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Enhancing the Resilience of Global Value Chain through the Adoption of Digital Twin and Big Data & Analytics

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Abstract

Global value chain relates to the full range of activities that economic actors engage in order to bring a product to the market. It is constantly changing, and modern technologies have a particular impact on it. Digital Twin and Big Data & Analytics are the forefront of these technologies. The aim of this thesis in particular is to answer whether the adoption of Digital Twins improves the resilience of global value chains. If so, what is their impact on business models. A qualitive study based on in depth analysis of illustrative examples was conducted. After a review of companies reports, articles, websites, journals, and articles it can be stated that proper implementation of Digital Twin and Big Data & Analytics can lead to overall increase in resilience, and efficiency of the Supply Chain.

La catena del valore comprende l'intera gamma di attività che gli attori economici intraprendono per portare un prodotto sul mercato. È in continuo cambiamento e le tecnologie moderne hanno un impatto particolare su di essa. Digital Twin è Big Data & Analytics sono le tecnologie all'avanguardia. L'obiettivo di questo tesi in particolare è rispondere alla domanda se l'adozione di Digital Twin migliori la resilienza delle catene del valore globali. In caso affermativo, qual e il loro impatto sui modelli di business. è stato condotto uno studio qualitativo basato su un'analisi approfondita di esempi illustrativi. Dopo una revisione di report aziendali, articoli, siti Web, riviste e articoli, si può affermare che la corretta implementazione di Digital Twin e Big Data & Analytics può portare a un aumento complessivo della resilienza e dell'efficienza della Supply Chain.

Introduction

New discoveries, inventions, and breakthroughs have always transformed the globe. Industrial revolutions are examples of enormous achievements that permanently altered the planet while considerably enhancing the level of living. It appears that we are currently witnessing the fourth revolution, known as industry 4.0, which is transforming the way global industries operate. According to the concept, Industry 4.0 refers to an integration of manufacturing operations system and information, and communication technologies (ICT) forming so-called Cyber-Physical System (CPS) (Wang, 2015; Jeschke, 2017). Its technologies are diverse and encompass more than 20 areas, but the following are the most important: artificial intelligence, augmented reality, robotics, big data analytics, blockchain, internet of things, RFID, simulation. Its technologies are various, and cover more than 20 positions, however these are the most vital: artificial intelligence, augmented reality, robotics, big data & analytics, blockchain, internet of things, RFID, simulation (Bai, 2020). The changes already brought by these technologies are immense. Many of the technologies in this set are interesting, but big data analytics and digital twin stand out in particular.

Previous studies on industry 4.0 technologies emphasize that these technologies when used for global supply chain have incredible capacity to interpret and capture data, while at the same time enabling them to do it cheaper than ever before (Ferrantino, 2019). At the current state of the art, it also widely known that digital twin and big data analytics can have a positive impact on supply chain's efficiency, safety, and decision making, improving supply chain performance in general (Rasheed, 2019; Tao, 2019).

However, no particular attention is paid on correlation between big data analytics and digital twin. Given the rapid development of these technologies, not only a large amount of new information is needed, but also an update of the old information. Such technologies are a subject to radical change, so the potential for the additional data is constant. Additionally, another unexplored issue is whether and how companies adapt their business models to the above-mentioned technologies. There is not much scientific literature highlighting the impact of new these technologies on how companies operate and how they shape business models.

In particular, this thesis seeks to answer the following research questions: Does the adoption of digital twins improve the resilience of global value chains? If so, what is the impact on business models?

In conclusion, these problems hold significant relevance for business. For many years due to globalization world has become more connected than ever before. Technologies can have lasting contribution to the functioning of the company. Data provided by this work can help managers with their decision-making related to the adoption of digital twin and big data analytics, and cooperation between them. It has been proved that the proper management of these resources can lead to an increase in competitive advantage. This work will provide data, along with practical recommendations by showing real potential of digital twin and big data analytics influence in creating the future of global supply chain. As cooperation between these technologies is not well studied, this work will provide significant contribution also for the academics.

Chapter 1 will include the general overview of Global Supply Chain, along with how it is correlated to industry 4.0 technologies with focus on Digital Twin and Big Data Analytics. This chapter will also provide detailed information about most important features of mentioned technologies, along with their advantages and disadvantages. There will also be a paragraph devoted to the future global supply chain. Chapter 2 will be focused on business model innovation, and its relationship with Digital Twin, with focus on how they cooperate, influence each other, and create ecosystems. Finally, chapter 3 will include illustrative examples of companies that incorporated digital twins into their supply chains. This chapter will describe how they process of implementation looked like, how it impacted resilience of their value chains, and at the end what was the final impact on the business models.

Chapter I Global Supply Chain

1.1. Supply Chain overview

Due to globalization supply chains are becoming more and more significant in the business sector for a long time. It is essential for modern trade, and it results in advancements in many areas. Businesses are now more interconnected than ever, and the supply chain may even play a bigger role. The supply chain is not exempt from the rapid progress of technology, since several element components are greatly impacted by it. Furthermore, as a result of COVID-19 pandemic, a lot of businesses discovered that it is difficult to run their business operations smoothly without a strong supply chain.

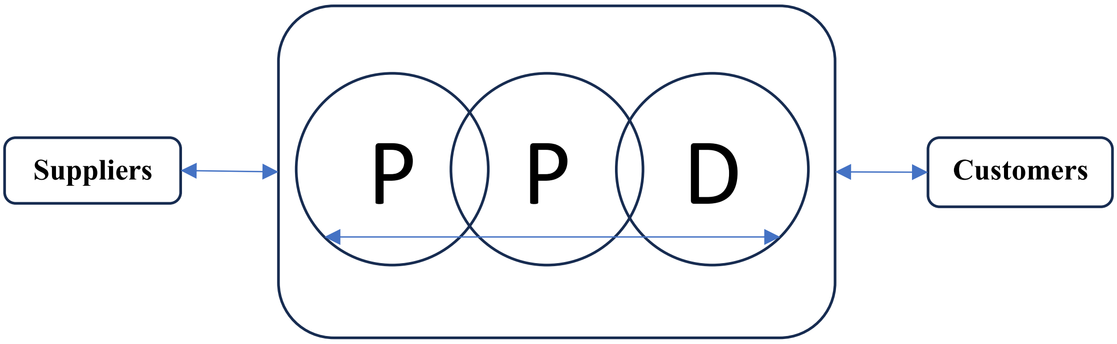
Many definitions of supply chain have been created. Ganeshan & Harrison (2002) provide a wide definition: "A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers". It is also possible to find more straightforward definitions, such as the one offered by Lambert (1998), which states that "supply chain is the alignment of firms that bring products or services to market"

Nonetheless, Mentzer's et al. (2001) definition – which defines a supply chain as "A set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows or products, services, finances, and/or information from a source to a customer" is the one which most effectively illustrates it. There are three levels of supply chain complexity that are covered by this term (Mentzer et al., 2001). Direct supply chain – consists only of a company, its suppliers, and a customer. Extended supply chain – includes also suppliers of instant suppliers, as well as customers of instant customers. Ultimate supply chain

– includes every firm/organization that takes part in all upstream and downstream activities of products, services, finances, and information from the final supplier to the final customer (Mentzer et al., 2001).

The supply chain typically consists of three traditional stages: distribution, production, and purchasing. Every one of these phases might consist of multiple facilities spread over various part of the globe (Felea & Albastroiu, 2013; Thomas & Griffin, 1996).

Figure 1 Internal Supply Chain



Source: Chen & Paulraj, 2004

However, it is possible to show a wider range of activities included in the supply chain. Although those activities differ from firm to firm, it is possible to identify the activities that are most like to be. They are split up into key and supporting activities. Key activities take place in every logistic channel, while supporting activities take place only depending on a company or industry (Hoang et. al, 2019).

Table 1 Key activities of the supply chain

Key Activities	**Decisions Associated**
Transportation	Transportation service selection, carrier routing, vehicle scheduling, rate auditing.
Inventory Management	Raw materials and finished products stocking, sales forecasting.
Customer service	Needs and wants for logistics customer service.
Information flows and order	Ordering rules.

Source: Hoang et al. (2019)

Table 2 Supporting activities of the supply chain

Support Activities	Decisions Associated
Warehousing	Space determination, stock placement, warehouse configuration.
Materials handling	Equipment selection, order-picking procedures.
Purchasing	Supply source selection, purchasing time & quantities.
Packaging	Handling, storage, protection from loss and damage.
Cooperate with production/operations	Sequence and time production output.
Information Maintenance	Information collection, data analysis, control procedures.

Source: Hoang et al. (2019)

As it was previously stated, the entire procedure and set of actions involved in moving information and commodities from the point of raw materials to the final customer of the commodity sector or services is called the supply chain. Supply chain management is the term used to describe the coordination of actions and procedures among supply chain participants (Felea & Albastroiu 2013; Handfield & Nicholis, 2003). Supply chain management can be defined as "management of material, money, men, and information within and across the supply chain to maximize customer satisfaction and to get edge over the competitors" (Shukla et al., 2011).

SCM's primary goal is to provide options than can enhance and build a sustainable competitive advantage by cost reduction, while at the same time not sacrificing customer happiness. Key component is making use of the knowledge, experience, abilities, and skills of the supply chain planning that make up a network of competitors (Mentzer et al., 2001). The question is whether companies should actively deal with supply chain. The costs associated with producing components, storing then, transferring money, and communicating information are all part of the supply chain. Numerous factors, including the enormous capital expenditure needed to operate worldwide firms, rising real estate expenses, contribute to the overall cost of the supply chain's tendency to rise (Koch & Tan, 2006). Nonetheless, meticulous planning in supply chain management with respect to material arrival, manufacturing schedule, and distribution minimizes loss of time and energy in addition to inventory and inventory costs (Varma et al., 2006). In many sectors, supply chain management significantly changes inventory investment and helps with reduction of economic volatility (Heng et al., 2005).

It is discovered that supply chain management (SCM) includes all aspects of planning, production and operations management required to introduce a product into a market, from obtaining raw materials to delivering the finished good. In relation to this there are many aspects and problems that need to be handled inside the supply chain (Shukla et al., 2011). Knowledge management – organizations require knowledge in order to meet client demands for personalized goods and services, as well as quicker, better service (Davenport & Klahr, 1998). Kowledge, which can be learned, and shared, is a measure of an organization's intellectual capital. It includes work-related experience, competence, know-how and best practices (Shukla, 2011). Knowledge management is the process by which individuals and organizations manage explicit and implicit data inside and across businesses in order to support the overall corporate strategy through improved decision-making, action, and output (Horwitch & Armacost, 2002). Customer – Supplier Relationship – being able to satisfy customers is essential for being competitive in today's market, and this can only be done by promptly attending to their demands. One approach to supply chain management that aims to solve inefficiencies in the chain is called efficient customer response (Shukla, 2011). Customer relations issue – customer relations procedures have an impact on a business's performance and ability to successfully manage its supply chain (Scott & Westbrook, 1991; Ellram, 1991; Turner, 1993). Managing upstream suppliers and integrating consumers downstream are essential components of effective supply base management. Every link in the supply chain functions as both a supplier and a client. A competitive edge may be produced in a variety of ways when a customer-driven corporate vision is implemented concurrently with efficient TQM and supplier base management methods. These include gains in market share, earnings, and customer happiness as well as decreases in inventory and cycle times and increases in production (Shukla et al., 2011). Logistics management – A model for managing product returns in reverse logistics was described by Srivastava & Srivastava (2006); Meade & Sarkis (2002). It was based on information on product ownership, average product life cycle, historical sales, predicted demand, and the potential effects of environmental policy initiatives. Reverse logistics is recognized as one of the most difficult supply chain problems. It is crucial that there be a suitable system in place to distribute the product to clients after it has been made. Partnership issues – global value chains are competing with one another rather than with individual enterprises as global marketplaces become more efficient. Executives are therefore forming supply chain alliances and working together in an effort to save expenses, enhance services, and obtain competitive advantage (Shukla et al., 2011). It is discovered that trust and technologically mediated communication are two ways in which cooperative relationships may be realized. Working together via intelligent e-business networks would provide every link in a value chain a competitive advantage that would allow them to prosper and expand (Horvath, 2001). According to research done by Frankel et al., (2002), one of the most popular uses of partnerships is the supply chain transportation and distribution services. The authors suggested that instead of investing time and money to create an internal supply chain, it is sometimes far more economical to collaborate with a shipping firm, and let them handle distribution at a cheaper cost than business could handle on its own.

As it was introduced at the beginning, most businesses in today's market understand how important it is to engage in a be aware of global marketplaces. Managing the global supply chain is a crucial business operations that hold great strategic significance, and it is a must for all companies. The four elements that drive globalization of operations, sometimes referred to as motivational factors, are as follows (Kouvelis & Su, 2005).

Global Market Forces – the need to develop a global presence to reduce foreign threats into the home market through a competitive balance, as well as the necessity of establishing a presence in overseas markets to capitalize on foreign demand and replace the demand at home lost to foreign imports, are some of the market forces driving globalization. A worldwide production and distribution network may occasionally be required if secondary markets for end-of-life items start to disappear (Kouvelis & Su, 2005). Technological Forces – many business aim for a worldwide market in order to take advantage of economies of scale, while also focusing on a specific niche market by setting themselves apart in a commodities market. This is essentially the worldwide mass customization of an item. Multinational corporations must draw on the technological know-how of different nations as technological manufacturing skills advance internationally and incorporate new technologies into their own products as needed to maintain a competitive advantage (Kouvelis & Su, 2005). Global Cost Forces – Experiences from past global expansion projects, including some of their failures, are perhaps the most widely acknowledged force behind globalization. These projects show that offshore sourcing costs should be carefully considered, encompassing not only direct cost but also quality, differential productivity, and design costs, as well as additional logistical and transportation costs. Direct labor frequently makes up such a small portion of the entire cost of the product that outsourcing is discouraged based only on the promise of lower labor expenses (Kouvelis & Su, 2005). Political or Macro-economic Forces – currency rate swings can have a positive or negative impact on international business. To mitigate negative swings, a portfolio choices and careful research are needed. The choice to globalize operations is also influenced by regional trade agreements like NAFTA. Last, but not least, the implementation of trade protection measures, such as tariffs, trigger pricing schemes, technical standards, health laws, local content requirements, and procurement policies, affects the location of a company's global operations and how it can optimize its supply chain (Kouvelis & Su, 2005).

Participation in global supply chains carries out a lot of advantages. Any possible disadvantages of a global supply chain are greatly outweighed by its advantages. Vidrova (2020) lists many crucial benefits of participation. Availability of excellent products - this is an opportunity to swiftly and effectively find top-notch items finished to the strictest quality controls. Because there is fierce competition in the global supply market, it is feasible to get supplies at a very reasonable price that will all be manufactured to very high standards without even having to go very far (Durana et al., 2019). Reducing costs - Businesses that are a part of an international supply chain are able to dive down costs, which guarantees both their financial sustainability and a solid place on market. One of the earliest applications of supply chain cost-reduction initiatives was global supply chains (Dobrodolac et al., 2018). Motivation to be better in business - Due to their involvement in the global supply chain, companies who had exclusively operated locally in the home market are now compelled to enhance their performance. This indicates that there is a strong motivation to do tasks correctly the first time end every time (Salaga et al., 2015). Reducing amount of stock - If businesses have adequate relationships and suppliers abroad, they may be able to lower the amount of stock that they need to hold. It implies that they can save money on things like transportation, theft, and storage. Reducing the total of these expenses undoubtedly contributes to enhancing the competitive advantage that a global supply chain offers (Delfmann & Albers, 2000). Securing of almost any item in easy way - Nearly any item now can be easily obtained due to the global supply chain, as practically everything is likely to be produced or manufactured in the world. Any item that wasn’t a typical item used to take a very long time to make. These days, it is easily purchased from the nation in where it was produced (Burnette & Autry, 2019). Continuous operation of the supply chain - Due to time variations across nations, the chain truly operates around the clock. It never sleeps and is always on the go. Individuals in the supply chain are operating on various continents and at different hours to satisfy the needs (Stank et al., 2014). New opportunities and markets - Adding yourself to the global supply chain opens up new markets as well. Because company already operates in China, a firm that chooses to source its goods from that country is probably going to want to explore other markets as well (Burnette & Autry, 2019; Gajanova et al., 2019). Learning from others - Various regions in the world have different business practices. Because they collaborate with firms worldwide, one of the most fascinating aspects of the global supply chain is the opportunity for businesses to learn from one another. Consequently, it is feasible to pick up new production techniques, distribution strategies, and commercial practices (Stank et al., 2014). Flexibility - A worldwide supply chain can’t only be implemented. It needs to be adaptable. Flexibility is constantly prioritized more in global supply chains, which maximizes flexibility across the chain and enables it to function as efficiently as possible (Stank et al., 2014). Greater chance to survive - Business operating within the framework of a global supply chain can succeed and even expand during a downturn in the economy. They have less chance of surviving if they are not a part of it. There is a straightforward law that states that a firm will undoubtedly lag behind companies that operate inside a global supply chain architecture (Burnette & Autry, 2019).

Even though it is clear that participation in global supply chains carry a lot benefits and potential, but of course everything has its pros and cons. Participation in this network entails risks.

Table 3 Risk Of Participation in the Global Supply Chain

Type of Risks	Source
Supply Risks	Supply, inventory, scheduling, and technology access disruptions, pricing increases, quality problems, unpredictability in technology, complexity of the product, regular modifications to material designs.
Operational Risks	Operations breakdown, insufficient capacity for production or processing, significant process variance, technological advancements, sifts in operational exposure.
Demand Risks	Launch of new products, fluctuations in demand due to fads, seasonality, and rivals' new product debuts, and systemic turmoil brought on by the Bullwhip effect's distortion and amplification of demand.

Security Risks	Infrastructure security, information systems security, and freight breaches due to terrorism, vandalism, criminal activity, and sabotage.
Macro Risks	Changes in the economy that affect prices, interest rates, exchange rates, and wage rates.
Competitive Risks	National governments' actions, such as sanctions or quota limitations.
Resource Risks	Unexpected need for resources.
Policy Risks	Absence of past information on rival actions and movements.

Source: Manuj & Mentzer (2008).

In addition to the external risk resulting from participation in the global supply chain, companies also make mistakes in managing them. This network provides new difficulties that must be handled to reduce risks and maximize benefits. And this is the exact moment when a lot of businesses attempting to make a name for themselves in international markets have lost focus (Vidrova, 2020). Some companies have low transparency in their supply chain. An increasing number of businesses are realizing that they need to manage the quantity of suppliers and carriers that are bringing in a broad range of international goods. The demand for control and transparency of logistics operations grows significantly with the number of imports and exports (Lamber & Cooper, 2000). Ignorance of business and delivery conditions (incoterms) is another vital problem. A firm that enters foreign markets without first taking the effort to learn about the Incoterms and researching the business circumstances of its partners runs the danger of encountering major issues and suffering losses (Vidrova, 2020). Poor inventory management along with poor forecasting nowadays are critical. Clients anticipate receiving their shipments quickly. Businesses that often find solutions for shipping delays or prolonged transit durations miss out on commercial prospects. Delivery periods can be somewhat lengthy hen production is outsourced, therefore it is important to take into account any measures that might assists businesses in reducing this time (Mentzer et al., 2006).

To conclude, supply chain is a vital component if every industry at local, and international level. It is easily possible to find benefits of involvement in such a system, as it helps for example with, cost reduction, and provides access to the new markets. However, there are some obstacles that come with it. These might be regulatory obstacles, or unpredictability connected to the geography. It also carries a lot of risks, which are necessary to be handled by every participant of the global supply chain.

1.2. Global Supply Chain and Industry 4.0 Technologies

Global competition is as important as ever. Market is changing like never before, and there is a need for the adaptation of production. Advancement in current producing technologies is needed, and the concept of Industry 4.0 which integrates business with all the players in supply chain is promising (Rojko, 2017). Industry 4.0 concept for the very first time was introduced during the Hannover fair event in 2011, which serves as the symbol for the beginning of the concept (Qin et al., 2016). By many, Industry 4.0 is considered to be a new industrial revolution, where integration between manufacturing systems, and information & communication technologies play a key role (Wang et al., 2020). The base of the revolution is so called Cyber-Physical Systems alongside already mentioned Information and Communication Technologies (ICT), mainly in manufacturing (Pires et al., 2019). They are significantly increasing competition and increasing customer demands. Companies are now also allowed to offer new digital solutions for customers (Dalenogare et al., 2018).

Industry 4.0 consists of many technologies, however there are the most notable ones. Internet of Things - It is considered to be the very first technology included in Industry 4.0. It is a global infrastructure, that gives people ability to make everything connected to the internet

(Zeinab, 2015). Billions of objects gather great amount of data, which help companies with efficiency, predictions, and processes (Dorsemaine et al., 2015). Another important technology is Artificial Intelligence – It is almost impossible to provide definition of Artificial Intelligence. It could be argued that definition provided by Dobrev (2004) "AI will be such a program which in an arbitrary world will cope not worse than a human" is the one that encompasses the most. Nowadays, AI has become widely popular, it may be considered as a buzzword. AI can provide humanity in many fields of technology such as machine learning, deep learning or neural network. In essence, AI is the study of science and engineering, where manufacturing of so called intelligent machines are undertaken. Human intelligence serves as a base for AI, however it must be noted that there are no biological limitations. This technology uses already recorded information, and can gain data from models, and foresee possible results (Chekuri, 2021). One of the further technologies is Big Data Analytics – According to Siemens and Long (2011) Big Data Analytics is "datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze". Moreover, Chen et al., (2012) call it "data sets that are so large (from terabytes to exabytes) and complex (from sensors to social media data) that they require advanced and unique storage, management, analysis, and visualization technologies". Some definitions look at Big Data Analytics more from analytical perspective, and tend to rather overlook the amount of gathered data. (Maltby, 2011). However, other definitions emphasize the massiveness of data needed to be analyzed. According to Ward and Barker (2013) "Big data is a term describing the storage and analysis of large and/or complex data sets using a series of techniques including, but not limited to: NoSQL, MapReduce, and machine learning. Regardless of the definition it is clear that big data is about analyzing, and collecting big chunks of data to discover trends, correlations or opportunities". Other developing technology is Robotics and Automation – Robotics as a technology have been used in factories for many years. However, this term in industry 4.0 no longer applies only to plants, but also to many other areas, such as military sector. Currently, main human ambition when it comes to robotics are to create machines that can move and act in complex environments, but also able to replicate people's social behavior, which will allow them to make moral decisions (Royakkers, & Est, 2015). One of the most important technologies is Digital Twin – Digital Twin technology offers the possibility to observe inner operations of any given system, the relation between different parts, and the possible future behavior of its physical equivalent (Botin-Sanabria et al., 2022). It is widely used, especially for real-time monitoring, for example General Electric uses this technology for maintenance of engines, through its own cloud-service platform (Wang et al., 2020). Additionally there is Additive manufacturing – AM is an approach where 3D design are possible to be built by a computer-aided design (CAD) file without any specific tools. It can be used for models, prototypes or used in practice. AM gives the possibility to make designs without geographical limitations. People are able to create, and change projects from anywhere. For the companies it is possible to allow customer for wider customization, and also making it more economical (Bandyopadhyay & Bose 2020). Augmented and Virtual Reality – Both of these technologies are a part of the so called "virtuality continuum" concept. According to Milgram & Kishino (1994) this term describes "Continuum that goes from reality itself to virtual reality generated by a computer. Within the virtual continuum, we find the subset of mixed reality, which has been defined as everything between reality and a totally virtual environment". In general it is a simulated environment where a person can experience telepresence (Steuer, 1992). At the current stage of the development this technologies are used primarily in gaming industries. However, it is also widely used in health sector, and education. Other important technology is Cloud Computing – This technology provides users services on-demand to many user at the same time on the internet. Consumers have the possibility to pay for the service that can adjust its capabilities in real time. Decrease or increase depending on the number of users, and it requires nothing more than computer and stable connection (Durao et al., 2014). Lastly, Blockchain – Blockchain is relatively new technology, as it was introduced not longer than 15 years ago. It is a underlying technology for bitcoin. Many countries attitude towards bitcoin was somewhat negative due to its complexity and safety concerns. In 2008 Nakamoto introduced how cryptology and open distribution ledger can incorporated to digital currencies (Nakamoto, 2008). Blockchain is a type of distributed ledger (data structure) which holds information about transactions or events. It is duplicated and shared between users of the network. Then it is validated and preserved by a network node (user) (Tama et al., 2017). This creates a situation where there is no need for any authority to keep control over it. It already has applications in many industries, and businesses.

These advanced technologies are making industries alter their processes completely. We've already observed a big leap towards digitization, and automation in business operations. Supply Chain networks already use different solutions in order to improve efficiency, transparency or resilience in many different areas of the company such as procurement, logistics, or planning. Currently, companies are able to make more precise forecasts, and planning due to increased efficiency of information about the flow of materials. More accurate real-time tracking information increases supplier performance, and make warehousing more efficient and reliable. Moreover, not only certain departments or daily operations are affected. Companies are already changing or adjusting their business or management strategies to new era. Which, one the other hand generates new challenges, barriers, or risks (Ghadge et al., 2020). Some new companies, and business models will emerge in the future. For example, the way products or services are delivered has already changed, and classical business models are already affected. According to Koh et al., (2019) there will be a need for digital models, where barriers of information, and physical structures are reduced to minimum.

One of the key characteristics of a supply chain is its resilience. Without it, companies cannot rely on it, because continuity of supply is at risk. Study presented by Qader et al., (2022), proves that industry 4.0 technologies have significantly positive impact on supply chain resilience. Study finds that due to implementation of industry 4.0 technologies companies are able to map their operations more visibly. Decision making is also improved since real-time information about raw materials or suppliers is more accurate. In general disruptions are more easily predicted, companies are able to prepare themselves for unpredictable events or the future, and the total quality of supply chain processes increases overall Qader et al., (2022).

There is no doubt that the entire supply chain will be affected by industry 4.0 technologies. According to Schroder et al., (2014) production process will be affected the most. New concepts, technologies, changes in hardware, and software will occur, and they will have real consequences for the value adding activities in supply chain (Schroder et al., 2014). There are 4 aspects in which production will be affected the most (Qin et al., 2016). Factory – All resources used for manufacturing will be connected, and information will be immediately exchanged. Plants will be able to predict malfunctions and take care of the maintenance. Simulation software's will take charge of production planning, and all the things possible to simulate. This type of manufacturing plant is already called smart factory (Lucke et al., 2008). Business – Revolution will increase communication efficiency between all the participants of the supply chain e.g. companies, factories, suppliers, customers. Real time data will be analyzed to decrease the risk of disruptions. It will be also possible to track C02 emissions generation with higher accuracy (Kagermann et al., 2013). Products – So called smart-products will be created. Products will have components or processors that will send feedback to the manufacturer, which will make the products more functional (Abramovici, 2013). Customer – Users will be able to order products with desired functions, even those which are not made in mass production. They will be able to change their order even at the last minute of production. Customers will also receive advice on how to use the products according to their behavior based on feedback (Schlechtendahl et al., 2015).

Another part of the supply chain, which is largely influenced by the above-mentioned technologies is procurement. It is one of the most vital areas of supply chain. According to study made by Glas (2016), thanks to industry 4.0 technologies procurement processes are enabled to be fully automated, moreover cooperation across international borders will be autonomous. However, it must be underlined that technologies will rather collaborate with procurement professionals to assure quality, and efficiency. These technologies are already optimizing inventory management. By making it online, managers are able to create order more efficiently, and when stocks are low. The result is high reduction of costs. Monitoring of raw materials is more accurate. The main works in those domain is done by ERP software's, where data-sharing plays a key role. Nowadays it is the mainstream technology for any supply chains (Simoes et al., 2023).

The role new technologies play in logistics cannot be overlooked. Transportation Management Systems allowed for cooperation, and easy flow of data between order management systems and distribution centers. Real-time data helps companies to increase efficiency of logistic operations. Other solution that come in hands is Intelligent Transportation Systems. Those are software's that help with transportation management. Through computing hardware, sensors, or data processing companies are able to increase safety and reliability of their operations. Thanks to such systems accidents rates drop, and sustainability of whole operations increased (Barreto et al., 2017). Literature review on technologies 4.0 impact on logistics done by Hamdi & Abouabdellah (2022), states, that not only companies will benefit from it, but also other stakeholders. Physical workload will be reduced due to programmable logic controllers in manufacturing, but also in transportation. Customers will receive cheaper services, as companies are able to save cost due to already mentioned increased in efficiency and transparency.

It must be emphasized that although industry 4.0 technologies currently have a great impact on the functioning of the supply chain, and will have an even greater impact, the implementation of the mentioned solutions is a difficult task. Many companies do not have the infrastructure or financial resources to incorporate digital solutions. There is also uncertainty about economic benefits that companies may have. There is a general worry about employment reduction due to automatization, and workers are resistant to adapt new solutions. From the macroeconomic side there is a lack of standards regulations, and certifications (Attiany et al., 2023).

To conclude even tough everything has its downsides., implementation of industry 4.0 technologies represent an unprecedented increase in efficiency, transparency, and reliability of the whole global supply chain. It is a revolution that will have a lasting impact on the way business is done, but also how the world functions. Thanks to people's cooperation with the best technological solutions, it is possible to increase work standards and care for the environment. Thus, when used properly, these revolution can change the world for the better in every way possible.

1.3. The Digital Twin

Michael Grieves and his collaboration with NASA's John Vickers are credited with creating the digital twin. In 2003, Grieves introduced the idea at a lecture on product life-cycle management (Grieves, 2014). At this time Grieves characterized virtual product representations as "…relatively new and immature" and data collected about physical products as "…limited, manually corrected, and mostly paper-based". According to the original definition a digital twin is a virtual representation of a physical product that has data about it (Jones et al., 2020). A physical product, a virtual representation of that product, and the bi-directional data connection that feed data from the physical to the virtual representation and information and processes from the virtual representation to the physical are three components that Grieves (2014) describes as which make up the Digital Twin. As the idea originates from the product-life cycle, it was put by Grieves (2014) in such a framework. The Digital Twin originates as a digital twin Prototype during the design stage. During the realize phase, a digital twin instance is created for every made product, and so called digital twin aggregate is the result of these instances. The digital twin environment, a virtual depiction of the physical product's surroundings that supports virtual methods like simulation, modeling, and assessment, contains both the instances and the aggregate (Jones, 2020). The "twin" concept was initially applied by NASA's Apollo space program. In order for the space vehicle on earth to mimic, imitate, and forecast the conditions of the other space vehicle in orbit, the program developed two identical space vehicles. The vehicle that was left on Earth was the identical vehicle to the one that carried out the mission in orbit (Liu et al., 2021).

A definition of DT would hardly be sufficient in light of the technology's numerous uses and multi-domain applications. Thus, it seems more sensible to analyze and list essential characteristics of DTs. They can be divided into basic, and advanced features.

Basic features – using digital entities to mirror-real world objects in order to train employees and investigate novel solutions. An additional primary objective of the DT is to furnish data and insights regarding the physical entity, such as its condition, new behaviors, patterns or anything that could assist the physical entity's manager in enhancing the entity's efficiency. This feature is especially important when the physical object (a space shuttle or a ship, for example) cannot be reached, when modeling the information is difficult (a human body), or when complex models and algorithms are required for knowledge extraction. At any point, the DT should be able to characterize the physical entity. This feature suggests that the physical entity being transferred to the DT will change in state (Lugaresi et al., 2023).

Advanced features – firstly, due to the availability of high-speed computational power and alignment with the physical entity state, DTs are able to numerically simulate future periods under specific scenarios. The outcomes of simulation can be used to support resource allocation, verify deliveries, estimate system performance, and more. Secondly, another advanced feature of DTs is their ability to provide automated feedback to the physical entity in a closed-loop control approach. This feature is particularly useful in situations where there is a high level of system complexity and it is impossible for humans to handle. In these situations, the DT can examine many options, and choose the best one. Thirdly, models that are used to deliver DT services may require significant updates in order to make them compatible with the current circumstances. Automated DT adaption to novel scenarios and system modifications is regarded as other advanced feature. Finally, driving force behind DTs is their use in supporting people in various capacities. As a result, they need to cover all available fidelities. On a shop floor, DT is used for production scheduling, this it is not very useful to simulate tool breakage or machine tool structure deformation. As a result, the granularity should be regarded as the another advanced feature (Lugaresi et al., 2023).

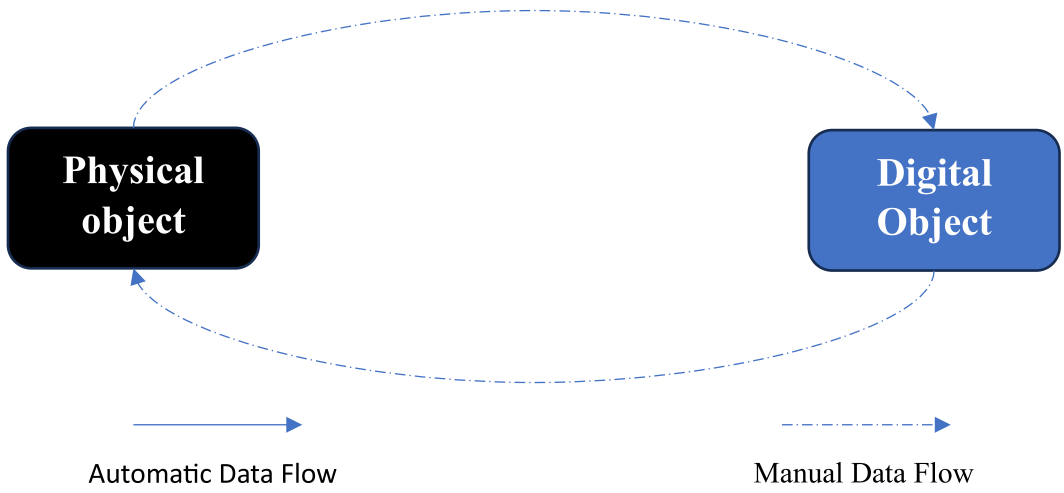
The current state of literature review defines and classifies digital twins according to their levels of integration and application domain (Botin-Sanabria et al., 2022). Firstly, Digital twin instance (DTI) – is as digital twin that has the ability to represent its counterpart over the course of time (Singh, 2021). Physical's twin changes and evolution are monitored. Any changes to the physical twin will have an effect on the digital twin. So, the monitoring is constant from the beginning to the end, and it forecasting its actions (Botin-Sanabria et al., 2022). Secondly, Digital twin prototype (DTP) – it has the ability to collect and saves important data and characteristics about the physical twin, which goals is to help in product creation and production processes. Important data connected to the manufacturing can be gathered from Computer-aided designs (CADs), bills of materials (BOMs), and drawings (Singh, 2021). The

DTP has the ability to simulate production scenarios and provide validation, assessment, and even quality control testing before the real manufacturing process begins, in compliance with DT criteria. By detecting defects or potential hazards in the physical twin before the manufacturing process begins, this method can lower production costs and save some operating time (Botin-Sanabria et al., 2022). Finally, Performance digital twin (PDT) – The PDT can track, compile, and evaluate data from products in more realistic and unexpected circumstances for physical twins (Singh et al., 2021). The PDT may process information being collected from the physical counterpart and produce actionable data that can be utilized for design optimization, creating maintenance strategies, and extracting conclusions form a product's performance by aggregating smart capabilities (Sharma et al., 2021).

When it comes to integration levels, digital twins are sorted as following:

a) Digital model – it will not have any automatic information flow from the real world to the virtual world in its fundamental design. This implies that any change need to be manually reflected, because the actual and virtual worlds are not automatically connected (Botin-Sanabria et al., 2022).

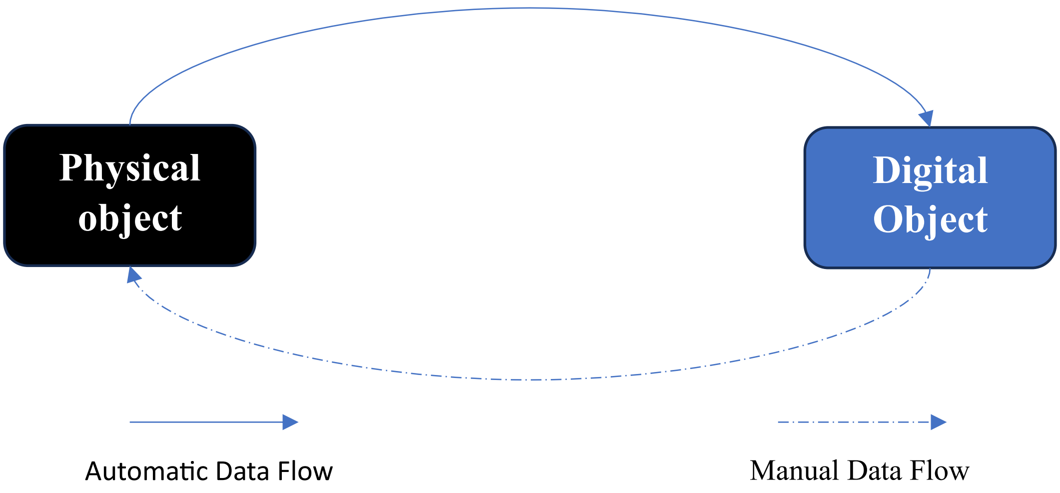
Figure 2 Digital model information flow



Source: (Eleftheriou & Anagnostopoulos, 2022).

b) Digital shadow – the integration of unidirectional automatic information flow from the real world to the virtual world will be made possible by the digital shadow (Juarez, 2021). A system that uses sensors to gather data from the physical model and send signals to the virtual model is the best way to illustrate this. As long as information flows automatically, it doesn't matter if it does so through polling or interrupting, the integration level can be identified using a digital shadow (Botin-Sanabria et al., 2022).

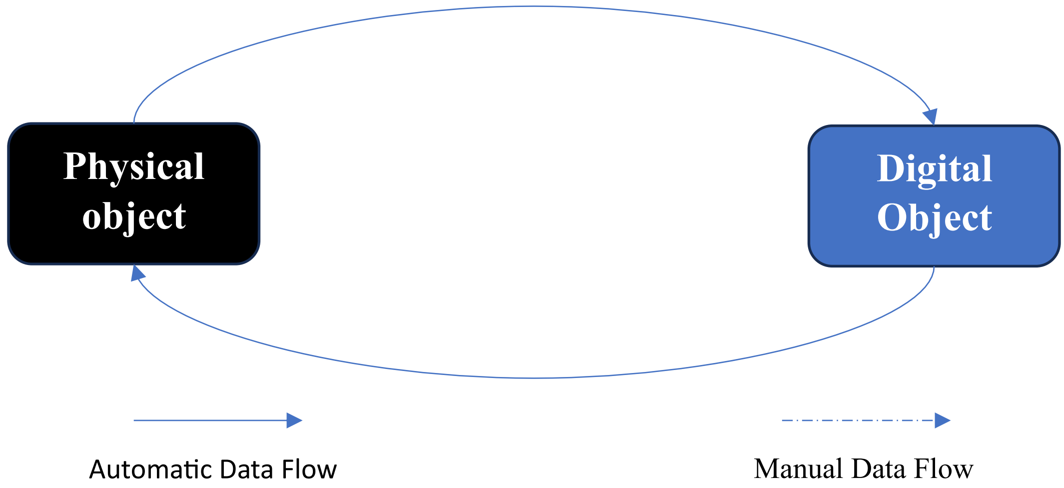
Figure 3 Digital shadow information flow



Source: (Eleftheriou & Anagnostopoulos, 2022).

c) Digital twin – a completely integrated twin in which there is a bidirectional interaction between the virtual and real worlds. So, that data is automatically transferred to and from each world. In this instance, data coming from the virtual world will be helpful in altering the physical model or giving actuators instructions on how to operate. On the other hand, information from the physical twin might automatically affect the virtual twin so that it accurately represents the state of things currently and the course of its physical counterpart's evolution (Botin-Sanabria et al., 2022).

Figure 4 Digital twin information flow



Source: (Eleftheriou & Anagnostopoulos, 2022).

In a way that is useful for users and stakeholders, the technology provides an in-depth understanding of the internal functioning of any system, the interactions between various system components, and the future behavior of their physical counterpart. It is used in some field, including smart cities, urban areas, freight logistics, healthcare, engineering, and the automotive sector (Botin-Sanabria et al., 2022).

Major disruptions occur in global supply chains as a result of both external and internal factors. Thus, there is need for digital twin technology to be a tool incorporated into business operations. The base of this idea it to create digital twin of a supply chain (Lugaresi et al., 2023). However, digital twin is one of the least researched technologies included in industry 4.0. Most papers describe potential or future uses of this technology, as it seems that use of this technology in supply chains is still in early use.

According to Wang et al., (2020), digital twin has enormous potential in supply chain planning. The demand projection is the initial stage of planning. The Forecast's results establish the necessary goods, quantities, and timetables. Demand forecasting is becoming more analytical instead of empirical. Thus, the foundation of demand forecasting is data. Numerous factors influence demand, therefore gathering a wealth of data to support forecasts in necessary. These data can be dynamically gathered from many sources thanks do DT. It can be done automatically, and dynamically, whereas traditional SCP frequently depends on human labor, and past cases for collection.

Aggregate planning is the process by which engineers control inventory, and production in order to meet. forecast demand. Digital twin aids engineers in three areas of aggregate planning. To begin with, DT assists engineers in tracking, and removing inventory, excess production, and regular production. Real-time production and inventory levels will be continuously recorded and uploaded by DT when DTS are applied to factories and warehouses (Wang et al., 2020).

Inventory planning will follow the selection of the aggregate planning. In aggregate planning, engineers oversee cycle, seasonal, and safety inventories to meet distributed supply needs. DT supports inventory planning using practices similar to those of aggregate planning. The supply chain's DT first gathers inventory from all available sources. Finally, when enough data is accumulated, DT will assist engineers in confirming the inventory planning. One method by which DT can forecast planning results is to extract cases from the past that share comparable inventory distribution and contextual data (Wang et al., 2020).

When it comes to manufacturing the digital twin can be useful not only for planning, but for all processes done in factories. They are able to make an exact replica of an actual factory. The implementation of data-driven production operations and digital twins can facilitate the creation of self-regulating factory setting that offers total operational transparency and adaptability. Factory operations can be changed into data-driven, evidence-based procedures by implementing connectivity and data tracking throughout the entire manufacturing process. This allows for the analysis of production bottlenecks, the prediction of future resource needs, and the tracking of product fault sources (Yuqian et al., 2020).

Although it has been emphasized that the technology is in its early stages, global industry giants are already using it. Using the idea, General Electric created an application known as the “Predix” platform, which is a tool for producing Digital Twins. Data monitoring and analytics are conducted using Predix (Magargle et al., 2017). On the other hand, Siemens has created a platform known as “Mind Sphere” that embraces the idea of Industry 4.0 and links physical infrastructure and machines to a Digital Twin via a cloud-based system. With the aim of revolutionizing businesses and offering Digital Twin solutions, it makes use of all connected devices and billions of data streams (Petrik & Herzwurm, 2019).

IBM’s Watson IoT Platform is marketed as a comprehensive tool for managing large-scale IoT systems in real-time using data from millions of devices. The platform offers additional features like cloud-based services, data analytics, edge capabilities, and blockchain services. This makes it a suitable platform for a Digital Twin system (Kumar & Jasuja, 2017). There are also open source solutions. The notable one is “Ditto” project by Eclipse. This platform allows for state management of Digital Twins, providing access to control over both physical and digital twins. The platform supports existing devices and simplifies the connection and management of Digital Twins (Damjanovic-Behrendt, 2018).

To summarize, digital twin technology provides a significant improvement in supply chain, by providing real-time simulation and optimization for many industries. Real-world application examples show its possibilities, ranging from improving manufacturing processes, to logistics, and inventory management. If the companies decide to keep up with digital twin technologies there is a possibility to create new opportunities for innovation, and collaboration. In the future, digital twin technology might be critical for the companies if they want to remain competitive.

1.4. The relationship between Big Data & Analytics and the Digital Twin

Nowadays, almost everything generates data. From businesses, institutions, systems to social medias. Almost everything is digitized or it is going to be digitized. So the amount of data sets will even increase. Large amounts of data can lead to lost or ignored information due to the time required to extract useful information from it (Kohl & Gupta 2021). Managing large amounts of data is a challenging task. Data analysis involves data mining, exploratory analysis, machine learning, and algorithms to extract meaningful information from large datasets (Elgendy & Elragal, 2014).

The influence this technology can have is immeasurable. Feng (2019) argues that big data analytics is crucial for decision making since it provides insight derived from different facts. This will make decision-making process more evidence-based. Therea are two primary methods of extracting insights from large data. Data management refers to the use of technology to acquire, store, and prepare data for analysis, whereas data analytics refers to approaches used to extract information from data. Big data analytics has been viewed as a subprocess of insight extraction. Big data analytics technologies include text, audio, social media, and predictive analytics. Big data analytics is the primary instrument for evaluating and understanding digital content, including social media and machine learning (Koonce & Tsaib 2000).

Big data is characterized by three variables: volume, velocity, and variety. Volume refers to the size and quantity of data in a record. Data sizes have grown massively. Traditional technologies have problems with storing and analyzing large datasets. Velocity means the pace at which data is recorder and processed. Big data is ideal for time-sensitive activities since it streams data and maximizes its value. The final component of big data is variety, which describes the diverse nature of data. Big data originates from a multitude of sources. It also includes geographic, 3D, audio, video, and unstructured text, such as log files and social media, whereas traditional databases were built for a smaller amount of organized data with predictable structures and fewer changes (Elgendy & Elragal, 2014; Gupta, 2014; Sagiroglu & Sinanc, 2013).

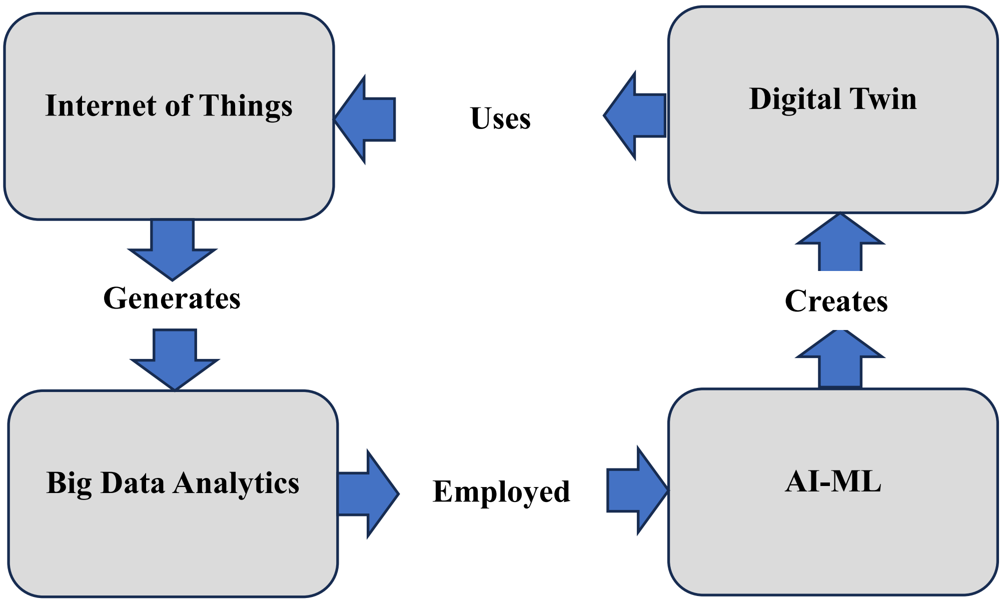
Some, authors like Arora & Goyal (2016) add two more variables to the equation. It is value, which is needed to analyze and interpret Big Data, it is important to extract useful information patterns using queries. Value refers to extracting insight from big data. The other one is veracity, which ensures proper and accurate information. To handle Big Data effectively, it's crucial to prioritize data quality, governance, and metadata management in addition to privacy, and security concerns.

Big data analytics combines approaches (e.g., measures of central tendency, graphs), information system software (e.g. data mining, sorting routines), and operations research methodology (e.g., linear programming) to identify and express patterns or trends in data (Schniederjans, 2014). Analytics approaches are classified into several categories. Firstly, Descriptive analytics – A graph is a basic statistical tool used to explain data in a database. Descriptive statistics include measurements of central tendency (mean, median, mode), dispersion (standard deviation), charts, graphs, sorting, methods, frequency distributions, probability distributions, and sampling techniques. This method identifies potential business prospects (Ajah & Nweke, 2017). Secondly, Predictive analytics – it involves using advanced statistical, information software, or operations research methodologies to find and construct prediction models for descriptive analysis. The results indicate potential for improving the firm's goods and services (Ajah & Nweke, 2017). Thirdly, Diagnostic analytics – it analyzes prior data to determine the reason of certain events. Diagnostic analytics help explain why certain particular events occurred based on data trends (Ajah & Nweke, 2017). Finally, Prescriptive analytics – uses mathematical tools from decision science, management science, and operations research to optimize resource allocation. Resources are allocated to capitalize on the projected opportunities (Parksoy, 2013).

Cooperation between a digital twins and big data analytics is a relatively unexplored issue in the scientific literature. It is much easier to find scientific works about the relationships between other technologies included in the 4.0 revolution, however it a common knowledge that digital twin technology cannot properly function without data. Comprehensive data is necessary to improve the efficiency, accuracy, and flexibility of DT-based services, such as performance forecasting, optimization of processes, and quality assurance. Moreover, real time data exchange enables coordinated actions. Firstly, real-time data from actual entities can dynamically change virtual model characteristics. Secondly, Data from DT-based services should be shared with physical entities to ensure rapid diagnosis, maintenance, and management (Zhang et al., 2022).

One of the primary components and essential elements of a digital twin is data. Data is used in both Big Data and Digital Twin processes, however Big Data processes data more quickly. We can develop a more efficient virtual representation and analysis by utilizing Big Data to improve Digital Twin, since it can provide better insights. Both these technologies play a part in producing a product that is more dependable and accurate. Digital twins can remove obstacles to data by connecting several stages of the product lifecycle. Big Data technology, on the other hand, can analyze data fast and offer insights to aid in decision-making (Tao et al., 2019). Big Data and Digital Twins compliment one other. In addition to being valuable component of the Digital Twin, Big Data may enhance the process of creating one. With the use of Big Data's capabilities Digital Twins can execute precise management in several areas. This is accomplished by enhancing the model that generates the digital twin using big data. It is a waste of resources and technology to ignore Big Data technology while implementing Digital Twins, especially in light of the fact that data is now regarded as the new global currency. In contrast, Digital Twin may be leveraged to enhance the devices designed to produce data, so enhancing the way Big Data is gathered and handled (Callista & Tjahyadi, 2022). Figure no.5 shows the relationships between the Digital Twin, Big Data Analytics, and other crucial industry 4.0 technologies.

Figure 5 Relationship between IoT, Big data, AI-ML, and Digital Twin

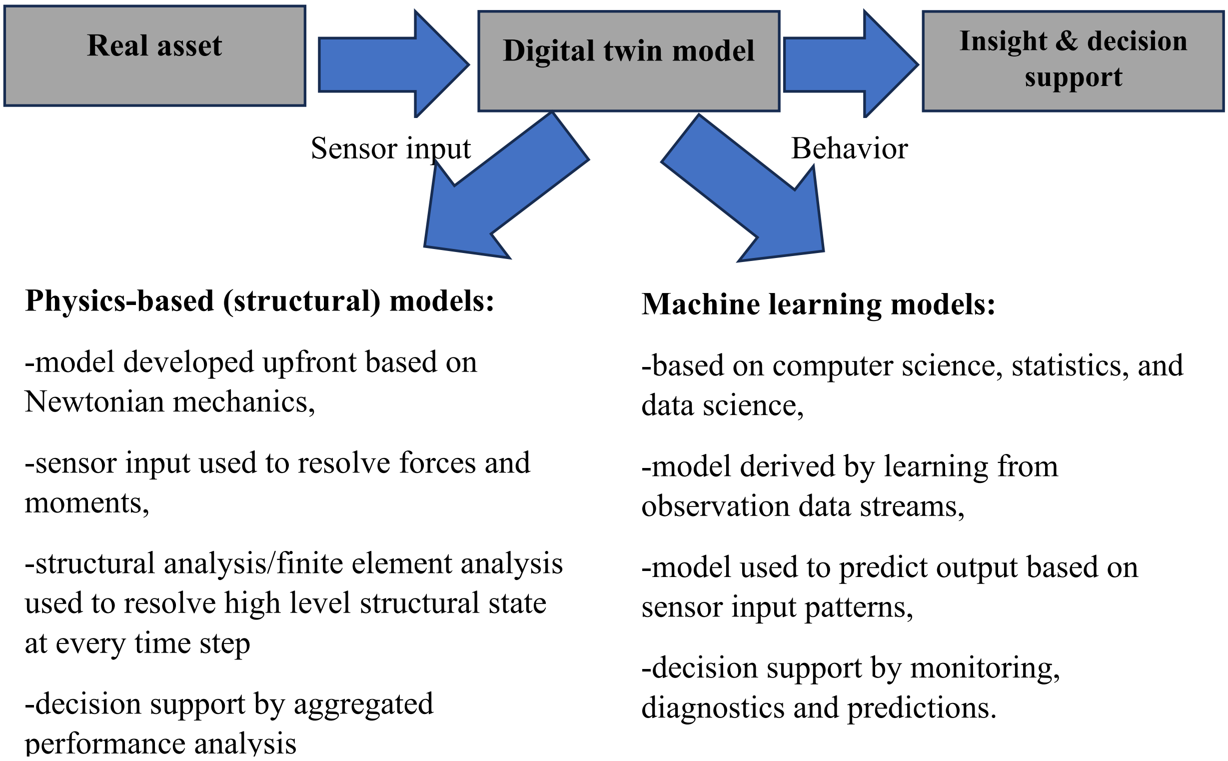


Source: Callista, M. & Tjahyadi, H., (2022)

However, Qi & Tao (2018) provides valuable contribution on the relationship between these technologies in manufacturing. According to Qi & Tao (2018) as manufacturing processes get more complicated, traditional methods for identifying issues become less effective. Data may reveal both obvious, and unseen difficulties in smart manufacturing. Big data increases efficiency, insight, and intelligence in manufacturing. Digital twin provide correlation and dynamic adjustments between industrial planning and execution, as well as digital fault prediction, diagnosis, and maintenance. Despite their differences, digital twins and big data serve complimentary functions in production. Big data plays a crucial role in the digital twin concept. Without large data, digital twin functions would be only theoretical. And, without a digital twin, big data analytics and actual production would not occur simultaneously. Combining digital twins and big data helps accelerate product development and verification by removing barriers across phases of the product lifecycle. There, integrating these technologies can lead to so called smart manufacturing.

Scholars have created some other interesting propositions of cooperation between the digital twin and big data analytics. According to Erikstad (2017) big data analytics can play vital role for the present and future of digital twins.

Figure 6 Physics-based vs machine learning based digital twins solutions



Source: Erikstad, 2017

Perhaps more than physics-based digital twins, technological advances in big data like machine learning and data analytics have gotten a lot of attention and are a significant element of the IoT landscape. They play an important role in gaining insight and understanding from the huge amounts of data generated by the extensive installation of sensors in the hull, mechanical systems, and deck equipment. The usage of machine learning models as the basis for digital twin solutions would be based on quite distinct concepts (Erikstad, 2017).

Rathore et al., (2021) identified main sectors where DT based systems are created with the use of AI and Machine Learning. Other, than smart manufacturing mentioned before.

Table 4 Main sectors of cooperation between Digital Twin and Big Data Analytics

Key Industries	
Prognostics and Health Management	a product's performance gradually deteriorates with continued usage, perhaps leading to malfunctions. Prognostics and health management, or PHM, is therefore essential to every industry. The PHM process includes regular health monitoring and the estimation of a product's remaining useful life. This use of DT is the second most significant, just after smart manufacturing. Based on the data produced by the equipment sensors, DT-based PHM continuously monitors the physical equipment, applies AI and big data analytics to diagnose and forecast the data, and suggests design guidelines for urgent maintenance (Rathore et al., 2021).
Power and energy	the majority of DTs in the power and energy industry are produced for fuel-related systems, cooling systems, wind-power farms, and electronic systems (Rathore et al., 2021). For example, by mimicking the voltage controller, the current control loop, and the regulated plant using three different neural networks (NNs), the digital twin of an inverter model was

	created. Real data from the physical model, where the back propagation (BP) technique is used to adjust the proportional-integral (PI) controller in real time, is used to train each of the three NNs (Song et al., 2020).
Vehicles and transportation	Alam & El Saddik (2017) created a vehicle digital twin in a vehicular cyber-physical system (VCPS) by simulating its acceleration, fuel usage, and airbag situation. In a similar fashion, Kumar et al., (2018) created virtual models of moving cars in the cloud that, using for or edge devices, acquired real time road and vehicle data to prevent traffic jams. Thorough the use of machine learning on historical data, the driver’s behavior and intention are forecast.
Healthcare	Human digitals twins make up a significant portion of AI-ML enabled DTs in the healthcare industry (Bjornsson et al., 2020; Liu et al, 2019;). Since it is presently impossible to mimic every feature of a human body, a human digital twin can only concentrate on a small portion of human biology. For instance, Barricelli’s et al., (2020) digital twin is centered on athlete fitness metrics.
Communications and networks	The digital twin of an interior space environment is implemented in the networking and communications sector to describe, forecast, and manage the terahertz (Thz) signal

	propagation characteristics in an indoor space (Pengnoo et al., 2020).

Source: Rathore et al., 2021; Song et al., 2020; Alam & El Saddik, 2017; Kumar et al., 2018; Bjornsson et al., 2020; Liu et al, 2019; Barricelli's et al., 2020; Pengnoo et al., 2020.

To sum, the cooperation between digital twin technology and big data analytics can provide changes for manufacturing and other industries. Organizations can achieve efficiency, productivity, and creativity beyond the previous levels. It is due to combination of simulation capabilities of digital twin and the possibilities of providing insights from big data. Those technologies can help with active decision-make and strategic planning in industrial processes, by providing real-time monitoring, predictive analysis, and optimization. Thanks to this companies can achieve a competitive advantage by adjusting to ever-changing customer needs. Furthermore, the big data analytics enables continuous feedback that enhances the precision and dependability of digital twin models. In the end, the combination of digital twin technology with big data analytics might be a start for a new era in intelligent manufacturing.

1.5. Advantages and Disadvantages of the implementation of the Digital Twins

The COVID-19 pandemic drove the size of digital twin industry to increase in a number of applications. In addition, a number of businesses are implementing Digital Twin technologies to optimize their supply chains and operational procedures in an effort to recover from the pandemic's economic effects (Attaran & Celik, 2023). The primary factor enabling the present pace is the declining cost of technologies that improve the Digital Twin, and IoT. Furthermore, Digital Twins have been utilizing essential commercial applications in recent years, and it is anticipated that the technology will spread to additional use cases, applications, and sectors.

Applications of digital twin technology have therefore been expanding rapidly (Verdouw et al., 2021).

The industrial adoption of DT will present a number of obstacles, which may be divided into three clusters: virtual modeling, organizational structure of the enterprise, and real-time data and synchronization (Pires et al., 2019).

Virtual modeling – in this instance, a number of issues still need to be resolved, including the virtual model creation and validation using AI. One of the main problems that is emerging is the absence of established methods and approaches for the validation of multi-stage virtual models. In actuality, both intrinsic and extrinsic factors in the real processes that the virtual models were built on must be checked against them (Rodic, 2017). It becomes time consuming to validate the virtual models due to a lack of methods and procedures. The difficulty in developing AI-based models is integrating the technology with the modeling methods that are currently in use (Pires et al., 2019).

Organizational structure of the companies – it is yet another important problem. Because of their highly divided architecture, which makes it challenging to access all the knowledge from various departments or sectors. Within the organization, information exchange and unity have grown to be significant challenges (Pires et al., 2019). This is because most organizations are not knowledgeable or skilled in digital engineering or how to organize the present corporate structures. This may make it more difficult to create the data flow structure needed to create a DT. This may make it more difficult to create the data flow structure needed to create a DT (Rhodes, 2017). Additionally, organizations display their perspectives in fragments, divided into categories like design, engineering, and production, each with information specific to the many systems and how to manage them. However, there is rarely any information exchanged between the various departments. The unification of structures is a crucial problems since using the DT requires having access to information from many structures (Grieves, 2017).

Real-time data synchronization – real-time connection and synchronization is significant difficulty since a DT cannot be properly executed without real-time access to the generated data. In reality, it is very difficult to connect and integrate the physical and virtual worlds. This is primarily because of the physical environment's unique characteristics, which include fuzziness, uncertainty and variability; the distinct scales of the physical and virtual spaces; and the constantly generated data form various entities (Tao & Zhang, 2017). It will be simpler to keep with real-time engagement if these challenges can be overcome. The synchronization between the virtual and physical models is essential for real-time synchronization, but it requires a breakthrough in high-speed transmission technology to no longer be an issue (Tao et al., 2018).

Even tough implementation of a digital twin is a long and difficult process, there are many additional values that successful implementation can provide.

Table 5 Digital Twin benefits

Real time monitoring and control	It can be challenging for large systems due to physical limitations. A digital twin is easily available from any location. The system's performance may be monitored and modified remotely using feedback systems.
Greater efficiency and safety	Digital twins aim to increase autonomy while retaining human supervision as needed. This will assign risky, dull, and unclean work to robots than can be remotely controlled by humans. This allows people to concentrate on more creative and inventive occupations.

Predictive maintenance and scheduling	Comprehensive digital twins enable real-time data generation from many sensors monitoring physical assets. Smart data analysis can discover system flaws early on. This will help schedule maintenance more efficiently
Scenario and risk assessment	Creating a digital twin of a system allows for better risk assessment through what-if scenarios. This system can be altered to create unexpected scenarios and study their response, including mitigation strategies. A digital twin is the only way to do this type of examination without compromising the actual asset.
Improved intra- and inter-team coordination and collaboration	Giving teams more autonomy and access to information improves synergies and partnerships, resulting to increased production.
Improved efficiency and speed	Real-time access to quantitative data and advanced analytics improves both of these values.
Customization of products and services	Customized products and services will become increasingly popular as market trends and stakeholder preferences evolve. Future factories will benefit from digital twins, allowing for faster, and smoother changes to meet changing demands.
Improved documentation and communication	Providing real-time information and automated reporting improves transparency by keeping stakeholders informed.

Source: (Oracle, n.d.; Rasheed et al., 2019).

Murgod et al., (2023) also provides couple of other significant benefits of digital twins strictly connected to the previous ones. These are firstly, improved product quality – Digital Twin is in charge of gathering and analyzing the vast quantity of real-time data. The designers uses the analysis to inform the development of the upcoming iteration of the product. The DT identifies all of the shortcomings and issues, which are then fixed in a later product release (Murgod et al., 2023). Secondly, Increased sustainability – One of the primary goals of industries is to promote sustainability through several efforts. They may replace the materials used in their product with more sustainable alternatives by using DT. They are able to monitor and regulate the production of scrap or carbons throughout the manufacturing process. By visualizing the process, the DT contributes to enhancing the system's overall performance (Murgod et al., 2023).

Thus, digital twin offers many potential positive effects for enterprises. It is clear that the implementation of this technology can bring many benefits, both financial and in other areas. However, there are also problems, disadvantages that this technology brings. Significant contribution to this issue is provided by Broo & Schooling (2023), which conducted semi-structured interviews with expert. Many significant concerns were raise. Respondents stated that convincing people to understand the value, change their behavior, and alter economic arrangements proves to be tough. Also, there are constraints to the amount of the competence to managing this kind of applications, as well as financial possibilities to made such investment. In general, participants examined the existing situation and provided feedback on human, organizational, and industry-level difficulties to implementing digital twins in infrastructure. Human elements such as cultural acceptance, skills, general grasp of advantages and business reasons, and the challenge of innovation and digital transformation were all heavily emphasized. Another significant issue concerned data. They addressed both technical problems such as data collection, storage, analysis, and integration, as well as non-technical elements such as data value comprehension, data operationalization procedures, and so on (Broo & Schooling, 2020).

According to Botin-Sanabria et al., (2022), there are 5 significant challenges across many domains when employing DT technology. Singh et al., (2021) suggests that issues may occur based on the application' s scalability and integration complexity.

Table 6 Issues related to Digital Twin

Issues related to data (trust, privacy, cybersecurity, convergence, and governance, acquisition and large-scale analysis)	Designers have a rough time replicating or modeling behaviors that cannot be quantified. This is the case with social disputes, sociopolitical concerns, social inequality, and the preservation of the environment (Singh et al., 2021; Kshetri, 2021; Carvalho & Da Silva, 2021).
Lack of standards, structures, and rules for DT implementation	Deployments of DTs are constrained due to the absence of norms and acknowledged interoperability, particularly in the industrial sector (Lim et al., 2020; Harrison et al., 2021).
High installation expenses due to the increasing number of sensors and processing resources required	The high cost of DT implementations is a limiting factor for their accessibility, particularly in nations with limited resources (Singh et al., 2021; Rathore et al., 2021; Kshetri, 2021).
The use of AI and big data used to meet long-term and large-scale data analytics requirements	Big data techniques and IoT technologies may greatly help successful DT deployments by analyzing vast amounts of data. Developing constant norms and standards might be challenging due to the flow of

	information from different levels of indicator systems (Juarez et al., 2021; Rathore et al., 2021; Oracle, 2018; Orozco-Messana et al., 2021).
Communication networks-related difficulties	5G communication interfaces are needed to improve speed and efficiency. According to Russell (2020), 5G technology is crucial for smart cities due to its ability to connect more sensors and devices, provide high-speed connectivity, improve reliability and redundancy, and consume minimal power. The authors also emphasize the importance of real-time data connectivity and operational effectiveness for DT, such as data value comprehension, data operationalization procedures, and so on (Broo & Schooling, 2020).

Source: Singh et al., 2021; Kshetri, 2021; Carvalho & Da Silva, 2021; Lim et al., 2020; Harrison et al., 2021; Rathore et al., 2021; Juarez et al., 2021; Oracle, 2018; Orozco-Messana et al., 2021; Broo & Schooling, 2020.

In conclusion, a complex environment with potential and difficulties for enterprises is shown by examining the benefits and drawbacks of digital twins. Businesses are able to make educated decisions and streamline procedures because of the previously unheard-of levels of efficiency, safety, and operational insights provided by real-time monitoring and simulation. Implementation, however, is seriously affected by issues with virtual modelling accuracy and the requirement for strong organizational structures. To fully realize the promise of digital twins, challenges related to data quality, interoperability, and the lack of standardized frameworks must be addressed. Despite various difficulties, it is impossible to undervalue the revolutionary potential of digital twins in transforming sectors like infrastructure, healthcare, and most off all manufacturing.

1.6. The future of the global supply chain

The international economy is influenced by a variety of factors, including, internationalization, globalization and glocalization, increased competition, outsourcing, innovation, shorter product life cycles, time based-competition, and shifting costumer purchasing habits and supply chain strategies. Logistics experts anticipate a growth in commodities in next years, in addition to the impact on the global economy (Szegedi, 2011; Gajanova et al., 2019).

Global supply chain changed significantly after COVID-19 pandemic. It is not unexpected that there have been several demands to reconsider how nations should set up their global supply chains in light of the complex disruption to the supply chain. The goal is to lessen reliance on foreign suppliers and shift production back home. These ideas of regionalizing and reshoring manufacturing to strengthen supply chains are appealing on some level. They actually align with previous recommendations made by development experts, economists, and geoscientists who have long argued that supply chains could be shortened. Government policies have also been impacted by these beliefs. President Biden signed an executive order in 2021 to strengthen the resilience of American supply networks, by reshoring (Panwar et al., 2022).

According to Lara & Wassick (2023) in the near future, virtual assistants that enable the use of cutting-edge analytical techniques will support the decisions made by supply chain experts. Decision makers will get alternative courses of action that will help them with their workflow, by providing the linkage of various events across the supply chain across time. Machine learning and logic may be used to find patterns in trends, spot departures from expected behavior, or detect other patters that indicate or predict practical business actions like chances to cut expenses or working capital. Over time, the range of automated decision-making will grow, and the need for human intervention will decrease. Supply chain decisions at the operational level will be routinely automated, similar to the degree of automation achieved in manufacturing.

Politics, the economics, and society will all drastically shift by 2040, putting new demands on industrial firms. The physical supply chain will face new difficulties as a result of the significant changes in nature. These developments, which might be characterized as megatrends, are already evident now. Megatrends have impacted the framework for economic activity and have slowly but steadily changed society as a whole over decades. Along with cultural and political trends, new technologies and inventions also play part in this (Schiffer & Dorr, 2020).

Based on reviews of the literature and professional outputs form both businesses and academia, the ten megatrends listed below might be recognized (Kuczyńska-Chałada et al., 2018; Zanker, 2018): Individualization, digitization/connectivity, demographic change, urbanization, globalization, sustainability and social responsibility, mobility, data security and ownership, servitization, knowledge culture and information society.

These megatrends have led to four major themes identified by Schiffer & Dorr (2020), which conducted a survey among company's management. 164 questionnaires were taken into the consideration. Technology – The amount of transportation worldwide will keep increasing in the near and medium future. On the other hand, the consumer goods industry will require more personalization, and rising regions like Asia or Africa will see a rise in the demand for these kind of items. In contrast, the industrial products will see a rise in global sourcing as a means of securing competitiveness and additional cost reduction. A supply chain that is in line with the newest technology is required as a result of the rise. For this aim, a wide range of technologies are now accessible. According to the respondents AI-related technologies are seen to have the best possibilities of succeeding. Application domains include the examination of substantial volumes of data quickly (Schiffer & Dor, 2020). Application areas include machine learning in cooperative supply chain networks, lowering fright costs, and enhancing delivery performance (Min, 2010). Nevertheless, this requires a lot of data. As a result, it is not possible to evaluate the succeeding technologies from the survey independently. For instance, sensors provide data automatically, which is more economical and frequent than human data entry. Big data organizes, maintains, and makes this information accessible. Autonomous driving is another technological advancement that will significantly affect the supply chain of the future. This is when operation will be fully taken over by the technology, whereas earlier technologies would assist human labor. In conclusion, the technological analysis indicates that lead time will be the metric that changes the fastest (Schiffer & Dorr, 2020). Value Adding – A new competitive landscape is being created by technological advancements in communication and information processing, ongoing organizational change, internalization and digitization of business systems and processes, and the focus on core competencies up to virtual companies. These developments suggest that logistics will continue to play a critical strategic role as a factor that adds value to a company in the future (Wildemann, 2016). As a result, logistics is now viewed as a way to set oneself apart from the competitors rather than just a source of expenses. The primary concept behind the phrase "value adding" is the practice of improving products throughout the value generation phase. However, value addition is also feasible when supply chain management is involved. Value Added Services is the buzzword that logistics service companies need to know. Offering the consumer an extra advantage or value or maximizing the cost-benefit ratio across the supply chain are the main goals here, not raising the worth of the tangible product. Customer loyalty and satisfaction both rise as a result. For instance, it would be feasible to provide supplementary goods associated with logistical services. These, days there are many ways to create value, from customizing e-commerce kits to adding discounts or pamphlets inside of deliveries. It is also possible to that by assuming control of the upstream and downstream processes, the logistics provider might lower the number of suppliers. It would be possible, for instance, to provide supplementary goods associated with logistical services (Schiffer & Dorr, 2020). Increasing safety is an additional aspect of value addition. This covers both controllable risks (like supplier errors or failures) and uncontrollable risks (like natural catastrophes or environmental effects) (Frunhofer IML, n.d.). Control tower – In many regions, the trade in services and data is already nearly as profitable as the trade in things. Future developments will see a rise in the significance of digital services due to the growing value of data and its analysis. For instance, a poll of forwarding industry specialists indicates that it will nearly never again be viable to deliver only physical items (VDMA, 2019). A significant competitive advantage is emerging from the recording of all pertinent transport parameters, their analysis, and the release of data/information to third parties. The networking of international transportation, and commerce firms is an additional options. Businesses are becoming more and more like complex-value creation networks where information has to be shared not just between two instances but between all of them. The challenge of effectively managing the whole supply chain as a result of increasing transit volumes, and the ongoing need for shorter lead-times is another concern. For instance, in the past, there would be correspondence and coordination of the transport with the freight forwarder and, if required, an agent. These day, portal systems are used at every stop in the transportation chain, and web platform solutions are provided by startups to assist all the participants (Schiffer & Dorr, 2020). Green logistics – The logistics industry needs to get greener very quickly. Companies, as well as legislators and environmental groups, as well as final customer, require this (Schiffer & Dorr, 2020). Though not entirely emission-free, logistics in 2040 is quite likely to be much more ecologically friendly. Numerous trends are pointing in this way. Both the amount of transportation and the number of players in the supply chain will rise as more items are shipped globally. Consequently, there will be a corresponding rise in any ecologically hazardous empty shipments and relocation procedures (M logistik, 2018). The circular economy's good trend of 100% material recycling indicates the need for additional transportation. Overall, this implies that even if they are operated without emitting any emissions, additional transportation vehicles must be built. Lastly, it need to be realistically projected that, among other things, airplanes and container ships probably won't be able to run entirely without heavy fuel oil in the next 20 years. Customer will be more and more eager to pay for an environmentally friendly and sustainable (whole) supply chain in the future (Schiffer & Dorr, 2020).

In summary, emergence of technological revelations will continue to change, and shape the global supply chain. It will bring challenges, and opportunities for businesses and industries. However it is impossible to predict future with high accuracy, because the frequency of changes is and will be very high.

Chapter II Business Model Innovation

2.1. Business Models

Business models have played a crucial role in the economic landscape since pre-classical times. Firms have historically stuck to a business model, but before to the mid-1990s, they often functioned based on conventional principles like those of industrial firms. In this model, a product or service is provided to a consumer, and revenues are eventually collected (Teece, 2010). Nevertheless, several experts agree that the Internet, along with other technical advancements, served as a catalyst for experimenting and inventing company models, thus generating fresh opportunities for business activities. As a result of this, several sectors saw significant transformations, leading to the emergence of entirely new directions and the creation of fresh value (Timmers, 1998; Amit & Zott, 2001; Afuah & Tucci, 2001).

The business model may be defined as a network of interconnected and interdependent activities that controls the way in which the organization conducts its operations with its stakeholders. In short, a business model refers to a collection of different activities, or an activity system, that are carried out to meet the projected needs of the market. The document establishes the specific individuals, whether internal or external business partners, responsible for executing specific tasks, and outlines the interconnections between these activities. The activity system of a corporation is characterized by three design elements: content, structure, and governance. Modifying any of these components requires altering the entire model. If the new business model is considered "new to the world" rather than simply "new to the company" it signifies a business model innovation (Zott & Amitt, 2017).

When it comes to business model innovation, organizations need to consider the extent to which the innovation changes the laws of the game. An effective method for assessing the extent of changes in a business model innovation is to employ two crucial strategy factors. The first variable refers to the extent to which the innovation renders existing products or services less competitive. The concept here is that when the rules of the game undergo significant changes, the new business model is expected to render products/services based on the old business model uncompetitive in the market targeted by the new business model. The second variable refers to the extent to which the new business model makes existing skills outdated. If the laws of the game in a new business model undergo significant changes, the required talents to pursue the new business model may be so distinct that old abilities become outdated.

The innovations, whether they are product, process, or organizational differ in terms of their level of novelty. This is because the degree of novelty is inherent to the innovation itself. Hence, the level novelty of an innovation may be classified into two distinct categories: incremental and radical (Souto, J., 2015). Radical innovation is defined as a crucial factor in promoting progress. It involves a process of creative destruction, which brings about a revolutionary transformation and breakthrough in product, method, or organization (Schumpeter 1934 & 1942). This form of innovation, in simpler terms, deviates from the existing structures, methods, activities, and products inside a company (Damanpour, 1996; Martinez-Ros & Orfila-Sintes, 2009). This kind of innovation is characterized by its high level of novelty and its separation from past ideas or methods. It is the outcome of non-obvious approaches or concepts. Therefore, a radical innovation presents significant obstacles and potential (Teece, 2010; Tushman & Anderson, 1986). On the other hand, incremental innovation refers to an innovation that has a relatively low level of originality. It also involves less risk and cost compared to radical innovation, but it has significantly less potential to positively affect a company's performance (Martinez-Ros & Orfila-Sintes, 2009; Tushman & Anderson, 1986). Incremental innovation is characterized by its lack of deviation from past products, processes, or organizational systems. Instead, it focuses on making significant improvements to these existing elements, resulting in a reduced degree of originality. However, a series of little and gradual improvements might ultimately lead to a radical innovation (Martinez-Ros & Orfila-Sintes, 2009).

Table 7 Types of business model innovation

<table>
<tr><td rowspan="4">Degree to which business model innovation renders existing products non-competitive</td><td>High</td><td>Position-building
Wal Mart’s move into rural areas</td><td>Revolutionary
Online auction versus offline auctions for many products. Refrigerators over harvested ice.</td></tr>
<tr><td>Low</td><td>Regular
Dell’s direct model in 1990s</td><td>Capabilities-building
Ethanol versus petrol, synthetic rubber over natural rubber, brick-and-mortar retail and online retail</td></tr>
<tr><td></td><td>Low</td><td>High</td></tr>
<tr><td colspan="3">Degree to which business model innovation renders existing capabilities obsolete</td></tr>
</table>

Source: Afuah, 2014

The two-by-two matrix is divided into four quadrants, each representing distinct sorts of business model innovation. The level of rule variation intensifies as one progresses from the graph’s starting point to the upper right corner. In a conventional business model innovation, the laws of the game remain largely unchanged. The most significant alterations are groundbreaking business model innovations that make current products uncompetitive and makes present capabilities outdated (Afuah, 2024).

Radical – in a regular business model innovation, a company utilizes its current capabilities such as value chain activities and underlying resources, to construct the new business model. The business model is designed to ensure that the current items in the market maintain their competitiveness. Essentially, items based on a traditional business model may capture a portion of the market from those using and outdated approach, but the latter may maintain sufficient profitability to be a strong competitor in the market. The business model used by Dell in the 1990s, with the introduction of its build-to-order strategy, may be classified as a conventional business model innovation. Dell adopted a direct-to-consumer sales approach, avoiding brokers, and allowing consumer to directly purchase their computer from Dell. Consumer had the possibility to customize their computers accordingly to their needs (Afuah, 2014).

Capabilities-building – in a business model innovation focused on capabilities-building, the required capabilities in the new model for value creation and capture are significantly distinct from those of the previous model. Nevertheless, goods that are based on traditional business models continue to be competitive. The modifications to the game's rules mostly revolve around capacities. We classify this business model as capabilities-building since the necessary skills and abilities required to implement the model must be developed from the bottom or obtained through alternative sources. For instance, a company that seeks to obtain energy from renewable sources is engaging in a business model innovation focused on establishing skills. This is necessary because the company needs to develop new abilities that are distinct from those used in petroleum-based business models (Afuah, 2014).

Position-building – in a position-building business model innovation, the introduction of products/services based on the new business model makes products/services based on existing business models lose their competitiveness. Nevertheless, the capabilities that support the new business model are predominantly identical to or derived form the skills that support the old business model. This strategy is referred to as position-building since it makes current items lose their competitiveness. Wal-Mart's entry into small communities in the United States was based on position-building business model. The company's business plan was primarily based on the same capabilities as the existing merchants' business models, or was developed on top of them (Afuah, 2014).

Revolutionary – in a revolutionary business model innovation, fundamental talents that support the new model are so distinct from those that support the old business model that these old abilities are mostly ineffective for pursuing the new business models (…). Products that are based on outdated business concepts are likewise made obsolete. A revolutionary model fundamentally redefines the concept of producing and extracting value in a market, while completely disrupting the traditional methods of conducting value chain operations. The game's regulations have been altered in terms of both capabilities and market conditions. This business model innovation is the most transformative. Notable examples of revolutionary business model innovations include the business models adopted by online auction companies like eBay. Online auctions require significantly different capabilities compared to offline auctions, rendering offline auction business models uncompetitive (Afuah, 2014).

Business model innovation, in this sense, refers to any form of innovation that either establishes a new market or undermines the competitive advantage of significant rivals. Business model innovation is sometimes confused with the development of new capabilities, such as new distribution channel, in many conversations. Business model innovation may or may not be present in this case. It is important to note that new capabilities are necessary for business model innovation, but they will only be considered as such if they significantly disrupt the competitive dynamics of an industry. There are many notable example highlighting this difference. Firstly, Dell – they revolutionized the cost structure of personal computer market with its build-to-order approach, which eliminated the expenses associated with retail stores.

This resulted in a significant reduction in working capital and allowed for greater customization options. Secondly, Netflix – mail-order DVD rental strategy revolutionized the cost structure of Blockbuster Video, which had previously revolutionized the cost structure of its smaller competitors. Netflix closed down physical stores and used a portion of the resulting cost saving to establish a pricing system that abolished penalties for returning items late.

Business Model Innovation encompasses two crucial aspects: the generation of value and the acquisition of wealth. Value creation refers to the process of identifying and understanding various values and how they are connected to one other (McGrath, 2010). On the other hand, value capture involves determining the methods through which value is supplied and converted into monetary gains (Teece, 2010). Kastalli and van Looy (2013) discovered that the implementation of an integrated product-service business model is crucial for the generation of value. Just providing a product and service is insufficient to generate and retain value. It is crucial to have a suitable business model innovation in order to capture value effectively. According to Johnson et al. (2008), business model innovation should provide a distinct value proposition, meaning that an alternative service cannot fulfill the same demand. Zott & Amit (2017) identify four key value drivers. Firstly, novelty – measure the extent of business model innovation that is represented by the activity system. Secondly, Lock-in – refers to the specific components of a business model that increase the cost of switching or provide additional benefits to encourage players to remain and engage in transactions inside the activity system. Thirdly, Complementarities – refers to the positive impact on value that arises from interconnections between different components of a business model. Finally, Efficiency – refers to the reduction in costs achieved by connecting different parts of the activity system (Zott & Amit, 2017).

Simply put, business model innovation refers to the development of a new or greatly enhanced set of activities that are necessary for creating a new value proposition. To fully understand this invention and its function in the innovation process, one must clarify the connections among knowledge, technology, and innovation, with a particular focus on the significance of industry-specific information. Therefore, innovation arises from the combination of several types of information, including technical, non-technical, and market knowledge. However, innovation requires the presence of creativity. Innovation emerges from creativity, and it is achieved when a novel concept is put into practice and effectively builds on a market opportunity. Consequently, a novel concept is implemented by integrating many forms of information and later brought into the market. Hence, a new business model offers alternative possibilities for utilization and exploration of information and technology, distinct from those explored by rivals. This facilitates the development of internal innovations, both incremental and radical (Souto, J., 2015).

To conclude, business model innovation has a positive relationship with a company's success, as indicated by studies conducted by Giesen et. al. (2010) and Huang et al. (2013). Park & Ro (2013) investigated the impact of entrance time and business model innovation on a company's performance in a new market. They demonstrated that pioneers who concentrate on product development centered may not be able to survive, whereas latecomers with appropriate BMI can emerge as a dominant force in the new market. Kastalli & van Looy (2013) discovered a strong correlation between the selection of a business model and the impact of complementary dynamics on product and service sales. The interaction between a service and product outcomes can have a significant impact on long-term performance (Kastalli et al., 2016). An organization's capacity to understand, control, and evaluate its fundamental capabilities is crucial for accomplishing its objectives through Business Model Innovation. Open innovation is becoming more and more relevant as component of a new business model (Nair et al., 2013).

2.2. The Relationship between Digital Twin and Business Model Innovation

Digital business concepts are increasingly challenging traditional methods of conducting company. Multiple firms explore innovative solutions by utilizing data and analytics (Gottlieb, J. & Rifai, K., 2017).. Technological progress and the process of digitization provide new prospects for organizations to reconsider and effectively employ methods of generating value for their consumers. Implementing a data-driven approach to their business model has been a successful transition for many organizations, but for others, failing to do so has served as a wake-up call or even led to their collapse (Fruhwirth et al. (2020) & Foss N.J., Saebi T., (2017). Data-driven business models are becoming increasingly popular in academic study due to continuous growth of data analytics and storage capabilities in firms operating in a data and platform economy (Zolnowski et al. 2016). In addition, data driven innovations are increasingly essential in both business and non-commercial sectors (Kühne B., Böhmann T., 2019).

While examining digital twins in the context of innovation, there are two possible approaches: seeing innovation as a process or as an end result (Crossan M.M. & Apaydin M.A., 2010). Viewed as a continuous method of innovation, a digital twin facilitates the generation of value by promoting cooperation throughout the whole value chain (Holopainen et al. 2022). If the emphasis is placed on innovation as a result, the utilization of a new product, service, process, or business model becomes the primary focus. In the literature, there is a an increase of product innovation, service innovation, process innovation, and business model innovation (Holopainen et al. 2022). Innovation encompasses the creation of new goods, services, processes, and business models, as well as the alteration of existing ones, and the transition from one product, service, process, or business model to another. Holopainen (2022) argues that the capability of digital twins to synchronize the physical and virtual realms also facilitates innovative business model transformations, hence altering current operational practices.

Digital twins in this context have a lot of potential when it comes to one of the most important features of Business Model Innovation, through value creation. For example, data are conceptual and require interpretation to provide information (or insights) that may be assimilated to develop knowledge. Knowledge is derived from information when it is placed inside a framework that imparts significance to it and involves a connection to actions or inactions resulting from deliberate decision-making (La Longa, F., 2012). Marakas (1999) has highlighted three essential elements of a decision support system: a knowledge base, a decision context and user criteria (or a model), and an interface to facilitate human/machine interactions. The actors themselves are vital, just like any other element, and a digital twin might serve as an equally crucial component of a decision support system. A digital twin encompasses these three essential elements and serves as a decision support system (Marakas, 1999). Zeng et al. (2013) have discussed the application of digital technology to assist human decision-making. More recently, researchers (Nadhan et al. 2018; Patricio et al. 2019) have examined the relationship between expert system guidance offered by cyber-physical-systems in various situations. The analyzed scenarios involved the use of a digital system, such as a simulation, artificial intelligence, or machine learning system, as a decision support tool. These system acknowledged the importance of the individuals involved in decision-making and their ability to take action. Digital technologies have systematized hidden information across several levels to facilitate the decision-making process, often combined with real-time operational and machine data (West et al. 2021).

Digital twins have also a lot of potential withing digitally enabled PSS. PSS, or Product-Service System, is a complex network including many individuals, organizations, and recipients. It is frequently utilized in the context of servitization where contracts are dependent on achieving specific outcomes or performance (Kuijken et al. 2017). Utilizing information systems or software service platforms to facilitate the generation of value inside systems is a crucial factor in the advancement of digitally-enabled PSS value offerings. According to Kutsikos et al. (2014), it is important to define the components of the service ecosystem in order to understand a digitally-enabled Product-Service System (PSS), which is essentially a digitally-enhanced ecosystem. This provides a method for making decisions on how to integrate the different components of a system and also gives a shared infrastructure for providing services. Gebregiorgis & Altmann's (2015) research verified that the information system's open nature and its capacity to provide continuous value creation need the establishment of a shared service infrastructure and collaboration among players to enable continual integration and value co-creation. Digital twins are a type of service platform that combines and shares information, and are a key components to connect different stages of the lifecycle and layers of architecture, commonly known as "hybrid simulation" in academic literature (Macchi et al. 2018).

Study done by Martinez et al. (2018) shows that manufacturers are transitioning from product-focused to service-focused models in order to increase value generation. They are capitalizing on the potential presented by digitization, namely through the use of Digital Twins, to enhance their operations and expand services across the whole lifespan of their goods. Their research (Martinez et al. 2018) has discovered two methods for enhancing organizations' business models. Digital Twins can enhance either the operational or customer-facing aspects of a company's business models. Four kinds of firms have been identified based on the degree of progress in both the back and front-end. Each category has a distinct approach to apply the concept of Digital Twins: 1) They posses the ability to construct both back-end and front-end systems, with a greater focus on enhancing the back-end processes. 2) They posses the ability to develop both back-end and front-end systems, with a greater emphasis on innovating front-end services. 3) They have the option to only prioritize back-end enhancements. 4) A few of them have already reached a high level of proficiency in both back-end and front-end improvement (Martinez et al. 2018).

Barth et al. (2023) work on Digital Twin's value creation potential stated that three dimensions are vital for every Digital Twin: data resources, external value creation, internal value creation. Internal value creation – Digital Twins serve as the central point for generating value in digital product service systems by facilitating the connectivity and interaction of internal and external processes and stakeholders. Digital Twins facilitate the integration of the product management hierarchy with the life cycle management procedures, hence enhancing internal value generation. By doing so, they help to decrease and control the complexity and diversity of variations in the internal processes that generate value. They do this by establishing connections between the essential data from separate internal systems, external systems, and the Internet of Things ecosystem, and then making it useful through data processing. Digital Twins provide a comprehensive perspective on the essential components that contribute to value production by preserving past data and providing access to it for the purpose of optimizing the current situation and predicting future outcomes (Barth et al. 2023). External value creation – The data-driven services that are produced are the central part of the value proposition, and may be delivered to both internal and external users. Digital Twins facilitate the connection between the SCP, systems, and system of systems throughout their usage phase with the MoL activities of the providers, in order to create external value. These features enable them to possess control, optimization, and even autonomy capabilities, therefore meeting the criteria to be labeled as "smart". Digital Twins let providers to guarantee that the services they offer deliver the stated value in terms of availability, performance, and quality in real-world usage (Barth et al. 2023). Data resources – Digital Twins allow users to participate in organization and analysis of data. This includes facilitating human understanding of data by providing well-prepared foundations for decision-making. Digital Twins have the capability to acquire knowledge from users' interpretation processes and judgements. As time progresses, Digital Twins will become more proficient at independently interpreting a larger amount of data. This capability serves as the foundation for reaching the "autonomy" stage in term of smartness maturity. Digital Twins have demonstrated their ability to provide a holistic strategy to generating value, encompassing internal services, market-side services, and complete data providing (Bart et al. 2023).

Van der Veen et al. (2023) conducted a study on how digital twin enables business model innovation for infrastructure construction projects. Suggested concept offers a range of operational business models for infrastructure development projects that may be derived from the implementation of the digital twin. This form of business model innovation may have a profound influence on the manner in which clients and construction businesses collaborate. Furthermore, it has the potential to expedite the process of infrastructure planning and contract allocation, while also enhancing efficiency throughout the building phase, leading to time and cost saving for the benefit of the general public. In conclusion, author identified five most promising business model innovations thanks to a digital twin (van der Veen et al. 2023):

Table 8 Business model innovations enabled by a digital twin

Business model innovation	Explanation
Digitalization	a digital twin encompasses several elements of the business model pattern of digitalization. The construction work will be provided to clients in a digital format, referred to as a twin. The construction plans, sequence planning, and cost planning are developed using digital models, such BIM4D. The building work is captured using sensors and the data is analyzed and shown digitally. Additionally, features include the comprehensive visual representation of the complete building site and the option for virtual site inspections (van der Veen et al. 2023).

Performance-based contracting	the business model pattern has a pricing structure that is determined by the level of performance delivered by a service or product. Customers typically do not purchase the product itself, but rather the outcome or benefit of the service, while the product usually remains in the possession of the client. The price is determined by the efficiency of the construction job, which is enhanced by the digital twin service. It is necessary to determine which construction has a considerable improvement in performance when a digital twin is used (van der Veen et al. 2023).
Revenue sharing	Within this particular business model framework, the generated money distributed among the many participants involved, including subcontractors. The stakeholders are compensated for the value-adding activities they conduct. The business model pattern of utilizing a digital twin in infrastructure development projects holds the greatest potential for business model innovation. By taking into account the benefits of reducing risk, ensuring cost security, and avoiding errors, as well as improving the efficiency of the building process, a higher value is achieved. This value is directly proportional to the volume of construction and enables a business model that involves sharing income based on turnover (van der Veen et al. 2023).

Leverage customer data	this pattern seeks to gather consumer data and leverage it for profitability. This data has the potential to enhance internal operations and be sols to other entities. Collecting and analyzing data from construction sites can be beneficial for the present project and also provides the opportunity to utilize or market it to other construction sites or sectors (van der Veen et al. 2023).

Source: (van der Veen et al. 2023).

Technology-business integration presents several tactics and predictions that enable higher-management to carry out sales efficiently. Consumer happiness is accomplished by paradigms such as mass individualization, which involve revenue structures, quality products, and co-creation. Furthermore, the trend of combining products and services into bundles becoming increasingly popular. This approach reduces the main expenses and improves efficiency by providing automated real-time suggestions based on current situation. By integrating and implementing appropriate business models, companies may strengthen their distinctive industrial expertise with digital transformation in order to maintain competitiveness. Digital Twin is not only a low-cost solution for enhancing corporate competitiveness, but it also brings benefits to various stakeholders, including consumers, management, and empowers workers to take on supervisory role (Lim et al. 2020).

2.3. Digital Ecosystems

Digital twins combine existing knowledge with digital artifacts, data, and models (Rosen, Fischer, and Boschert 2019). When it comes to effective use of digital twins, there is a need for the exchange of information among suppliers, manufacturers, and customers which are involved in digital twin operations. This relationship show the qualities of a digital ecosystem, since it involves individuals and organizations, which together share digital artifacts and model in digital platforms (Rosen, Fischer, and Boschert 2019). There are a lot of digital twin ecosystem definitions, in the literature. Liu, Mevendorf, and Mrad (2018) proposed that the digital twin ecosystem includes sensors and metric based technologies like Internet of Things, modeling and simulation, and machine learning. Ezliharasu, Skaf, and Jennions (2019) suggested that a digital twin ecosystem refers to the external surroundings that support the functioning of the digital twin. The ecosystem has three most important components: the product lifetime, a digital representation of the twin, and data that connects the physical products to its digital counterpart (Ezliharasu, Skaf, and Jennions, 2019).

In essence, a digital twin ecosystem is often described according to the concept of a digital ecosystem. However, a digital twin ecosystem is not only a digital platform for exchanging information and expertise. In the future, a broader range of enterprises will be impacted by innovative digital twin technologies. The collaboration and exchange of digital objects in digital twin-based ecosystems will occur dynamically to collectively generate value in various value chains (Rosen, Fischer, and Boschert 2019). This implies that digital twins establish connections not just between individual things, systems or supply chains. In their 2015 study Rong et al. (2015) examined ecosystems based on the Internet of Things (IoT) and found three key components: the central firm that is in charge of providing the platform, product or service which are the basis of the system, and all stakeholders involved. Similarly, a digital twin-based ecosystem may be described as a sophisticated system that involves several stakeholders who contribute to the mutual development and collaborative production of the ecosystem. Based on the concept provided by Senyo, Liu, and Effah (2019), a digital twin business ecosystem (DBE) is described as a socio-technical network which consists of individuals and organizations which work together to generate value by using digital twin technologies.

The findings of the study conducted by Kokkonen et. al (2023) indicate that at the company level, there is a full understanding of the advantages of implementing a digital twin business environment. The respondents frequently agreed that the firms' attention are more focused on digital twin business ecosystems due to the opportunity they provide for new business. Companies understand their duties within the ecosystem at the corporate level and also recognize potential avenues to enhance their sales volume inside ecosystems. Furthermore, with regards to the potential to offer current services and solutions inside digital twin business ecosystems, the organizations also emphasized the chance to create new features or entirely new services or businesses that would benefit these ecosystems. For instance, the digital twin service providers interviewed all agreed that joining a digital twin business ecosystem would provide them additional sales prospects by allowing them to share their experience with other operators inside the ecosystem.

Findings of the study done by Kokkonen et. al (2023) indicate that the advantages of digital twin ecosystems are linked to learning and growth within the organization, in addition to potential opportunities for new business. Companies seek not just financial gains from digital twin business ecosystems, but also value knowledge acquisition and learning opportunities from other operators. Seeking to use the knowledge and skills of other participants in the ecosystems, suppliers and users of the digital twin services are actively seeking ways to improve their own operations and drive organizational growth and innovation. Both digital twin service providers and utilizers are interested in gaining a detailed understanding of the technological capabilities offered by a digital twin business ecosystem. Additionally, they seek to learn more about the roles, duties, and expectations of enterprises operating within the ecosystem. In addition, the organizations also indicated a desire to create innovative business models and revenue streams using digital twin business ecosystems.

The survey findings also indicate that at the corporate level, respondents emphasized the significance of resource utilization as a valuable advantage of a digital twin business environment. They referred to digital twin business ecosystems as a means to facilitate worldwide collaboration. This viewpoint was predominantly articulated by those affiliated with small and medium-sized enterprises (SMEs). Furthermore, the potential to expand global business opportunities and the capacity to efficiently manage human resources by using other operators within the digital twin business ecosystem were seen as significant advantages of the ecosystem. The sharing and scaling of human resources within the ecosystem can improve and harmonize ecosystem operations by eliminating redundant and overlapping activities and roles in the service and solution delivered. Therefore, it would also facilitate the merging of several divisions inside the organization (Kokkonen et. al, 2023).

Although the study's findings indicate that both digital twin service providers and utilizers acknowledge the advantages of accessing digital twin business ecosystems at the firm level, it becomes increasingly challenging to identify these benefits when the focus switches to the ecosystem level. Although the corporations have said that they are actively seeking chances to create digital twin business ecosystems and acknowledge the necessary conditions for them, it appears to be challenging to clearly define the advantages at the ecosystem level. Both the digital twin service providers and utilizers have expressed a desire to develop new business models and revenue strategies through digital twin business ecosystems. However, they have found it challenging to understand how these business models should be implemented in practice. The interviews uncovered commercial challenges related to transitioning from a single service provider to an ecosystem operator. The final consumer may not be inclined to cover the costs of all services, which are considered relevant in the ecosystem. In order to create digital twins on an ecosystem level, a service provider may need to make sacrifices on its own profit margins in order to offer the most optimal solution to then end client. The interview results indicate that service providers are changing their perspective from just focusing on raising their own sales volume within the ecosystem, to instead prioritizing the optimization of the whole solution's functionality and cost-effectiveness, even if it means a drop in the business margin of an individual service provider (Kokkonen, et. al 2023).

Although, there are difficulties in realizing the advantages of digital twin business ecosystems at the ecosystem level, the primary benefit that is emphasized by both service providers and users is the inter-organizational value. There was a widely held belief that by incorporating the most effective strategies and talents of each ecosystem operator, it would be feasible to more effectively meet consumer demands and enhance the customer's convenience (Kokkonen, et. al 2023).

To sum up, benefits of digital twin business ecosystems look as the following:

Table 9 Benefits of digital twin business ecosystems

	Company level	Ecosystem level
Benefits	New business: -more sales volume, -opportunity to develop new functionalities or totally new products for a new business, -opportunity to make one's own expertise more widely available to others. Resource utilization: -integration of company silos, -enable scalability and human resources through partners, -international collaboration. Learning and development:	Inter-organizational value: -making the customer's life as easy as possible, -better fit for customer needs, -possibility for new business and value.

	-opportunity to benefit from expertise of others, -knowledge acquisition and learning from other operators, -possibility to develop own operations, -innovation and renewal.	

(Kokkonen, et. al 2023).

2.4. Digital Twin and design thinking

Digital Twins are implemented to facilitate the interaction between an information system and its physical equivalent, as well as to enhance its usability. Moreover, digital twins are typically generated to assist users in their duties. For instance, in the context of manufacturing, digital twins may be employed to strategically plan and regulate physical machinery (Singh, et al. 2021), as they accurately replicate the actual counterpart. Digital twins have the capability to examine the present system and provide enhanced understanding of the collective data from various system components (Kirchof, et al. 2020). By utilizing digital twins for design thinking, our aim is to redefine the concept of digital twins and develop a digital model that assists users of design thinking methodologies in a ways that are like to the mentioned digital twins. Thus, starting point is the identification of a physical counterpart, and a method to generate the digital twin. In the context of design thinking, physical twins refer to the actual design objects that represent the information, structure, and design of a new service that represent the information, structure, and design of a new service or product that is being developed. The physical twin consists of both a tangible representation and an immaterial component (Karagiannis, 2024).

The implementation of the digital twin relies on conceptual modeling. Conceptual modeling involves separating key characteristics of recognized ideas within a domain to enhance their utility and comprehensibility (Mayr & Thalheim, 2020). This process is comparable to the use of visual representation in design thinking workshops. In addition, the process of making physical situations machine processable is achieved by establishing the overall framework of a conceptual modelling approach, as described in Karagiannis & Kuhn, 2002. The digital twin of design thinking is not only a visual representation of the physical design item, but rathe a complex structure that can be analyzed and annotated by machines, while yet maintaining its visual appeal for human users. Hence, the design can be enhance by incorporating additional attributes to the figures or by directly including textual descriptions in the model. Additionally, explicit reactions between the objects can be stated, which in the physical version are only implied through their position and the visual representation of the human users (Karagiannis, 2024).

Table 10 Comparison of different types of digital twins, with digital twin for design thinking

Features	Kind of digital twin	Digital Twin in Production	Digital Twin of Systems	Digital Twin for business models
Physical Twin		Physical objects	Systems	Designs for innovative scenario using tangible objects
Digital Twin		Data software	Model of the system, data from a system, services for using data and models, software	Conceptual methods, software
Relation between digital and physical		State of physical and digital twin is mirrored	Data integration form the system and invoking services	Enrichment to improve conceptual design
Operations		Control planning and execution of physical systems, analysis	Control and analyze systems, integrate system components	Aggregate and enrich information, fast prototyping, input for further

			usage, support, design process, documentation.
Software tools	e.g. Azure Digital Twins	e.g. MontiArc, Ros	e.g. Scene2Model

Source: Karagiannis, 2024

Various methodologies can facilitate the transformation of a tangible object into its digital counterpart, establishing a connection between the physical and digital components. Two versions were selected and applied for the transformation in Scene2Model. One approach is to supplement the paper figures with tags that may be readily detected by a camera, as described in Muck & Palkovits-Rauter 2022, Miron et al. 2019). The system should posses the capability to capture an image of the scene together with associated labels and analyze it in a manner that can be correlated with model entities. The photographs may be captured using either a smartphone or a web camera. In order to organize a design thinking workshop, it is necessary to create and attach tags on paper figures. An alternative method involves utilizing artificial intelligence (AI) to facilitate the direct identification of the illustrations in the article, as described in the work of Much & Utz (2023).

The digital twin used in Scene2Model establishes a relationship between design artifacts and realized storyboards, allowing for analysis and simulation. For example, it is possible to determine the most probable scenario that will occur in a business model, taking into account that the associated storyboard is not linear but may encompass many action routes. Regarding capacity analysis, it is common for the same actors and stakeholders to participate in many scenarios. As a result, it is possible to develop an overview of their duties and accompanying responsibilities. A key feature of the digital twin is its capacity to provide a comprehensive perspective on the physical twin, such as the planned product or service, particularly in the context of design thinking. The Scene2Model tool fulfills this need by producing a digital storyboard that includes all scenes, providing a thorough overview of the low-fidelity prototype that was developed. The storyboard does not always present the scenes in a sequential manner. The scenarios can be organized in a manner that closely replicates the many choices explored during a workshop, either by following separate routes or by being placed in together. Moreover, a system that enables the automated conversion of physical design objects into digital representations for business models is advantageous for monitoring the progression of the creative landscape over time. This capability permits repeated cycles of invention (Karagiannis, 2024).

Creativity and co-creation serve as the foundation for innovative business models. The interaction between stakeholders, peers, domain experts, and other players generates a wide range of knowledge, which in turn leads to the introduction of new ideas, experiences, services, and products for consumers (Heydrich, 2020). The following passage presents a case study title “Edomae-Sushi” from Hara & Masuda work in 2016. This case study serves as an experience report on the process of co-creating and constructing an innovative business model utilizing the storyboarding technique with the digital twin mentioned before. This use case falls under the category of a business model that aims to innovate services, with a specific emphasis on evaluating and dividing costumer into segments for the purpose of providing tailored services. Japanese culture embodies a sophisticated and deeply established history of hospitality. The explicit authenticity and continuous delivery of sustainable value (Karagiannis, 2024).

The Edomae-Sushi business mostly depends on the knowledge of the customer and the supplier. The service’s unique feature consists of two ordering methods, without a set menu as everyday consumption heavily depends on new market goods. The restaurant’s counter-style structure lets guests and skilled sushi chefs engage directly, which at the end aims to improve the eating experience (Karagiannis, 2024).

The goal was to provide customized services tailored to every customer. To offer the most appropriate service, master sushi chef must be skilled at identifying different customer types (Karagiannis, 2024).

A design thinking workshop was carried out to gather the necessary professional expertise for customer type identification. Participants included researchers acting as customers and cooks as well as professionals in Japanese services. They developed a scenario by grouping customer to three segments: new, repeat, and semi-repeat, by using haptic figures, and digital twin. Thanks to this two things, scenes were created with various customer interactions, such as the 'new consumer' and 'repeat consumer' created in the workshop. Digital twins created from these situations were improved using techniques like leading to the table, offering recommendations, and serving sushi. This method effectively caught the complex nature of Japanese Hospitality. The outcomes were presented to improve Japanese Creative Services in many areas. The success of this session resulted in a new use case in hotel hospitality based on even more detailed customer patterns proposed (Karagiannis, 2024).

To conclude**,** both physical and digital twins were crucial in developing a shared knowledge of the scenario and the criteria to co-create a unique proposal for personalized service delivery in the hotel sector. Therefore, storyboarding with Scene2Model for the design phase of creative business models can be applied in many fields, including the service and hospitality sector where many different aspects should be considered and evaluated by the stakeholders towards a more sophisticated and personalized service. Presented case, mostly relates to the world of traditional Japanese services and Japanese hospitality, where the fundamental requirement resides in the thorough awareness of the contextual nuances by the stakeholders. This high-level conceptual method presented here helps to capture this implicit information in a clear and understandable way, thus facilitating external access to it. Throughout the workshop phase it was clear that the quick conversion of the physical scenes into digital twins is absolutely crucial to better fit the early prototype of the intended planned service. The utility of digital twins for business models also comes from the element of model dependency resulting from Scene2Model tool use. More information and annotations help the digital artifacts to capture the assumptions and knowledge transfer amongst the involved stakeholders. Depending on the digital artifacts, analysis and different searches may be conducted to produce value and insights from early on and to evaluate the aspects of the scenario with most importance. Building on the collective intelligence gaining access to the digital artifacts, it promotes value co-creation of the related business model ecosystem and integration with the previously existing corporate assets and know-how.

Chapter III Illustrative examples

3.1. Methodology

For this section a qualitative study based on in depth analysis of illustrative examples was conducted. To goal was to use specific, detailed, real life application of digital twins, and at the end measure how it affected specific areas of the companies. Data was collected from the various sources. Companies reports, articles, and websites were analyzed. Journals, articles, external companies reports were also used for this purpose. There were several reasons for the companies to be selected. Firstly, companies operate in distinct industries, for example aerospace (Rolls Royce), logistics (CEVA), thanks to this it was possible to show different challenges and opportunities regarding the topic. Secondly, all of the companies are considered as one of the levels in respective industries, but also they are the leaders of digital twin implementation. Thirdly, all of the companies operate on global level, and their supply chains span throughout entire world, which also allows this paper to show how challenges and opportunities enhance resilience of supply chain. Finally, in all of the companies digital twins with the help of business data & analytics business model was reshaped, and some of them moved to servitization. It also has to be emphasized that all of the companies were similar in terms of their size. Research done about SMEs would not be able to show full range of possibilities and potential impact of digital twin, and areas related to the business model. However, the industries in which companies operate varied. For example Rolls Royce research was done mainly about their aerospace sector, but also automotive, while DHL is from logistics area. The reason for that, was to check whether digital twin's impact can be noted in several different value chain sectors. Data analysis was based on qualitative methods, as other methods would not be effective.

3.2. Rolls Royce

Rolls-Royce originated from Royce Limited, an electrical and mechanical corporation founded by the English engineer Henry Royce in 1884. Nonetheless, the formal establishment of the Rolls-Royce corporation occurred in 1906, following to the great triumph of its initial line of automobiles (Rolls Royce, 2024).

Nowadays, company operates in many industries. Company is one the biggest aero engines manufactures, with the range of production from commercial aircrafts to business aviation market. In 2023, this division made around £850M of profits, and stand for around 33% of market share of large engines globally (Rolls Royce, 2024). However, this manufacturing capabilities are not only used for commercial aircrafts, but also for military purposes. Rolls Royce is in charge of manufacturing of aero engines for military transport aircrafts, but also for aircrafts with combat capabilities. It also supplies nuclear propulsion plant of all of the UK Royal Navy's submarines. This branch received around £9.2B of orders in 2024 (Rolls Royce, 2024). Company is also a leading provider of solutions for onsite power and propulsion, with around £413M in profit (Rolls Royce, 2024). However, the most renowned branch of Rolls Royce is its automotive division. Company has been on of the leaders of luxurious car industry. In, 2024 Rolls-Royce achieved another record in company's history, by delivering 6,032 motor vehicles to clients in over 50 countries worldwide (Rolls Royce Press Release, 2024).

Rolls-Royce has consistently been a leader in engineering and technological innovation. Recently, the company has entered the digital area by using the capabilities of Digital Twin technology. Main thing about this technologies is the creation of carefully designed virtual replicas of real items or systems. These digital replicas allow engineers and designers to replicate, examine, and enhance goods and processes in a virtual setting, before their physical construction or implementation is done. (Goldenberg, 2024).

The use of digital twins in Rolls-Royce engineering was about a significant transformation, revolutionizing the way this aerospace industry leader tackles design, maintenance, and innovation. Originally, digital twins were created as virtual duplicates of actual engines, the purpose of it was to improve the understanding of their operational features. Over time, these digital structures have developed into advanced system that not only accurately replicates their physical counterparts in real time, but also has the possibility to forecast future performance and possible breakdowns. By utilizing advanced analytics, data from the Internet of Things, and powerful machine learning algorithms, Rolls-Royce was successfully able to enhance their engine performance, minimize periods of inactivity, and customize plans for preventive maintenance. This shows a notable transition of the company towards becoming proactive in digital area. (Goldenberg, 2024).

Rolls-Royce's digital twin technology is built upon a complex fusion of essential components that are carefully combined to imitate and forecast the actual performance of their engines. The key component of this is the sophisticated modeling software, which accurately reproduces physical events. Thanks to this engineers are enabled to predict the performance of engines in different situations. In addition, sensor data analytics is essential in this context. By utilizing extensive operational data collected from sensors integrated into functioning engines, the system acquires the capability to continuously monitor the condition and anticipate maintenance requirements in real-time. In addition, machine learning algorithms constantly improve these forecasts by learning from additional data to improve future precision. Collectively, these elements are the fundamental structure of Rolls-Royce's digital twins, by providing advanced understanding of engine performance and reliability (Goldenberg, 2024).

By implementing this so called Digital First, data centric approach, Rolls Royce aims to provide value to its clients by using digital twins in production, component, product, fleet, and enterprise. Their enterprise modelling tool is now providing valuable information on client operations. It results in a decrease in aircraft downtime, a reduction in life cycle cost, and an optimization of future performance based on their customers' Key Performance Indicators (KPIs). By generating digital replicas of Rolls-Royce power and propulsion systems, company will decrease the duration, expenses, and environmental impact of testing, while fulfilling the essential criteria set by governments throughout the globe. The capability to generate a digital replica of a 'product' has already been showcased in Rolls-Royce's Civil Aerospace division. This replica went through a comprehensive blade off simulation that not only resulted in cost savings of over £20M, but also enhanced safety measures. The simulation demonstrated satisfactory performance across a wider range of conditions compared to a single isolated test. The organization is utilizing digital design and inspection to construct component twins, so enhancing power and propulsion performance and deepening comprehension of component degradation and behavior (Rolls Royce, 2022).

Rolls Royce's utilization of digital twins in aviation engine maintenance is a major advancement in predictive analytics and operational efficiency. This cutting-edge technology generates a digital duplicate of the airplane engine, allowing engineers to observe, examine, and mimic real-life circumstances without any physical interference. Thanks to the use of specific data collected from engine sensors, the digital twin has the capability to anticipate probable malfunctions, enhance maintenance planning, and enhance engine design for future versions. It improves dependability and safety, and it also decreases downtime and maintenance expenses. It is possible due to perpetual feedback loop between the virtual model and its physical counterpart (Goldenberg, 2024).

Rolls-Royce has utilized digital twins to transform its production procedures leading to an important increase in productivity. Through the creation of virtual reproductions of their motors and components, they are able to replicate the complete lifespan of their goods inside a digital setting. This advanced technology enables the continuous monitoring and proactive maintenance, detecting possible problems before they even occur. As a result, it decreases the amount of time that a system is not functioning and lowers the expenses related to fixing and unexpected servicing. In addition, Rolls-Royce enhance the design and performance of its goods by regularly evaluating data from these digital replicas. This innovative approach not only simplifies and optimizes the production process, but also make the provision of more dependable engines to their potential customers more possible (Goldenberg, 2024).

An outstanding achievement of Rolls-Royce's utilization of digital twin is seen in its aerospace sector, where the technology has greatly improved engine performance and enabled accurate predictive maintenance. Rolls-Royce has utilized virtual reproductions of their aircraft engines to replicate and evaluate real-world circumstances, eliminating the requirement for actual prototypes. This method has not only improved the process of development but also enhanced fuel efficiency and minimized pollution (Goldenberg, 2024). Also, Rolls-Royce uses digital replicas to continuously check the well-being and state of its engines in real-time. The digital twin has the capability to gather data from many sensors, including those measuring temperature, pressure, and vibration. It then analyzes this data to detect possible problems and enhance fuel efficiency. Moreover, digital twins have the capability to forecast the durability and efficiency of the engines (Gerardino, 2023).

Rolls-Royce is one of the leaders of digital twin technology and there is a increasing scope of future possibilities. Rolls-Royce's digital twin breakthroughs are changing the aerospace industry, marine, and energy industries. Through the utilization of advancements in artificial intelligence and machine learning, these digital replicas will accurately anticipate maintenance requirements, enhance real-time performance, and enable the creation of more environmentally-friendly engines by simulating different fuel types and combustion techniques (Goldenberg, 2024).

To conclude, Digital Twin models used by Rolls Royce effectively represent the utilization of real-time data, consistently acquiring knowledge and upgrading itself to precisely mirror real-world operational situations. By utilizing the digital replica, engineers may conduct a greater range of tests compared to physical testing. This enables them to recreate severe situations and get a deeper understanding of behaviors. Additionally, it can forecast the operational behavior of engines by various airlines in different geographical areas, providing a more comprehensive understanding of the engine's performance throughout its lifespan (Brownlow, 2024). All of these improvements lead to absolute increase in value chain resilience and other related operations. Resilience was improved especially in aerospace sector, where digital twins allow to predict, and monitor their actions. In the end data from digital twins provide potential warnings earlier than previously, which decreases likelihood of disruptions in company's supply chain. Also as it was written, by investing in Digital Twin Rolls Royce allowed themselves to increase response time. Such a results made Rolls Royce adjust their business model. Before digital twin era Rolls Royce used to buy engines for their aircrafts, take core of the maintenance, and their own stock spare parts. Thanks to digital twin company started using subscription model, meaning manufacturers are paid only when their engines are working. Thus, every single engine has a digital twin, and are constantly monitored, which also at the end improves resilience of their supply chain (The Economist, 2024).

3.3. Siemens

Before the 1850s, the transmission of information was significantly limited by the speed of transportation. Intercontinental communication meant significant delays, which often lasted weeks or even months. Even in a single country, the spread of news was slow. However, everything was changed with the invention of electrical telegraphy. Simens made a significant contribution to the era of modern communication with the invention of the pointer telegraph. It all happened in 1847, and was the beginning of Siemens as we know it (Siemens, 2024).

Siemens AG is involved in the manufacturing and distribution of equipment used for power generation, power transmission, and medical diagnostics. The company functions through many divisions, including power & gas, energy management, building technologies, mobility, digital factory, process industries & drives, siemens healthcare, and financial services (Forbes, 2024).

Siemens has adopted an innovative and well-planned strategy to achieve success in the Metaverse. Peter Koerte, the chief technology and strategy office of Siemens, has stated that while they do not have complete understanding of the Metaverse, they possess a concept of its potential and are determined to influence its development. Siemen's implementation methods revolves around the utilization of digital twins. Siemens considers digital twins to be the fundamental components of the Metaverse. The most important part is Siemens' vast collection of simulation, optimizing, testing, and design technologies that connect factories to digital twin in the Metaverse (Goldenberg, 2023).

Siemens has utilized a digital twin to create a new factory in Beijing. This digital twin accurately replicates the industrial machines, people, robots, and materials, which allows them to test and optimize equipment and processes. The productivity of this new plant is reported to be 20% higher than of existing ones. Significantly, by using these types of simulations, Siemens' industrial clients may not only identify and implement improvements in efficiency, but they can also establish the basic for data-centric observations that influence factory layout, maintenance, product development, and personnel administration, by taking training and automation into consideration. Siemens is now working on creating a digital replica of an existent city named

Siemensstadt, which will serve as a smart city and be referred to as Siemensstadt Square. This initiative is part of their efforts to showcase the industrial Metaverse and is expected to be completed by 2025. Siemens will analyze, and optimize several aspects of this digital twin city, including calculating the necessary types of buildings, simulating staffing needs, and optimizing traffic patterns (Goldenberg, 2023).

Siemens has implemented its factory automation technology in 30% of all manufacturing equipment, making its design and product lifecycle management solutions essential in the majority of industrial enterprises. These technologies produce vast amounts of data from manufacturing machines, which may be used to adjust a digital replica of the production process in the Metaverse, using real-time data sourced straight from the factory floor. The real-time data stream may be utilized to develop more efficient factories, enabling Siemens to promptly detect and address production bottlenecks and quality flaws during the design phase. Siemens aims to revolutionize the process of constructing factories for the production of innovative goods in many sectors. During the covid pandemic, Siemens faced a scarcity of semiconductors. To address the problem, Siemens decided to create a digital replica of a circuit board, known as a digital twin. This digital twin was used to reconfigure the design of a circuit board, by including new components and enhancing its efficiency. As a result, Siemens was able to speed up the production of the redesigned board with a few days. It was a significant improvement as typically six-month timeframe is required by conventional methods. Siemens Digital Industries has achieved a remarkable 25% increase in sales over the previous 2 years, going from $15 billion to $20 billion. This growth was accomplished by shifting its digital twin portfolio to an industrial metaverse cloud (Goldenberg, 2023).

Siemens has introduced two significant initiatives to strengthen their industrial Metaverse cloud (Goldenberg, 2023). As s primary action, Siemens has developed the Xcelerator digital business platform and partner ecosystem to facilitate the rapid digital transformation of both Siemens and external companies. Also, in June 2022 Siemens entered into a partnership with the American high-tech firm Nvidia to integrate Siemens' Xcelerator digital business platform with Nvidia's Omniverse platform. This collaboration aims to enable the Industrial Metaverse and assist companies in the creation and operation of Metaverse applications (Goldenberg, 2023).

Siemens manufactures a diverse selection of industrial turbines and recently purchased the Rolls-Royce energy gas turbine and compressor division. Afterwards, Siemens unveiled a novel aero-derivative gas turbine (SGT-A65) that was developed using the purchased assets. The use of an externally built turbine posed several obstacles in terms of its manufacture and maintenance, including unanticipated concerns related to its performance and support during operation. The excel-based forecasting techniques utilized by Siemens at that period proved to be ineffective in adapting to the new conditions. The magnitude of the data exceeded the capacity of Excel to handle, and the outcomes lacked sufficient clarity to easily identify bottlenecks and promptly discover solutions. In order to address the problems, decisionLab and Siemens have put up a digital twin called ATOM. The ATOM digital twin leverages the rise of digital technology throughout Siemens' engineering and production operations. It leverages the abundant data available to connect customers, supply chain, manufacturing, and maintenance, aiming to enhance productivity and efficiency in customer service and asset management. ATOM does this by accurately representing the complex details of customer operations, maintenance facility operations, engine characteristics, and supply-chain logistics, and it is doing that over the whole fleet and operational cycle (anylogic, 2023)

Creating a digital twin requires a sophisticated simulation environment, and developers frequently employ a software development methodology related to the issue. The simulation software must possess significant adaptability in order to effectively represent diverse levels of business processes and handle different levels of complexity. DecisionLab selected AnyLogic as the primary solution tool because of this reason. In this instance, a fundamental component of the model was constructed utilizing several autonomous aspects, any by employing agent-based modeling, it became possible to accurately depict the essential nuances. In order to construct the model, the developers collected data related to many elements of Siemens gas turbine fleet operations from: customer operations (under what environmental circumstances, such as temperature, do client utilize the turbines in their operations), maintenance facility operations, engine characteristics (it refers to many failure modes that are specifically connected with distinct components of an engine), supply-chain logistics (anylogic, 2023).

At the end, DecisionLab has developed a very advanced digital replica that has all the necessary features requested by Siemens. The ATOM-twin simulation model allows users to capture and predict key performance indicators of the entire fleet operations of Siemens aero-derivative gas turbines. It also enables visualization of fleet and maintenance facility operations, identification of system bottlenecks, and the ability to run both quick 'what if' and detailed scenarios to assist in investment decision-making. Despite its complexity, decisonLab provided a user-friendly and interactive system that could be used throughout the business. Atom is a versatile tool that can effectively respond to the requirements of both upper-management and analysts (anylogic, 2023).

Siemens also uses its digital twin capabilities in healthcare. Mater Private Hospital in Dublin is a prominent establishment in Ireland for radiologic imaging and cardiac treatment. The hospital's intention to modernize its imaging fleet and optimize departmental operations prompted discussion regarding the advantages of digital twin technology between hospital administration and Siemens Healthineers, a longstanding partner. The collaborative team consisting of Mater Private Hospital and Siemens Healthineers Value Partnership constructed a model of the existing radiology activities in order to asses the current layouts and identify possible enhancements. An on-site evaluation of one week was carried out, which including conducting workshops, interviewing stakeholders, and observing processes. Ultimately, a digital replica was generated, enabling the collaborators to simulate various situations and determine the optimal utilization of equipment, as well as evaluate the feasibility of a physical arrangement. At the end, Digital Twin reduced time for CT scans of 13 minutes, 34 minutes for MRI. Patient turnaround (arrival to departure) was lowered to 28 minutes for CT scans, and 34 minutes for MRI. Also, equipment utilization increased, CT usage increased by 26 percent, and MRI usage increased by 32 percent. Also, it enabled the hospital to lower staffing costs, by decreasing MRI overtime by 50 minutes, leading to a decrease of pay day. The primary advantage that the collaboration may provide is the enhancement of the patient experience. The Mater Private digital twin provides a detailed projection of the duration that a patient will spend at each stage of their radiological trip. This enables the strategic allocation of waiting periods in each sector, so maximizing space use and enhancing the overall patient experience (Siemens, 2019).

As it was written, Beijing digital factory of Siemens is a perfect example of how digital twins can be used for resilience purposes. Every part of manufacturing process is replicated, which allows the company to predict scenarios or events. Thus, disruptions have a higher chance of prediction before they even occur. Also, as business model innovation, digital twin facilitated the company to create digital business platform, which coordinates digital twin with for example metaverse solutions. At the end, customers are able to enhance their operations based on real time data.

3.4. Coca-Cola HBC

Dr. John Pemberton introduced his refined syrups to Jacobs' Pharmacy in downtown Atlanta on May 8, 1886. It was the very first moment when the first serving of Coca-Cola was dispensed. Starting with that singular, famous beverage, they have transformed into an entire beverage corporation. Over 2.2 billion servings of Coca-Cola beverages are consumed daily in more than 200 nations and territories. Currently, they have developed a collection of beverages that are strategically positioned in different sectors of drinks. They have a range of prominent brands in North America and worldwide, including trademark Coca-Cola, Sports, Juice & Dairy Drinks, and Alcohol Ready-to-Drink beverages (CocaCola, 2024).

Coca-Cola HBC is overseeing and enhancing its distribution network in a CIS country. This strategy enhances the adaptability and dependability of the firm, but there is also a downside, since it also adds complexity to the movement of products within different regions. Their decisions are impacted by the volatility of local transportation costs, seasonal variations, and excessive concentration. In addition, an escalation in supply chain complexity increases expenses related to storage, transit, and delivery. The complex structure of the company's supply chain contributed to its complexity. For example, the items have the option to be transported directly from a manufacturing facility to either wholesale or retail clients, either through cross-docking or by utilizing a regional warehouse. The company's distribution network concept aims to optimize the supply chain. Throughout order to reduce expenses, and maximize efficiency throughout the entire country, the management of Coca-Cola HBC made the decision to develop a representation of the existing supply chain. The model needed to take into the account the corporate push-pull policy at various stages of the supply chain and assist in optimizing the inventory in the warehouse. The NFP consulting business was tasked with the development of the model. The purpose of the model was to provide assistance: enhance the efficiency of the supply chain by minimizing unnecessary levels and identifying the most optimal supplier activities; minimize the expenses associated with the transportation and handling of commodities; compute safety stock in real-time based on demand while maintaining service level. Implementing this supply chain optimization strategy would allow Coca-Cola HBC to expand the use of advanced supply chain planning methods across the whole national network. This would result in increased capacity and a more comprehensive understanding of logistics investments (anyLogistix, 2023).

Coca-Cola HBC familiarized themselves with many software options for supply chain and logistics optimization and ultimately chose anyLogistix. AnyLogistix supply chain optimization software offers superior logistics optimization capabilities compared to its rivals. Additionally, it enables consultants to meticulously simulate supply chain situations. Furthermore, both the consultants and the customer expresses their admiration for the software's user-friendly design, comprehensive collection of reports, and its ability to be expanded upon. The consultants sought to use the created methodology to utilize anyLogistiX supply chain optimization for: optimization and the placement of the second-tier warehouses in order to reduce the expenses associated with direct delivery, to choose the most efficient kind of transfer, crossdocking or warehousing, to maximize the efficiency and minimize the expenses associated with the "warehouse-warehouse" transportation routes, to define the most efficient routes for transporting goods from the warehouse to wholesale clients, to calculate the most efficient amount of safety stock needed in the warehouses to uphold the desired level of service (anyLogistix, 2023):

The team sought to have a deeper understanding of how alterations in the efficiency of manufacturing sites that have overlapping functions will impact the overall functioning of the whole supply chain. In order to achieve this objective, the model incorporated production limitations specific to each site, including various commodities and restrictions on line productivity. Additionally, the supply chain key performance indicators (KPIs), were created in relation to their respective values. Subsequently, the team utilized the supply chain optimization capabilities of anyLogistix to determine the optimal limitations for locations, by taking into account their capacity and demand. In order to tackle this difficulty, the consultants enhanced the efficiency of product movement at several stages of the supply chain. Factors such as production limitations, warehouse and transportation capacity, safety stock, delivery frequency, and other relevant variables were taken into account. In addition, they conducted a comparison of several supply tactics, including direct supply through multiple modes of transportation, storage in warehouses at production sites, local delivery to warehouses operated by third-party logistics providers, cross-docking, and indirect supply through distributors. The experts, thanks to supply chain optimization trials were able to determine the ideal quantity and placement of second-tier warehouses. In order to demonstrate efficacy of the experimental findings, the researches conducted a comparison between the expenses associated with the existing warehouse structure and the proposed updated alternatives. They considered two transportation alternatives: using distributors or cross-docking. Previously, the client firm distributed its products directly to shops, but they were exploring other methods of delivery through regional and federal distribution centers (DCs). The consultants utilized the model to calculate the potential cost reduction that may be achieved by transitioning to the new store maintenance plan, as well as determining the required number of trucks in this scenario. The project team devised and expanded MRP algorithm for tracking the flow of goods, which was built upon demand forecasts and integrated into the model. The partners' 3PL warehouses were evaluated for their utilization levels, specifically in terms of maintaining the desired stock level as per the pull policy. Simultaneously, the fluctuation in manufacturing output was mitigated by the implementation of a buffer product stock strategy at the plant warehouses. The team also computed the inventory level in each warehouse and identified the peak periods of warehouse use. The estimation also included the potential impact on the service level resulting form changes in the target values of safety stock, available vehicles, and their load (anyLogistix, 2023).

The consultants were able to effectively manage the supply chain using the supply chain optimization model established in anyLogistix, which allowed for the consideration of various planning horizons. Coca-Cola HBC acquired a decision support system capable of rapidly evaluating multiple logistics and manufacturing methods. The user will receive a new supply chain design, along with the precise number of vehicles needed and the appropriate load for each vehicle. The company's supply chain managers may now select the most lucrative locations for direct delivery based on meticulous assessments of expenditures for each store in the network. The model is very adaptable, allowing Coca-Cola HBC professionals to efficiently modify it for the purpose of testing new supply chain configurations. One such configuration is the reduction of second tier warehouses through the use of cross docking. Also, it is able to minimize the duration of last-mile delivery time, minimize the expenses associated with transporting goods or people, manage safety stock levels and uphold a desired quality of service (CocaCola, 2024).

But these are not all of the improvements made by digital twin in CocaColaHBC. A collaborative effort with Microsoft resulted in the development and evaluation of a virtual replica of a manufacturing line at Edelstal. This technology belongs to the domain of the "Industrial Metaverse" and has been globally tested for the first time in this particular context. It enables virtual engagement, analysis, and testing without any need for intervention on the operating system like never before. The utilization of Digital Twin technology not only enhances the efficiency of the production line, but also enables a more precise reduction in energy and water usage. Technological advancements provide an unmatched edge for sustainable growth (Coca-Cola HBC, 2024).

The adoption of Automated Yard Management was a crucial milestone in their logistics transition to industry 4.0 standards. Through the use of streamlined procedures and cutting-edge technologies, they have successfully decreased the average duration that tracks remain on their premises. For the process of constructing customer specific mixed orders, Coca-Cola utilizes smart glasses equipped with voice control. This technology enables pickers to have their hands available for other tasks. The tray's image, number, and amount are visually presented, while a QR code is automatically scanned to confirm the picking process. Vision Picking minimizes picking errors and immediately alerts pickers when products require replenishment. Laser Guided Vehicles (LGVs) are advanced material handling vehicles that determine their position by laser beam scanning. Autonomous vehicles take control of automated transportation duties formerly performed by a supervisor software. They navigate to designated pick-up and drop-off locations as required, also they are able to respond appropriately when encountering other autonomous vehicles or anything else obstructing their path. Since 2016, they have been employed in storage operations in bottling facility in Edelstal (Coca-Cola HBC, 2024).

To conclude, Coca Cola uses similar approach to digital twins. The Company creates virtual representation of their processes related to supply chain, which help them optimize the decisions and reduce potential failures. It has dramatically changed the approach of the company. Through the cooperation with Microsoft, company was able to create replica of their plant in Edelstal. At the end, the company was able to increase efficiency, and resilience of their global supply chain, which serves as change in their business model towards supply chain that is less disruptive.

3.5. CEVA Logistics

CEVA Logistics offers supply chain management solutions to many industries like automotive, retail, industrial, healthcare, technology, eCommerce, energy, and aerospace. The organization has experience in the field of freight management and contract logistics. The company generated annual revenue of $16B. CEVA oversees 125 retail logistics agreements across 25 nations and oversees the strategic supply chains of eight out of the top 10 global retailers. CEVA employed Simul8's digital twin technology to develop a simulation-driven digital replica – a virtual depiction of their actual operational processes – for the purpose of consistently enhancing resource allocation at one of their fashion retailer's fulfillment sites and minimizing yearly operational expenses (Simul8, 2024).

The total value of online sales in Western Europe, including the Untied Kingdom, Germany, France, Netherlands, Italy, and Spain, amounted to about £330 billion in 2022. About 20% of that, was accounted to Germany. The recent growth in demand has intensified the expectations placed on distributors to provide prompt and effective client experiences. For example, CEVA's customer required very fast and economical solution to manage the swift movement of substantial quantities of merchandise at its Brandenburg fulfillment center. However, typical characteristics of fast fashion posed several obstacles for logistics management, such as fluctuating stock demand, the requirement for prompt and precise turnaround times, and the necessity to closely monitor fulfillment center expenses. Moreover, the complex framework of the fulfillment center's activities posed challenges in manually evaluating the daily, weekly, or yearly effects of proposed modifications or enhancements to the supply chain network. For instance, conducting experiments in an actual operational setting where the merchant is required to ensure timely order fulfillment to satisfy customer demand might have substantial repercussions. The fulfillment center needed to determine the ideal number of personnel every shift in order to maintain a specific utilization percentage and prevent the system from being overloaded while still ensuring smooth operations. By utilizing Simul8's simulation-powered digital twin technology, planners may experiment with novel procedures and deploy modifications to the supply chain network without affecting ongoing operations (Simul8, 2024).

CEVA collaborated with Simul8 to develop a digital twin that utilizes simulation technology and its connected to real-time data from the fulfillment center's system. The project started by collaborating with the fulfillment center's planners in order to understand their daily operations and Key Performance Indicators (KPIs). These KPIs include metrics such as order processing time, throughput, resource usage, and customer satisfaction. The implementation of this advanced planning served to mitigate the potential fluctuations in system volume, but at also it was important to establish detailed guidelines for the simulation (Simul8, 2024).

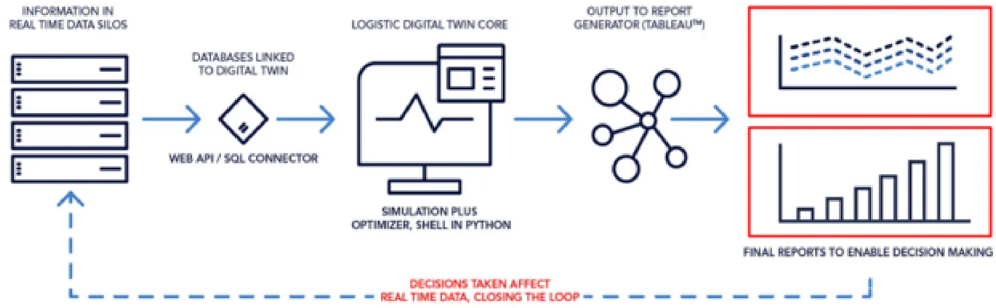
When constructing the digital twin, three aspects of the fulfillment center's activities were taken into account, namely (Simul8, 2024). Inbound phase – utilizing measures such as supplier direct receipt and supplier direct put away facilitated the assessment of the efficiency in obtaining items directly from suppliers and precisely storing them in the facility. The efficacy of internal goods transfers inside the center was evaluated through the assessment of Key Performance Indicators (KPIs) for products received and put away within the warehouse. The assessed KPIs for returns received and put away focused on the efficient handling of returned items, resulting in simplified operations and reduced processing time. Storage space – the efficient management of storage was crucial for the daily operations of the fulfillment center. Logistics manager utilized the rotation index statistic to assess the effectiveness of inventory rotation. The digital twin, which was powered by simulation, collected significant data on the rates at which items were turned over and at the same time, it considered the usage of storage space. By analyzing the rotation index, they were able to optimize storage arrangements, choosing tactics, and stock placement in the long run to achieve maximum efficiency and reduce mistakes. Outbound phase – The initial key performance indicator (KPI) during the outbound stage was the act of picking. Through the assessment of the precision and effectiveness of the picking process, managers at the fulfillment center were able to improve in a lot of areas. For example, they were able to enhance methods, warehouse arrangements, and resource distribution in order to increase the speed of order fulfillment. Additional KPIs during the outbound phase were sorting, packing, vector sorting (which involves categorizing products according to shipping vectors or destination), and truck loading. By examining these methods, logistics managers were able to enhance the efficiency of sorting, packaging, and loading operations, resulting in improved outbound logistics and reduced delays. A conventional digital twin offers a fixed portrayal of the existing condition of a system. By using simulation technology, the digital twin gained the ability to comprehend the dynamic behavior of the system, including its process rules and the relationship between different elements.

This technology allowed CEVA to perform ongoing “what if” analysis. It enabled sophisticated optimization by executing several permutations to assess and subsequently optimize the various possible options. The simulation-powered digital twin can provide process owners with valuable insights into the most effective corrective measures to be taken in response to various inputs, prospective obstacles, or alterations in the operating environment. In addition, the powerful simulation engine allows the digital twin to dynamically alter, allowing for rapid modifications based on new data to predict future process performance. By using simulation-powered digital twin technology, the fulfillment center was able to get detailed insights into its dynamics operations. This resulted in a reduction of risk, eliminated downtime, and sped the time it took to bring products to market (Simul8, 2024).

After the development of the simulation-driven digital twin, fulfillment center planners could effectively manage resources and accurately identify the required number of people for each stage. The outcome generated an average reduction of 200 labor hours per week and a 2% increase in overall capacity throughout the entire organization. In addition, the digital twin provides hourly updates and transmits vital information to the control room operators at the fulfillment facility. This data includes comparisons of real inventory with projected and simulated inventory. The outcomes allowed managers of the fulfillment center to enhance the allocation of staff members based on certain days and shifts. This not only enhanced usage rates, but also guaranteed that the system never experienced excessive stress. The control room operators utilized data visualization software to monitor KPIs related to the inbound phase, storage space, and outbound phase on a daily basis. The data obtained from this monitoring method was inputted into the simulation to guarantee that the system produced predictions using real-world measurements (Simul8, 2024).

However, CEVA developed their own LDT (logistics digital twin) afterwards over a year ago. The LDT utilizes real-time data from many sources both within and outside the warehouse. The primary component of the LDT is a discrete events Monte Carlo simulation engine. It is essentially a black box that utilizes algorithms based on a mathematical model of repetitive random sampling of data to get numerical outcomes. The core engine is situated at the Größbeeren location and is responsible for monitoring, analyzing, and predicting physical activity based on real-time data gathered from both cloud and on-premise databases. The objective is to assist management in making informed decisions on the allocation of resources within the various processing areas of the warehouse. The LDT performs data processing and validation on the received data, and subsequently utilizes it to execute scenarios, relying on estimates of the anticipated client count at certain time intervals. The system integrates the resulting forecasts with several KPIs related to production. It then monitors the expected volumes in comparison to the actual volumes handled in the warehouse. This provide a comprehensive overview of the optimal performance that may be achieved, as well as the performance of various regions and components inside the warehouse in connection to this optimal outcome. Once the tool reaches its maximum capacity and is operated by skilled personnel, it will minimize idle time and enable the control room to monitor warehouse activities in almost real-time. This will ensure that production remains in line with the projected plan. The insights will enable the warehouse staff to optimize resource use and enhance the overall operational capacity of the facility (CEVA Logistics, 2024).

Figure 7 Movement of data through the digital twin



Source: CEVA Logistics, 2024

The central LDT engine acquires real-time activity tracking data from the warehouse management system database and other databases, which is then processed and verified by the simulation. After the digital twin's core engine has analyzed the data, it transmits the information to the reporting tool called TableauTM, which presents the data in the control room as charts. At this location, a skilled operator has the ability to make informed judgments on the allocation of resources required for future shifts in the warehouse. The LDT presents its finding using Tableau on hourly basis, enabling managers to compare processed quantities and determine the most efficient deployment of personnel and resources. The operator's actions play a crucial role in completing the information loop of the digital twin, as these decisions have a direct impact on the data gathered by the database. Facilitating seamless integration between the physical and virtual realms is a crucial aspect of operating a digital twin. There need to be a continuous flow of information between the two worlds (CEVA logistics, 2024).

To conclude, LDT (logistics digital twin) helped CEVA in a same manner as for the other companies mentioned in this paper. CEVA gained the possibility of predicting possible disruptions, and predict future performance more accurately. By the constant access to the data the quality of the whole process of logistics was increased. Overall resilience was improved.

Based on this company was able to move into more data-driven model. Access to the data reduced costs, and reduced disruptions in all of the processes.

3.6. DHL

DHL is the leading brand in the field of logistics. DHL divisions provide a comprehensive range of logistics services, including national and international package delivery, ecommerce shipping and fulfillment solutions, international express, road, air, and ocean transport, as well as industrial supply chain management. DHL has a workforce of around 395,000 individuals spread throughout 220 countries globally. The company considers itself to be a safe and dependable link between people and businesses, by facilitating the smooth and sustainable flow of global trade. DHL is strategically positioned as “The logistics company of the world” because to its tailored solutions for growing areas and industries such as technology, life sciences, and healthcare, engineering, manufacturing & energy, automobility, and retail. DHL is part of the DHL group. In 2023, the Group’s revenues exceeded 81.8 billion euros. (DHL, 2024).

Their services mainly cover (DHL, 2024): international express, air and ocean fright, European road fright, contract logistics, document management and outsourcing, domestic and cross-borders parcel services, fulfillment solutions (DHL, 2024). Nevertheless, industry specialists predict that the worldwide number of package shipments will increase to a huge amount of 256 billion by the year 2027, with a constant increase in demand. Consumer purchasing patterns are always in a state of transition, and the expectation for same-day or next-day delivery has become the standard. This has raised the demand for the logistics sector to optimize its operations in order to provide uninterrupted client service. Consequently, distributors have made it a point to utilize technology in order to educate their methods for fulfilling orders. Enhanced efficiency and productivity can lead to decrease in warehouse expenses, enhance customer happiness, and simplify the tasks of pickers. DHL acknowledged that the use of manual processes to predict staffing levels for its picking operations contributed to decreased productivity at its Louveira distribution hub in Sao Paulo State, Brazil. It was also creating problems with customer relationship management. The logistics company engaged with Simulate, a Simul8 channel partner in Brazil, to create a simulation-based digital twin for regular operational planning. This initiative aimed to tackle the complex challenges in warehouse processes and find possible opportunities to improve the allocation of picking staff resources (Simul8, 2024).

Time usually means problems in a distribution center. The unpredictable nature of incoming orders create challenges with accurate forecasting and assigning resources. Which in turn makes it difficult to meet daily picking objectives and assure timely delivery of items to consumers. In addition, the rise of e-commerce, particularly in the fast fashion industry, has lead to a rapid rotation of designs and frequent introduction of new products. As a result, distribution centers are under increased pressure to efficiently handle and ship orders in a timely manner. McKinsey discovered that 23% of consumers were prepared to pay extra for receiving their orders on the same day. This highlights the need of having a flexible and efficient fulfillment strategy to keep up with fast-paced nature of product availability (Simul8, 2024).

The primary objective for DHL's Louveira distribution facility was to efficiently allocate resources in order to satisfy customer demand and achieve daily performance goals. A simulation-driven digital twin was necessary to regularly modify resource allocation in response to a dynamic environment. The center manages over 5,000 product SKUs, and logistics managers traditionally depended on Excel spreadsheets to determine the appropriate number of pickers required for each shift. When predicting the necessary workforce, shift managers had to take into account the daily demand level and the complex aspects of the picking process, like the time required to find an item, the package size, and whether it can be easily accessed or requires the use of a forklift. During the initial twenty days of the month, the quantity of parcels collected remains stable. However, in the latter 10 days of the month, there is a significant increase in order numbers, necessitating the need for more pickers. If there is a shortage of pickers during a shift and it becomes evident that the set objectives will not be achieved, DHL is obligated to communicate with its clients and notify them that their products will not be delivered on that day. As a result, DHL had difficult and tense relationships with clients and faced the risk of damaging its brand. DHL was unable to provide any assurance that consumers would get their items punctually. Additionally, it increased the burden on DHL's employees and supply chain infrastructure as they hurried to fulfill orders, resulting in errors in the selection process (Simul8, 2024).

Warehouse managers discovered that implementing daily digital procedures including using a simulation-powered digital twin, would allow them to accurately predict the required number of pickers for each shift. This would enable them to effectively satisfy customer demand and enhance the overall customer experience. Moreover, by developing a digital twin for regular operational planning, it would ensure the process remains effective in the future. This would allow management to anticipate and determine the necessary number of workers needed on a weekly, monthly, and yearly basis. Simulate provided an internal training program to a specialized team that DHL has designated to manage the project. The simulation team employed Simul8's advanced technology and specialized knowledge in the field of logistics to develop a digital twin of DHL's warehouse management system. Additionally, they constructed a simulation, referred to as the 'Crystal Ball', which accurately forecasted the required staffing levels for each shift. The digital twin of the warehouse management system, powered by simulation, was utilized to gain insights into the daily operations of the center. This includes analyzing the daily order productivity, processing time for orders, and identifying the busiest shifts that require additional pickers to manage the heightened demand. Afterwards, the real-time data obtained from the warehouse management simulation was entered into the Crystal Ball software to produce precise predictions of the staffing needs for each shift. The integration of the Crystal Ball simulation with the simulation-powered digital twin enhanced the operational efficiency of warehouse processes and consistently mitigated resource-related challenges. The approach lasted nearly five months to finish and involved creating many conceptual simulations to guarantee that the final specification met the team's desired degree of accuracy. The project was complex, requiring the mapping of all 5,000 product SKUs into the simulation. Additionally, limitations such as time of day, month, or year had to be taken into account. After completion, the team had access to a digital twin, that could be utilized indefinitely for regular operational planning and could adapt to the center's expanding activities. The advantage of conceptual simulations allowed the team to evaluate practical situations in a hypothetical setting, so influencing future decision-making procedures (Simul8, 2024).

The accuracy of the Crystal Ball was 98%. After incorporating the simulations into their daily routine for a period of two years, the firm observed a notable rise in production and a reduction in challenges cause by insufficient resources. Significantly, it cultivated stronger alliances with clients and minimized disruptions in the company's supply chain network, resulting in enhanced profit margins, increased customer happiness, and improved decision-making (Simul8, 2024).

As it was stated previously, DHL is also one of the market leaders in contract logistics. In 2020 company introduced first digital twin of a warehouse in the Asia-Pacific area for Tetra Pak. The main objective of this project was to enhance supply chain efficiency by optimizing operations, increasing flexibility, and reducing costs. The warehouse is among the largest Tetra Pak warehouse globally and serves as the first smart warehouse for DHL in the Asia-Pacific region, functioning as a digital twin. After implementing an integrated supply chain for Tetra

Pak in Singapore, the digital twin receives up-to-date data from the physical warehouse in Singapore and regularly performs real-time adjustments. DHL Supply Chain is prioritizing the implementation of advanced technologies and simplified operations, including the utilization of IoT technology in industrial vehicles. The DHL Control Tower monitors the movement of incoming and departing products to guarantee that all items are promptly and accurately stored within 30 minutes of being received. Tetra Pak has created an intelligent storage solution that monitors and replicates the physical state and inventory levels of individual items in real-time. This system enables seamless and continuous coordination of activities, detects problems, and enhances safety and efficiency in the warehouse. DHL Supply Chain Singapore have extensive knowledge and experience in the region when it comes to fulfilling specific client requirements. The company offers Third-Party-Logistics (3PL) solutions, allowing customers to delegate their logistics administration and operations (Galea-Pace, S., 2020).

Similarly like in the other cases, the implementation of digital twin allowed DHL to analyze real time data, which as a consequence leads to optimization of the processes. By implementing WMS (warehouse management system) DHL gained the possibility to predict disruptions, and increase overall efficiency, which at the end must improve resilience of company's supply chain. When it comes to business model, DHL also shares a lot of similarities with other companies. There was a shift towards data-based business model. The company was able to offer data-drive logistics solutions, which reduced cost, increased operational efficiency, and improved customer satisfaction.

3.7. Key Takeaways

To summarize main findings from this section, table no. 11 was created. It is divided into main findings about digital twin impact on the resilience of the value chain of the companies, and the impact on their business models.

Table 11 Key findings related to resilience and business model

Company	Resilience	Business Model
Rolls-Royce	Digital twin gave the possibility to monitor engine performance in real time. At the end, failure prevention was increased as well as overall downtime in supply chain.	Product sales changed to so called “Power by the Hour” model, where customer pays for engine uptime.
Siemens	Digital Twin helped optimize operations in the factory, and predict possible bottlenecks. This enabled company to predict disruptions, but also react faster to their occurrence, which leads to increase in resilience overall.	Overall, it allowed the company to provide services like “Xcelerator” platform. Which means a change from manufacturer to a service provider.
Coca-Cola HBC	Digital Twin allowed company to optimize and simulate logistics, along with areas related to warehousing. At the end it reduced transportation disruptions, delays etc, increasing overall supply chain efficiency and resilience.	Company moved to a data-driven logistics model.
CEVA Logistics	Digital Twin help with managing demand, and resource allocation. This increased the resilience of the whole company, by allowing them to anticipate peak or seasonal demand.	Company has changed from reactive logistics company, to proactive one, where data-driven solutions are the basis.

DHL	Digital Twin brought optimization of warehouse operations, and prevention of disruptions in logistics chain.	Company was able to offer predictive logistics services, by reducing errors. At the end model was adjusted to more service-focused one.

As it is shown in table number 11, all of the companies benefited from the adoption on digital twin along with big data & analytics. It can be said that these technologies have cross-industrial applicability, for example companies that operate in logistics, healthcare, or aerospace have seen significant benefits. All of these companies have been setting new standards when to comes to key factor like efficiency, resilience, and decision making. Also, supply chain itself have been reshaped. Companies right now, have to meet certain standards, which were defined by industry leaders, that use digital twins and other related technologies. It can also be stated that real-time data gathered thanks to this technologies was a key factor. Thanks to the integration of live data solutions companies were able to respond faster and more effectively to business challenges. As an example, Rolls Royce thanks to real-time data was able to monitor performance, detect anomalies, and predict maintenance needs. At the end it saved them time, increase overall efficiency, ale reduced some costs. The adoption of digital twin brought similar results, and opportunities to mentioned companies. Most important part that affected companies was the ability to gather real-time data, along with real-time monitoring. It is the most important advantage of digital twin implementation. Companies were able to identify issues, bottlenecks, and other problems more accurately, and sometimes before they even occur. It also had a significant impact on their business models, by enabling them to transition from traditional solutions to more data-drive or service-oriented ones (example Rolls Royce "Power by the Hour", Siemens "Xcelerator). At the end it allowed them to provide additional value for the customers. At the end overall efficiency, and even sustainability were increased. Also, digital twin allowed some of the companies to create feedback loops, by gathering data, which allowed them to drive constant improvements. At the end, it means that companies were not able to just solve current problems, but also it enabled them to predict future, potential events. It can be stated that companies that have the access to this kind of data, which usually is of high quality, are able to more easily adjust to market needs, or general challenges. Data allows companies to offer tailored solutions straight to their customers, example "Power by the Hour" of Rolls Royce, which doesn't look like standard sales model, but rather model based on uptime. The basis of it is continuous feedback, and access to the data, which is the most typical feature related to digital twin, and big data & analytics technologies. Finally, by helping companies manage their resources, reduce for example energy or water consumption, all of the industries mentioned are support sustainability initiatives. For example, companies have an easier way to identify which material or resources can be recycled. At the end, such advancements help in global sustainability related issues.

Conclusion

This research paper aimed to answer whether the adoption of digital twins improve the resilience of global value chains, and if so, what is their impact on business models. To answer such a research question, illustrative examples were used. It is clear that digital twins with proper implementation can improve the resilience of global value chains. All the companies were able to mainly improve efficiency of their operations, reduce their cost. Also, they were able to predict potential failures faster, and more accurate. Vulnerabilities can be easily forecasted, logistics optimized, and in general total increase in efficiency. When it comes to business models, digital twins point companies towards more data-driven, and flexible business structures. Thanks to digital twin companies have the possibility to focus on long-term plans, rather than short term gains. In conclusion, digital twin can not only improve global value chain resilience, but also change the structure of how traditional business operates.

Some of the findings are in line with the current literature related to the topic. Rasheed et al. (2016) in his paper related to digital twin and other enabling technologies identified that this technology increases efficiency and safety of human work. It also enables companies to gather more data leading to an increase in predictive maintenance and scheduling. The results are also in line with research done by Lugaresi et al. (2023) that digital twins by leveraging data provided by them enable companies to make wiser decisions that increase overall economical and operational efficiency. By enabling companies to have comprehensive view of their entire supply chain it allows them to make more informed decisions, and optimize their processes. It especially correlates with findings about Coca Cola HBC, where digital twins allowed the company to gather data, which at the end was used to optimize logistics processes, especially ones related to warehousing. Findings are also correlated with another features that are in the current literature. According to illustrative example related to Siemens it was found that digital twin enabled the company to predict bottlenecks, which resulted in an increase of overall resilience. It is in line with current research where it is stated that digital twin allows companies to mitigate potential risk related to supply chain, leading to an increase in overall quality of resilience operations (Ivanov & Dolgui, 2019). However, there are also new findings, related especially to how the impact of digital twins, and big data & analytics affects business models of the companies. There is an existing research on how data based tools can support processes related to business model innovation (Fruhwirth et. al, 2020). However research papers do not show or prove how companies move towards service orientated business models after implementing digital twins, which was the case of Siemens or DHL mentioned in illustrative examples section.

This research has a potential to contribute to the academic disputes regarding the impact of advanced technologies on business, with emphasis on digital twin, and global value chain management. This paper show how business models respond to adoption of novel technologies like digital twin. It also provides valuable insight for managers, and private sector practitioners. Mangers responsible for actions related to value chain, or other related areas, can use this information to enhance visibility of their value chain, predict potential disruptions, and mitigate risk, and also improving general efficiency, and reducing costs by properly introducing such technologies into their business expertise. The paper also provides valuable information on how business models should react in order to stay in touch with new potential technologies, that can change whole industry. It proves how important it is for the companies to invest in digital solutions, such as digital twin, which at the end can unlock the potential of their company.

However, several limitations must be acknowledged. This study is based on theoretical implications, and illustrative examples, which do not guarantee that complex real-world applications were properly captured. Also, it must be stated that digital twin is the technology that evolves rapidly. Which means that current research is limited to how the companies were able to capture its value, which may be different across industries, companies, geographical or political borders. Moreover, challenges associated with digital twin, such as high initial cost, limit the widespread of this technology among small and medium sized enterprises (SMEs). Also with the advancement of other Artificial Intelligence technologies, it is impossible to predict at this moment cybersecurity problems related to this.

Given the nature of digital twin, there is a wide range of areas that can be the object of the future research. It is still widely unknown how digital twin can benefit companies with smaller range of possibilities (e.g. SMEs). Since it is relatively new technology it will be important to check what is the long term impact of digital twins. However, the most unknown and interesting area is related to other industry 4.0 technologies. It is still relatively unexplored area on how digital twin cooperates with different technologies, potential impact, disruptions, and long term costs of the cooperation between these technologies. Another interesting aspect to explore would be the cybersecurity. Digital Twin along with Big Data analytics is based on huge amount of sensitive data. There is an area to discover on how companies should base their safety measures against potential data breaches, but also on how the companies should make responsible and secure decisions. There is currently lack of papers related to cyber risk mitigation strategies, or measures. Given how fast such technologies excel, it will be critical for the companies to understand this aspect, which leaves a lot of potential research opportunities for the future. Another unexplored aspect would be the ethical and social repercussions of such technologies. Researches have the potential area to measure how such technologies influence job displacement, and inequalities between people and organizations. Finally, there is also a need for detailed instructions and measures on how legal frameworks related to these technologies should be created.

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