurred in the interviews.

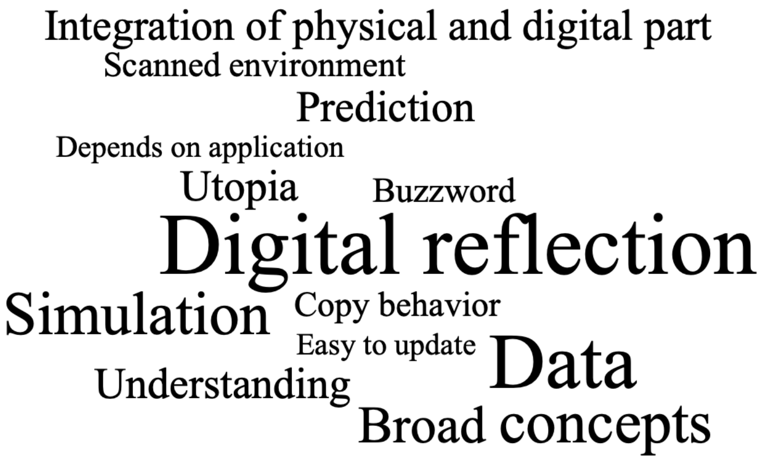

Figure 4.2: Word cloud showing common industry ideas and thoughts of what a digital twin is. The bigger the words, the more frequently mentioned by the interviewees.

4.1.3 Comparison between literature and interview data

The following three sub-sections present comparisons between the literature and the industry's perception of the digital twin concept on the areas *life-cycle perspective*, *real-time* and *information flow* are presented.

Life-cycle perspective

As the second most common category among the investigated literature definitions presented in Table 4.2, the life-cycle perspective is mentioned in 31% of the definitions. Almost all of the interviewees perceived it as beneficial if the digital twin would cover the whole life cycle of what it is representing, saying that the longer time it covers the more value the digital twin can bring. However, most of the interviewees agree that it could be defined as a digital twin even thought the whole life-cycle is not covered. In brief, both literature and the interviewees perceive the life-cycle perspective as an important part of the digital twin concept.

Real-time

Regarding real-time updates of digital twins, 20% of the investigated definitions in the papers suggest that a digital twin should have real-time updates, thus being the third most common category found in the investigated literature definitions presented in Table 4.2. The industry, more particularly the supplying companies, on the other hand, mention that the update of the digital twin depends on the application and that it could still be a digital twin even if it is not updated in real-time. Hence, there is a difference in how the literature and the industry interpret real-time in relation to the digital twin concept. The real-time aspect is more important in the literature than in the industry.

Information flow

Bidirectional information flow occurred only in 2 of the 59 the literature definitions, ending up as the least frequently used category for defining a digital twin, as summarized in Table 4.2. Even though bidirectional information flow rarely appeared explicitly in literature definitions it was still mentioned and discussed in many of the papers. In relation to this, the industry is split regarding the information flow between the physical and digital part of the digital twin. Some interviewees mention that bidirectional flow could be important, but again, application of the digital twin is central. When choosing which direction of the two-directional flow is the most important, all interviewees state that information flow from the physical part to the digital part as more important. No interviewee considered information flow from the digital part to the physical part as most important. Most of the interviewees think that it could be a digital twin even though there is no bidirectional flow, while a few interviewees consider that some sort of loop or two way communication between the physical and digital parts is essential for it to be called a digital twin. To conclude, there is a rather shattered view in the industry and the literature on how the information flow should really go.

4.1.4 Summary of RQ1

The concept of digital twins is scattered in both the literature and in the industry. It has become a buzzword highly mentioned in recent papers but some people in industry tend to avoid it due to its elusiveness. This study has found the integration and connection of a physical and a digital part to be one of the most important ingredients in the concept together with the representation of the whole life-cycle and real-time reflection of the object it represents. Further, the industry argues that the information flow from the physical to the digital part is the most important direction between the parts.

4.2 RQ2 - Usage and benefits of digital twins

In this section findings from the interview study answering research question number two will be presented. The research question is: *What are the main uses and benefits of the digital twin concept in the manufacturing industry?* In order to understand how the manufacturing industry can take advantage of the digital twin concept, it is necessary to understand what types of digital twins that exist and how they are used.

4.2.1 Types of digital twins

In the executed interviews with supplying companies different types of digital twins were mentioned. Most interviewees stated that this division of digital twins mostly depends on what the digital twin is used for, that it can be divided into different types due to the use case. Another way to distinguish digital twins into types, mentioned in the interviews, was the level of detail of the object reflected in the digital twin. For example, a digital twin can reflect a whole factory with a low level of detail or it can reflect a component in a machine with very high detail and correctness. Moreover, a few interviewees argue that a digital twin can be split into different types with regard to the development phase and the use phase of the object it represents.

From the interviews two different types of digital twins are identified, each with different characteristics and use areas. No company spoken to deliver a digital twin that is identical to digital twins delivered by any other company, but similarities between the different companies' digital twins could be distinguished and therefore these two types of digital twins are presented. The types are product digital twin and factory digital twin. An initial and general illustration of the two different digital twin types is presented in Figure 4.3. It roughly explains the core for each digital twin type such as what it reflects, update frequency, data flow and use areas. Further explanations of the two types are given in the following sections. Regardless of the type of digital twin, they are used for the purpose of gathering data and improving businesses through becoming more effective and efficient.

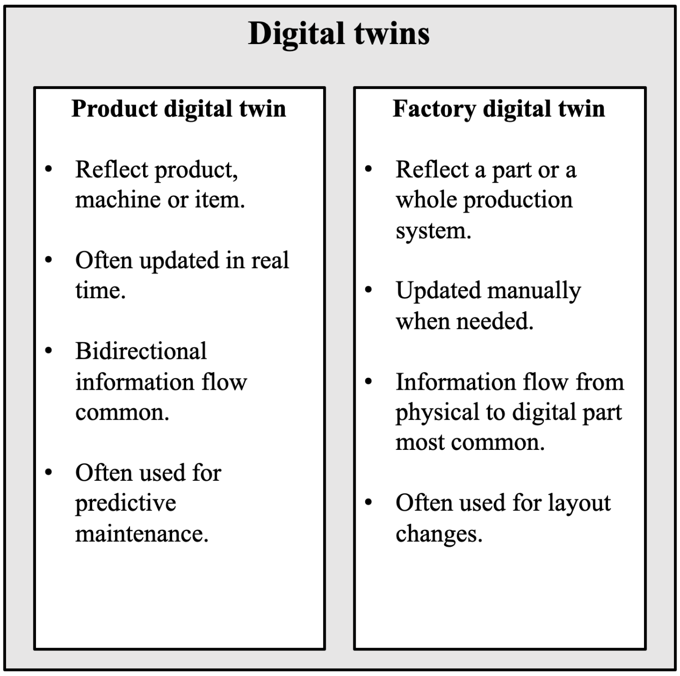

Figure 4.3: The core aspects and a general summary of the two different types of digital twins identified in the interviews.

Product digital twin

A product digital twin reflects either a product, machine or a physical item. It can, for example, be a boat propeller, a robot or a bridge that has a digital copy. The digital copy can, for example, be composed of a Three-dimentional (3D)-model and data from sensors attached to the physical item. The product digital twin is generally the most developed of the two digital twins mentioned. It is not uncommon that a product digital twin can reflect real-time of its physical asset and a bidirectional flow between the digital and the physical parts are found relatively often.

Product digital twins can be used to monitor the condition of its physical asset and in that way planning of maintenance is facilitated. Due to the fact that the condition can be monitored, the life length of critical components can be predicted and tactically replaced before failure. This makes products more adaptive to its users' behavior and over-dimensioned products can be avoided. Not only money can be saved by using the right material and replacing components at the right time, but the environment can also be taken into consideration by using components as long as possible.

If product digital twins are used in production environments representing for example machines or robots they can entail faster and less problematic ways to make changes and do setups. For instance, a robot can be programmed digitally in advance and the new movements can be tested virtually before they are implemented at site, thus decreasing the time for changeovers and ramp-ups.

Factory digital twin

The factory digital twins identified in the interviews reflect a part of, or a whole, production system. This digital twin visualizes the inside of a plant such as production lines, machines, tools, staircases, doors and storage locations. A common type of factory digital twin is the 3D-scanning of a plant with data connected to the 3D-scan. The connected data could, for instance, be general information regarding maintenance that is visualized at the same place in the scan as it should be executed in the real factory. However, there might be more types of factory digital twins used in industry today, but the one mentioned is the only one identified in interviews in this study.

A factory digital twin does not commonly reflect real-time and often the information flow is one-directional going from the physical object to the digital representation. Thus, how it looks inside the plant is commonly reflected to a digital copy but information back to the physical production from the digital copy is uncommon. The update of the twin is generally not in real-time, update of the 3D-scan is done manually and when the need arises. The data connected to the 3D-scan, machine data for instance, can be updated in real-time, however, this is not a common approach used today in the companies participating in this study.

A factory digital twin is mostly used for layout changes, rebuilding and development projects inside a factory. A 3D-scanning generates a point cloud that can be exported into suitable CAD-software. In the software, additional CAD-models can be included which allows the user to build up a new production environment to make sure everything fits together and collisions are avoided. The point cloud can also be used to validate 2D-drawings and make sure that they are up to date. While performing the 3D-scanning it is common that the scanning tool takes pictures covering 360° of the surroundings. These pictures are then merged into curved panorama pictures that provide a holistic view of the scanned environment. An example of a scanned environment is presented in Figure 4.4.

Figure 4.4: An example picture of how a scanned environment could look like. The picture represents a part of Virtual Manufacturing's production site in Linköping.

The pictures are placed above the point cloud making it possible to get a realistic view of the environment and at the same time allowing measurements and similar in the view. The obtained view is an indoor street view which enables its user to walk around in the environment digitally on a screen. The indoor street view gives a distinct overview of the facility. It also enables a good channel for communication and visualization since it puts people on common ground. It also saves traveling time and money when making it possible to digitally visit factories located far away.

4.2.2 Levels of digital twin

Two different types of digital twins have now been presented. However, it could be interesting to evaluate different levels of digital twins from the literature as well to clearer map its usability. The literature describes a wide variety of levels a digital twin could be split into. Earlier in this report, the level of integration and maturity levels of digital twins in section 2.1.4 were presented as modern concepts from the academic literature. Both of these classifications can be applied to the two types of digital twins earlier stated. These classifications are however not established in the industry as only one interviewee mentioned a similar classification.

4.2.3 Digital twins in the future

The identified digital twins in the industry have come different far in their development, including different amounts of data. Companies have also come different far in their implementation of digital twins, where some companies have implemented it in the whole company while others have test implemented it in a few departments. The interviewees, however, believe in growing interest and development of the concept in the coming years. For the companies working with product digital twins, future wishes for standardization of digital twin's software, accessories and components have been identified. The requested standardization is for enabling collaboration of software from different suppliers, collaboration of old and new software systems, and connecting different product digital twins with each other creating groups of product digital twins. There is a vision that these product digital twin groups in the future will be so expansive that they will merge into a factory digital twin. Further, companies working with factory digital twins want to see more integrated links between data and graphics in the digital twin. More specifically they seek the possibility to integrate real-time data from machines, robots, Automated Guided Vehicles (AGV), material flows and other production-related information into the factory digital twin.

4.2.4 Summary of RQ2

Two types of digital twins have been identified and presented from the industry while addressing the question of how the manufacturing industry can benefit from the digital twin concept. These two are product digital twin and factory digital twin. The product digital twin is the more detailed of the two and is often updated in real-time, while the factory digital twin creates a more holistic view of a production facility and not usually updated in real-time. The usage of these digital twins, in different ways, improves businesses through more efficient and effective ways of working. Moreover, saving time and resources is facilitated by information gathering and deliberate ways of handling information.

4.3 RQ3 - Implementation recommendations

In this section findings from both the literature and the interview study answering research question number three will be presented. The research question is: *Which factors are important for a successful implementation of a digital twin in manufacturing industry?* In order to answer this question background information on what implementation obstacles regarding digital twin the industry is facing today must be examined.

4.3.1 Implementation obstacles of digital twins

Even though ignorance of the concepts of digital twins has been identified, several of the interviewees from the supplying companies claim that it is easy for their customers to understand the benefits and advantages of having a digital twin, but that the implementation is more troublesome. In the following sections, obstacles for implementing digital twins are presented.

Change resistance

The most commonly mentioned implementation problem, in the interviews, in the industry today is people being resistant to change connected to long, historical, habit driven ways of working and a doubtfulness to new things and changes. Some interviewees refer the implementation problems to the conservative nature of the manufacturing industry as such, and that change management is required for company employees to accept changes, embrace new routines and apply new ways of working. There is also a view that smaller, younger companies generally easier accept new concepts and changes than older and bigger companies do. A telling quote from an interviewee summarizing this finding is that:

"*Everybody is positive for change, but no one wants to change*"

Data management

Data acquisition and data management are also mentioned as implementation obstacles for digital twins today. It has to be ensured that the digital twins are fed with accurate and high-quality data for it to present reliable results. There is also a skepticism to data management and data security aspects connected to digital twins as a part of Industry 4.0 since it is characterized by connectivity, data sharing and cloud solutions.

Communication of data

Another implementation obstacle for digital twins mentioned by several of the interviewees is the quantity and variety of data systems and different data system suppliers. For a digital twin to function, data flow between systems is required, but this data flow is considered difficult to achieve in many companies today. A reason for this is separate systems that cannot communicate, systems losing information in the transferring process or usage of outdated systems that lack synchronization capabilities. For example can the ERP system or the MRP system be outdated and have difficulties communicating with other systems within the company.

Value versus price

In addition to the above-mentioned implementation problems, some of the managers interviewed mentioned that another obstacle for implementing a digital twin is that the value created from a digital twin does not overcome the price of it. A suggested theory is that employees further down in an organization, possibly with deep technical comprehension, see the value of a digital twin while managers, higher up in the organization, working with less technical questions, are not as easily impressed. The vagueness of the concept makes it a challenge for people to understand the full potential of having a digital twin.

Lack of knowledge and time

Lastly, the absence of ISO-standards connected to the concept of digital twins results in ignorance and spread interpretations within the industry of the concept which in turn impedes implementation. Lack of time is also identified as an obstacle for digital twin implementations. Some interviewees argue for the importance of being prepared, that it takes time to introduce a digital twin, time that many companies may not have or are not willing to reserve for an implementation. In addition, other more specific problems for individual companies are also declared as implementation obstacles of digital twins in companies today.

4.3.2 Recommendations for implementation of digital twins

If a digital twin were to be implemented in a company, how, when and where does one begin? Below are recommendations connected to the implementation and startup phase stated without taking their internal order into consideration. The recommendations, some anchored in the literature, are a result of the findings in the interview study with both the supplying and receiving companies and address the implementation obstacles in the previous section.

Establish clear use case for the digital twin

Firstly, the use case is central and needs to be known before implementing a digital twin. A tendency can be seen that a lot of new technologies are implemented within the manufacturing industry because the companies perceive a need to be updated, but without any further established purpose or specific goal in mind. Findings from this study show that it is important to know what type of data that are the desired output from the digital twin and what type of data the digital twin needs to be fed with, before implementing it. The reason for this is that the input data often needs to be produced by the company itself, such as production data, maintenance data or quality data. Therefore, the company that is implementing a digital twin should reflect on what desired outputs the digital twin should deliver and if there is enough data accessible for the digital twin so it can deliver what is desired. There is no need to implement a digital twin that can not be fed with data of adequate quality for its purpose. Right input data sounds trivial but several of the interviewed receiving companies express difficulties with the presentment of it.

Use the same software supplier to the largest extent possible

Secondly, use manufacturing software from the same supplier to the largest extent possible, or make sure that the software are compatible so that the different software systems can communicate and exchange information with each other. The advantage of using the same supplier is that the probability that new software can communicate with the old one increases and this establishes a safer future for the company.

Show concrete examples of digital twins

Thirdly, to enable easier understanding and acceptance of the concept of digital twins in companies, showing concrete examples of the digital twin in question is preferable before implementation. It could be an example of a similar situation where it got implemented, how it is used and the successful output of it. From the interviews, it can be concluded that it is easier for people to both understand and trust a digital twin, in terms of cybersecurity and the value it creates, if they can see how it looks and works.

Communicate clearly and expect low knowledge of the concept

Fourthly, expect low general knowledge of the digital twin concept in the industry and communicate clearly. Due to that the concept of digital twins is newly arisen on the market, the knowledge about the concept and its pros and cons varies. The interpretations of the concept of digital twins are also very diversified. People see simulation, virtual commissioning, 3D-scanning etc. as digital twins. Because of the vagueness of the term digital twin, the varying knowledge and the wide array of interpretations, it is good to expect that miss-understandings easily can appear within this area and that clear communication is extremely important.

Expect and handle change resistance

Lastly, work with change management to involve people and increase their acceptance to change. As earlier mentioned there is a big resistance to change within the manufacturing field due to long historical ways of doing things. Kotter (1995) has presented eight steps of reasons for why transformation efforts fail. These eight steps, which are presented in Figure 4.5 and described in the following text, could be applied on a transformation journey for introducing a digital twin and to avoid implementation failure.

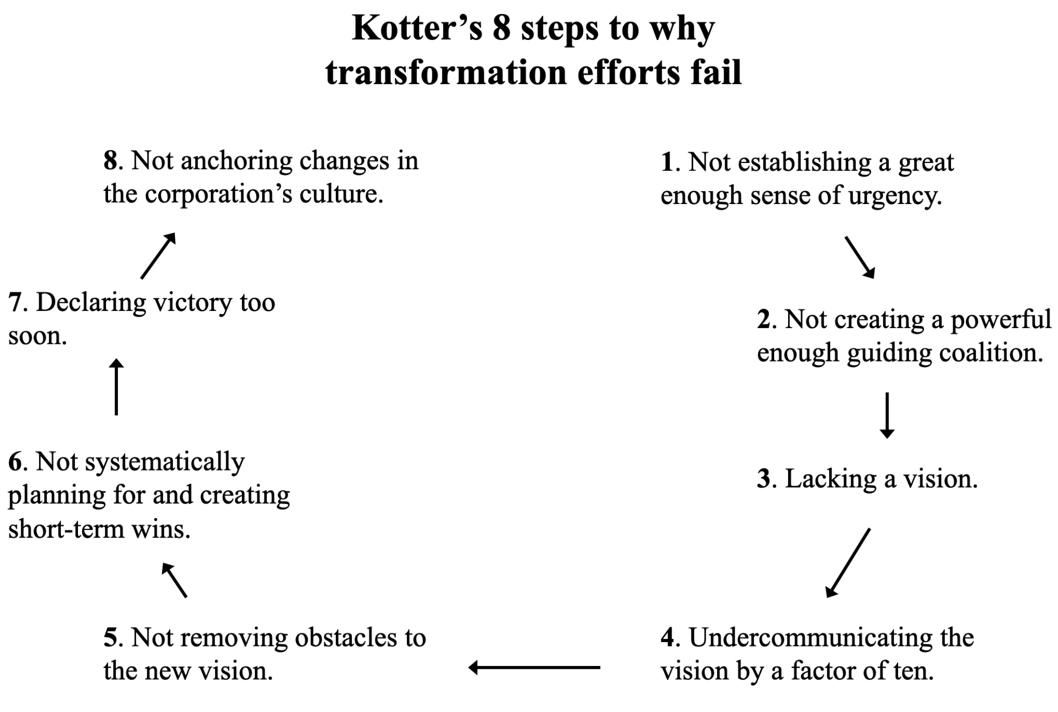

Figure 4.5: An illustration of Kotter's eight steps to why transformation efforts fail. Picture adapted from Kotter (1995).

1. Kotter's first step to unsuccessful change is to not establish a sufficiently great sense of urgency. To get a transformation change to start, aggressive cooperation between people is required (Kotter, 1995).

2. The second step towards failure is to not create a powerful enough guiding coalition. The head of the organization needs to be involved in big organizational changes among with 5-50 others, depending on the size of the organization, to get a shared commitment for establishing great performance through renewal (Kotter, 1995).
3. The third step is the lack of a vision that is easy to communicate and understand (Kotter, 1995).
4. The fourth one is under communicating the vision by a factor of ten. The vision needs to be spread so all employees are willing to help to achieve it (Kotter, 1995).
5. The fifth one is not removing obstacles to the new vision. It can both exist obstacles inside people heads or actual physical obstacles, in both cases it is important to remove them (Kotter, 1995).
6. The sixth one is to not systematically plan for and create short-term wins. It is important to set short term goals in order to motivate employees and plan for the long term goal (Kotter, 1995).
7. The seventh one is declaring victory too early. It can take time before changes sink deeply into the structure of an organization, and before that, the new approach is very fragile (Kotter, 1995).
8. The eighth and last step of Kotter's steps towards failure is to not anchor changes in the corporation's culture. Changes stick when they become a part of the culture within the organization, before that they can easily be removed if the pressure for change is released (Kotter, 1995).

This is Kotter's way of seeing change efforts and resistance. But there are more studies on the subject. Perceived resistance can be handled by seeing resistance as a way of feedback (Ford and Ford, 2010). Much of the resistance can be experienced as harder than it is depending on the mindset of the receiver of the resistance (Ford and Ford, 2010). To understand every stakeholder's perspective of the change it is important to motivate the change for the people involved. One way to motivate people is by setting goals. Two types of goals are performance goals and learning goals (Seijts and Latham, 2012). A performance goal is a specific goal that is easy to determine if it has been reached or not, for example to sell for 3 million dollars (Seijts and Latham, 2012). A performance goal forces the employee to use strategies and tactics that are already proven to be effective, only when the employee has already the desired knowledge for a task this type of goal is preferable (Seijts and Latham, 2012). A learning goal focuses on the learning process and to acquire the right knowledge and skill, for example, to find two strategies for increasing sales (Seijts and Latham, 2012). Learning goals draw away focus from the end result and make the employee focus on the effective task process (Seijts and Latham, 2012). It can also prove effective to use sub-goals if the end-goal takes a long time to reach (Seijts and Latham, 2012). Sub-goals keep the motivation for the employees and hinders procrastination. A suggestion when implementing a digital twin, where the long goal may be a performance goal, to increase efficiency with x% in ten years, is to set sub-goals along the way as learning goals to ensure that employees understand what they are doing and how to exploit the digital twin in the best way.

Below is a condensed list of the implementation recommendations suggested in this section.

- Establish a clear use case for the digital twin.
- Use the same software supplier to the largest extent possible, or make sure that the software are compatible so that the different software systems can communicate and exchange information with each other.
- Show concrete examples of digital twins. This enables easier understanding and acceptance of the concept for people.
- Communicate clearly and expect general low, or varying, knowledge of the digital twin concept.
- Expect and handle change resistance.
  - Use Kotter's eight steps to avoid that change implementations fail.
  - See resistance as a way of feedback and try to use it in a good way.
  - Set clear goals both to motivate employees but also to see that the change develops in the right direction.

4.3.3 Summary of RQ3

In order for the manufacturing industry to benefit from the concept of digital twins implementation obstacles of today needs to be overcome. Clear communication within the company regarding the change, declared purpose of the digital twin that will be implemented, integrated software and computer systems within the whole company and change management to drive the change implementation need to be managed if the true benefits of the digital twin should be obtained.

5
Discussion

In this chapter, the methodology used in the project is discussed, and thoughts on the results of the study are presented. Aspects regarding sustainability and ethics are presented thereafter, followed by a section of suggestions for further research on the digital twin topic. The chapter's structure is illustrated in Figure 5.1 below.

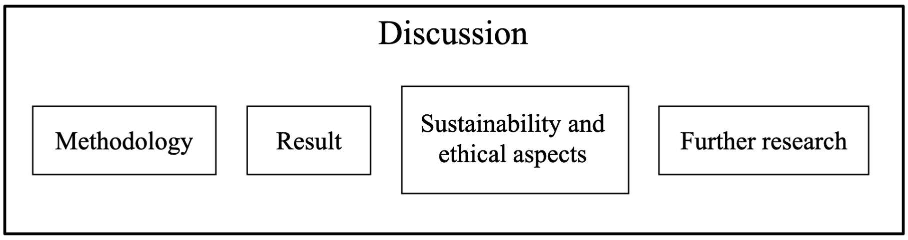

Figure 5.1: An illustration of the structure of the chapter. First will a discussion of the methodology be presented, followed by a discussion of the result, sustainability and ethical aspects and at last further research suggestions on the topic.

5.1 Methodology

In the following section, essential parts of the methodology used in the project will be discussed and evaluated. The research team's, as well as the interviewees' impact on the study, will be discussed followed by a discussion on the execution of the interview study and the coding process. Lastly, a section on transparency of the project is given.

The influence of the literature study and the research team

The selection of academic literature and papers on digital twins at the beginning of the project had a large impact on the continuing of the project work. The papers chosen provided background knowledge in the field of interest but also formed the foundation of the seven definition categories identified in the literature review presented in Table 4.1. Further, parts of the interview guides are built around the seven definition categories identified from the literature. Hence, the interpretation of the literature definitions affected not only the outcome of the literature review but the foundation of the interview study as well. Since not all existing papers on digital twins were examined, some crucial definitions on digital twins might have been missed, and there is a risk that the papers included in the project and the way the seven definition categories was created would not correspond to a similar investigation including more or other papers on the subject. However, since the papers were selected from citation frequency and many of the papers referred to one another or provided similar digital twin definitions, the belief is that the sources included in the literature study on digital twins are credible and that the definitions give a fair view of the core of the concept. The people conducting the study also have a great impact on the result of it. All people have diverse knowledge and backgrounds which affect the way they work and interpret results. Hence, it is possible that the result of the study could have been different if the research team consisted of other people. The research team behind this kind of study will always be a factor that affects the results of it, this can be good to take into consideration. However, in this study, to get a broader perspective, the result of the study have been discussed with people outside of the research team.

Interviewees' impact on the study

The interviews conducted for the thesis were held with people at companies either supplying digital twins or receiving digital twins. When companies were contacted and asked to participate in the interviews the research team's own personal network and contact information found through web pages and similar were used. In total, 26 persons were interviewed at 19 different companies. The interviews constitute a substantial part of the study and hence the interviewees' answers compose an important part of this study as well. Due to personal interpretations, knowledge levels, and open formulated questions, different interviewees gave different answers to the same question, and therefore it is inescapable that the result of the study is affected by the individuals being interviewed. To capture differences and similarities within the same company were several people, with different backgrounds and work titles, at the same company interviewed in the extent permission was given. In brief, the study has been affected by the people being interviewed, other interviewees could have given another outcome of the thesis. Furthermore, it could be discussed how well the outcomes from interviews executed mainly in the Gothenburg region agree with the results if a similar study was performed at another geographical location in Sweden or elsewhere in the world. How mature the manufacturing industry of Gothenburg is compared to other places could of course impact the relevance and validity of the results, and other results may have been achieved if the study was performed elsewhere. Hence, taking the industry maturity aspect into consideration could be appropriate while viewing the results.

The execution of the interviews

When conducting interviews there is always a risk for misunderstandings and misconceptions. There is also a risk of the interviewee being affected by the persons executing the interviews when answering the questions. To avoid this from happening, notes were taken during the interviews and all interviews were sound recorded. In addition, effort was made to ask the interview questions in a way that would not bias the interviewee. Further, there was an endeavor to conduct each interview face to face and with two persons from the research team, one asking the main questions and the other one taking notes. Involving two people is also beneficial since two people hearing the same interview minimizes the risk of misinterpretations. However, due to the Covid-19 outbreak in the spring of 2020 were around half of the interviews forced to be conducted digitally, but the execution was still the same with two people conducting the interviews, one asking questions and one taking notes. How much the digital execution of the interviews has affected the outcome of the study is difficult to say. The quality of the connection in the digital interviews was varying and therefore could some misconceptions have arisen. However, the research team became more and more familiar with performing interviews digitally and the negative impact is considered low.

The execution of the coding

After each interview, the sound recording was transcribed and coded. Depending on how the coding is executed there is a risk that some parts will be amplified while others will be missed or overlooked. The way the coding was performed can depend on the executor's previous knowledge and experience. In this case, the interviews were coded by the same research team that conducted the interview guides and performed the interviews and therefore there is a risk for biased mindsets. However, the person performing the coding needs to have insight into what information is of interest and therefore it is inevitable that the person will have preconceptions of what he or she will find. In this thesis, interviews were coded as soon as possible after they were executed to avoid interpretations affected by other, forthcoming, interviews. In addition, the recorded material from each interview was used during the coding process to clarify emphasis when the transcripts were unclear, this ensured that the interviews were interpreted as good as possible.

Language translations

The interview part of the project was conducted in the native language of the research team. The interview guides were developed in Swedish, the interviews were performed in Swedish followed by transcription and coding in the same language. The results were translated into English first at the end of the project. When working in this manner, there is a risk that information has been lost in translation. Especially in the interviews where the words and the expressions used by the interviewees have been translated, the true meaning or intention of the interviewee might have been lost or altered. However, caution was taken in the translation process to mitigate this risk.

Transparency

For the sake of transparency, allowing external revision of the executed work and working methods leading the work to the presented results, all material concerning the thesis has been saved and documented in an online folder. Excluded material from the thesis regarding for instance the literature study, including all considered papers and their related reading notes have been stored in the folder. This together with the Excel-sheet showing the included digital twin definitions from the papers and the creation of the definition categories. As for the interview study, the recorded interviews, the transcripts, and the corresponding coding are stored in the online folder as well. Hence, the material used and developed in the study is available if further interest of the study, the results or the methodology used, arises.

5.2 Results

In this section, the result of the thesis will be discussed and examined further. Firstly, the industry's and academia's perceptions of the digital twin concept are discussed followed by a discussion on the implementation recommendations. The relation between the product digital twin and the factory digital twin is examined, and lastly, a potential third type of digital twin will also be presented and discussed.

Perceptions of digital twins

It could be seen that there is a difference in how the papers and the industry present and interpret the concept of digital twins. There is also a difference in how well-informed people within the industry are of the concept. The interviews in the study were conducted with people with different educational backgrounds and it could be seen that interviewees with higher educational degrees often were closer in their interpretations to the definitions of digital twins given in the literature. Interviewees not as highly educated had often heard of the concept of digital twins but had difficulties explaining it in further detail. This knowledge diversity tends to result in interviewees having diverse perceptions of the advantages and usability of a digital twin, nevertheless, they are still confident that a digital twin is needed within their company. It seems like people want to implement a digital twin only to digitalize the company, to be updated, and follow the development trend. People seem to be worried that their competitors will be successful within Industry 4.0 and therefore they mindlessly need to try as well even though they are not sure of what they want to establish or in what ways a digital twin can be useful for them. This can result in employees not understanding the purpose of having a digital twin and not having the required skills and knowledge for using it in a proper way.

Recommendations

Recommendations on where to begin an implementation of a digital twin and useful tips along the way have been given. These recommendations and tips are highly general and are deemed to be applicable in most companies, however, it is important to accentuate that every recommendation or tip is not suitable for all situations. A successful change transformation depends a lot on the change in question as well as on which type of company that is regarded and its organizational structure.

Relation between product digital twin and factory digital twin

In this thesis, the product digital twin and the factory digital twin are presented. There is a fine line between product digital twin and factory digital twin. If several product digital twins are put in a row to visualize a whole production segment it may easily be interpreted as a factory digital twin. If this occurs, it is perhaps not so important to separate a product digital twin from a factory digital twin, the important aspect is what benefits the digital twin entails. Further, the development of the technology behind digital twins evolves extremely fast and in near future, there is a possibility that a factory digital twin can reflect the real world in the same detail as a product digital twin. If this would be a reality, why distinguish between the two types? Why not only call them digital twin? Furthermore, it is interesting to reflect on human interactions and influence on a factory digital twin. Human movements and ways of acting are highly unpredictable. If a factory digital twin becomes as highly detailed as a product digital twin, how does one visualize and mimic the human impact and her irrational decisions in such a connected system? Maybe digital twins are only applicable to systems with higher levels of automation and low human involvement (Shao et al., 2019). It could also be questioned if a factory digital twin ever will have the need of the same detailed level as a product digital twin, if there will be any use for such a tool. But, at the same time as the concept of factory digital twin evolves the use case for it could change or evolve as well, and application areas for it could arise. Questions and speculations like this are difficult to answer today, since the concept of digital twins is in its infancy, but likely is that time will tell.

Platform digital twin

In this thesis product digital twin and factory digital twin have been identified both in literature study and interview study. However, it is possible that a third type of digital twin exists. This third type was identified in the interview study and could be called platform digital twin. It is more ambiguous than the two earlier mentioned. What differs a platform digital twin from the other two is that it does not have to reflect physical items. This is opposite to how a digital twin is identified in this thesis, which is "*A digital twin has a digital or virtual part, a physical part and a connection between them*". Further, this third type has not been identified in the studied literature but has only occurred in the conducted interviews. This is the reason why platform digital twin is brought up in the discussion chapter rather than the result chapter. A platform digital twin can also be said to be more of an enabler of product digital twins and factory digital twins. It can, for example, visualize an organization or the development work of a new product that may not even exist physically yet. A platform digital twin addresses an enterprise in a wider context, where different processes and domains in an enterprise are integrated digitally.

The platform is built up by a portfolio of software and applications for creating digital twins of products or production systems. The different software can, for example, be 3D-modeling tools, simulation tools, data analytic tools, social and collaborative applications, and information applications. The platform digital twin is fully digitized and the software tools are able to connect and work together. A generic structure of a platform digital twin is visualized in Figure 5.2, where the different software and applications are illustrated with blue circles, the connection between them with crosshatched lines and the platform holds them together. As can be seen in the figure, an important feature of a platform digital twin, which is enabled by the collaboration potential between the software, is to gather and present the information in one place, this is visualized by a computer screen in the picture.

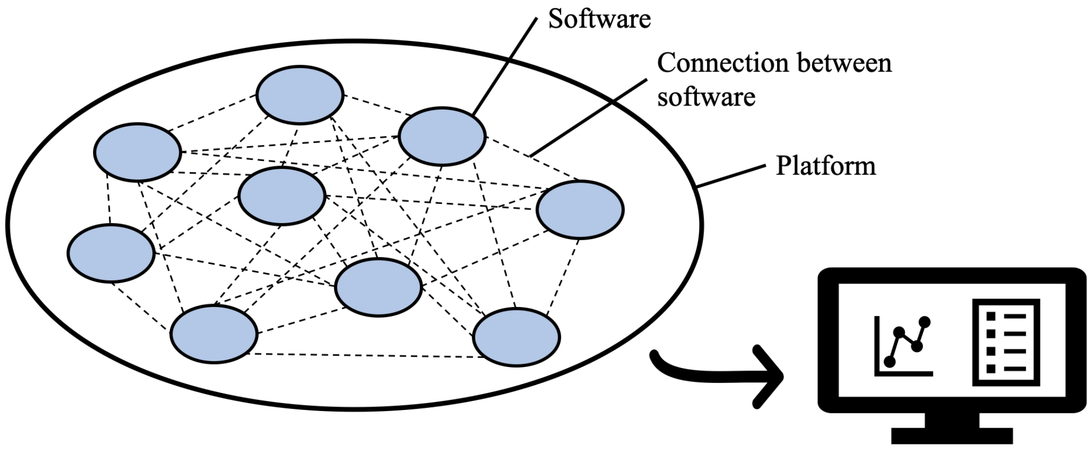

Figure 5.2: A generic structure of a platform digital twin. The platform contains integrated software that enable gathering and visualization of data in one location and creation of digital twins.

Often the different software constituting the platform is delivered by the same company and therefore the company can ensure that the different software are collaborative with each other. Using the same distributor of software is often a prerequisite for collaboration between them, this due to the fact that no standards have been developed in relation to manufacturing software. The collaborative aspect enables its user to create a digital twin adapted to the purpose of its existence. Thus, a platform digital twin can look extremely different from case to case. The platform digital twin may have either bidirectional or one-directional information flow depending on how the digital twin is constructed and what purpose it has. In some cases, there is a fine line between a platform digital twin and a well developed IT-system.

The common goal of platform digital twins built up by different sets of software is that the integration of data and information enables a holistic environment of the business. A platform digital twin is often used to visualize the whole life-cycle of an object, to have data accessible along with visualizations and applications for managing different life phases of a product or a process. Hence, the PLM concept is central and the platform is a way to realize and implement PLM. It is not uncommon that a life-cycle perspective needs several different software depending on where in the life-cycle the object is.

The desire for a digital twin

When performing this thesis work it could be interpreted, both from the literature study and from the interviews, that a digital twin is the goal when implementing a virtual model. Hence, interviewees tend to call all types of virtual models for digital twins. For example, some interviewees see 3D-CAD models, simulation, offline robot programming, and 3D-scanning as digital twins. But what if a digital shadow or digital model, from the modern concept of "level of data integration", presented in section 2.1.4, would suffice? Even if a digital shadow solves the initial problem, people appear not to be satisfied until they have something that can be called a digital twin or before a real digital twin is implemented. The urge and search for a digital twin in industry today is fascinating since the digital twin seems to be the ultimate target almost regardless of what the purpose behind the implementation of it might be. Why has it become like this? Is it a way for companies to stay tuned, show that they are updated? Are companies afraid to miss the next technology innovation and fall behind competitors on the market? What ever the reason might be, the result is that almost all sorts of virtual models are referred to as digital twins and trigger the confusion of the digital twin concept.

Moving on, is the narrow definition of a digital twin, given by many papers and its authors, truly achievable? If it is achievable, is it desired? The virtual models existing today entail a lot of features that are desired when it comes to digital twins, but few or almost none entails every feature a digital should include, according to some of the papers. The technology for achieving digital twins are perhaps existing today, it all depends on the definition of digital twins, but the problem seems to be scaling up interaction with other systems making it useful in industry. Leading to the next question, have these highly developed digital twins really a purpose to fill? Some of the digital twins existing today seem to already struggle with being more technically developed than the industry can handle. Simply said, the digital twins include more features than what is usually used today. Is there really a general need for even more developed digital twins than the ones existing today?

5.3 Sustainability and ethical aspects

Considering the methodology used and findings attained from the research there is a potential impact on all three of the sustainability aspects: economic, environmental, and social.

Economical and environmental sustainability

From an economical point of view, a digital twin can contribute with higher productivity and better resource exploitation which in turn results in an economic gain for companies implementing a digital twin, given that the implementation is successful. Not only economical profits can be seized from aware use of resources, but the environment may also benefit if digital twins are used for predictive maintenance or process parameter optimization. Resource visualization provided by a digital twin allows companies to act in the best possible way and keep both the economic and the environmental aspects in mind in each situation. For instance, better prediction of components life lengths can result in that components are being changed when actually needed, neither too soon wasting still functional equipment, nor too late jeopardizing operational functionality. The predictive maintenance also allows efficient co-exchange of components, resulting in reduced downtime of machines or production lines, which is preferable from an economical perspective.

Social sustainability

Regarding the third part of sustainability, the social aspect was considered when choosing the methodology for the study. The inclusion of interviews in the study as an additional part of the literature review ensures that also social aspects, such as thoughts and perceptions from individuals working in contexts where digital twins emerge, are considered. Not only the methodology used in the study affect the social sustainability aspect, but so does the concept of digital twins. Implementation of digital twins, as a part of Industry 4.0 and digitalization of companies, is unfamiliar to many people and companies, and can cause certain concern among people. In the long run, a fear of lost jobs due to the emerging of digital twins has been identified. On the other hand, it has been argued that a digital twin more likely will rearrange job functions so that monotonous jobs disappear in favor of more demanding jobs.

Ethical aspects

Suppose implementations of digital twins really reduce job opportunities, it could be argued whether or not digital twins are ethically defensible. Moreover, there is a lot of data connected to a digital twin that might be sensitive or confidential, both from security aspects regarding the company but also personal aspects with data connected to specific people. How this data is gathered, where it is stored, who has access to it, and how it is used are other things that can be discussed from an ethical standpoint. If the data concern specific individuals it is important that the data are anonymous and that it can not be linked to that person.

5.4 Further research

The ambiguity of the digital twin concept in the literature as well as in industry has been experienced consistently during this thesis. Compared to the literature's relatively narrow digital twin definitions, the industry has broader interpretations of the concept and these are not always anchored in the literature. Therefore could further research investigate in how the evolution of the definition of digital twins can merge to a common understanding in both academia and industry. In order for the industry to harvest the benefits of digital twins, further research could also investigate how the concept could be made more comprehensible, valid in both academia and industry and how misunderstandings between academia and industry can be avoided. The ISO-standard regarding digital twins within manufacturing, that is currently being developed, could possibly be one way to handle the issue, but there could be more ways.

6
Conclusion

The concept of digital twins is diffuse. There is no established definition that can thoroughly describe the digital twin concept alone, but several interpretations occur in the field. The result of this thesis has been developed by conducting an interview study with 26 interviewees built on an analysis of the concept of digital twins within 23 scientific papers. The digital twin has been defined as: " *A digital twin has a digital or virtual part, a physical part and a connection between them*". This study has also identified the integration and connection of a physical and a digital part to be one of the most important ingredients in the concept, together with the representation of the whole life-cycle and real-time reflection of the object it represents. Furthermore, two types of digital twins have been identified in academia and in the industry: product digital twin and factory digital twin. These digital twins enable, among other things, improved productivity and efficiency in the manufacturing industry which is the core of Industry 4.0. The function and features of the product digital twin identified in the industry today are the closest ones to the literature definitions encountered in academia. An additional third digital twin type has been mentioned in industry, but not in academia, namely the platform digital twin. When implementing digital twins in the manufacturing industries change management, clear communication, compatible systems and clearly stated use cases regarding the digital twin need to be established. The concept of digital twins is still in its infancy, more attention and clarification need to be put on the subject for it to be even more useful and beneficial for the manufacturing industry in the future.

Bibliography

Ameri, F., & Dutta, D. (2005). Product Lifecycle Management: Closing the Knowledge Loops. *Computer-Aided Design and Applications*, *2*(5), 577–590. doi:10.1080/16864360.2005.10738322

Borth, M., Verriet, J., & Muller, G. (2019). Digital twin startegies for SoS: 4 challlenges and 4 architecture setups for digital twins of SoS. In *14th annual conference system of systems engineering* (pp. 164–169). doi:10.1109/SYSOSE.2019.8753860

Boschert, S., Heinrich, C., & Rosen, R. (2018). Next Generation Digital Twin. In *Proc. tmce* (pp. 209–218). Las Palmas de Gran Canaria: University of Technology.

Bryman, A., & Bell, E. (2011). *Business research methods*. Oxford university press.

Chandra, Y., & Shang, L. (2019). *Qualitative Research Using R : A Systematic Approach*. doi:10.1007/978-981-13-3170-1

Culot, G., Nassimbeni, G., Orzes, G., & Sartor, M. (2020). Behind the definition of Industry 4.0: Analysis and open questions. *International Journal of Production Economics*. doi:10.1016/j.ijpe.2020.107617

Ford, J. D., & Ford, L. W. (2010). Stop Blaming Resistance to Change and Start Using It. *Organizational Dynamics*, *39*(1), 24–36. doi:10.1016/j.orgdyn.2009.10.002

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2019). Digital Twin: Enabling Technology, Challenges and Open Research. Retrieved from http://arxiv.org/abs/1911.01276

Ganesh, K., Mohapatra, S., Anbuudayasankar, S. P., & Sivakumar, P. (2014). ERP as a Business Enabler. In *Enterprise resource planning: Fundamentals of design and implementation* (pp. 1–35). doi:10.1007/978-3-319-05927-3

Grieves, M., & Vickers, J. (2016). Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In *Transdisciplinary perspectives on complex systems: New findings and approaches* (pp. 85–113). doi:10.1007/978-3-319-38756-7{_}4

Haag, S., & Anderl, R. (2018). Digital twin - Proof of concept. *Manufacturing Letters*, *15*, 64–66. doi:10.1016/j.mfglet.2018.02.006

Hammond, M., & Wellington, J. (2012). *Research methods: The key concepts*. Routledge.

Kobryn, P. A. (2019). The Digital Twin Concept. In *Frontiers of engineering: Reports on leading-edge engineering from the 2019 symposium* (Vol. 49, *4*, pp. 16–19). National Adacemies Press.

Kotter, J. P. (1995). Leading change: Why transformation efforts fail. *Museum Management and Marketing*, *11*(May-June), 20–29.

Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W. (2018). Digital Twin in manufacturing: A categorical literature review and classification. *IFAC-PapersOnLine*, *51*(11), 1016–1022. doi:10.1016/j.ifacol.2018.08.474

Lee, J., Bagheri, B., & Kao, H. A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, *3*, 18–23. doi:10.1016/j.mfglet.2014.12.001

Lu, Y., Liu, C., Wang, K. I., Huang, H., & Xu, X. (2020). Digital Twin-driven smart manufacturing: Connotation, reference model, applications and research issues. doi:10.1016/j.rcim.2019.101837

Madni, A., Madni, C., & Lucero, S. (2019). Leveraging Digital Twin Technology in Model-Based Systems Engineering. *Systems*, *7*(1), 7. doi:10.3390/systems7010007

Miller, A. M., Alvarez, R., & Hartman, N. (2018). Towards an extended model-based definition for the digital twin. *Computer-Aided Design and Applications*, *15*(6), 880–891. doi:10.1080/16864360.2018.1462569

Negri, E., Fumagalli, L., & Macchi, M. (2017). A Review of the Roles of Digital Twin in CPS-based Production Systems. *Procedia Manufacturing*, *11*, 939–948. doi:10.1016/j.promfg.2017.07.198

Rasheed, A., San, O., & Kvamsdal, T. (2019). Digital Twin: Values, Challenges and Enablers. Retrieved from http://arxiv.org/abs/1910.01719

Reilly, K. O., Paper, D., & Marx, S. (2012). Demystifying Grounded Theory for Business Research. *Organizational Research Methods*, *15*(2), 247–262. doi:10.1177/1094428111434559

Rosen, R., Fischer, J., & Boschert, S. (2019). Next generation digital twin: An ecosystem for mechatronic systems? In *Ifac-papersonline* (Vol. 52, *15*, pp. 265–270). doi:10.1016/j.ifacol.2019.11.685

Rosen, R., Von Wichert, G., Lo, G., & Bettenhausen, K. D. (2015). About the importance of autonomy and digital twins for the future of manufacturing. In *Ifac-papersonline* (Vol. 28, *3*, pp. 567–572). doi:10.1016/j.ifacol.2015.06.141

Saldana, J. (2011). *Fundamentals of qualitative research*. Oxford University Press, Incorporated.

Saracco, R. (2019). Digital Twins: Bridging Physical Space and Cyberspace. doi:10.1109/MC.2019.2942803

Schleich, B., Anwer, N., Mathieu, L., & Wartzack, S. (2017). Shaping the digital twin for design and production engineering. *CIRP Annals - Manufacturing Technology*, *66*(1), 141–144. doi:10.1016/j.cirp.2017.04.040

Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M., & Wahlster, W. (2017). *Industrie 4.0 maturity index*. Munich.

Seijts, G. H., & Latham, G. P. (2012). Knowing when to set learning versus performance goals. *Organizational Dynamics*, *41*(1), 1–6. doi:10.1016/j.orgdyn.2011.12.001

Shao, G., Jain, S., Laroque, C., Lee, L. H., Lendermann, P., & Rose, O. (2019). Digital Twin for Smart Manufacturing: the Simulation Aspect. In *Winter simulation conference* (Bolton 2016, pp. 2085–2098). doi:10.1109/WSC40007.2019.9004659

Stecken, J., Ebel, M., Bartelt, M., Poeppelbuss, J., & Kuhlenkötter, B. (2019). Digital Shadow Platform as an Innovative Business Model. *Procedia CIRP*, *83*, 204–209. doi:10.1016/j.procir.2019.02.130

Sudarsan, R., Fenves, S. J., Sriram, R. D., & Wang, F. (2005). A product information modeling framework for product lifecycle management. *CAD Computer Aided Design*, *37*(13), 1399–1411. doi:10.1016/j.cad.2005.02.010

Tao, F., & Qi, Q. (2019). Make more digital twins. *Nature*, *573*(7775), 490–491. doi:10.1038/d41586-019-02849-1

Tao, F., Zhang, H. [He], Liu, A., & Nee, A. Y. (2019). Digital twin in industry: State-of-the-art. *IEEE Transactions on Industrial Informatics*, *15*(4), 2405–2415.

Tao, F., & Zhang, M. (2017). Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing. *IEEE Access*, *5*, 20418–20427. doi:10.1109/ACCESS.2017.2756069

Tao, F., Zhang, M., & Nee, A. (2019). Background and Concept of Digital Twin. In *Digital twin driven smart manufacturing* (pp. 3–28). doi:10.1016/b978-0-12-817630-6.00001-1

Wagg, D., Gardner, P., Barthorpe, R., & Worden, K. (2020). On Key Technologies for Realising Digital Twins for Structural Dynamics Applications. In *Model validation and uncertainty quantification, volume 3* (pp. 267–272). Springer. Retrieved from http://www.springer.com/series/8922

Wagner, J., Constantin Grothoff, Epple, U., Drath, R., Malakuti, S., Grüner, S., Hoffmeister, M., & Zimermann, P. (2017). The role of the Industry 4.0 asset administration shell and the digital twin during the life cycle of a plant. In *Ieee international conference on emerging technologies and factory automation (etfa)* (pp. 1–8). doi:10.1109/ETFA.2017.8247583

Walsh, I., Holton, J. A., Bailyn, L., Fernandez, W., Levina, N., & Glaser, B. (2015). What Grounded Theory Is . . . A Critically Reflective Conversation Among Scholars. *18*(4), 581–599. doi:10.1177/1094428114565028

Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: State of the art and future trends. *International Journal of Production Research*, *56*(8), 2941–2962. doi:10.1080/00207543.2018.1444806

Zhang, H. [Haijun], Zhang, G., & Yan, Q. (2019). Digital twin-driven cyber-physical production system towards smart shop-floor. *Journal of Ambient Intelligence and Humanized Computing*, *10*(11), 4439–4453. doi:10.1007/s12652-018-1125-4

Zheng, P., Lin, T. J., Chen, C. H., & Xu, X. (2018). A systematic design approach for service innovation of smart product-service systems. *Journal of Cleaner Production*, *201*, 657–667. doi:10.1016/j.jclepro.2018.08.101

A
Interview guides

A.1 Questionnaire for companies supplying digital twins

1. Introduction
   (a) Can we record this interview?
      i. *The material recorded in this interview can become a part of the report of our work and also a part of our presentation at the end of our work. We will also take notes during the interview for the same reason.*
   (b) *We have split this interview into different areas. Firstly, we will start with some questions to understand your company. Secondly, we will ask general questions about the definition of digital twins. Lastly, we will ask and talk about your specific digital twin.*
   (c) Do you want to be anonymous in our report and study?
      i. If yes. Can we use your title as an ID?
      ii. If no. What is your name?
      iii. If no. What is your title?
   (d) For how long have you worked at this company?
   (e) For how long have you had the position you have now?
      i. Did you have any prior position at this company?
      ii. What kind of education do you have?

2. General information
   (a) Background to project
      i. *Our names are Jenny and Klara, we are studying the master program Production Engineering at Chalmers. Right now we are doing our master thesis at Virtual Manufacturing in Gothenburg.*
   (b) Scope of project
      i. *We want to evaluate the concept of digital twins. We want to know how far the market for digital twin has reached and what tools that are desirable for a digital twin to entail.*
   (c) Scope of interview
      i. *We want to know how you see the concept of digital twins and also how your specific digital twin looks like and works.*

3. Map company context
    (a) Can you shortly describe what your company is working with?
        i. What are your work tasks?
    (b) For how long have your company worked with digital twins?

4. General digital twin definition
   For the following questions, we would like you to think as general as you can and not think of some specific digital twin you are familiar with.
    (a) Generally, how would you describe the concept of digital twins?
    (b) When did you first hear about the concept of digital twins?
    (c) Have you reflect anything about if it is possible to split up the concept of digital twins into different levels or groups?
        i. If yes, can you describe how these levels or groups looks like?
    (d) Would you say that it is important that a digital twin is updated in real-time?
        i. If yes, why?
        ii. If no, why?
    (e) Would you say that it is an digital twin even if it is not updated in real-time?
        i. If yes, how often do the digital twin need be to updated to be able to be classified as a digital twin according to you?
    (f) *If a digital twin consists of a physical part and a corresponding digital part and a link between them.*
        i. Would you say that it is important that a digital twin enables bidirectional information flow between the physical part and the digital?
            A. If yes, why?
            B. If no, why?
        ii. Would you say that it is a digital twin even if the information flow is not bidirectional?
            A. If yes, which direction is the most important?
    (g) Would you say that it is important that a digital twin can be used during the whole life cycle of its corresponding physical part?
        i. If yes, why?
        ii. If no, why?
    (h) Would you say that it is a digital twin even if it can not be used during the whole life cycle of its corresponding physical part?
    (i) Do you think there is something more that strongly defines a digital twin that we have not talked about?
        i. If yes, what?

5. Company-specific digital twin
   During this part of the interview are we going to focus on your company and your definitions and experiences of digital twins, we would like your answers to be based on your company and what you are working with.

(a) Do you have a digital twin at your company?

If yes:

  i. Do you want to tell us how your digital twin works?
  ii. What is your digital twin used to accomplish?
  iii. How many data programs are required for managing your digital twin?
  iv. Within which area are your customers working?
    A. Are there any specific types of customers you focus on?
    B. If several different types of customers; Do your digital twin works and looks the same independent of the customer? If no, what is different?
  v. How is information updated in your digital twin?
    A. How often is it updated?
  vi. Is the information flowing from the physical part to the digital or in the opposite direction?
  vii. What are the advantages of your digital twin?
  viii. Do you see any obstacles for your customers to implement your digital twin?
  ix. Do you see any obstacles for your customers to use your digital twin?
  x. Do you see any weaknesses with your digital twin?
  xi. If you were allowed to dream freely, what would you like to develop with your digital twin?
    A. Do you think this development is possible with the technology available today or do you think it lies far in the future?
    B. Is the development of your digital twin something you focus on or are you happy with how it looks and works today? If a focus, can you give us an approximate number of hours per week?
  xii. Based on your interpretation, would you say that your digital twin is in front of development when it comes to digital twin on the market or not?
  xiii. Would you say that the market is adoptive for a digital twin?
  xiv. How do you find customers? Do they come to you or do you reach out to them up?
  xv. Would you say that it is easy or difficult to make companies understand what value they can get from implementing a digital twin?

If no:

  i. Why? What hinders you from getting one?
  ii. Is a digital twin something you would like to have?
  iii. If you were allowed to dream without freely, what should your digital twin look like and how should it work?
    A. Do you think this development is possible with the technology available today or do you think it lies far in the future?
  iv. Within which area are your customers working?
    A. Are there any specific types of customers you focus on?
  v. Do you see any obstacles for your customers to implement a digital twin?

vi. Do you see any obstacles for your customers to use a digital twin?
vii. Would you say that the market is adoptive for a digital twin?
viii. Would you say that it is easy or difficult to make companies understand what value they can get from implementing a digital twin?

6. Sum-up
   (a) To summarize the interview
      i. Do you think there is something else that we should bring with us from this interview that we have not talked about?
      ii. Do you know any other company that s a digital twin that we should talk with?
         A. If yes, do you have contact information?
      iii. We would also like to talk to manufacturing companies that have used or can benefit from using a digital twin, do you know any company that we should talk to?
         A. If yes, do you have contact information?
   (b) To confirm what we already asked, do you want to be anonymous in this study?
   (c) *As we said before, this information gathered here today will be used in a report and a presentation, you are welcome to take part of both. If you are interested in this we can give you more information.*
   (d) *Lastly we would like to thank you so much for taking the time to participate in this interview.*

A.2 Questionnaire for companies receiving digital twins

1. Introduction
    (a) Can we record this interview?
        i. *The material recorded in this interview can become a part of the report of our work and also a part of our presentation at the end of our work. We will also take notes during the interview for the same reason.*
    (b) *We have split this interview into different areas. Firstly, we will start with some questions to understand your company. Secondly, we will ask questions targeted towards the concepts of Industry 4.0 and digital twins in order to understand if and how you work with or could use digital twins in your business.*
    (c) Do you want to be anonymous in our report and study?
        i. If yes. Can we use your title as an ID?
        ii. If no. What is your name?
        iii. If no. What is your title?
    (d) For how long have you worked at this company?
    (e) Would you say that you have a technical interest?
    (f) For how long have you had the position you have now?
        i. Did you have any prior position at this company?
        ii. What kind of education do you have?

2. General information
    (a) Background to project
        i. *Our names are Jenny and Klara, we are studying the master program Production Engineering at Chalmers. Right now we are doing our master thesis at Virtual Manufacturing in Gothenburg.*
    (b) Scope of project
        i. *We want to evaluate the concept of digital twins. We want to know how far the market for digital twin has reached and what tools that are desirable for a digital twin to entail.*
    (c) Scope of interview
        i. *We want to know how you see the concept of digital twins, what you want out of the concept, how it can be used and what value it can bring to your daily work.*

3. Map company
    (a) Can you shortly describe what your company is working with?
        i. Could you describe how you work with:
            A. Production planning?
            B. In-house logistics?
            C. Change processes?
            D. Layout changes?

(b) How does your company work with digitalization?
(c) How do you work with digitalization in your daily work?
(d) Have you heard about the concept Industry 4.0?
  i. If yes, how would you describe it?
  ii. If no, describe it:
  Industry 4.0 is the fourth industrial revolution. From articles read one could describe it as smart production where the connectivity of machines are central and sensors are playing an important role. The goal is factories in which machines could communicate with each other, develop intelligence and take own decisions.
(e) Does your company strive towards becoming closer to Industry 4.0?
  i. If yes, how? What tools do you use?
  ii. If no, do you know why?

4. Knowledge and usability of digital twins
(a) Have you heard of the concept of digital twins?
  i. If yes, what does the concept mean to you? → Track 1
  ii. If no → Track 2

Track 1:
(b) In what context have you heard of digital twins?
(c) Do you at your company have something that you would classify as a digital twin?
If yes:
  i. What do you have and how does it work?
    A. How and how often is it updated?
    B. How does information flow to and from it?
    C. How much historical data is the digital twin built on? What parts of the products/assets life cycle are represented in the twin?
  ii. In what context do you use it?
  iii. What persons/work roles use it? Do you use it?
  iv. What are the benefits of using the digital twin?
  v. What software do the digital twin require?
  vi. How available is the digital twin for the employees?
  vii. Is there something that you feel is missing in your digital twin today?
  viii. Is there something in your digital twin that does not function as well as you would have wished it to?
  ix. Do you perceive it easy or difficult to gather necessary data to the digital twin?

If no:
(d) Do you think a digital twin could be useful at your company?
  i. If yes, in what context?
  ii. If no, why?

(e) If you had a digital twin, what would you want to get out of it?
(f) What persons/work roles could benefit from using it if it were to be implemented?
(g) What hinders you from implementing one?
(h) Do you see any obstacles for using a digital twin at your company?

Track 2: Describing material of the digital twin concept
According to literature, and previous people spoken to, there is no clear definition or common perception of what a digital twin really is. However, when breaking down the concept in order to make it more comprehensible one could describe a digital twin as a physical object, a digital representation of the physical object, and a link between them. We have, in the literature, found a 3-level model of digital twins dependent on the degree of data integration. The first level is called digital model, the second digital shadow , and the last digital twin (Show explanatory pictures).

With this explanation in mind:
(i) Do you, as far as you are concerned, have any of these levels of digital twins in your company?
If yes:
   i. What do you have and how does it work?
   ii. In what context do you use it?
   iii. What persons/work roles use it? Do you use it?
   iv. What are the benefits of using the digital twin?
   v. What software do the digital twin require?
   vi. How available is the digital twin for the employees?
   vii. Is there something that you feel is missing in your digital twin today?
   viii. Is there something in your digital twin that does not function as well as you would have wished it to?
   ix. Do you perceive it easy or difficult to gather necessary data to the digital twin?

   If no:
   x. Do you think a digital twin could be useful at your company?
      A. If yes, in what context?
      B. If no, why?
   xi. If you had a digital twin, what would you want to get out of it?
   xii. What persons/work roles could benefit from using it if it were to be implemented?
   xiii. What hinders you from implementing one?
   xiv. Do you see any obstacles for using a digital twin at your company?

5. Sum-up
   (a) To summarize the interview

i. Do you think there is something else that we should bring with us from this interview that we have not talked about?
ii. We would also like to talk to manufacturing companies that use or can benefit from using a digital twin, do you know any company that we should talk to?
  A. If yes, do you have contact information?

(b) To confirm what we already asked, do you want to be anonymous in this study?

(c) *As we said before, this information gathered here today will be used in a report and a presentation, you are welcome to take part of both. If you are interested in this we can give you more information.*

(d) *Lastly we would like to thank you so much for taking the time to participate in this interview.*