Sustainable competitive advantage through the implementation of a digital twin

Ukko Juhani, Rantala Tero, Nasiri Mina, Saunila Minna

Sustainable competitive advantage through the implementation of a digital twin

Juhani Ukko, Tero Rantala, Mina Nasiri, Minna Saunila
LUT University, Finland

Abstract

This chapter discusses how and under what conditions firms implementing digital twins can build a sustainable competitive advantage. A digital twin refers to a precise virtual copy of a machine or system that can be utilized across a wide range of corporate operations. However, the digital twin can be a major investment, and companies need to know which operations to focus on in the long run and what type of competencies are needed to succeed in the implementation and use of a digital twin. Therefore, the primary contribution of this chapter is its construction of a multidimensional model for managing a digital twin-driven operation based on insights from multiple disciplines and the dynamic-capabilities view of the firm. The model illustrates the interplay between company competencies, strategic direction, and sustainability performance in the implementation of a digital twin. Further, nine propositions related to requisite competencies and the strategic direction of digital-twin implementation are offered.

Keywords: digital twin; DT; implementation; strategy; competence; performance; sustainability performance; proposition

15.1 Introduction

Digital-twin technology is revolutionizing industry. Everything in the physical world can be replicated in the digital space using a digital twin (Qi *et al.*, 2020). Many companies and technical fields already use a digital twin to spot problems and increase efficiency using sophisticated models that can mirror almost every facet of a product lifecycle, a process, or a service (Tao *et al.*, 2019; Qi *et al.*, 2020).

A digital twin refers to precise virtual copies of machines or systems that include the process of physical-to-virtual and virtual-to-physical twinning (Jones *et al.*, 2020; Qi *et al.*, 2020). The combination of both connections allows for continuous cycle optimization, because possible physical states are predicted in the virtual environment and optimized for a specific goal (Jones *et al.*, 2020). Using physical modeling for the real-time simulation of a vehicle is one example.

So far, the discussion on digital twins has mainly focused on the physical modeling of products and production systems, where modeling refers to the process of representing a physical entity in digital forms that can be processed, analyzed, and managed by computers (Qi *et al.*, 2020). In addition to physical modeling, Qi *et al.* (2020) present that together with AI and machine learning, a digital twin can be used for simulation, monitoring, diagnostics, prognostics and optimization, as well as for the training of users, operators, maintainers, and service providers. Vijayakumar (2020) showed that a digital twin could be effective, for example, in predicting customer needs and sales or in managing a supply chain. It seems that digital twins in all forms can provide comprehensive support for decision-making covering a wide range of company operations. However, Qi *et al.* (2020) argue that implementing a digital twin is a complex and lengthy process that needs multiple technologies and tools to work together. They go on to say that many companies and researchers remain unfamiliar with the key technologies and tools of digital-twin technology, mainly because of this complexity and the difficultly in integrating the requisite engineering disciplines.

Based on the notions above, digital twins can be utilized across a wide range of corporate operations. However, implementing a digital twin can be a major investment, and companies must know which operations to focus on in the long run and what type of competencies are needed to succeed in the implementation and use of a digital twin. For example, Jones *et al.* (2020) state that given the potential costs and challenges for the infrastructure and workflow changes needed to effectively implement digital twins in an industrial context, the lack of a clear understanding of the scale and nature of the benefits that will be gained remains a substantial obstacle. They continue by saying there are very few examples of validation and quantification of any perceived benefits against existing processes and systems with very few papers demonstrating tangible improvements over current norms. Jones *et al.* (2020) also expressed concern that without substantial effort to

describe and quantify benefits, it is difficult to claim that the digital twin concept is the most appropriate solution to the challenges faced by any given industry. Therefore, it is worth first exploring and then justifying what possible strategic directions a company must face. It is equally important to study what kind of competencies the chosen strategic direction demands and what kind of benefits should be expected.

In response to the above-mentioned research gap, this chapter contributes to the understanding of how and under what conditions firms implementing digital twins can build a sustainable competitive advantage. This is achieved through the construction of a multidimensional model for the implementation of a digital twin. Furthermore, nine propositions are forwarded and justified to assist in positioning further research into the consequences of implementing digital twins.

This chapter is structured as follows. First, the model and its theoretical grounds and descriptions of the key concepts are presented. In the third section, the requisite competencies and research propositions are revealed. Next, conclusions for management research and practice are presented. Finally, the chapter presents some limitations and further research directions.

15.2 A Multidimensional model for the implementation of a digital twin

15.2.1 Theoretical underpinnings

Understanding how and under what conditions firms facing digital transformation, specifically implementing digital twins, can build a sustainable competitive advantage is an unanswered question. Because implementing a digital twin requires a clear understanding of the operation and a collaborative establishment of clear objectives (for example, in terms of promoting continuous change and introducing new methodologies) new competencies and knowledge are needed to stay ahead of competitors. Therefore, the competencies needed to successfully implement a digital twin can be considered an important source of sustained competitive advantage. The dynamic-capabilities view offers great potential for studying this type of change in firms. According to Teece *et al.* (1997, p. 516), dynamic capabilities are "the firm's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments".

Therefore, the dynamic-capabilities view deals with the competencies that enable firms to adapt to their operating environment (Teece *et al.*, 1997).

A dynamic-capabilities view is likely to bring value to the digital transformation study, because functioning in a turbulent operations environment requires the firm to focus beyond its traditional core competencies. Teece (2014) uses the term "ordinary capabilities" to refer to the competencies that enable executing administrative and operational assignments necessary to keep the firm in operation. These include accounting and sales, for example, which are easily replicable and by themselves can no longer sustain competitiveness. To achieve sustainable competitive advantage, unique capabilities are needed that are hard to replicate and that govern the rate of change in a firm's ordinary capabilities (Teece, 2014). These difficult-to-replicate capabilities are referred to as "dynamic capabilities" that enable a firm to enhance and direct its ordinary capabilities toward sustained competitive advantage (Teece, 2018). As a result, a firm's resources must be developed and coordinated to address digital transformation in the operating environment. Dynamic capabilities, therefore, are used in the implementation of a digital twin as an appropriate theoretical foundation to reveal the competencies that shape and direct traditional competencies such as product development, marketing, and production.

15.2.2 Defining a digital twin

Along with using the most recent information technologies related to, for example, the internet of things or different types of cloud technologies for data management (Jiang *et al.*, 2014; Xu *et al.*, 2014), the implementation of digital twins is increasing in contemporary operations environments (Tao *et al.*, 2018). At the general level, a digital twin can be considered a digital replication of, for example, a product or physical space. A digital twin is not just a 3D-level visualization of the physical product, machine, or factory. Typically, it also includes the same functionalities as its physical twin. One of the most commonly recognized definitions of the digital twin was offered by Glaessegen and Stargel (2012). They contended that a digital twin is an integrated multiphysics, multiscale, probabilistic simulation of a complex product that closely replicates its geometry and functionality. Tao *et al.* (2018) have further argued that a digital twin can be considered an integrated multiphysics and probabilistic demonstration of a complex physical product that utilizes
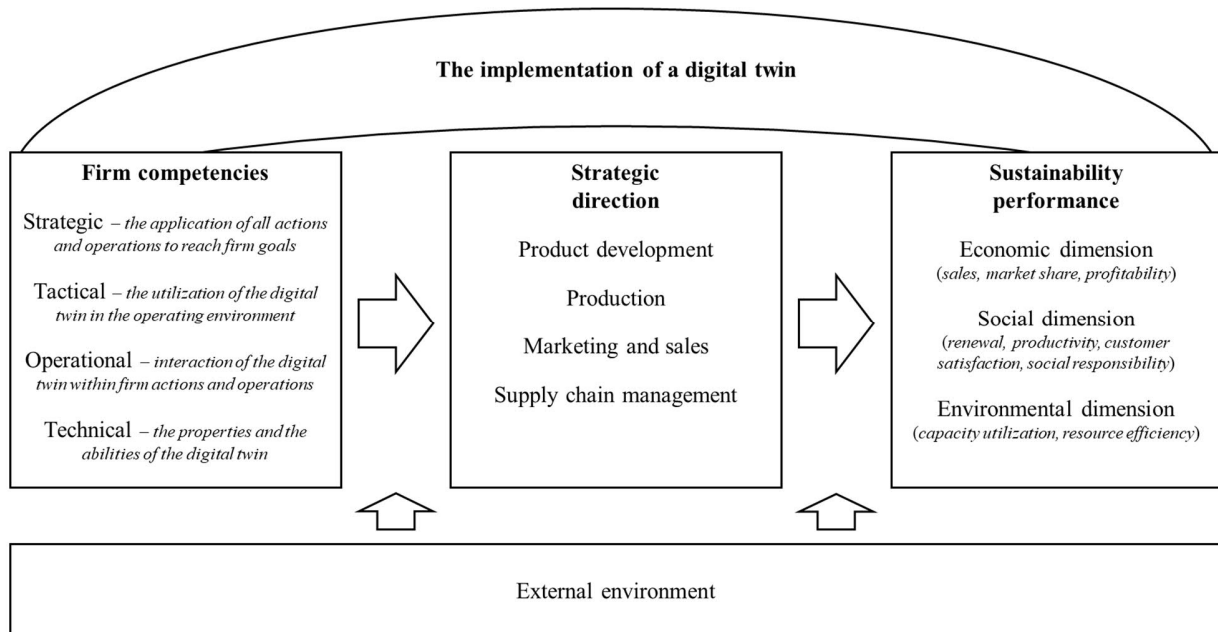
advanced models and sensors to reflect its physical twin. According to Glaessegen and Stargel (2012), digital-twin technology comprises three parts: the physical product, the virtual reflection of that product, and the connection between physical and virtual life. Further, according to Tao *et al.* (2019), a digital twin can be considered a bridge or linkage between physical and digital worlds. As such, digital twins give companies the ability to visualize and status their operations from thousands of miles away (Porter *et al.*, 2015).

Previously, different types of digital twins have usually been used in error diagnosis, predictive maintenance for factories and machines, and in performance analysis (Tao *et al.*, 2019). Even though these activities are still important and valid uses of digital twins, more recent implementations also consider other important activities. For example, current utilizations include product design and development and sales and marketing activities. Today, companies are more frequently using the rich data provided by digital twins to better understand and operate their connected products (Porter *et al.*, 2015).

15.2.3 Description of the model

This chapter examines the pathways for implementing a digital twin. Digital twins in product development, production, marketing, sales and delivery allow firms to operate sustainably. These physical entities, virtual counterparts, and the in-between data connections (Jones *et al.*, 2020) enable firms to connect with products and services (Cenamor, *et al.*, 2017) with the aim of building a sustained competitive advantage. Therefore, the digital twin concept is dynamic in that a firm's competencies need to be constantly evolving. In addition, it may take years before digital transformation results in added value for the firm (Kohtamäki *et al.*, 2020). The term "sustainability performance" is used here to describe the comprehensive and long-term effects that digital-twin implementation can bring. Digital transformation-driven digital-twin implementation shapes and directs a firm's competencies, which then results in strategically directed outcomes and a further sustained competitive advantage. The various elements of digital-twin implementation is presented in Figure 15.1. These will be described further in the following paragraphs.

Figure 15.1. Model of a digital-twin implementation

The implementation of a digital twin

Firm competencies

Strategic – *the application of all actions and operations to reach firm goals*

Tactical – *the utilization of the digital twin in the operating environment*

Operational – *interaction of the digital twin within firm actions and operations*

Technical – *the properties and the abilities of the digital twin*

Strategic direction

Product development

Production

Marketing and sales

Supply chain management

Sustainability performance

Economic dimension
(sales, market share, profitability)

Social dimension
(renewal, productivity, customer satisfaction, social responsibility)

Environmental dimension
(capacity utilization, resource efficiency)

External environment

Firm competencies

In today's digital transformation environment, where digitalization has changed patterns of work and business, it is necessary for firms to be equipped with different competencies that are compatible with the new ecosystems (Kohtamäki *et al.*, 2020; Longo *et al.*, 2017). Competencies will integrate knowledge and skills to help companies adapt to the new business environment and build successful businesses (Fowler *et al.*, 2000).

Firm competencies based on strategy and strategic decision-making concentrate on the integration of "corporate-wide technologies and production skills into competencies that empower individual businesses to adapt quickly to changing opportunities" (Hamel and Prahalad, 1990, p. 81). Therefore, to be successful in the current dynamic environment, firms must have strategic competencies that work together to apply all actions and operations to reach the final goal (Matt *et al.*, 2015; Sia *et al.*, 2016). Companies should prioritize their strategic initiatives to best impact their markets (Kohtamäki *et al.*, 2020).

Strategic competencies encompass the results of a firm's capabilities to distinctively integrate its resources with strategic business processes (Huikkola and Kohtamäki, 2017). Access to large

amounts of data provides opportunities in a digital twin, but without a coherent use strategy, these opportunities can become data-overload problems (Lenka *et al.*, 2017). Therefore, to support strategic competencies, a strategy is needed to effectively employ digital twinning in the operating environment (Lenka *et al.*, 2017; Kohtamäki *et al.*, 2020). Firms operating in digital transformation without tactic or business model fail to successfully collect, analyze, and exploit the real-time data (Huikkola and Kohtamäki, 2017).

Additionally, when competing in an ecosystem characterized by swift technological growth, operational competencies and routines to support both strategic and tactical competencies are a necessity (Matt *et al.*, 2015; Kohtamäki *et al.*, 2020; Ukko *et al.*, 2019). According to Matt *et al.*, 2015, the cross-functional characteristic of digital transformation has obliged firms to be aligned with other functional and operational strategies (Matt *et al.*, 2015). Therefore, operational competencies concentrate on the interaction of digital twins within a company's actions and operations (Longo *et al.*, 2017). Finally, in addition to strategic, tactical, operational competencies, firms need technical competencies to be able to propose effective solutions, which can guarantee the firms position as a technology leader (Huikkola and Kohtamäki, 2017).

Firms equipped with digital twins are characterized by the seamless integration of sophisticated manufacturing capabilities with digital infrastructures and with the ability to capture, produce, and distribute smartness through enhanced monitoring, analytics, modeling, and simulation (Longo *et al.*, 2017). Therefore, their technical competencies focus on the properties of the abilities of the digital twin (Longo *et al.*, 2017; Qi *et al.*, 2020).

Strategic direction

Due to the rapid growth of digital technologies in various areas of business operations, many researchers argue that digitality should be integrated in the business strategy, and moreover, that digitality should be considered the main part of the business (El Sawy *et al.*, 2016; Sia *et al.*, 2016; Ukko *et al.*, 2019). According to Matt *et al.* (2015) considering digital transformation as a strategic issue, digital technologies often affect large parts of companies and even go beyond their borders by impacting products, business processes, sales channels, and supply chains. They go on to say

that with digital transformation strategies, the potential benefits of digitization are manifold and include increases in sales or productivity, innovations in value creation, and novel forms of interaction with customers. Consequently, the connection of digital twins to the strategy can be seen as equally important, at least in regard to the presented benefits.

For example, Jones *et al.* (2020) present many potential and perceived benefits that have been highlighted in literature and industry relating to the digital twin concept such as:

- reducing costs, risk, and complexity, minimizing design and reconfiguration time;
- improving after-sales service, efficiency, maintenance decision making, security, safety and reliability, manufacturing management, processes and tools;
- enhancing flexibility and competitiveness of manufacturing system; and
- fostering innovation.

However, to gain a more structured description of the benefits of various operations, the use of digital twins must be examined through the different functions of the company.

So far, the strategic directions for and research into digital-twin technology has been largely concerned with data management and data usage techniques of physical modeling, simulation, and optimization (Jones *et al.*, 2020). Qi *et al.* (2020) state that modeling is arguably the cornerstone of digital twinning, and that it provides an information representation methodology for product design, analysis, computer numerical control (CNC) machining, quality inspection, and production management. As a result, strategic directions with regard to digital-twin implementation have so far focused on physical modeling and simulating the company's internal functions such as product development, production, and product lifecycle management.

A more novel strategic direction, in addition to using a digital twin for physical assets, is to apply digital-twin technology to non-physical modeling such as predicting customer needs (Vijayakumar, 2020). This can be made more effective by developing the digital twin to track customer behavior dynamically, logging the products they purchase and recording their level of satisfaction, *etc*. Similarly, the digital twin of a supply chain could track transportation, inventory, demand, and the capacity of the physical supply chain to make real-time decisions on the product

(Vijayakumar, 2020). This adoption of a supply chain digital twin can be considered a balancing act between logistical variations and customer requirements, enforcing the production of the right products at the right time, and promoting and achieving higher future revenue and sales (Vijayakumar, 2020). Therefore, the strategic directions regarding the implementation of non-physically modeled digital twins can relate to the company's external functions such as supply chain management, customer relationship management, and sales promotion.

Sustainability performance

Rapid advancements in technological issues have enhanced organizational performance in the last couple of decades, but at the same time, the advancements have led to growing expectations for sustainable business operations. With the emergence of industry 4.0, organizations expand their knowledge to transform their focus from performing economically to further excelling socially and environmentally. Therefore, organizations should operate in a competitive environment to produce sustainable competitive advantage and pursue the triple bottom line that results in a proper balance between economic, social, and environmental dimensions (Gupta *et al.*, 2020). The sustainable performance of a practice is the integration of economic, social, and environmental performances in business process operations (Chardine-Baumann & Botta-Genoulaz, 2014).

Economic sustainability performance focuses on the financial business value including increases in sales, market share, and profitability (Nasiri *et al.*, 2018). Digital transformation and drastic changes in the business ecosystem bring about the demand for procedural changes through the emergence of industry 4.0, which leads to business profitability. Economic sustainability performance supports the development of an ecosystem for financial growth in business process operations and promotes opportunities to oblige stakeholder preferences in terms of social and environmental aspects (Gupta *et al.*, 2020).

Social sustainability performance addresses issues regarding social and personal needs in the places people live and work. These issues include wellbeing, social responsibility, renewal, productivity, and customer satisfaction (Nasiri *et al.*, 2018). Advanced companies who utilize real-

time data are struggling to reach a high level of social performance by engaging moral standards, trust, and free discussion (Gupta *et al.*, 2020).

Environmental sustainability performance refers to the creation of business profit while conforming to environmental policies and standards as well as resource efficiency and capacity. As one of the outstanding tools in industry 4.0, a digital twin can enhance environmental sustainability performance through real-time monitoring to optimize resource consumption and reduce toxic emission (Nasiri *et al.*, 2018).

External environment

A company's external environment can be defined and understood as the different types of stable rules, social level standards, and cognitive structures (Scott, 1995) as well as the environmental aspects such as weather that are either guiding, favoring, or restricting its businesses and operations. As such, the external environment of companies comprises different aspects and continuous changes to which companies must adapt.

To be able to operate in these continuously changing environments, companies are trying to gather and analyze important data from their external environment. Digital twinning can play an important role while gathering and analyzing data from external operations and business environments. According to Tao *et al.* (2018), digital twin-driven virtual verification can be utilized to better follow and understand a company's environment, its materials, and the physical characteristics of its customers. As such, the utilization of a digital twin can, for example, be targeted to follow the changes in the prices of raw materials or how the changes in weather conditions affect operations.

External environment effects can also be estimated and analyzed in product development via digital twinning. For example, Tao *et al.* (2018) suggested that designers could install assembly sensors in the conceptual design phase to provide various data from the environment to be used in the design process.

15.3 Requisite Competencies and Research Propositions

15.3.1 Linking competencies to the strategic direction of a digital twin

Early phases of product development are sometimes "fuzzy", because there is a lack of information about the initial solution and final application of the product. As a result, companies utilize digital solutions (*e.g.* a digital twin) to virtually visualize multiple product solutions and their application. Managers and the people who engage in decision making should commit to this virtual working environment and consider strategic sustainable initiatives in the initial product development phase (Hallstedt and Isaksson, 2017). According to Tao and his colleague (2018), the successful development of a digital twin for product development necessitates having advanced technical knowledge and digital technologies for data acquisition and exploitation in every stage of product lifecycle. Additionally, the exploitation of real-time information is challenging without also having the ability to manage, process, and analyze the large amount of data (Tao *et al.*, 2018).

Based on the preceding discussion, the first proposition can be shaped as follows.

P1: Firms that are strong in the necessary competencies are more successful implementing a digital twin to improve **product development**.

One key aspect of leveraging digital twins is the facilitation of production and manufacturing processes. Digital twins could enable designers to simulate the entire factory design process with respect to factory layout, equipment configuration, material handling, buffer capacity, *etc.* (Zhang *et al.*, 2017; Guo *et al.*, 2019; Qi *et al.*, 2020). This can be achieved by focusing on the development of a simulation-based approach for plant design and production planning where modeling and simulation approaches can be applied to develop digital-twin models of the plant (Zhang *et al.*, 2017; Qi *et al.*, 2020).

However, to successfully deploy digital twinning on such a scale, companies must have the necessary competencies, for example, the management and operational competencies. Ukko *et al.* (2019) argue that in addition to understanding their business, managers must be familiar with

existing digital tools, applications, and solutions. They need to have a clear vision for utilizing digitality in the company now and in the future and need to build a management culture that supports the utilization of digitality in the company. Similarly, operational competencies include proficiency in adopting and implementing digital tools and solutions and the ability to make use of them as a natural part of business processes (Peng *et al.*, 2008; Benitez *et al.*, 2018; Ukko *et al.*, 2019).

Continuing this line of thought, the second proposition is as follows.

P2: Firms that are strong in the necessary competencies are more successful implementing a digital twin to improve **production**.

Through the contemporary possibilities of integrating with mobile internet, cloud computing, big data, and other recent technologies (Qi *et al.*, 2020), companies now have the opportunity to adopt and utilize digital twins in their marketing and sales activities. Currently, digital twins can be found in smart cities, manufacturing, cargo shipping, and automotive industries (Qi *et al.*, 2020). Within these industries, the utilization of digital twins can support, for example, product launches and marketing based on relevant customer data (Tao *et al.*, 2018). Tao *et al.* (2018) further argued that as part of company sales processes, digital twins can make customer preferences and the location distribution of orders available and also support after-sales services.

As the implementation of digital twins in sales and marketing operations provides companies with new types of possibilities and options, it becomes necessary to find the most suitable ways to support those operations. Digital twinning results in an abundance of data from many different sources, but not all are valuable from the sales/marketing perspective.

As such, a third proposition can be presented.

P3: Firms that are strong in the necessary competencies are more successful implementing a digital twin to improve **sales and marketing**.

Digital twins provide great value beyond the boundaries of individual firms, but at the same time, their implementation in the supply chain context necessitates high-level competencies. The required competencies are not purely technological. Firms also must deal with the challenges associated with interpreting the data and taking action based on the insights gained (Srai *et al.*, 2019). Specific knowledge regarding the behavior of the physical object (of the digital twin), such as its quality evolution, is required to optimize the supply chain from transport to storage and beyond (Defraeye *et al.*, 2019). Liotine (2020) uses the term digital innovation to describe the linked supply chain competencies needed to sense the variability in demand and adjust production capacity to optimize the supply chain in terms of timely deliveries and reasonable inventories.

A fourth proposition follows based on these considerations.

P4: Firms that are strong in the necessary competencies are more successful implementing a digital twin to improve **supply chain management**.

15.3.2 Linking strategic direction of a digital twin to sustainability performance

Digital twinning provides many opportunities in every stage of product development through advanced computing and by providing novel tools for simulation and data analysis and digitalized data (Qi *et al.*, 2019). Digital-twin technology in product development makes it possible to estimate performance early, which results in savings of time and cost (Wagner *et al.*, 2019) and gains in energy efficiency (Horváthová *et al.*, 2019). Designers believe that the development of efficient physical artifacts is more challenging without the comprehensive availability of manufacturing knowledge in the early stages of product development. The digital twin can help via knowledge discovery in the database and the optimization of each process based on prior product data. These benefits result in sustainable performance (Wagner *et al.*, 2019).

As a result, a fifth proposition can be stated as follows.

P5: The more a digital twin is used to improve **product development**, the higher the level of sustainability performance.

It has recently been demonstrated that in production management, digital twins enable the optimal (re)configuration of on-site resources, equipment, work-in-progress, and workers through the simulation, verification, and confirmation of process planning and production scheduling (Zhang *et al.*, 2018; Qi *et al.*, 2020). With regard to control and execution, digital twins can be used to track everything that occurs in the physical world to subsequently perform operational forecasting, optimize control strategy, and align actual processes with planning (Sun *et al.*, 2017; Vachálek *et al.*, 2017; Senington *et al.*, 2018; Qi *et al.*, 2020).

Qi *et al.* (2020) present that by using twin data such as sensor data, energy costs, or performance factors, the optimization service tools are triggered to run hundreds or thousands of what-if simulations to evaluate readiness or to make necessary adjustments to current system set-points. From a production management perspective, this makes possible a controlled and optimized system designed to achieve various sustainability functionalities such as providing higher security and safety (social aspect), decreasing energy and material consumption (environmental aspect), and decreasing costs (economic aspect) (Chen *et al.*, 2015; Jones *et al.*, 2020; Qi *et al.*, 2020).

Therefore, based on the notions above, a sixth proposition is presented.

P6: Making greater use of a digital twin to improve **production** results in a higher level of sustainability performance.

The utilization of digital twins in marketing and sales processes provides companies possibilities to improve their sustainability. For example, the use of digital twins, for example, in exhibition marketing and individual sales processes can help companies to reduce the amount of physical material needed to demonstrate their products and services. In addition, the real-time tracking of logistics (Tao *et al.*, 2018) and warehouse inventories make it possible to minimize unnecessary product movement. Tao *et al.* (2018) further present that in the area of after-sales services, digital twinning can provide maintenance data which help companies to predict and improve product lifetime and help to minimize product failures. Qi *et al.* (2019) further argued that digital twins can be utilized widely among different industries to optimize product lifecycles and services

making them more sustainable. The utilization of digital twins as a part of sales and marketing operations, therefore, can help to minimize physical demonstration and decrease unnecessary people and product logistics, both of which help companies to operate in a more sustainable manner.

Based on this discussion, a seventh proposition is offered.

P7: Making greater use of a digital twin to improve **sales and marketing** results in a higher level of sustainability performance.

Digital twins have several positive implications for the supply chain as well. According to Marmolejo-Saucedo *et al.* (2019), digital twins can help supply chain members to decrease costs. Because the supply chain is more connected and more real-time information is available, decisions can be made in real time, and potential flaws can be more rapidly fixed. Defraeye *et al.* (2019) have applied a digital twin to predict quality loss in complex-shaped fruits. They concluded that the digital twin helped to enhance the logistics process by reducing food losses, thereby making the supply chain more sustainable. Further, digital twins can provide greater sustainability performance for the supply chain by reducing inventory, enhancing product/service quality and environmental compliance, and improving livelihood and resource efficiency (Srai *et al.*, 2019).

Based on the evidence presented above, the following eighth proposition is established.

P8: Making greater use of a digital twin to improve **supply chain management** results in a higher level of sustainability performance.

15.3.3 External environment as moderator

The concept of a digital twin includes real-time interactions with the external environment. The external environment constitutes various uncertainties and constraints that are monitored by sensors and manipulated by actuators that form the backbone of a digital twin (Tao *et al.*, 2019). Digital twins can assist companies in responding to environmental changes to maintain optimized

production in the pressure of everchanging external constraints (Min *et al.*, 2019). Qi *et al.* (2019) has characterized these types of behavioral models in terms of responding mechanisms that assist in coping with changes in the external environment. These responses to the external environment help these models to enhance the simulation service performance of a digital twin (Qi *et al.*, 2019).

Based on the research into the external environment facilitating digital-twin implementation, the following ninth proposition is provided.

P9: The external environment will moderate the relationships among organizational competencies, the strategic direction of digital twin use, and sustainability performance.

15.4 Conclusions

Theoretical implications

This chapter has contributed to the understanding of how and under what conditions firms implementing digital twins can build a sustainable competitive advantage. The chapter constructed a multidimensional model capable of managing a digital twin-driven operation based on insights from multiple disciplines and a dynamic-capabilities view of the firm. It has highlighted the benefits the model brings to understanding the interplay between firm competencies, strategic direction, and sustainability performance in the implementation of a digital twin. Further, nine propositions are offered related to the requisite competencies and strategic direction of digital-twin implementation. The model provides a robust theoretical basis for future research into the consequences of digital-twin implementation. Therefore, this multidimensional view of digital-twin implementation is important for the following reasons.

First, a focus of digital twin research has been in product and production development (Vijayakumar, 2020). However, digital transformation in products or in production alone is inadequate to achieve long-term competitiveness (Rantala *et al.*, 2019). Therefore, this type of focus on explicit areas of digital-twin implementation may limit their effectiveness; whereas a wider perspective on the strategic direction of digital-twin implementation facilitates expanding

its interaction into all areas of the firm to achieve sustainable competitive advantage. Second, the model will help companies implementing digital-twin technology to identify and develop organizational conditions and competencies needed to fulfill their strategic objectives. Third, the model establishes clear connections between firm competencies, strategic direction, and sustainability performance in the implementation of a digital twin.

The study suggests that firm competencies at different levels affect the strategic direction of a digital-twin implementation. Strategic direction refers to using a digital twin to improve product development, production, sales and marketing, or supply chain management. Further, greater use of a digital twin makes possible a higher level of sustainability performance. In this regard, the model identifies technical, operational, tactical, and strategic competencies as four separate but related competencies that are likely to influence the implementation of a digital twin and, consequently, sustainability performance.

Managerial implications

From the perspective of management, this chapter provides an important contribution that can increase and support the practical level utilization and adoption of digital twins for companies. Firstly, the chapter increases the practical level understanding of the multidimensional nature of digital twins by providing a comprehensive view of the different possibilities of how and under which conditions digital twins can be adopted. Further, and more importantly, this chapter gives practitioners an understanding of how and under which conditions digital-twin technology can be realized to build a sustainable competitive advantage.

In addition to discussing multiple different uses for digital twins and their connections, the chapter provides a multidimensional model that can be utilized to implement a digital twin in practice. The presented model can be utilized as a practical level tool that provides different implementation pathways. These different pathways can increase the practical level understanding of the role of competencies and the strategic directions in implementation of a digital twin.

Limitations and further research directions

Although this chapter provides a comprehensive understanding of the different possibilities for how and under which conditions digital twins can be implemented and utilized in companies, some limitations remain concerning the results of the chapter. The arguments made concerning the interplay between firm competencies, the strategic direction of digital-twin use, and their connection to sustainability performance, as well as the presented model for implementation of a digital twin are mainly theoretical and based on the prior literature. As such, more empirical evidence to further explore the presented model is recommended.

While the theoretical nature of the chapter can be considered a limitation, it also provides important and interesting avenues for further research. This chapter offers nine propositions that link competencies to the strategic direction for digital twinning and link strategic direction to sustainability performance. These propositions provide important and interesting avenues for further research in the field of implementation and the use of digital twins, either individually or in different combinations.

References

Benitez, J., Chen, Y., Teo, T. S., & Ajamieh, A. (2018). Evolution of the impact of e-business technology on operational competence and firm profitability: A panel data investigation. Information & Management, 55(1), 120-130.

Cenamor, J., Sjödin, D. R., & Parida, V. (2017). Adopting a platform approach in servitization: Leveraging the value of digitalization. International Journal of Production Economics, 192, 54-65.

Chardine-Baumann, E., & Botta-Genoulaz, V. (2014). A framework for sustainable performance assessment of supply chain management practices. *Computers & Industrial Engineering*, *76*, 138-147.

Chen, D., Heyer, S., Ibbotson, S., Salonitis, K., Steingrímsson, J. G., & Thiede, S. (2015). Direct digital manufacturing: definition, evolution, and sustainability implications. Journal of Cleaner Production, 107, 615-625.

Da Xu, L., He, W., & Li, S. (2014). Internet of things in industries: A survey. IEEE Transactions on industrial informatics, 10(4), 2233-2243.

Defraeye, T., Tagliavini, G., Wu, W., Prawiranto, K., Schudel, S., Kerisima, M. A., ... & Bühlmann, A. (2019). Digital twins probe into food cooling and biochemical quality changes for reducing losses in refrigerated supply chains. Resources, Conservation and Recycling, 149, 778-794.

El Sawy, O. A., Kræmmergaard, P., Amsinck, H., & Vinther, A. L. (2016). How LEGO built the foundations and enterprise capabilities for digital leadership. MIS Quarterly Executive, 15(2).

Fowler, S. W., King, A. W., Marsh, S. J., & Victor, B. (2000). Beyond products: new strategic imperatives for developing competencies in dynamic environments. Journal of Engineering and Technology Management, 17(3-4), 357-377.

Glaessgen, E., & Stargel, D. (2012). The digital twin paradigm for future NASA and US Air Force vehicles. In 53rd AIAA/ASME/ASCE/AHS/ASC structures, structural dynamics and materials conference 20th AIAA/ASME/AHS adaptive structures conference 14th AIAA (p. 1818).

Guo, J., Zhao, N., Sun, L., & Zhang, S. (2019). Modular based flexible digital twin for factory design. Journal of Ambient Intelligence and Humanized Computing, 10(3), 1189-1200.

Gupta, S., Meissonier, R., Drave, V. A., & Roubaud, D. (2020). Examining the impact of Cloud ERP on sustainable performance: A dynamic capability view. *International Journal of Information Management*, *51*, 102028.

Hallstedt, S. I., & Isaksson, O. (2017). Material criticality assessment in early phases of sustainable product development. *Journal of Cleaner Production*, *161*, 40-52.

Hamel, G., & Prahalad, C. K. (1990). The core competence of the corporation. Harvard business review, 68(3), 79-91.

Huikkola, T., & Kohtamäki, M. (2017). Solution providers' strategic capabilities. Journal of Business & Industrial Marketing, 32 (5), 752-770.

Jiang, L., Da Xu, L., Cai, H., Jiang, Z., Bu, F., & Xu, B. (2014). An IoT-oriented data storage framework in cloud computing platform. IEEE Transactions on Industrial Informatics, 10(2), 1443-1451.

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

Kohtamäki, M., Parida, V., Patel, P. C., & Gebauer, H. (2020). The relationship between digitalization and servitization: The role of servitization in capturing the financial potential of digitalization. Technological Forecasting and Social Change, 151, 119804.

Lenka, S., Parida, V., & Wincent, J. (2017). Digitalization capabilities as enablers of value co-creation in servitizing firms. Psychology & marketing, 34(1), 92-100.

Liotine, M. (2020). Unlocking digital innovation: guiding principles for driving digital technology in the supply chain. Technology in Supply Chain Management and Logistics: Current Practice and Future Applications, 143.

Longo, F., Nicoletti, L., & Padovano, A. (2017). Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. Computers & industrial engineering, 113, 144-159.

Marmolejo-Saucedo, J. A., Hurtado-Hernandez, M., & Suarez-Valdes, R. (2019). Digital Twins in Supply Chain Management: A Brief Literature Review. In International Conference on Intelligent Computing & Optimization (pp. 653-661). Springer, Cham.

Matt, C., Hess, T., & Benlian, A. (2015). Digital transformation strategies. Business & Information Systems Engineering, 57(5), 339-343.

Min, Q., Lu, Y., Liu, Z., Su, C., & Wang, B. (2019). Machine learning based digital twin framework for production optimization in petrochemical industry. International Journal of Information Management, 49, 502-519.

Nasiri, M., Rantala, T., Saunila, M., Ukko, J., & Rantanen, H. (2018). Transition towards sustainable solutions: Product, service, technology, and business model. *Sustainability*, *10*(2), 358.

Peng, D. X., Schroeder, R. G., & Shah, R. (2008). Linking routines to operations capabilities: A new perspective. Journal of operations management, 26(6), 730-748.

Porter, M. E., Heppelmann, J.E. (2015). How smart, connected products are transforming companies. Harvard business review 93 (10), 96-114.

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., ... & Nee, A. Y. C. (2020). Enabling technologies and tools for digital twin. Journal of Manufacturing Systems.

Scott, R.W. (1995), Institutions and Organizations, Sage, Thousand Oaks, CA.

Senington, R., Baumeister, F., Ng, A., & Oscarsson, J. (2018). A linked data approach for the connection of manufacturing processes with production simulation models. Procedia CIRP, 70, 440-445.

Sia, S. K., Soh, C., & Weill, P. (2016). How DBS Bank Pursued a Digital Business Strategy. MIS Quarterly Executive, 15(2).

Srai, J. S., Settanni, E., Tsolakis, N., & Aulakh, P. K. (2019). Supply Chain Digital Twins: Opportunities and Challenges Beyond the Hype. Paper from 23rd Cambridge International Manufacturing Symposium, University of Cambridge, 26 –27 September 2019.

Sun, H., Li, C., Fang, X., & Gu, H. (2017, December). Optimized throughput improvement of assembly flow line with digital twin online analytics. In 2017 IEEE International Conference on Robotics and Biomimetics (ROBIO) (pp. 1833-1837). IEEE.

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. *The International Journal of Advanced Manufacturing Technology*, *94*(9-12), 3563-3576.

Tao, F., Sui, F., Liu, A., Qi, Q., Zhang, M., Song, B., ... & Nee, A. Y. C. (2019). Digital twin-driven product design framework. International Journal of Production Research, 57(12), 3935-3953.

Teece, D. J. (2014). The foundations of enterprise performance: Dynamic and ordinary capabilities in an (economic) theory of firms. Academy of Management Perspectives, 28(4), 328-352.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. Strategic Management Journal, 18(7), 509-533.

Teece, D. J. (2018). Business models and dynamic capabilities. Long Range Planning, 51(1), 40-49.

Ukko, J., Nasiri, M., Saunila, M., & Rantala, T. (2019). Sustainability strategy as a moderator in the relationship between digital business strategy and financial performance. Journal of Cleaner Production, 236, 117626.

Vachálek, J., Bartalský, L., Rovný, O., Šišmišová, D., Morháč, M., & Lokšík, M. (2017, June). The digital twin of an industrial production line within the industry 4.0 concept. In 2017 21st International Conference on Process Control (PC) (pp. 258-262). IEEE.

Vijayakumar, D. S. (2020). Digital twin in consumer choice modeling. Advances in Computers, 117(1), 265-284.

Zhang, H., Liu, Q., Chen, X., Zhang, D., & Leng, J. (2017). A digital twin-based approach for designing and multi-objective optimization of hollow glass production line. Ieee Access, 5, 26901-26911.

Zhang, H., Zhang, G., & Yan, Q. (2018, March). Dynamic resource allocation optimization for digital twin-driven smart shopfloor. In 2018 IEEE 15th International Conference on Networking, Sensing and Control (ICNSC) (pp. 1