Digital transformation with digital twins - distinct mechanisms of enabling and controlling uses

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Abstract

This study examines the connection between digital twin mechanisms and digital twin uses. We examined digital twins through three dimensions: navigation; interaction; and discovery. The effects were examined by considering two different uses: enabling use and controlling use. This study found a direct and positive relationship between the interaction mechanism and the enabling and controlling uses of digital twins. The results also indicated the nonexistence of any relationship between the navigation and discovery mechanisms, and digital twins' enabling and controlling uses. The results indicate that digital twin realism exerts a negative moderating effect on the relationship between digital twins' discovery mechanism and controlling use. Managers can leverage research findings as they adopt new digital tools to support their service businesses and management needs. For example, managers can leverage research findings by using digital technologies to inspire and motivate employees to fulfill organizational objectives.

Keywords: digital twin; organizational control; enabling use; controlling use

1 Introduction

Digitalization through new technologies is becoming one of the main drivers of innovation in all sectors (Qi et al., 2021; Urbinati et al., 2020). In the search for competitiveness, companies increasingly have started providing digital services to accompany their existing service offerings (Nasiri et al., 2020; Garzella et al., 2021; Tsou and Chen, 2021). Digital twins are among the technologies that serve as novel platforms that enable innovative services. *Digital twin* refers to a digital replica of a physical entity, such as a product, process, or system. With advanced information technologies, sensor updates, and use of data, digital twins can mirror almost every aspect of a service, process, or product (Qi et al., 2021), providing novel service innovation and value creation opportunities for companies (Blichfeldt and Faullant, 2021). Already, digital twins have various applications that can be used in different business areas (Fuller et al., 2020; Qi et al., 2021; Rasheed et al., 2020). Technical solutions offered by digital twins are evolving rapidly and their application is constantly becoming easier and more cost-effective (Parmar et al., 2020). However, little is known about the mechanisms through digital twins benefit firms' processes.

Considering that physical entities' behavior might differ in various circumstances and within different objectives (Qi et al., 2018), employing a service-oriented digital twin model by embedding different digital twin components into services with integrated descriptions (Wang and Xu, 2014; Zhang et al., 2019) can provide opportunities for both controlling and enabling use. A digital twin as a service for controlling functions can be related to condition monitoring and quality control by constraining behavior with the aim of delivering tasks based on defined objectives (Rasheed et al., 2020), whereas a digital twin as a service for enabling functions can be related to virtual experiences, giving space to each member to think outside the box to enhance a digital twin's strategic benefits (Berisha-Gawlowski et al., 2021; Tao et al., 2019a). Thus, a digital twin as a service through simulation either can restrict employees' functions based on firms' objectives or provide open spaces for creating innovative solutions and creative ideas (Berisha-Gawlowski et al., 2021; Rasheed et al., 2020; Tao et al., 2019a). Despite growing interest, research on which digital twin mechanisms contribute to their various uses remains lacking.

This study contributes to this literature gap by examining the connection between digital twin mechanisms and digital twin uses. The research questions are as follows: (1) which digital twin mechanisms affect different uses of digital twins, and (2) does digital twin realism moderate the relationship between digital twin mechanisms and digital twin uses. The study is based on an analysis of a Finnish survey of 139 respondents. We examined digital twins across three dimensions: navigation; interaction; and discovery. The effects were examined by considering two different uses: enabling use and controlling use. The study contributes to research and practice as follows. First, the study diverges from previous technical-oriented research by investigating digital twins in a service context. Second, this research is the first to examine digital twins' effects systematically, depending on how they are used in service operations. The presented consequences of using digital twins can guide further studies by offering precepts on how digital twins can be understood and managed in service business settings. Furthermore, by using this study's results, managers can enhance their companies' digital transformation by acknowledging digital twins' multiple facets.

2 Conceptual model

2.1 Definitions of key concepts; the digital twin mechanisms and forms of use

Digital twin mechanisms; interaction, navigation, discovery

Digital twin, which is revolutionizing businesses with a wide range of value-added characteristics, can be applied to many industries and technologies (Qi et al., 2021; Rasheed et al., 2020). The original digital twin model was introduced by Grieves in 2002 and included three main parts: physical products in real space; virtual products in virtual space; and data connections that integrate virtual and physical products jointly (Grieves, 2014). To define the concept and its mechanisms, a *digital twin* can be describing to a digital replica of a physical entity, such as a product, process, or system (He and Bai, 2021; Parmar et al., 2020). It hast the ability to provide a connection between a physical entity and its virtual counterpart by utilizing sensors, delivering real-time information through that connection (Tao et al., 2018b). Digital twins have already been used in several application areas, e.g., smart cities, manufacturing, health care, and aviation (Fuller et al., 2020; Barricelli et al., 2019), but combining a digital twin with a service is a promising research direction (Tao et al., 2018a). In terms of the service sector, our research focuses on certain digital twin mechanisms and its various forms of use as a service.

Digital twins with many value providing features and innovation opportunities (Rasheed et al., 2020) can enhance service operations, such as structure monitoring, forecasting, and in-time maintenance (Tao et al., 2018a). By utilizing advanced technology, digital twins enable a deeper *interaction* mechanism between users and between product and user (e.g., Berisha-Gawlowski et al., 2021). This is reflected in closer cooperation between companies and customers across product life cycles (Tao et al., 2018b). Using digital twin technology during the design phase as an open platform, customers can monitor the progress of the digital model's design, implement and test modifications in the digital model, and provide the company with direct online feedback on product features (Zhang et al., 2019; Tao et al., 2019c). The interaction mechanism is reflected in more efficient communication and information sharing on social networks without physical constraints and regardless of the number of individuals, leading to better collaborations (Aheleroff et al., 2020; Rasheed et al., 2020). In addition, the possibility of using digital twins and their simulation models enables self-expression by acting as a facilitator of learning by creating room for experimenting and allowing users to be creative (Berisha-Gawlowski et al., 2021; Boschert and Rosen, 2016).

Digital twins also enable other mechanisms – *navigation* and *discovery* – by leveraging Industry 4.0 technologies such as Internet of Things (IoT), the cloud, big data, and artificial intelligence (AI) (Aheleroff et al., 2020; Qi et al., 2021). A simple example of the *navigation* mechanism is real-time product delivery tracking in which the map provides a digital model of a city, updated in real time, that shows the delivery location (Zhang et al., 2019). The customer can monitor the delivery process, including when the product arrives at the desired location, from the mobile application. On the other hand, service providers, can navigate the functionality and problem areas of their customer's products, and provide insights and solutions to them remotely, or locate their customer service in optimal locations according to customer needs (Parmar et al., 2020). According to Bertoni and Bertoni (2022) digital twin is envisioned as a virtual testing tool which is able to *discover and navigate* all kind of problems, like product defects, and thus significantly reducing the time to market for new concepts.

The development of digital twins and their simulation techniques will lead to significant improvements in complexity management, supporting the *discovery* of creative solutions in a virtual world (Boschert and Rosen, 2016). Digital twins' ability to synchronize the real and digital worlds allows users (employees, designers, operators, maintenance personnel, etc.) to utilize digital twins to monitor and master complex systems (Tao et al., 2018a; Weyer et al., 2016). Also, these simulation-based solutions enable anticipation, rapid change, and optimization, as well as experimentation and discovery of completely new solutions to real world challenges and tasks (Bertoni and Bertoni; 2022; Berisha-Gawlowski et al., 2021; Boschert and Rosen, 2016).

Digital twin`s forms of use

We reviewed literature related to different uses of digital twins. They can be used to inspire and motivate users to search for, examine, create, and expand efforts in a positive way to fulfill organizational objectives (Berisha-Gawlowski et al., 2021). The user can try out new solutions in the digital world, then implement the best ones in the real world, providing a whole new opportunity to do creative work (Boschert and Rosen, 2016). By implementing and encouraging forward-looking creative ideas and strategic initiatives while maintaining interactive relationships with employees, organizations can enable new services through digital twins while enhancing existing services through new data that digital twins provide (Tao et al., 2018a). For example, this *enabling use* of a digital twin can be utilized to improve shopping, reservations, and entertainment services.

One of the most significant benefits of digital twin technology is that it can be used to update the real-time status of a twin's physical object with advanced sensors and communication technology (Tao et al., 2018b). This enables real-time monitoring of a delivery task in line with objectives by constraining behavior (Rasheed et al., 2020; Zhang et al., 2019; Tao et al., 2018a). With communication tools, information can be transformed transparently and remotely for different users, allowing results to be controlled to adhere to desired standards and objectives using feedback mechanisms (Rasheed et al., 2020). This *controlling use* of the digital twin can be utilized as a service, e.g., real-time monitoring of energy consumption analyses and forecasts (Tao et al., 2018b).

2.2 Hypotheses development

2.2.1 Digital twin mechanisms and their enabling use

While digital twins can provide their users with an increasing number of possibilities to interact through different channels and contexts with different stakeholders, they provide plenty of possibilities for different types of enabling activities that can inspire and motivate employees to search for and explore new ways to develop operations and businesses. Viewing a digital twin as a collaboration mechanism or platform (Cheng et al., 2020) can increase its usefulness, such as employees' opportunities and motivation to interact with customers, e.g., ideating and creating new businesses or solutions. Along the lines of viewing a digital twin as a collaboration mechanism, it facilitates communication (Tao et al., 2018b) between stakeholders. Contemporary examples of this are when machines, production lines, or even whole factories are designed, built, and operated on digital twin platforms between designers and customers, and when new residential houses or cars are designed in real time between designers and customers. Utilizing digital twins for navigation purposes allows for, e.g., clear goals, routes, or settings, as well as the ability to track them. Enabled by real-time navigation provided by digital twins, planned destinations or routes can be modified and updated as needed (Zhang et al., 2019). Navigation-based digital twins can enable their users, e.g., with map-based route planning (Aheleroff et al., 2020) that helps users navigate in the virtual and real worlds. These navigation environments also help enable, e.g., real-time monitoring of public transportation and the presentation of information from different service providers based on spatial information. Using a digital twin for discovery purposes allows for holistic perception of complex issues, as well as identification of related needs. In addition to opportunities to operate more comprehensively in complex surroundings, using a digital twin for discovery purposes also generates opportunities to tackle challenges (Berisha-Gawlowski et al., 2021; Boschert and Rosen, 2016). The possibility of solving complex real-life problems in virtual settings (Tao et al., 2018a; Boschert and Rosen, 2016) can encourage forward-looking creative ideas and strategic initiatives, as well as support interactive relationships inside and outside organizations. Based on the aforementioned argumentation, the following hypothesis is presented:

H1. Perceptions of digital twin mechanisms affect their enabling use:

- H1a. Perceiving a digital twin as an interaction mechanism affects its enabling use.
- H1b. Perceiving a digital twin as a navigation mechanism affects its enabling use.
- H1c. Perceiving a digital twin as a discovery mechanism affects its enabling use.

2.2.2 Digital twin mechanisms and their controlling use

It has been demonstrated that a digital twin can be used for monitoring, simulation, verification, diagnosis, prognosis, optimization, etc. (Cai et al., 2017). However, another view strongly asserts that a control system needs to be viewed as a social system that enables learning in autopoietic networks, requiring interaction and collaboration mechanisms (Bititci et al., 2012). Therefore, it can be assumed that a digital twin's interactive features are related to its use for control purposes. A digital twin also can be utilized for navigation in many ways, e.g., in a virtual factory. In this case, it is possible, e.g., to demonstrate and consider safety rules, monitor optimized routes, monitor and optimize product flows, and simultaneously compare flows with objectives and standards (Delbrügger et al., 2017). The navigation mechanism also enables real-time product delivery tracking, including the product's arrival at the desired location (Zhang et al., 2019). All these functions can be monitored by using a digital twin and compared with standards and objectives at both the individual function and strategic management levels (Aheleroff et al., 2020). Therefore, it can be assumed that a digital twin's navigation features are related to its use for control purposes. Furthermore, digital twins significantly improve the monitoring and management of complex systems because they enable simultaneous presentation of important issues related to a specific purpose (Boschert and Rosen, 2016). In particular, simulation-based solutions from digital twins provide many possibilities to create and discover innovative solutions and future creative ideas, which may be based on a specific goal or intuition alone (Berisha-Gawlowski et al., 2021; Rasheed et al., 2020; Tao et al., 2019a). For example, simulation-based experimentation and discovery can be related to anticipation, rapid change, and optimization, which involve directing employees toward a desired goal, or even to free intuition-based development (Boschert and Rosen, 2016; Berisha-Gawlowski et al., 2021; Rasheed et al., 2020). Based on the aforementioned argumentation, the following hypothesis is presented:

H2. Perceptions of digital twin mechanisms affect their controlling use:

H2a. Perceiving a digital twin as an interaction mechanism affects its controlling use.

H2b. Perceiving a digital twin as a navigation mechanism affects its controlling use.

H2c. Perceiving a digital twin as a discovery mechanism affects its controlling use.

2.2.3 Realism as a moderator

Realism, in the context of digital twins, refers to the extent to which the digital twin is a true representation of the physical counterpart. Realism can be achieved through three domains of reality. The first is empirical and is associated with experience, the second is related to events that can be experienced directly and indirectly, and the third is a generative system that adds to the first two domains and other relevant events (Vega and Chiasson, 2019). A digital twin’s power relies on the amount of data collected directly from the real word and processed into meaningful value for both manufacturers and end users (Zheng and Sivabalan, 2020). When it comes to enabling services that inspire employees to provide innovative solutions that go beyond data processing, digital twin realism might not be applicable because people’s behavior is not systematic (Berisha-Gawlowski et al., 2021). A digital twin provides a digital model of physical artifacts in a digital manner to replicate their behavior in terms of interacting with surroundings, mapping rules or strategies, and functioning to handle challenges (Tao et al., 2018b). Considering that digital twins are exact copies of physical artifacts and systems, realism can enhance the virtual model’s accuracy (Zheng and Sivabalan, 2020). However, representations of realism in unconscious, unquestioned, and tacit knowledge in human skills are critical because they are changeable and grow gradually (Berisha-Gawlowski et al., 2021).

Utilizing a digital twin as a service within functions to motivate employees to create novel insights to deal with challenges and firms’ objectives is challenging because it needs the ability to deal with ambiguity, which is a unique characteristic in humans. To enhance realism in a digital twin’s performance of such activities, a virtual model is needed to learn from humans’ interactions and discover a pattern, then imitate how humans contend with conflicting, vague, and incomplete information, which is not enough with current knowledge (Berisha-Gawlowski et al., 2021). Thus, based on this discussion, the following hypothesis is presented:

H3. Realism moderates the relationship between digital twin mechanisms and their enabling use.

A digital twin reflects integration of a virtual model with physical entities, along with mapping connections between the virtual and physical worlds (Qi et al., 2019; Tao et al., 2019b). A digital twin, by collecting and storing – as well as simulating and predicting – the operational route of processes and entities in both virtual and physical worlds, can provide huge potentials in different domains, such as effective information sharing, optimized resource allocation, and fault recognition (Tao et al., 2019b; Xu et al., 2019). As noted by Qi et al. (2019), the central part of a digital twin is the virtual model; therefore, it is critical that the twin have a deep understanding of the physical world. However, the digital twin’s reliability has been enhanced by processing and combining data collected from both the physical world and virtual model, which can enhance the digital twin's accuracy. Furthermore, different digital twin dimensions interact with each other through connections, and the digital twin cannot be actualized and used appropriately to enhance controlling use solely through the realism of a digital twin and isolation.

There are some technical, ethical, privacy, and security challenges with digital twin realism (Qi et al. 2019; Rasheed et al., 2019). Considering that a digital twin builds on physical entities that are implemented based on physical rules and uncertain environments, technologies that continuously update the model based on real-world data are needed (Qi et al. 2019). Thus, digital twin realism can be hampered by uncertainty in the environment, and uncertainty limits the digital twin's full potential as a service to control use, such as the diagnosis and prognosis process in healthcare (Leser et al., 2020). According to Qi et al. (2019), the virtual model is created based on physical entities, along with many internal and external interactions, presenting some challenges within a complex system. Thus, the establishment and development of digital twins in complex systems can be time-consuming. Although a digital twin, through ultra-realistic simulation, tries to exercise ubiquitous control of the system, restrictions in real world data processing could be another challenge that might hamper adoption of a digital twin to control use (Zheng and Sivabalan, 2020). Thus, based on the aforementioned debate, the next hypothesis is presented:

H4. Realism moderates the relationship between digital twin mechanisms and their controlling use.

2.3 Research model and hypotheses

Figure 1 depicts the research model and hypotheses, which have been built on previous literature on digital twins in the service context. Interaction, navigation, and discovery are listed as three critical mechanisms associated with utilizing digital twins in both enabling and controlling uses. Furthermore, realism, with more emphasis on actual representation of digital twins, is applied as an important factor that can alter the association between digital twin mechanisms and different uses of a digital twin as a service.

3 Research methodology

3.1 Sample and data gathering

The study aimed to investigate digital twin mechanisms' role in their enabling and controlling uses, and to investigate how digital twin realism moderates the influence of the two uses of digital twins. The study used survey data collected from university students in which each respondent was asked to convey their experiences with digital twin mechanisms and use. The study was limited to Finland, using a concentration of students from a variety of backgrounds, namely technology, business, and health care. A random sample was used to select 139 students from a total population of around 1,000. This population was the approximate number of students that spend time on campus on a daily basis. Random sampling was deemed necessary to ensure an unbiased set of responses, i.e., in which anyone in the population had the same probability of being selected for the study. In this type of research, a total of 139 valid responses is viewed as sufficient in terms of sample size (Krejcie and Morgan, 1970) and response rate (Saunders et al., 2007). The obtained data can be described as follows: 46% of the respondents were less than 25 years old; 34% were between 25 and 40; and 20% were over 40 years old. Altogether, 43% of the respondents were females and 57% males.

A group of researchers tested the survey questionnaire, after which a final structure was settled, and the survey was administered to the respondents. Survey data collection was moderated by five researchers from the digital technologies and service business fields.

3.2 Variable measurement

The study's dependent variables were digital twins' enabling and controlling uses. A scale was informed by previous research to reflect digital twins' two uses: enabling, i.e., inspiring and encouraging one to search for, explore, and create (Boschert and Rosen, 2016; Berisha-Gawlowski et al., 2021), and controlling, i.e., monitoring and comparing tasks and/or objectives (Tao et al., 2018a; Zhang et al., 2019; Rasheed et al., 2020). This part included eight items divided into the two distinct uses of digital twins; every item was assessed using a seven-tier Likert scale (with responses ranging from strongly disagree to strongly agree) to determine whether respondents use digital twins for predefined purposes. Five items comprised the scale for enabling use, and three comprised the scale for controlling use, as presented in Table 1.

Table 1. Survey items and reliability and validity measures

Dimension	**Form of items**	**Items**	**Loadings**	**CR**	**AVE**	**α**
Interaction	Digital twins associated with the following terms [Totally disagree (1) – Totally agree (7)]	1 Collaboration	0.822	0.79	0.50	0.65
		2 Communication	0.709			
		3 Self-expression	0.666			
		4 Social life	0.604			
Navigation	Digital twins associated with the following terms [Totally disagree (1) – Totally agree (7)]	1 Rules	0.715	0.81	0.58	0.64
		2 Clear goals	0.768			
		3 Strategy	0.803			
Discovery	Digital twins associated with the following terms [Totally disagree (1) – Totally agree (7)]	1 Complexity	0.893	0.89	0.79	0.75
		2 Challenge	0.893			
Controlling use	Used digital twins for the following purposes [Totally disagree (1) – Totally agree (5)]	1 Training	0.551	0.83	0.49	0.74
		2 Monitoring energy consumption	0.633			
		3 Weather	0.752			
		4 Health	0.788			
		5 Tracking my expenditures	0.743			
Enabling use	Used digital twins for the following purposes [Totally disagree (1) – Totally agree (5)]	1 Reservations	0.794	0.84	0.64	0.72
		2 Shopping	0.807			
		3 Entertainment	0.799			

The digital twin mechanisms as independent variables were divided into interaction, navigation, and discovery. The interaction scale comprised four items concerning the extent to which digital twins associate with collaboration, communication, self-expression, and social life (e.g., Boschert and Rosen, 2016; Aheleroff et al., 2020; Berisha-Gawlowski et al., 2021). The navigation scale comprised three items that dealt with the extent to which digital twins associate with rules, clear goals, and strategy (e.g., Zhang et al., 2019; Aheleroff et al., 2020). The discovery scale comprised two items that dealt with the extent to which digital twins associate with complexity and challenges (e.g., Boschert and Rosen, 2016; Berisha-Gawlowski et al., 2021). A seven-tier Likert scale, with responses ranging from strongly disagree to strongly agree, was utilized for all independent variables.

The moderating variable, digital twin realism, comprised a single item. *Realism* refers to the extent to which the digital twin is a true representation of the physical counterpart. The respondents were asked to indicate whether they viewed realism as an essential feature of the digital twins that they used. This scale also utilized a seven-tier Likert-scale, with responses varying from strongly disagree to strongly agree.

The control variables included respondents' gender and age. These were controlled in the models because they could have affected digital twin content and functionalities and, thus, the results.

3.3 Data analysis

Data analysis comprised several stages to ensure validity, reliability, and unidimensionality standards. First, the scales were tested for unidimensionality with factor analysis. Table 1 presents the loadings of each item into corresponding variables. None of the items suffered low-factor loadings (<0.40). The assessment of convergent validity, which describes whether the items reflect a common construct, was positive, as the average variance extracted (AVE) values were larger than the threshold (0.50) proposed to authorize the utilization of the construct (Hair et al., 1998). The AVE of controlling use was slightly below the threshold, but as the other values were acceptable, it can be viewed as sufficient for testing the hypotheses. Internal consistency was analyzed further by calculating composite reliability (CR) values, and all constructs were above the 0.70 benchmark (Fornell and Larcker, 1981). Second, discriminant validity was tested by collating the square root of the AVE and the construct intercorrelations (Table 2). As the square root of the AVE was larger than the correlation between each factor pair, discriminant validity was ensured. Thus, all the constructs possessed the requirements for unidimensionality. Finally, reliability was tested using Cronbach's alpha values. All the alpha values exceeded the minimum acceptable value of 0.6 (Taber, 2018). Thus, the constructs' reliability was ensured.

Table 2. Correlation matrix

	Mean	St. Dev.	1	2	3	4	5	6
1 Interaction	4.57	1.07	1.000					
2 Navigation	4.41	1.21	.407***	1.000				
3 Discovery	4.08	1.36	.185*	.173*	1.000			
4 Realism	4.72	1.60	.170*	.268***	.112	1.000		
5 Controlling use	2.97	0.98	.383***	.125	.049	.069	1.000	
6 Enabling use	3.59	1.10	.241**	.003	-.042	-.028	.583***	1.000

Sig. *** ≤ 0.001, ** 0.001 < p ≤ 0.01, * 0.01 < p ≤ 0.05

4 Results

Tables 3 and 4 present the findings from the three-step regression analyses. During the first phase, only control variables were entered into the model. During the second phase, the independent variables were entered into the model. During the third phase, the moderation variable was entered, and during the fourth phase, its interactions with the independent variables were entered.

Table 3 provides the results regarding digital twins' enabling use. In H1, we predicted that perceptions of digital twins as interaction, navigation, and discovery mechanisms affect their enabling use. The findings from Model 2 presented in Table 3 supported H1a ($\beta = .343$, $p \leq .001$). H1b ($\beta = -.060$, ns) and H1c ($\beta = .007$, ns) were not supported; thus, the relationship between digital twins as interaction mechanisms and their enabling use was confirmed. Model 4, shown in Table 3, did not support realism's moderating role regarding digital twin mechanism-enabling use links. Model 4's interaction terms between the interaction mechanism and enabling use, between the navigation mechanism and enabling use, and between the discovery mechanism and enabling use were insignificant ($\beta = .015$, ns, and $\beta = .051$, ns, and $\beta = -.066$, ns, respectively). Thus, H3 was not supported.

Table 3. Regression results for enabling use

Models		β	SE	St. β	t	R^2	Adj. R^2	SE	F
1	(Constant)	3.621	.298		12.153	.004	-.011	1.108	.269

	Age	-.003	.009	-.032	-.360				
	Gender	.124	.195	.056	.636				
2	(Constant)	2.340	.576		4.062	.101	.065	1.066	2.835*
	Age	-.006	.009	-.059	-.692				
	Gender	.198	.190	.089	1.040				
	Interaction	.343	.096	.334	3.568***				
	Navigation	-.060	.084	-.066	-.710				
	Discovery	.007	.071	.008	.096				
3	(Constant)	2.441	.601		4.059	.104	.061	1.068	2.411*
	Age	-.006	.009	-.059	-.695				
	Gender	.200	.190	.090	1.052				
	Interaction	.348	.097	.338	3.593***				
	Navigation	-.049	.086	-.053	-.562				
	Discovery	.008	.071	.009	.108				
	Realism	-.037	.061	-.053	-.603				
4	(Constant)	2.436	1.500		1.624	.128	.064	1.066	1.998*
	Age	-.004	.009	-.041	-.464				
	Gender	.161	.192	.072	.835				
	Interaction	.271	.295	.263	.919				
	Navigation	-.240	.260	-.264	-.923				
	Discovery	.285	.196	.347	1.452				
	Realism	-.057	.284	-.082	-.200				
	Interaction*Real.	.015	.061	.125	.239				
	Navigation*Real.	.051	.056	.459	.914				
	Discovery*Real.	-.066	.041	-.566	-1.612				

*** $p \le 0.001$, ** $0.001 < p \le 0.01$, * $0.01 < p \le 0.05$

Table 4 provides the results regarding digital twins' controlling use. In H2, we predicted that perceptions of digital twins as interaction, navigation, and discovery mechanisms affect their controlling use. The findings from Model 6, presented in Table 4, supported H2a ($\beta = .349$, $p \le .001$). H2b ($\beta = .030$, ns) and H2c ($\beta = .047$, ns) were not supported; thus, the relationship between digital twins as interaction mechanisms and their controlling use was confirmed. Model 8, presented in Table 4, supported realism's moderating role regarding the discovery mechanism-controlling use link. Model 4's interaction terms between the discovery mechanism and controlling use were significant, but negative (β = -.078, p ≤ .05), indicating support for H4. Realism negatively moderated the relationship between digital twins as a discovery mechanism and their controlling use. However, the interaction terms' regression coefficients between interaction mechanism and controlling use, as well as between the navigation mechanism and controlling use, were insignificant (β = .004, ns, and β = .037, ns, respectively).

Table 4. Regression results for controlling use

Models		**β**	**SE**	**St. β**	**t**	**R^2**	**Adj. R^2**	**SE**	**F**
5	(Constant)	3.005	.262		11.482	.001	-.015	.972	.035
	Age	-.002	.008	-.019	-.219				
	Gender	.025	.172	.013	.146				
6	(Constant)	1.117	.484		2.310	.174	.141	.894	5.269***
	Age	-.004	.007	-.048	-.587				
	Gender	.132	.160	.068	.824				
	Interaction	.349	.081	.389	4.323***				
	Navigation	.030	.071	.037	.418				
	Discovery	.047	.060	.065	.787				
7	(Constant)	1.039	.505		2.058	.176	.136	.896	4.417***
	Age	-.004	.007	-.048	-.581				
	Gender	.130	.161	.067	.808				
	Interaction	.346	.081	.385	4.260***				
	Navigation	.021	.073	.026	.289				
	Discovery	.046	.060	.064	.773				
	Realism	.028	.051	.047	.553				
8	(Constant)	.268	1.248		.214	.212	.153	.887	3.618***
	Age	-.001	.007	-.014	-.170				
	Gender	.102	.161	.053	.635				
	Interaction	.316	.245	.352	1.287				
	Navigation	-.098	.217	-.124	-.455				
	Discovery	.383	.163	.533	2.348*				
	Realism	.162	.237	.270	.685				
	Interaction*Real.	.004	.051	.039	.078				
	Navigation*Real.	.037	.047	.377	.786				
	Discovery*Real.	-.078	.034	-.765	-2.285*				

*** $p \leq 0.001$, ** $0.001 < p \leq 0.01$, * $0.01 < p \leq 0.05$

5 Discussion

The results contribute to digital transformation literature as follows (Nasiri et al., 2020; Garzella et al., 2021; Tsou and Chen, 2021). While the study aimed to examine which digital twin mechanisms affect digital twins' enabling and controlling uses, the results revealed several interesting effects concerning how perceptions of digital twins affect their use. First, the findings demonstrated that the perception of a digital twin as an interaction mechanism affects its enabling use. The interaction experience seems to be the key point that allows for digital twins' enabling use to result in something new and further expand efforts in a positive way in fulfilling organizational objectives. From this perspective, this study's results support those from previous studies (Berisha-Gawlowski et al., 2021) that found utilization of digital twins enables deeper interactions, e.g., closer relationships between companies and customers across product life cycles (Tao et al., 2018b). This study's results also highlight the importance of understanding and considering the digital communication platform when organizations are searching for ways to inspire and motivate their employees to discover and create something new and innovative through the enabling use of digital twins. Despite digital twins' technological possibilities, human aspects' important role should not be ignored (Rantala et al., 2021). This is probably why an insignificant relationship was found between navigation and discovery mechanisms, and digital twins' enabling use. Even though previous studies have touted the possibilities and advantages that navigation (Zhang et al., 2019) and discovery (Boschert and Rosen, 2016) can provide with digital twins, this study's results did not find significant effects between these mechanisms and digital twins' enabling use. Even though they provide advanced technology-based opportunities, they lack the interaction mechanism that would support communication between humans and, thus, support their creative thinking and development of innovation solutions.

Second, the findings demonstrated that viewing a digital twin as an interaction mechanism positively affects the use of a digital twin for controlling purposes. This result strongly supports the prior statement that a digital twin allows for efficient communication and information sharing in social networks without physical constraints and regardless of the number of individuals, leading to better collaborations (Aheleroff et al., 2020; Rasheed et al., 2020). This, in turn, strongly supports Bititci et al. (2012), who emphasized that to get the most out of the control system, it must be used as a social system that enables learning in autopoietic networks. Furthermore, a relationship between a digital twin's navigation mechanism and controlling use was not found. The navigation mechanism refers, e.g., to real-time product delivery tracking, including the delivery's arrival point, and a comparison of the outcome with desired goals (Zhang et al., 2019). The explanation for the insignificant relationship can be that navigation is viewed as more of a monitoring task than an intention to affect people's behavior (managerial controlling mechanism). Finally, no significant connection was found between a digital twin's discovery aspect and controlling use. Prior discussions around digital twins indicated that they either restrict employees to operating based on firms' objectives or provide open spaces for creating innovative solutions and future creative ideas (Berisha-Gawlowski et al., 2021; Rasheed et al., 2020; Tao et al., 2019a). This study suggests that digital twins currently are being used for the latter purpose, i.e., intuition-based development.

Third, the results indicated that realism cannot significantly moderate the relationship between digital twin mechanisms and enabling use. Thus, it can be concluded that a digital twin, as a service for enabling uses that involve inspiring employees to generate innovative ideas to achieve company goals, cannot be encouraged by realism. Relying on the critical application of realism in systematic activities (Berisha-Gawlowski et al., 2021; Zheng and Sivabalan, 2020) and inspiring employees to create new ideas are non-systematic; therefore, digital twin realism cannot be influential between different digital twin mechanisms and when digital twins are utilized as a service in enabling use. Another reason is that realism is built on both direct and indirect experiences (Vega and Chiasson, 2019) that are gained by doing specific activities in the past. However, digital twins' enabling use concerns forward-looking ideas that are associated with being willing to use modern ideas in the future. Thus, realism cannot affect the strength of the relationship between digital twin mechanisms and enabling use because they conflict with each other.

Fourth, the results revealed that realism negatively moderates the relationship between discovery, as one of the digital twin mechanisms, and controlling use. This corresponds with previous research (Qi et al., 2019, Rasheed et al., 2019) that noted potential technical, ethical, privacy, and security issues with digital twin realism for complex systems. It can be concluded that digital twin realism cannot reduce a system's complexity to enhance controlling use, and actually can elicit a lack of focus, resulting in unwanted results, because complex systems have many different internal and external objects (Qi et al. 2019) that can cause digital twin realism to result in lost concentration from tracking, monitoring, and managing a particular use of digital twins to control. Furthermore, digital twins paved the way for visualizing critical parts, and in the case of digital twin complexity, visualization of complex systems with all objects results in decentralization, thereby hindering the positive consequences from controlling use.

6 Conclusions

6.1 Theoretical implications

This study examined which digital twin mechanisms affect different uses of digital twins – the first to examine digital twins' effects systematically depending on their type of use in service operations. The study's significant novelty entails examining the moderating effects from digital twin realism on the relationships between digital twin mechanisms and different uses of digital twins. The study found a direct and positive relationship between the interaction mechanism and digital twins' enabling and controlling uses. Increased interactivity within digital twins signals positive evidence of the extent to which a digital twin can (1) inspire and motivate users to search for, explore, create, and expand efforts in a positive way to fulfill organizational objectives, as well as (2) monitor delivery tasks in line with objectives by constraining behavior. This evidence implies that a digital twin's ability to promote collaboration, communication, and self-expression indicates that the digital twin can act as an initiative of enabling and controlling behavior. The results demonstrate that digital twin realism exerts a negative moderating effect on the relationship between the discovery mechanism and digital twins' controlling use. Thus, the evidence implies that no matter how true the digital twin's representation is, it is not enough to cover the complexity of the physical counterpart if the digital twin suffers from a lack of focus. Finally, the results also indicate the nonexistence of any relationship between digital twins' navigation and discovery mechanisms and enabling and controlling uses. Thus, navigation and discovery mechanisms do not necessarily bring anything new to enabling and controlling functions. Instead, interaction is the significant novelty that the digital twin can bring to the management of the interplay between digital and physical entities.

6.2 Managerial implications

This article contributes to knowledge about how advanced technologies, such as digital twins, can be utilized to support the service industry. This is the first study to examine the effects from digital twins systematically depending on their type of use in service operations. Utilizing advanced technology, digital twins serve as novel platforms that enable innovative services. Also, digital twins act as a communication platform that enables learning and socialization, in which different parties can develop something new together. Digital twins also can be integrated into firms' service processes, enabling deeper interaction mechanisms between users and between products and users. In the study, the interaction mechanism was highlighted and embraced four items in dealing with the extent to which digital twins associate with collaboration, communication, self-expression, and social life. Managers can leverage research findings as they adopt new digital tools to support their service businesses and management needs. For example, managers can leverage research findings by using digital technologies to inspire and motivate employees to search for, explore, create, and expand efforts in a positive way in fulfill organizational objectives. Furthermore, using this study's results, managers can enhance their companies' digital transformation by acknowledging digital twins' multiple facets.

6.3 Limitations and further research

The results provide interesting explanations of different digital mechanisms' role in the different uses of digital twins, coupled with the moderating role of digital twin realism, i.e., the extent to which a digital twin is the true representation of the physical counterpart. The following limitations can be covered in future studies. One limitation that should be taken into account is that this study was conducted in a developed country, so new evidence from future research may contain different results based on the level of the research setting's well-being and technological development, among other factors. Also, the sample may have affected the results, which should be validated with data from different regions and samples. As the study investigated digital twins from a business perspective, it provides broad opportunities for further research. The study also verified that the measurement scales used to gauge digital twin mechanisms were reliable and valid. Future research may add new constructs to the research model to improve coverage of the results.

References

Aheleroff, S., Xu, X., Zhong, R. Y., & Lu, Y. (2020). Digital Twin as a Service (DTaaS) in Industry 4.0: An Architecture Reference Model. Advanced Engineering Informatics, 47, 101225.

Berisha-Gawlowski, A., Caruso, C., & Harteis, C. (2021). The Concept of a Digital Twin and Its Potential for Learning Organizations. In Digital Transformation of Learning Organizations (pp. 95-114). Springer, Cham.

Bertoni, M., & Bertoni, A. (2022). Designing solutions with the product-service systems digital twin: What is now and what is next?. Computers in Industry, 138, 103629.

Bititci, U., Garengo, P., Dörfler, V., & Nudurupati, S. (2012). Performance measurement: challenges for tomorrow. International journal of management reviews, 14(3), 305-327.

Blichfeldt, H., & Faullant, R. (2021). Performance effects of digital technology adoption and product & service innovation–A process-industry perspective. Technovation, 102275.

Boschert, S., & Rosen, R. (2016). Digital twin—the simulation aspect. In Mechatronic futures (pp. 59-74). Springer, Cham.

Cai, Y., Starly, B., Cohen, P., & Lee, Y. S. (2017). Sensor data and information fusion to construct digital-twins virtual machine tools for cyber-physical manufacturing. Procedia manufacturing, 10, 1031-1042.

Cheng, J., Zhang, H., Tao, F., & Juang, C. F. (2020). DT-II: Digital twin enhanced Industrial Internet reference framework towards smart manufacturing. Robotics and Computer-Integrated Manufacturing, 62, 101881.

Delbrügger, T., Lenz, L. T., Losch, D., & Roßmann, J. (2017, September). A navigation framework for digital twins of factories based on building information modeling. In 2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA) (pp. 1-4). IEEE.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. Journal of marketing research, 18(1), 39-50.

Garzella, S., Fiorentino, R., Caputo, A., & Lardo, A. (2021). Business model innovation in SMEs: the role of boundaries in the digital era. Technology Analysis & Strategic Management, 33(1), 31-43.

Grieves, M. (2014). Digital twin: manufacturing excellence through virtual factory replication. White paper, 1, 1-7.

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (1998). Multivariate data analysis. Upper Saddle River; New Jersey, Prentice Hall.

He, B., & Bai, K. J. (2021). Digital twin-based sustainable intelligent manufacturing: A review. Advances in Manufacturing, 9(1), 1-21.

Holopainen, M., Ukko, J., Saunila, M., Rantala, T., & Rantanen, H. (2021). The digital twin combined with real-time performance measurement in lean manufacturing, In Ukko, J., Saunila, M., Heikkinen, J., Semken, R.S. and Mikkola, A. (Eds.) Real-time Simulation for Sustainable Production: Enhancing User Experience and Creating Business Value, Routledge.

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. Educational and psychological measurement, 30(3), 607-610.

Leser, P. E., Warner, J. E., Leser, W. P., Bomarito, G. F., Newman, J. A., & Hochhalter, J. D. (2020). A digital twin feasibility study (part II): non-deterministic predictions of fatigue life using in-situ diagnostics and prognostics. Engineering Fracture Mechanics, 229, 106903.

Meierhofer, J., West, S., Rapaccini, M., & Barbieri, C. (2020). The digital twin as a service enabler: From the service ecosystem to the simulation model. In International Conference on Exploring Services Science (pp. 347-359). Springer, Cham.

Nasiri, M., Ukko, J., Saunila, M., Rantala, T., & Rantanen, H. (2020). Digital-related capabilities and financial performance: the mediating effect of performance measurement systems. Technology Analysis & Strategic Management, 32(12), 1393-1406.

Padovano, A., Longo, F., Nicoletti, L., & Mirabelli, G. (2018). A digital twin based service oriented application for a 4.0 knowledge navigation in the smart factory. IFAC-PapersOnLine, 51(11), 631-636.

Parmar, R., Leiponen, A., & Thomas, L. D. (2020). Building an organizational digital twin. Business Horizons, 63(6), 725-736.

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., ... & Nee, A. Y. C. (2019). Enabling technologies and tools for digital twin. Journal of Manufacturing Systems.

Saunders, M., Lewis, P., & Thornhill, A. (2007). Research methods for Business Students, 4th edition, Pearson Education Limited, England.

Stark, R., Damerau T. (2019). Digital Twin. In: The International Academy for Production Engineering, Chatti S., Tolio T. (eds) CIRP Encyclopedia of Production Engineering. Springer, Berlin, Heidelberg.

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., ... & Nee, A. Y. C. (2021). Enabling technologies and tools for digital twin. Journal of Manufacturing Systems, 58, 3-21.

Rasheed, A., San, O., & Kvamsdal, T. (2020). Digital twin: Values, challenges and enablers from a modeling perspective. IEEE Access, 8, 21980-22012.

Taber, K. S. (2018). The use of Cronbach’s alpha when developing and reporting research instruments in science education. Research in Science Education, 48(6), 1273-1296.

Tao, F., Zhang, H., Liu, A., & Nee, A. Y. (2018a). Digital twin in industry: State-of-the-art. IEEE Transactions on Industrial Informatics, 15(4), 2405-2415.

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

Tao, F., Liu, W. R., Zhang, M., Hu, T., Qi, Q., Zhang, H., ... & Huang, Z. (2019a). Five-dimension digital twin model and its ten applications. Computer Integrated Manufacturing Systems, 25(1), 1-18.

Tao, F., Qi, Q., Wang, L., & Nee, A. Y. C. (2019b). Digital twins and cyber–physical systems toward smart manufacturing and industry 4.0: Correlation and comparison. Engineering, 5(4), 653-661.

Tsou, H. T., & Chen, J. S. (2021). How does digital technology usage benefit firm performance? Digital transformation strategy and organisational innovation as mediators. Technology Analysis & Strategic Management, 1-14.

Urbinati, A., Chiaroni, D., Chiesa, V., & Frattini, F. (2020). The role of digital technologies in open innovation processes: an exploratory multiple case study analysis. R&D Management, 50(1), 136-160.

Vega, A., & Chiasson, M. (2019). A comprehensive framework to research digital innovation: The joint use of the systems of innovation and critical realism. The Journal of Strategic Information Systems, 28(3), 242-256.

Wang, X., & Xu, X. (2014). Virtualise manufacturing capabilities in the cloud: requirements, architecture and implementation. International Journal of Manufacturing Research, 9(4), 348-368.

Zhang, H., Ma, L., Sun, J., Lin, H., & Thürer, M. (2019). Digital twin in services and industrial product service systems: Review and analysis. Procedia CIRP, 83, 57-60.

Zheng, P., & Sivabalan, A. S. (2020). A generic tri-model-based approach for product-level digital twin development in a smart manufacturing environment. Robotics and Computer-Integrated Manufacturing, 64, 101958.