Impacts of digital twins on new business creation: insights from manufacturing industry

Mira Timperi, Kirsi Kokkonen, Lea Hannola and Kalle Elfvengren

Abstract

Purpose – *Digital twins (DTs) and other data-based solutions are gaining an increasing foothold in manufacturing business, whereas a mere physical product is often insufficient to satisfy all customers' expectations. As a result, companies are seeking novel ways of value creation, and one exciting opportunity is the use of DTs in new business creation, where they can offer diverse possibilities for innovative businesses. This paper aims to examine the impacts and challenges of DTs on new business creation in the manufacturing industry.*

Design/methodology/approach – *This study used a qualitative research approach, which combined semistructured interviews and an iterative Delphi study as research methods. The participants for the interviews and Delphi study were from different sectors and roles in the manufacturing industry. Altogether, 10 interviewees from eight companies took part in the interviews, and the expert panel of the Delphi method contained 12 professionals.*

Findings – *The results of the study indicated that DT can significantly impact the business models of manufacturing companies. DT can enhance operations, offer cost savings and business growth and allow stakeholders to focus on core competencies while developing their businesses. Several challenges for leveraging DT were identified, such as data ownership, resource allocation, internal bureaucracy and the difficulty of demonstrating the actual value of data-based services to potential customers.*

Originality/value – *This paper provides a structured expert-led assessment of the potential impacts of DT utilization in the creation of new business opportunities.*

Keywords *Digital twin, Manufacturing industry, Data-based business, Data-based services, Service business*

Paper type *Research paper*

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1. Introduction

We are in the middle of the Fourth Industrial Revolution (Industry 4.0), where existing manufacturing technologies are merging with modern information and communication technologies (Haag and Anderl, 2018), and thus, reshaping business processes in various industries (Bakhtari *et al.*, 2021). To survive in the changing environment, companies must re-evaluate their strategies (Guo *et al.*, 2022) and operations (Koh *et al.*, 2019) and adapt to new digital landscapes (Albukhitan, 2020) while implementing more service-oriented business models (Paiola and Gebauer, 2020). Consequently, manufacturing companies have shifted their thinking from selling products to offering solutions, resulting in changed business models – today's customers seek solutions and buy results instead of mere means of production (Donoghue *et al.*, 2018; Berman, 2012). Accordingly, companies in manufacturing industries now aim to pursue competitive advantages through service innovations (Feng and Ma, 2020).

The above-mentioned transformations require resources, capabilities and technologies (Chen *et al.*, 2021), which makes it vital to explore how different systems and functions, such as digital twins (DTs) and manufacturing operations, can best work together to provide foundations for a novel business and collaborative value creation. One potential technology to keep up with the changes is the DT, a versatile tool for various instances. Previous studies have indicated that it enables collaborative environments, data-based decision-making and enhanced business processes (Marmolejo-Saucedo, 2020; Sahal *et al.*, 2021). Moreover, it may provide openings for new businesses (Segovia and Garcia-Alfaro, 2022) while optimizing current operations (Hou *et al.*, 2021).

However, despite the increased attention, there are still some barriers hindering the digital transformation and DT development, such as insufficient competencies, systems and technologies (Neto *et al.*, 2020), lack of resources (Falah *et al.*, 2020) and variable understandings of DTs' characteristics and definitions (VanDerHorn and Mahadevan, 2021). These issues represent a research gap and form a need for further research. Hence, this study aims to fill the gap by clarifying how DTs can promote new business creation in the Finnish manufacturing industry by answering the research question:

RQ1. What are the possible impacts of emerging DTs on new business creation in the manufacturing industry?

The study also explores the significant challenges associated with DT utilization.

The empirical research is a case study of multiple manufacturing companies, consisting of two research methods: semistructured thematic interviews and an iterative Delphi survey. The interviews and the Delphi survey were conducted during the "Towards Commercial Exploitation of Digital Twins" (DigiBuzz) project (2019–2022). The project stemmed from company-based needs: it aimed to find the best solutions for DT utilization, new business generation and service business in the Finnish manufacturing industry, where companies increasingly seek ways to meet their goals in the transition toward digitalized business. The results of this paper contribute to three aspects:

1. the features and definitions of the DT in the eyes of manufacturing industry professionals;
2. the challenges and impacts of DT utilization; and
3. future opportunities for DTs in new business creation.

2. Literature review

The DT is one of the main concepts of the Industry 4.0 revolution in manufacturing industries (Negri *et al.*, 2017; Haag and Anderl, 2018). For example, Pang *et al.* (2021) have described DTs as a "cornerstone of digital transformation". The concept of DT origins from Michael Grieves' presentation in 2003 at the University of Michigan (Grieves, 2014). Since then, descriptions of DTs have evolved, emphasizing, e.g. the interdependency between different systems (Glaessgen and Stargel, 2012), physics-based modeling, the system's life-cycle view (Donoghue *et al.*, 2018) and synchronization and real-time optimization between the virtual and real system (Negri *et al.*, 2017). In conclusion, a DT is a concept of creating a digital copy of a real physical object and synchronizing data between the physical and digital versions. The aim of a DT is an accurate simulation and monitoring as well as optimization of the physical object (Hou *et al.*, 2021; Batty, 2018).

The DT technology has potential to enhance business processes (Bhandal *et al.*, 2022) and create new business (Holopainen *et al.*, 2022; Segovia and Garcia-Alfaro, 2022). However, it is still a bit unclear where it can bring the most benefit and value. In practice, the maturity levels of DT utilization, the solutions used, and the definitions of what is understood to belong to the DT concept still vary across industries and between different companies

(VanDerHorn and Mahadevan, 2021; Tao *et al.*, 2019). For some companies a DT can be a light mock-up of a product without a link to reality, but for others, DTs are highly developed real-time simulation models of a factory or a construction site (Rantala *et al.*, 2021). In addition, modeling reality in a DT is a complex task that involves multiple sensors, multifunctional models, multisource data and various services. Thus, creating a univocal reference architecture for a DT is difficult, but vital: this is visible in current DT solutions using different technologies, interfaces, communication protocols, models and data (Semeraro *et al.*, 2021); hence, hindering its potential (Shahat *et al.*, 2021).

Regardless of the level of a DT and the challenges of its complexity, the technology may offer a lot of value-adding potential for manufacturing companies (Kurvinen *et al.*, 2022), and manufacturing has, therefore, been recognized as one of the most promising environments where DTs may be successfully applied (Cimino *et al.*, 2019). Thus, as one of the key digital technologies in the manufacturing context, DTs can remarkably contribute to the development of new product-service offerings in manufacturing companies (Meierhofer *et al.*, 2020; Negri *et al.*, 2017). Jones *et al.* (2020) studied research publications from the past decade and found that research on DTs has focused mainly on the realization, support and use phases of the product lifecycle. These include, e.g. product design, real-time monitoring, optimization of production processes, production system management support and maintenance (Cimino *et al.*, 2019; Tao *et al.*, 2019). Recently, the attention of companies has turned to the constantly increasing amount of data gathered from machines and manufacturing processes and its business potential for different actors (Olaf and Hanser, 2019). This data gives manufacturing companies new opportunities to recognize the needs for variable services in different product life-cycle stages (Baines and Lightfoot, 2014; Wuest and Wellsandt, 2016), and boosts manufacturing companies' endeavors toward a more service-oriented business approach (Kjaer *et al.*, 2019).

Thus far, however, DT integrations throughout the entire product life-cycle or production system are still rare (Semeraro *et al.*, 2021; Zheng *et al.*, 2018). In previous research, Hannola *et al.* (2021) identified and analyzed the needs of manufacturing companies looking to develop digital approaches, such as DTs. Their study confirmed previous observations that the industrial needs for DTs or simulation models emphasize the new product development or maintenance phases, whereas the perceived need for virtual models covering entire lifecycles remains rare. Nevertheless, industrial companies have realized the value that DTs or simulations might bring, for example, to marketing processes, and how they could increase sales and promote service businesses. In addition, the utilization of DTs in education and training was mentioned, among others, as one of the needs of industrial companies (Hannola *et al.*, 2021). Moreover, Kritzinger *et al.* (2018) have highlighted the need for further research in the form of case studies in industrial environments to evaluate the possible benefits of DTs. Reciprocally, several authors have recognized the need for investigating how to tackle the observed challenges related to the integration of DTs in the manufacturing context (Fuller *et al.*, 2020; Semeraro *et al.*, 2021).

As Semeraro *et al.* (2021) have noted, DT solutions need multiple system interfaces, functions, communication protocols and data to work together in a compatible way, which poses both technical and business-related challenges. For example, Friederich *et al.* (2022) have recognized data heterogeneity as a significant, topical problem of DT utilization. DTs may present problems also regarding data ownership and security issues (Fuller *et al.*, 2020), collaboration models and openness between different actors (Fuller *et al.*, 2020; Meierhofer *et al.*, 2020), and with the creation of novel customer value and business models (Camposano *et al.*, 2021; Olaf and Hanser, 2019). Moreover, the gains of acquiring or using a solution must exceed its related pains, such as the needed resources and costs, and convincing customers of these benefits before the purchasing decision can be challenging (Khalifa, 2004; Lyly-Yrjänäinen *et al.*, 2019).

3. Research methodology

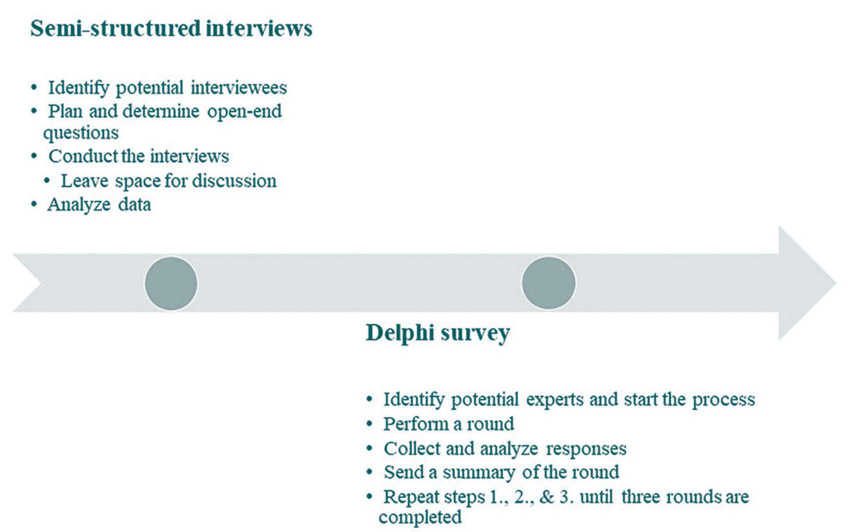
This study uses a qualitative research approach consisting of semistructured thematic interviews and an iterative Delphi survey. These methods served the goals of this research, as according to Miles *et al.* (2020), qualitative data enables the chronological flow of events and consequences while deriving credible explanations. It focuses on real-life context and is useful in exploring new ideas and hypotheses. Moreover, the choice of methods is important when intending to obtain the best answers: one should select the most suitable methods to produce them (Miles *et al.*, 2020).

The first method, semistructured interviews contain a pattern of preordained, open-ended questions and questions that emerge during discussions between the interviewer(s) and interviewee(s) (DiCicco-Bloom and Crabtree, 2006). The method enables focused interviews while giving space for new pertinent ideas (Adeoye-Olatunde and Olenik, 2021).

The second technique, the Delphi method is well-known and traditionally used in forecasting and collecting in-depth views of experts. It gained a role as a planning technique somewhere around the 1970s, thanks to Norman Dalkey and Olaf Helmer from the RAND Corporation (Ringland and Schwartz, 1998). According to Linstone and Turoff (1975, p. 19), the Delphi method structures the group communication process while allowing a group of individuals to manage a multifaceted problem. One way to describe the Delphi method is a collaborative forecasting technique (Bañuls and Turoff, 2011). It is based on expert panel surveys promoting discussion; the individuals in the expert group can present their opinions throughout several survey rounds. The chosen experts answer the survey questions, and the researchers then analyze the responses given, after which further survey rounds are performed based on the opinions expressed. The desired goal of the Delphi process is to get a common analysis or opinion from the expert group about the topic, which is under investigation. In this research, the Delphi method was expected to be effective in forming a common view of professionals related to the business effects of DTs in Finnish manufacturing companies. Figure 1 illustrates the research process step by step.

Ten professionals from eight companies took part in the thematic interviews. All of them worked in the manufacturing industry but came from different sectors. The selected group

Figure 1 Research process and methods



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size was seen to serve its purpose and goals: it allowed in-depth interviews while saturating the data to the point where the same subjects were mentioned repeatedly by different persons. As usual for thematic interviews, the interview situations were relatively free-form. Presented questions were based on a framework including nine key themes selected and validated during internal discussions of the research group: technical requirements, competition views, value creation matters, customer needs, present solutions, sales matters, potential issues, network aspects and future visions.

The Delphi expert panel consisted of 12 professionals, which was found as a suitable group size for this research. According to Lilja *et al.* (2011), the Delphi method does not set limits on the group size. The main task is to include people who have a profound knowledge/experience in the studied area. Due to this, the size of the group remains in most cases small (Lilja *et al.*, 2011). The selected Delphi panelists in this research were all known professionals who were involved in the DigiBuzz project.

The research team contacted the interviewees and the panelists via email before the interviews and the first round of the survey to ensure their commitment and instruct them on practical matters. The interviews were carried out via online collaboration software. All sessions were recorded and reinforced with written transcripts. Obtained data were classified with thematic analysis – a method to identify themes and patterns from qualitative data (Maguire and Delahunt, 2017). The method is useful, as the recognized themes and patterns, derived from the data set, then form answers to research questions (Kiger and Varpio, 2020). The Delphi survey contained three cycles. Each cycle was followed by a summary of the previous one and a request to participate in the next round. Findings from both the thematic semistructured interviews and the Delphi survey are presented in the following section.

4. Findings

This study sought answers to the question of how DTs can contribute to new business creation in the manufacturing industry. The research was conducted by examining industry professionals' perceptions of DTs, ascertaining the challenges that companies have faced or are likely to face when implementing DTs and surveying future opportunities for DTs in the field.

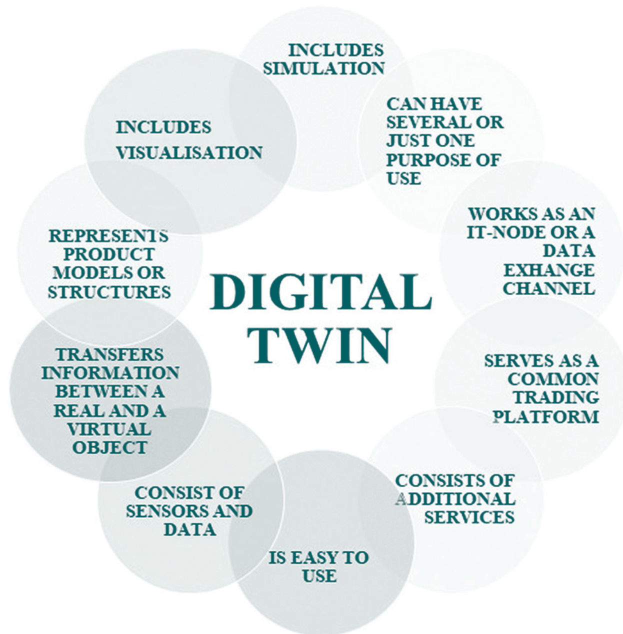
4.1 What makes a digital twin?

Industry experts were asked to describe which features, functionalities and characteristics they consider essential for DTs. Figure 2 illustrates the versatile results.

One interviewee explained that the DT is a simulation model which entails sensors, measurement data, status changes and interaction with reality. Simulation was mentioned multiple times, although one professional made a notification that a simulation feature alone is insufficient to meet the definition of a DT, meaning that the object must be connectable to some counterpart, and changes made to the physical product should transfer back into the DT. If the connection is lacking, it is a mere simulation model and not a DT. The DT links digital and physical versions with real-time data exchange and works as an IT "node" for data obtained from sensors.

One professional presented the idea of there being many different DTs. Variations of DTs can include, for example, the above-presented simulation model or a 3D and usage data model. Overall, many interviewees mentioned the representation of product models as being archetypical of DTs, especially 3D models of physical objects. One panelist saw the DT as a structure. He gave an example of a DT serving as a product model with different solution levels: the solution can be adapted to a light version, such as a PowerPoint

Figure 2 Features of digital twins



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presentation or, depending on the application, to a more complex version involving multiple actors.

A general trading platform could enable DT stakeholders to access data, develop service offerings and purchase external, additional services. However, the platform's cost structure must be straightforward without lengthy training or deployment processes. Visualization was mentioned as a significant feature of DT: it provides new possibilities for sales through product presentation and customer-specific configuration, for service and maintenance through training and better management of customer-specific configurations and for end-user/customer collaboration through data uploading to customer's visualization systems.

The broadest opinion of the DT contained three different interpretations:

1. The DT is a physics-based, real-time or non-real-time simulation model, which imitates processes, produces additional information and generates increased knowledge.
2. The DT does not mean only parameters in a 3D model but includes added data analytics or data-based value.
3. The DT covers product information. The DT engages through the product's lifecycle from planning to use. Moreover, the DT is not a mere design model for planning but a complex, operational 3D model producing information.

Other mentioned features were standardized operating methods, easy connectivity, smooth cooperation with systems and good data security. DTs should be easily expandable and support prototyping. To summarize, the DT is a working solution for testing, modeling and optimizing products and production. It enables new solutions and eases connections between the virtual and real world: the DT represents a physical device's digital performance, which includes the design, production and usage of equipment.

4.2 Impacts of digital twin utilization

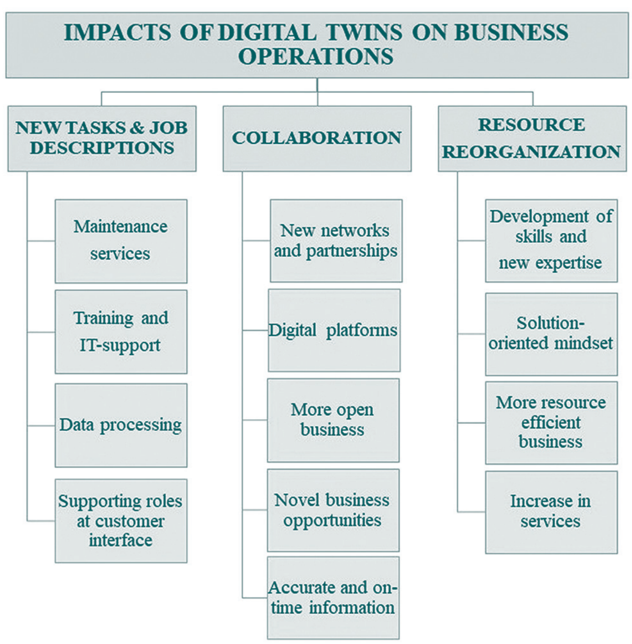
The above-mentioned features and functionalities of DTs affect manufacturing business operations in various ways. Thus, one goal of this research was to assess these possible impacts. Three main categories for DTs' impacts on business operations were formed on the basis of the responses given: (i) *new tasks and job descriptions*; (ii) *collaboration*; and (iii) *resource reorganization* (Figure 3).

Many respondents felt that DT utilization would result in *new tasks and job descriptions*. They stated that implementing DTs will likely create a need for new responsibilities, especially in maintenance services, training and in some narrower areas like data processing. The increasing number of data-based services and greater use of DTs will, in their view, create a need for new trainers and IT support staff, especially at the customer interface.

Some manufacturing industry professionals stressed the importance of *collaboration* and partnerships. They pointed out that collaboration networks and interfaces are necessities for DT utilization. One panelist explained that DTs create a wide range of diverse opportunities if the parties first agree on the rules of data utilization. Moreover, DT-based information allows the development of new value-adding service providers, who can ensure that parties around the DT can focus on their core business. Another expert stated that partners and stakeholders working together around the DT could obtain more accurate and up-to-date information. Furthermore, the professionals mentioned the need for functioning relationships between different actors and effective collaboration on value creation. In conclusion, it was felt that an open mind, trust, support and a partnership approach are central to effective exploitation of the opportunities offered by DTs.

Many professionals mentioned lack of resources, inadequate planning and lack of advanced technology as factors slowing down the development and deployment of the DT;

Figure 3 Impacts of digital twins on business operations



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hence, more attention needs to be given to *resource reorganization*. Moreover, DT development requires a lot of input, and organizations need a lot of good examples for novel methods to gain a foothold in their operations. It was emphasized that mere technology is not enough: businesses need skilled people:

> "The implementation of digital twins is usually under the responsibility of one department or one person. If that person leaves or the department priorities change, the DT experiment suffers the consequences. Another risk is that the implementation process cannot produce desired results due to incorrectly defined needs. This can lead to the DT project being declared unnecessary or unsuccessful and thus rejected".
> – #Anonymous expert

The experts, furthermore, emphasized that although changes in business models are likely to occur, the process involves a lot of uncertainties. It was felt that a proactive attitude toward leveraging digital solutions is vital, and the point at which profit is generated will shift to a different position. It was considered that manufacturing industry is in a state of transformation, and business is evolving from selling physical devices toward service business approaches and more complex solutions:

> "I assume that if we cannot do it, someone else in this business will".
> – #Anonymous expert

4.3 Challenges of digital twin-related data sharing

The interviewees evaluated potential challenges and risks of more open data sharing and utilization of digital solutions. Three main categories for challenges of DT-related data sharing were formed on the basis of the responses given: (i) *privacy and safety*, (ii) *data and information flow*; and (iii) *other issues* (Figure 4).

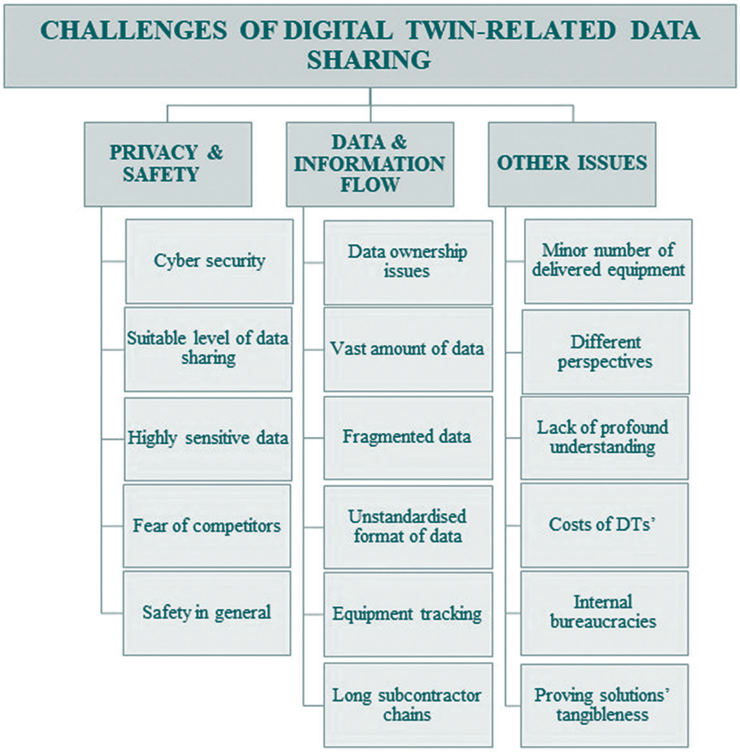
Privacy and safety risks were considered challenges in many companies. The experts specified cyber security issues as being an area of concern if data are shared in too detailed a form. They also added that finding the right level of sharing is complicated, as the data can be sensitive, and customers are often each other's competitors. As a result, many companies are careful about whom to grant access to their data and technological know-how. Moreover, many companies have little desire to share, for example, material properties with outsiders to avoid leaking sensitive information. However, a few experts mentioned that the problem could be more about external safety threats like hackers. The last interviewee stated that their company has customers from both viewpoints: some are willing to share their data, and others are not.

Among privacy and safety concerns, the interviewees noted the *issue of inefficient data and information flow*, which is a problem principally with long product lifecycles. Extensive subcontractor chains and product ranges can also cause conflicts, and inconsistency in information management can later cause problems in equipment tracking. The experts mentioned that the data are often fragmented, and thus, problematic to process, analyze and use without automation. The data may also come from various sources and decades, and hence, are challenging to interpret and scale. For example, the owner of goods in a virtual warehouse is not necessarily the company itself but its subcontractors. Even though outsourcing can bring benefits, it may cause difficulties in reporting and on the financial side:

> "Global information flow should be more consistent".
> – #Anonymous expert

Although the above-listed challenges were the most common ones, also *other issues* emerged: different perspectives affecting data needs, the challenging role of being a small supplier, customers' lack of profound understanding, costs of the DTs, internal

Figure 4 Challenges of digital twin-related data sharing



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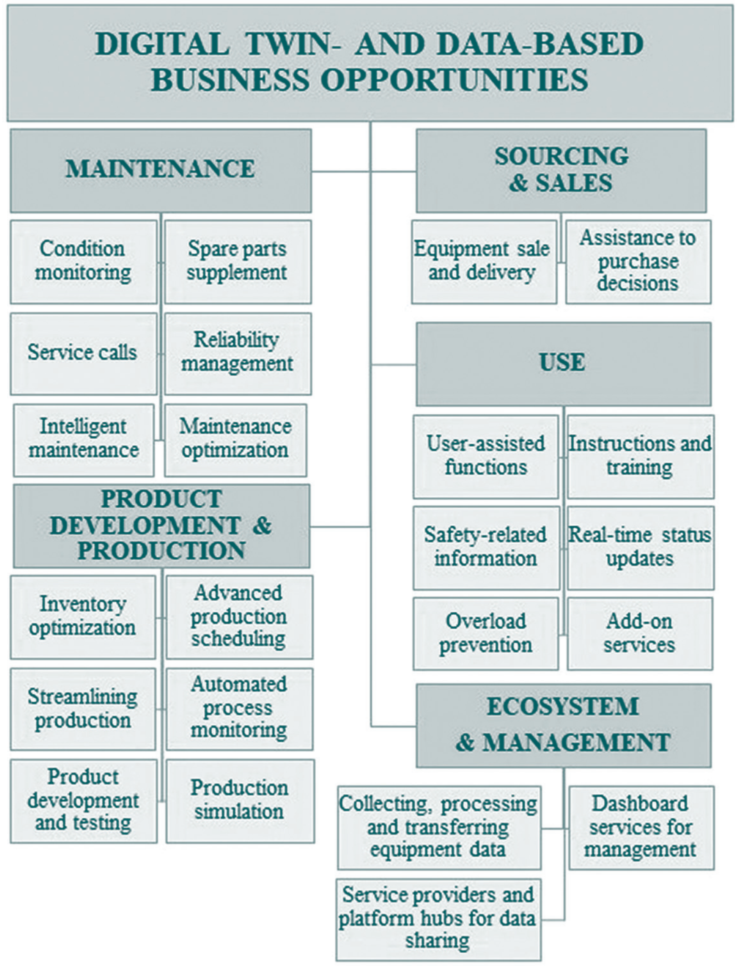
bureaucracies and proving the concreteness of data-based solutions. It was felt that communication with customers should be simplified and cannot include the most technically advanced terms. It was pointed out that the equipment either works or does not work. Furthermore, adding sensors to devices will likely increase the price of products, which raises the question of how to convince customers to pay the extra costs? Internal bureaucracies may also affect the efficiency of sensors and data utilization. Hence, the idea "from information to functionality" needs to be tangible: data alone are mere information, but when the information is processed, it can turn into profits:

> "If customers buy digital services, they want to see the solution to benefit their profitability".
> – #Anonymous expert

4.4 Opportunities for new business creation from digital twin utilization

The interviewees and survey panelists shared their visions of the future of data-based solutions, services and data productization and the benefits it could bring. In addition, they considered possible future investments of the companies they represent. One major topic was new service business enabled by digital solutions and DTs. The Delphi survey asked the panelists to provide concrete examples of possible new service businesses. The interviews addressed the topic from the perspective of what kind of future the companies predict for data-based solutions and services. Figure 5 shows opportunities for data-based business creation based on DTs identified in the interviews and Delphi survey.

Figure 5 Digital twin- and data-based business opportunities



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Five main categories for potential growth areas of DT- and data-based business were formed on the basis of the responses given:

1. maintenance;
2. sourcing and sales;
3. product development and production;
4. use; and
5. ecosystem and management.

Maintenance includes opportunities for DTs in equipment condition monitoring, service calls and delivery of spare parts, reliability management, intelligent maintenance and maintenance optimization. Here DT-based solutions can extend equipment life span if integrated with compatible and systematic information. According to the experts, this category could benefit most from DTs. At its best, a DT can eliminate the need for time-consuming manual data entry.

The *sourcing and sales* theme contains sale and delivery of new equipment, for example, when equipment breaks or otherwise reaches the end of its life. Continuing with this theme, the experts mentioned DT provided data as reasonable support for purchasing decisions, as companies can make their choices based on real data instead of mere estimations.

The third theme, *product development and production*, includes spare part inventory optimization (based on change history and product usage data), product development and testing, advanced production scheduling and simulation and streamlining the production with automated process monitoring. One professional specified that DTs could work as support for prototypes, and thus, help companies achieve their goals earlier and with enhanced quality. Other benefits for product development could be improved data collection and processing. Moreover, successful deployment of a DT can reduce labor and material costs when devices are tested virtually before the actual operations.

The fourth main theme is the *use* phase of the equipment or operating environment. The use phase contains a lot of potential opportunities for DT-based solutions and services, such as user-assisted functions, instructions and training, safety-related information collection and dissemination, real-time status updates, overload prevention functions and add-on (additional) services based on data outside the equipment.

The fifth and last identified top-level theme is the *ecosystem and management* perspective. The professionals felt that industrial ecosystems need tools for collecting, processing and transferring equipment data. They also need service providers who can share the DT-based information via their platforms. Continuing this theme, one expert stated that a machine learning-based data generator could help collect, process and transfer equipment information as decision-making support for managers. Moreover, the experts offered a vision for leveraging DTs and other data-driven services in stakeholder collaboration and customer relationship management. One expert divided the DT stakeholders into two classes: the information producers and the information users. Possible users could include manufacturing, actors who handle customer deliveries and sales departments if it can be ensured that the information required for those functions is generated in a systematic and compatible manner without re-entry.

5. Discussion and conclusions

The DT is a buzzword of our time, and many researchers have conducted studies about DTs in recent years (Kurvinen *et al.*, 2022; VanDerHorn and Mahadevan, 2021; Semeraro *et al.*, 2021), but a widely used, shared understanding of the concept remains elusive. The interviewees and panelists of this research showed variability in their understanding of DTs, from simplistic versions focusing on data-based simulation to much more complex solutions. The differences in understanding of the DT concept support the observations of Tao *et al.* (2019) and Rantala *et al.* (2021), who indicate that the maturity levels of DT utilization, solutions and definitions can differ significantly between companies and industries, from light to complex versions.

The interviews and expert panel survey confirmed many previous observations (Segovia and Garcia-Alfaro, 2022; Bhandal *et al.*, 2022; Meierhofer *et al.*, 2020; Negri *et al.*, 2017) about DTs' versatile possibilities in several applications. In the context of this study, the DT technology was seen to provide prospects for multiple business areas, from maintenance-related functions to ecosystem and management views and so on. When analyzing the results, one may notice that the areas shared a common fundamental factor, the increased reliability arising from the combined effects of many aspects, such as quality assurance, transparency, efficiency, enhanced security and other supporting functions.

However, the results of this study indicate that the development of new business based on DTs still involves several challenges. Major challenges are related to data ownership, internal bureaucracy and the difficulty of demonstrating the actual value of data-based services to potential customers. Customers seek concrete benefits from DTs. This observation can be confirmed by existing literature – the studies by Khalifa, (2004) and Lyly-Yrjänäinen *et al.* (2019) also concluded that customers need to be convinced about the overall advantages of a solution that considerably exceeds any disadvantages to encourage customers to make a purchasing decision. Furthermore, there is an obvious need for more open arrangements and infrastructures for data sharing and shared goals among the actors involved in developing new DT-based businesses. In addition, the results reinforce concerns presented e.g. by Semeraro *et al.*, 2021, that the technology related to DTs is still too underdeveloped, and the incompatibility of systems causes significant challenges. These issues mean additional work in the deployment and integration phases.

Research results reinforced that companies need to revise their old business models to make room for new ways for data and DT-based value creation. The interviewees and Delphi panelists saw stakeholders' access to data as an enabler for developing their service offerings, especially maintenance-related functions. This observation corresponds with the study of Olaf and Hanser (2019), according to whom companies are directing their attention toward the business potential of data from manufacturing machines and processes.

To conclude, future possibilities for DTs and data-based business are promising, and the technology may enable various benefits for multiple actors. The research question of this study:

RQ2. What are the possible impacts of emerging DTs on new business creation in the manufacturing industry?

Obtained versatile results, which *contributed to the theoretical discussion* by clarifying the concept of DT based on the viewpoints of manufacturing professionals. Moreover, this study has complemented the previous notions in the academic literature on the benefits and challenges of DT utilization by revealing several promising business opportunities for DTs in the manufacturing context. Furthermore, the results investigate the current issues in DT exploitation, such as the lack of technological compatibility, the need for more open collaborative activities and the need for internal integration of DTs in different systems. Given that the manufacturing industry has been recognized as one of the most promising contexts for DTs (Cimino *et al.*, 2019), the results of this study remarkably advance the understanding of DTs' contribution to boosting service-based business development in manufacturing companies and their ecosystems.

As *a practical contribution*, this study provides insights for several actors around DTs, especially technology developers, by presenting the requirements and necessaries of DTs from the viewpoint of stakeholders and customers: attention should be given to standardized operating methods, smooth connectivity and information exchange, adaptability, extensibility, ease of use, visualization, security and collaborative value creation. If DTs receive the essential resources required, including specialists and time for the development process, DTs can streamline operations, provide internal benefits and help stakeholders develop their businesses.

Furthermore, the specialists of this study claimed that their customers have more and more data- and service-related needs. DTs may shake up the manufacturing industry and shift the point of making profits to a different position as the service business becomes more prominent. If companies are eager to invest significantly in DTs, they need enough resources for their development and deployment phases. The responsibility for DT implementation should not be given to someone in addition to their other duties, as it might hinder progress. One answer could be a nominated expert or a working group that pushes the development of DTs forward and identifies the resources it requires to thrive. Concrete benefits can arise with streamlined operations in value networks and internal advantages such as business growth and cost savings. For example, companies can focus on their core competencies and obtain more accurate, up-to-date information if they learn to exploit the new forms of collaboration that the DT enables. Also, possibilities for new value-adding service providers could emerge based on the information provided by DTs.

When analyzing the limitations of this study, it should be noted that the lack of a commonly shared understanding of the DT concept caused slight challenges in determining whether the interviewees and panelists discussed actual DTs or described data-based solutions in general. Furthermore, as the Delphi panelists and interviewees participated in a DT development project, they had an interest and a relatively positive attitude toward the matter, which may affect the results and conclusions of this research.

The future of DTs in the manufacturing industry is likely to hold new routines, business practices and innovative business models that reinforce more efficient, competitive and sustainable production. However, there are still more areas to explore, such as DT-based solutions throughout product and service lifecycles, from initial ideas to disposal or reuse and the possible sustainability contributions of these solutions. Other examples of relevant and topical future research directions could be DT-related resource and competence views. Overall, additional research and a unified perception of DTs are required to tackle the uncertainties and ambiguities still surrounding the topic and hindering progress in the area.

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