

A complexity management approach to servitization: the role of digital platforms

Ville Eloranta

Aalto University, School of Business, Helsinki, Finland, and

Marco Ardolino and Nicola Saccani

*Laboratorio RISE, Dipartimento di Ingegneria Meccanica e Industriale,
Università degli Studi di Brescia, Brescia, Italy*

Abstract

Purpose – This study aims to enhance the theoretical foundations of servitization research by establishing a theoretical connection with complexity management. The authors develop a conceptual framework to describe complexity management mechanisms in servitization and digital platforms' specific role in allowing synergies between complexity reduction and absorption mechanisms.

Design/methodology/approach – A theory adaptation approach is used. Theory adaptation introduces new perspectives and conceptualization to the domain theory (servitization, with a focus on the role of digital platforms) by informing it with a method theory (complexity management).

Findings – This study provides four key contributions to the servitization literature: (1) connecting the servitization and complexity-management terminologies, (2) identifying and classifying complexity-management mechanisms in servitization, (3) conceptualizing digital platforms' role in servitization complexity management and (4) recognizing digital platforms' complexity-management synergies.

Originality/value – This study highlights that by using digital platforms in servitization and understanding the platform approach more thoroughly, companies can gain new capabilities and opportunities to manage and leverage complexity.

Keywords Complexity, Servitization, Digital, Service operations

Paper type Research paper

1. Introduction

In recent decades, a trend of traditional manufacturers increasing their businesses' amount of service offerings has emerged. The literature has referred to this transition using the term "servitization" (Baines *et al.*, 2009; Vandermerwe and Rada, 1988). Companies create more value and make competitive imitation harder by creating more diverse offerings for their customers and forming more interconnected networks with their stakeholders on both the demand and supply sides (Andreassen and Lidestadt, 1998; Gebauer *et al.*, 2013; Kohtamäki *et al.*, 2019b). Through this process, they aim to better fit with the increasingly complex business environment, which is characterized by significant multiplicity, diversity, interdependence and variability (Kohtamäki *et al.*, 2019b; Kreye *et al.*, 2015; Raja *et al.*, 2018; Zou *et al.*, 2018).

In servitization, increased complexity has emerged from service processes and offerings themselves as businesses consider the needs of many diverse stakeholders, both within and



outside of companies (Jovanovic *et al.*, 2019; Raddats *et al.*, 2016; Spring and Santos, 2014). Complexity has also originated from service organizations' increasing embeddedness in networks with many inter- and intra-organizational relationships (Henneberg *et al.*, 2013; Gebauer *et al.*, 2013). Over the last decade, the increasing adoption of digital technologies has also expanded servitization's complexity. Through "smart" connected products (Porter and Heppelmann, 2014), big data and analytics (Opresnik and Taisch, 2015), the internet of things (IoT), digital platforms (Jovanovic *et al.*, 2021), and augmented reality (Mourtzis *et al.*, 2017), service offerings have diversified and service processes have been re-engineered. Service networks' reach has also extended due to the rapidly expanding connectivity between individuals, organizations and machines (Baines and Lightfoot, 2014).

Despite its inherent link with servitization, increased complexity poses significant challenges (e.g., Raja *et al.*, 2018; Beltagui, 2018; Valtakoski, 2017; Eloranta and Turunen, 2016; Kreye *et al.*, 2015; Benedettini and Neely, 2012a, b). Companies have been encountering significant difficulties as they seek to provide customized solutions in a cost-effective manner (Gebauer *et al.*, 2005). Uncertainties surrounding service offerings and delivery processes (Valtakoski, 2017), as well as difficulties in capability management, have increased (Beltagui, 2018). Moreover, digital servitization specifically faces challenges stemming from the "digitalization trap" (Gebauer *et al.*, 2020b) – that is, the risk of inadequate revenue increases from investments in digitalization.

To address the challenges of increased complexity, servitization scholars have suggested service standardization and modularization, as well as network orchestration and integration (Brax *et al.*, 2017; Kohtamäki *et al.*, 2019a; Kreye *et al.*, 2015; Paiola *et al.*, 2013; Sjodin *et al.*, 2016; Valtakoski, 2017; Windahl and Lakemond, 2006). The recent servitization literature has also specifically proposed that using digital platforms to organize service businesses may significantly help manage complexity (Eloranta and Turunen, 2016; Cenamor *et al.*, 2017; Perks *et al.*, 2017).

Instead of examining the specific methods or results of increasing or decreasing complexity in servitization, the current study focuses on complexity management: finding the proper balance between *complexity reduction* and *complexity absorption*. Through complexity reduction, companies reduce the variety in their responses to environmental stimuli; conversely, through *complexity absorption*, companies try to represent their environment in multiple ways and pursue diverse responses (Boisot and Child, 1999). The extant servitization research has mainly approached complexity reduction vs absorption as an "either-or" question; we, in contrast, reveal the synergies between these two seemingly opposing methods of complexity management. Also, while the extant analyses of complexity management in servitization and digital servitization have employed the terminology native to servitization, we emphasize a more context-agnostic complexity-management vocabulary.

Thus, this study aims to enhance the theoretical foundations of servitization research by establishing a theoretical connection with complexity management. Methodologically, we adopted a theory-adaptation approach (Jaakkola, 2020) in which servitization, and especially digital platforms, constitutes the domain theory and complexity management constitutes the

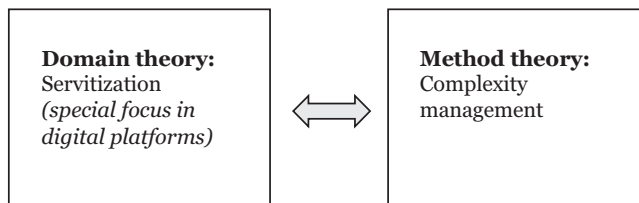


Figure 1. This study's domain theory and method theory

method theory (Jaakkola, 2020) (Figure 1). Through theory adaptation, we develop a conceptual framework to describe complexity management mechanisms in servitization and digital platforms' specific role in allowing synergies between complexity-reduction and -absorption mechanisms.

Additionally, our research addresses more abstract concerns in the servitization domain. The limited theoretical foundations of servitization research have been questioned (Rabetino *et al.*, 2018). Similarly, researchers have highlighted the need to adopt a more integrated perspective in order to understand servitization's underlying logic and mechanisms (Kohtamaki *et al.*, 2019a) and integrate servitization into its adjacent research fields (Rabetino *et al.*, 2018). Furthermore, digital servitization – the essential new domain of servitization research – remains in its infancy, “requiring thorough definition and conceptualization” (Kohtamaki *et al.*, 2019b, p. 383).

The remainder of the current paper is structured as follows. In the next section, we describe the domain and method theories. Then, we build a conceptual framework using theory adaptation. Next, we illustrate this framework with two example cases. A discussion of the results and implications of our theorizing then follows, and the paper's final section concludes.

2. Theoretical background

2.1 Theoretical approach

This study makes a theoretical connection between servitization research and complexity management research, especially within the digital-servitization context. We focus on conceptualizing how servitized companies can both control and accommodate complexity.

We adopted a *theory adaptation* approach, aiming to “change the scope or perspective of an existing theory by informing it with other theories or perspectives” (Jaakkola, 2020, p. 22). This approach has previously been applied in different fields of management studies, such as environmental sustainability (Hazen *et al.*, 2020; Nylund *et al.*, 2021), marketing (Williams *et al.*, 2020), and media (Dal Zotto and Omid, 2020). Theory adaptation revises a domain theory (the area under study) using a method theory (the theory used for adaptation), and it introduces new perspectives that usually challenge existing constructs, theories and assumptions (Jaakkola, 2020; MacInnis, 2011). In our work, servitization – and especially digital platforms – forms the domain theory. Complexity management Figure 1 illustrates our research approach.

2.2 Domain theory: servitization

Traditional manufacturers are shifting from transactional, product-based businesses to more co-creationary relationships with their customers (Lightfoot *et al.*, 2013). This transition has been called “servitization” (Baines *et al.*, 2009; Vandermerwe and Rada, 1988). Servitization is motivated by financial, marketing, and strategic reasons, which entail changes to strategic visions and business models (Baines *et al.*, 2009; Adrodegari and Saccani, 2017).

Servitized companies develop, integrate, and sell complex solutions (Kohtamaki *et al.*, 2019a), which they deliver through use-, outcome- or performance-based contracts (Baines and Lightfoot, 2014). Servitization establishes new requirements and exposes companies to new risks (Nordin *et al.*, 2011; Kindström and Kowalkowski, 2014), calling for a broader range of capabilities than traditional manufacturing required (Ulaga and Reinartz, 2011). To fit their organizational arrangements to new offerings portfolios, firms often embrace a network or ecosystem perspective (Gebauer *et al.*, 2012, 2013; Alghisi and Saccani, 2015; Skylar *et al.*, 2019a).

Digitalization affects servitization. Digital technologies – such as big data and analytics (Opresnik and Taisch, 2015), the IoT (Rymaszewska *et al.*, 2017; Eloranta and Turunen, 2016; Ardolino *et al.*, 2018; Naik *et al.*, 2020), cloud computing (Wen and Zhou, 2016), digital platforms (Cenamora *et al.*, 2017; Kohtamaki *et al.*, 2020a; Jovanovic *et al.*, 2021; Kapoor *et al.*, 2021), and augmented reality (Mourtzis *et al.*, 2017) – enhance “smart connected products” (Porter and Heppelmann, 2014) and powerfully enable servitization (Paschou *et al.*, 2020). Servitization’s adoption of digital technologies, software, and digital platforms has been labeled “digital servitization” (Kowalkowski *et al.*, 2017a). Digital servitization describes the convergence between servitization and digitalization (Gebauer *et al.*, 2020a); it represents a large-scale “transformation in processes, capabilities, and offerings within industrial firms and their associated ecosystems, to progressively create, deliver, and capture increased service value, arising from a broad range of enabling digital technologies” (Sjodin *et al.*, 2020, pp. 479).

Servitization research has always been conducted close to empirical phenomena, and the related research results have achieved high practical relevance. Servitization research spans the domains of general management, operations management, marketing management and service management (Lightfoot *et al.*, 2013; Raddats *et al.*, 2019). However, despite the steady growth of the servitization-related literature, this research domain remains at a nascent stage of theory-building (Kowalkowski *et al.*, 2017b). Rabetino *et al.* (2018, p. 361) analyzed a sample consisting of 1,092 articles about servitization and found that 85% “do not build up their theoretical framework from a grounded theory but merely combine arguments from previous servitization-related research.” Therefore, researchers have argued that servitization research uses limited theoretical foundations (Rabetino *et al.*, 2018; Kohtamaki *et al.*, 2019b) and that this research would benefit from both the integration and unification of findings from different theoretical perspectives, as well as interplay analysis among different servitization domains (Kohtamaki *et al.*, 2019a). Furthermore, a theoretical analysis of the convergence between servitization and digitalization requires thorough definition and conceptualization (Kohtamaki *et al.*, 2019b).

2.3 Method theory: complexity management

The *complexity* concept has been developed in the systems-analysis context to describe multiplicity, diversity, interconnectivity, co-evolution and self-similarity between a system’s elements (Kauffman, 1992; Birkinshaw, 2013). Complexity emerges from “partially connected agents whose interaction gives rise to complex behavior that is characteristic of these systems” (Eisenhardt and Piezunka, 2011, p. 508).

While rooted in mathematical and biological systems (Sanger and Giddings, 2012), the social sciences have already investigated *complexity* for over two decades, especially in economics and organizational analysis (Murray, 1998; Smith, 2005). Herein, the concept of complexity is used when understanding the concept to understand organizations’ external environments and organizations’ fit with their environments (Zhang, 2017), especially when these environments are characterized by uncertainty and turbulence (Smith, 2005).

Based on the work of McKelvey and Boisot (2009), we can use the variety of environmental stimuli to indicate an environment’s complexity. According to Ashby’s (1956) concept of *requisite variety in biological systems*, agents deal appropriately with their environments if they find a fit between their internal variety and their environments’ variety. However, while biological systems progress evolutionarily, interpretative systems – such as organizations – use intentional and planned behaviors to decode and react to external-environment changes (Beer, 1985).

Organizations have two different ways to manage complexity (Boisot and Child, 1999): (1) *complexity reduction*, which simplifies interpretations of an environment and keeps the

variety in an organization's responses low, and (2) *complexity absorption*, which implies multiple – and even opposing – interpretations of an environment. Reduction and absorption strategies address two domains of complexity: cognitive and relational. *Cognitive complexity* refers to the variety of information that actors exchange, while *relational complexity* describes the structures of actors' interactions (Ashmos *et al.*, 2000).

The primary complexity-reduction methods are abstracting stimuli (reducing the number of categories that must be considered to comprehend phenomena) and codifying stimuli (assigning data to categories and giving them form) (Boisot and Child, 1999). In the cognitive-complexity domain, abstraction and codification reduce the number of business goals, simplify strategic activities, and formalize decision-making patterns (Ashmos *et al.*, 2000). In the relational-complexity domain, abstraction and codification instead reduce systems' numbers of interacting elements and interdependencies (Ashmos *et al.*, 2000).

Complexity absorption entails “creating processes or *ad hoc* structures that facilitate information exchange and allow the generation of multiple interpretations of information” (Ashmos *et al.*, 2000, p. 581). In the cognitive-complexity domain, *absorption* refers to pursuing multiple goals and strategies, thereby creating options, portfolios, and risk-hedging strategies while avoiding commitments to any single high-risk–vs–high-return path. In relational complexity, *absorption* implies increasing the number of participants and their interdependencies, thereby enhancing networking, fostering collaborative partnerships and decentralizing decision-making (Ashmos *et al.*, 2000).

Several studies have applied a complex-system perspective to multinational organizations, ecosystems, integrated software and distributed environments (Burnes, 2005; Hurlburt, 2013; Manson, 2001; Phillips and Ritala, 2019). Complexity-management practices have been assessed especially in supply chain management (e.g., Perona and Miragliotta, 2004) and project management (e.g., Maylor and Turner, 2017).

2.4 Adapting servitization theory from a complexity-management perspective

Servitization increases business complexity. Complexity emerges from service processes themselves (Raddats *et al.*, 2016; Spring and Santos, 2014), as well as organizations' embeddedness in service networks with numerous inter- and intra-organizational relationships (Henneberg *et al.*, 2013; Perks *et al.*, 2017; Gebauer *et al.*, 2013). Moreover, the adoption of digital technologies, alongside the interplay between digitalization and servitization, promotes complexity (Kohtamäki *et al.*, 2020b; Gebauer *et al.*, 2020b; Kohtamäki *et al.*, 2019b). Simultaneously, however, digitalization can help coordinate this complexity (Sklyar *et al.*, 2019b).

In a literature review, Zou *et al.* (2018) identified four dimensions of complexity in servitization:

- (1) *Multiplicity*: the number of service components, stakeholders, and interactions among these components and stakeholders (Brax and Visintin, 2017; Eloranta and Turunen, 2016; Gebauer *et al.*, 2013; Smith *et al.*, 2014).
- (2) *Diversity*: the variety of units, activities, and actors involved in developing and delivering servitized offerings – for example, the variety of customer requirements for satisfaction with customized offerings (Raja *et al.*, 2018; Raddats *et al.*, 2016; Song and Sakao, 2017).
- (3) *Interdependence*: dependencies between actors and components in servitized offerings, which inherently relate to both the transition from transactional to relational approaches (Oliva and Kallenberg, 2003; Kreye, 2019) and the development of new services (Kindström and Kowalkowski, 2009).

-
- (4) *Variability*: variations in customer requirements during servitized offerings' lifecycles (Howard *et al.*, 2014; Valtakoski, 2017; Kreye, 2019) and in service processes' *divergence* (Shostack, 1987; Kreye *et al.*, 2015).

When discussing complexity management, the literature has emphasized modularization and standardization paradigms (Pekkarinen and Ulkuniemi, 2008; Brax *et al.*, 2017; Fargnoli *et al.*, 2018; Salonen *et al.*, 2018; Rajala *et al.*, 2019). *Modularization* is a system's division "into components that are only loosely coupled with other components and, thus, have only limited interdependencies and are mediated by defined interfaces" (Valtakoski, 2017 p. 142). *Standardization* refers to commonality of components across different solutions that make them easily repeatable (Salonen *et al.*, 2018).

Leveraging on modularization and standardization, a *modular solution design* can be achieved, which relies on modular systems of standardized components (Davies *et al.*, 2007), and stands at the basis of solution productization and mass customization (Salonen *et al.*, 2018) according to an *industrializer* servitization trajectory (Kowalkowski *et al.*, 2015). Kapoor *et al.* (2021) found through a multiple-case study that manufacturers with wide portfolios of servitized offerings and diverse customer bases emphasized modular offerings, while companies facing rapidly increasing, widespread demand for services focused on standardization.

Thus, while servitization research has already adopted the complexity-management perspective (e.g., Raja *et al.*, 2018; Beltagui, 2018; Valtakoski, 2017; Eloranta and Turunen, 2016; Kreye *et al.*, 2015; Benedettini and Neely, 2012a, b), studies have mostly focused on complexity reduction using hierarchic structures to organize service systems; meanwhile, little attention has been devoted to complexity absorption (Eloranta and Turunen, 2016). Also, potential synergies between the two complexity management mechanisms have been overlooked. Moreover, with few exceptions (Zou *et al.*, 2018; Eloranta and Turunen, 2016), such analysis has cleaved to the servitization context, using servitization-specific terminology.

2.5 A specific interest area in theory adaptation: digital servitization platforms

The literature has widely accepted digital platforms' role in complexity management since their organizing systems allow for "maximizing the variety of contributions [to the system] [...] while maintaining coherence through a minimum level of hierarchy" (Consoli and Patrucco, 2011, p. 201). However, the literature has approached digital platforms from different disciplinary perspectives.

First, product-innovation research has regarded a *platform* as a "set of subsystems and interfaces characterized by a common structure from which a company can efficiently develop and manufacture a family of products" (Ardolino *et al.*, 2020, p. 2). Product-innovation platforms help develop new affordances and support generativity (Nambisan, 2017) – that is, platforms help embrace complexity. They maintain system structures through modularity, common rules and protocols (Gawer and Cusumano, 2014; Bresnahan and Greenstein, 1999). A platform's complementary elements are integrated among themselves and with the platform's core (Baldwin and Clark, 2000), based on standardized architectures.

Second, economists have studied platform thinking from a marketplace perspective (Hagiu and Wright, 2015). The "multisided market" approach has accentuated platforms' role in matching demand with supply, as well as promoting cross-side network effects (Gawer and Cusumano, 2014; Muzellec *et al.*, 2015). The advent of digital technologies and, above all, the Internet has led to businesses' spreading out, based on digital, multisided platforms (Ardolino *et al.*, 2020). This approach has used marketplace logic to expand the reach and variety of contributions to a system while keeping interactions standardized by defining their mediums of exchange and marketplace ownership (Täuscher and Laudien, 2018).

Third, the meta-organizational approach has combined the previous two major approaches (Gawer, 2014). From this perspective, platform users' cooperation extends to all business processes, enabling (1) the creation of nested structures, including several organizations, and (2) the facilitation of diverse resource combinations. The literature has referred to these platforms as "industry platforms" (Gawer and Cusumano, 2014), "platform organizations" (Gawer, 2014), and also, sometimes, "service platforms" (Chesbrough, 2010) and "engagement platforms" (Breibach *et al.*, 2013). The scale, reach and embeddedness of these platforms have made structural control challenging. Consequently, in stable environments, meta-organizational platforms may suffer performance problems – but, in fast-evolving markets, quick adaptation benefits can compensate for probable process-performance losses (Autio *et al.*, 2018).

Servitization research has identified platforms as servitization enablers. Platforms integrate technological components (Cenamor *et al.*, 2017; Pirola *et al.*, 2020) and connect actors within ecosystems (Kohtamäki *et al.*, 2019b). Platforms also allow for coping with integrated solutions' increased complexity as "companies utilize digital platforms to address more complex customer problems by analyzing and combining data about various products in the platform ecosystem" (Gebauer *et al.*, 2020c).

The literature has emphasized platforms' potential in managing service-business complexity, allowing diverse offerings alongside operational efficiency and reducing transaction costs (Cenamor *et al.*, 2017; Kamalaldin *et al.*, 2020; Kohtamäki *et al.*, 2019b, 2020a; Sklyar *et al.*, 2019a). However, the related analysis has mainly applied a complexity-reduction perspective, as in service-modularization and integrated solution-development discussions (Kapoor *et al.*, 2021). Platforms, however, also contribute to complexity absorption – for example, through orchestrating service innovation and provision networks in the servitization domain (Eloranta and Turunen, 2016). Moreover, while digital servitization platforms allow for standardization and reduce transaction costs (Kohtamäki *et al.*, 2019b), platforms also constitute relation-specific investments that should foster close relationships among customers and providers (Kamalaldin *et al.*, 2020).

Further digital-servitization research on platforms' role from an ecosystem perspective has been called for (Kohtamäki *et al.*, 2019b). A growing interest has focused on platform-based business models' configuration and evolution (Jovanovic *et al.*, 2021; Tian *et al.*, 2021; Kapoor *et al.*, 2021). However, digital platforms' contribution to servitization complexity management has not yet been conceptualized.

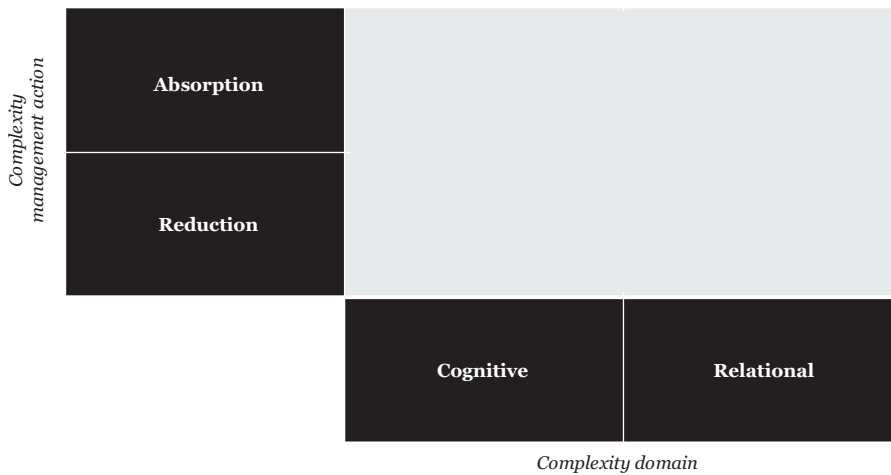
3. Framework development

3.1 Framework foundations

We summarized our theory-adaptation process and its results in a conceptual framework (Figure 2). The framework's vertical dimension exhibits different approaches to complexity management: reduction and absorption. *Complexity reduction* means simplifying the interpretation of a complex environment, whereas *complexity absorption* describes allowing (and purposefully generating) multiple interpretations of an environment. The framework's horizontal dimension represents complexity's two different domains: cognitive and relational. *Cognitive complexity* refers to the variety of exchanged information, while *relational complexity* describes the structure of interactions among actors.

3.2 A complexity-management perspective on servitization

To continue our theory adaptation, we applied our research framework to our domain theory, servitization, by inserting the complexity-management mechanisms that the servitization literature has identified (Figure 3) to Figure 2. These mechanisms are linked to the core



Complexity management approach to servitization

629

Figure 2. Our conceptual framework using complexity's dimensions and domains

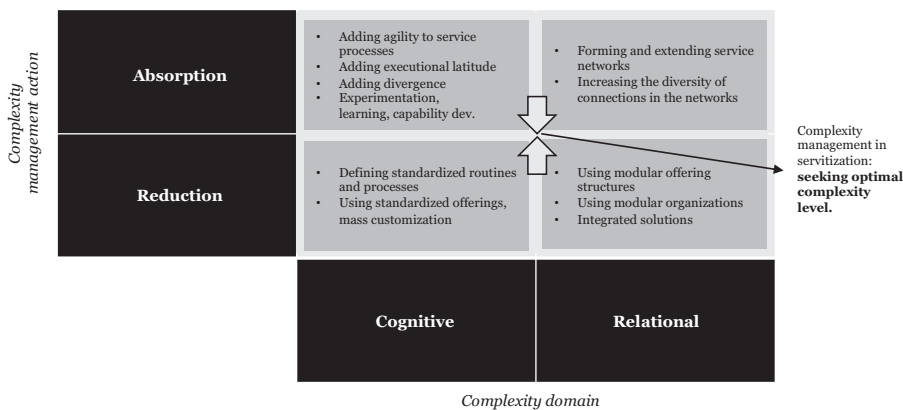


Figure 3. Our conceptual framework applied to servitization

complexity-reduction methods (abstraction and codification) and to complexity absorption (pursuing multiple goals and strategies, as well as increasing the number of participants and their interdependencies in a system).

In servitization, enhancing customer involvement and meeting individualized needs increase representations of reality (Andreassen and Lindestad, 1998) and uncertainties surrounding the offering and delivery processes (Valtakoski, 2017). From the complexity-management perspective, this process involves absorbing complexity in the cognitive domain – extending the variety of firms' processes and offerings and pursuing multiple business goals.

In the relational domain, complexity is absorbed by embedding service organizations into large-scale organizational networks and ecosystems, which are characterized by numerous inter- and intra-organizational relationships (Gebauer et al., 2013; Kohtamäki et al., 2019b). Service and solution networks can be considered complex systems that continuously develop (Basole and Rouse, 2008). Networking also increases within firms (Jovanovic et al., 2019); Beltagui (2018) revealed that the service business's increasing complexity challenges

companies' capability development, necessitating more experimentation and evolutionary learning, which leads firms into more flexible and decentralized structural arrangements. In the complexity-management language, this process involves increasing the number of participants and their interdependencies in business systems.

However, simultaneously, firms try to avoid the challenges of increased complexity. In the cognitive domain, companies simplify their offerings and create productized solutions and mass-customized services (Eloranta and Turunen, 2016; Salonen *et al.*, 2018; Kohtamäki *et al.*, 2019a). Firms also standardize their processes of developing and delivering offerings (Kohtamäki *et al.*, 2019a). In other words, firms categorize (codify) their offerings and processes and also simplify (abstract) them.

In the relational domain of complexity, firms reduce complexity with modularization techniques (Valtakoski, 2017; Kreye *et al.*, 2015) to manage offerings, processes and organizations; modularization works by simplifying structures and dividing these structures into components. Firms also organize their service networks into stable structures; in large networks of actors that co-create value, manufacturers usually act as integrators (Windahl and Lakemond, 2006) and orchestrators (Paola *et al.*, 2013).

However, while complexity-reduction mechanisms control complexity, they also entail a risk of forming excessively rigid structures that fail to serve diverse customer needs and may contradict servitization's fundamental aim (Agarwal and Selen, 2009; Kowalkowski *et al.*, 2012). This risk is due to the mechanisms of complexity-absorption and -reduction challenging each other, especially in the cognitive domain. Firms are faced with an either-or decision (Kohtamäki *et al.*, 2020a) in seeking optimal complexity levels – for example, choosing between agile processes and standardized processes or between adding divergent offerings or increasing their standardization. In the relational domain, the counteractive tendency is less prevalent: service networks can be extended and diversified while their structure is sustained by modularization. However, the servitization literature strongly reflects the tendency to integrate (build stable networks around orchestrators); therefore, practically, complexity management is often steered primarily toward reduction mechanisms.

3.3 Augmenting our framework from a platform perspective

To highlight digital platforms' potential in servitization from a complexity-management perspective, we further developed Figure 2, this time including the complexity management mechanisms that the platform literature has identified (Figure 4).

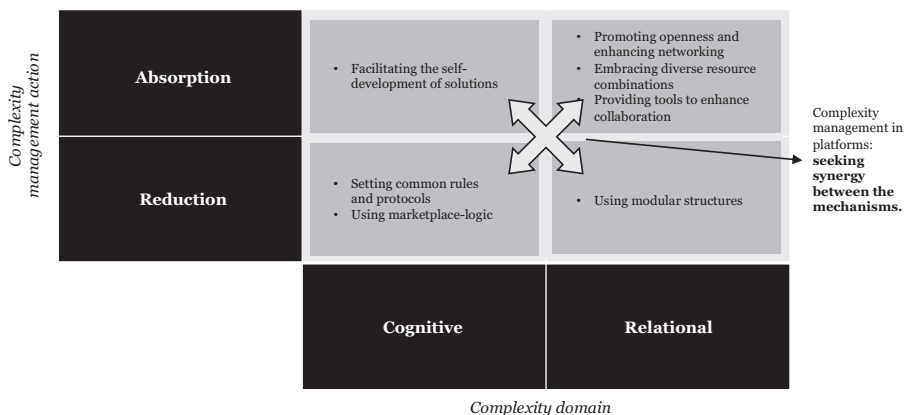


Figure 4.
Our conceptual framework applied to platforms

The complexity of platforms' interactions is reduced through common rules and protocols (Constantiou *et al.*, 2017), such as platforms' application programming interfaces (APIs) and device interoperability protocols, which refer to the theoretical construct of codification. Platforms also reduce complexity by organizing themselves as marketplaces (Hagiu and Wright, 2015), a specific abstraction-driven way to simplify actor-to-actor interrelations and divide labor across platforms. These methods – common rules and protocols, as well as market logic – reduce complexity in the cognitive domain. In turn, as a platform-related complexity-reducing mechanism, modularity (Boudreau, 2010; Cenamor *et al.*, 2017) operates in the relational domain. It uses codification's theoretical approaches to divide system architecture, and it uses abstraction to simplify system architecture. Platforms exhibit modularization by dividing independent components based on their core functionality.

For complexity absorption, digital platforms have deployed tools that allow platform users to self-develop solutions. Practically, these tools include software development kits and customization wizards for users and developers. Platforms also offer collaboration tools to facilitate users' interactions. These approaches drive experimentation and adaptation on platforms; self-development and collaboration push platforms to evolve continuously. In complexity management, these mechanisms pursue multiple goals and strategies.

There are also complexity absorption mechanisms in platforms. Platforms can be open, promoting networking (Choi *et al.*, 2019; Abhari *et al.*, 2017; Broekhuizen *et al.*, 2019); that is, they increase the number of participants and their interdependencies. Also, platforms can specifically facilitate the formation of diverse resource combinations (Wei *et al.*, 2019; Abhari *et al.*, 2017). Practically, this facilitation entails allowing the mutual exposure of platform users' selected resource and capability pools through interfaces, thereby flexibly forming novel resource-and-capability combinations. Also, the recent platform literature has included case studies on platforms that have decentralized their governance and ownership (Chen *et al.*, 2020), which has further empowered these platforms' users while increasing and diversifying the number of interdependencies between them.

In analyzing the complexity-absorption and -reduction mechanisms, we see that in platforms, these mechanisms work in synergy (Figure 4). Platforms seem able to maximize a system's variety while maintaining coherence (Consoli and Patrucco, 2011, p. 201). The related decision is not to define an "optimal" level of complexity but, rather, to manage complexity via some complexity-absorbing mechanisms (and domains) and then mitigate potential issues with complexity-reducing mechanisms (and domains).

Specifically, the mechanisms meant to maintain cognitive stability (complexity reduction) and relational diversity (complexity absorption) seem to have notable synergies. The mechanisms for common rules and protocols – as well as marketplace creation – standardize interactions in a system. These mechanisms allow more degrees of freedom to grow and diversify the relational domain. A platform's scale and reach can, thereby, expand without the significant risk of resource depletion. Also, increasing relational stability has synergies with growing cognitive diversity. Practically, reducing the number of parts in a system's architecture through a modularization mechanism seems to allow for interpretative flexibility regarding interactive content, driven by the mechanisms of self-development solution tools and enhanced collaboration between platform stakeholders.

This quest for synergy between complexity mechanisms and domains contrasts with how the servitization literature has approached complexity, as we noted earlier. The servitization literature has regarded complexity management mostly as either-or decisions – selecting desired levels of complexity (Kohtamaki *et al.*, 2020a). Therefore, our complete framework highlights the following argument: by using digital platforms in servitization and understanding the platform approach more thoroughly, companies can gain new capabilities and opportunities to manage and leverage complexity.

3.4 Illustrating our framework

Although this study remains conceptual, we use two illustrative examples of IoT platforms to show a practical application of the complexity management approach through digital platforms in the servitization context. We also highlight the interplay between complexity-management mechanisms.

The first example is ThingWorx by Parametric Technology Corporation, a digital platform meant to provide manufacturers advanced services that are integrated into tangible assets in the domains of remote monitoring, asset optimization, and workforce efficiency. The second example is Siemens's MindSphere, a platform-based solution that has extended Siemens's offering portfolio to industrial services for own and third-party assets. [Table 1](#) summarizes the complexity-management mechanisms that these illustrative companies have adopted.

For complexity absorption, in the cognitive domain, both platforms provide tools and specific development environments that enable customers to build and then integrate their applications and services. Developers can, thus, create applications, connect assets, collect data, and provide IoT services to industrial customers.

The two example platforms are also characterized by mechanisms to absorb complexity in the relational domain. Both platforms promote open, collaborative approaches among developers. ThingWorx enhances collaborative hosting sessions in specific online communities, while MindSphere uses an open-source tool for developer communities to share resource and libraries.

ThingWorx has also created a worldwide vendor and service-provider ecosystem, as well as an application-enablement platform where participants can learn how to build their own IoT applications. Similarly, MindSphere has built an ecosystem comprising application developers, system integrators, technology partners, and infrastructure providers. Thus, these platforms allow users to combine different resources in order to create advanced solutions.

Moreover, the platforms have deployed complexity-reduction mechanisms in both the relational and cognitive domains. Both platforms provide alternative ways to connect with any device, including edge agents, protocol adapters, native device clouds, third-party device cloud support, and application APIs. Therefore, connected-product providers have a set of standards and rules that helps them work with an entire IoT ecosystem's interoperability.

In addition, both platforms provide marketplaces, allowing users to build and sell their own IoT applications and find market-ready solutions. As these marketplaces grow, developers have more opportunities to build their solutions using comprehensive catalogs of prebuilt and tested components. Marketplace-logic simplifies the interactions between different parties, and thereby reduces complexity.

Finally, both example platforms use modular IoT application-platform architecture. Through interchangeable modules and easily configurable native functionalities, users can benefit from the platforms' flexibility and customized functionality while receiving cost-efficient, timely updates and carrying out agile development paradigms.

These two examples also help us discuss the interplay between complexity-reduction and -absorption mechanisms ([Figure 5](#)). The synergy between cognitive-complexity reduction and relational-complexity absorption (relationship 1 in [Figure 5](#)) is visible in the platforms' adoption of common rules and protocols, as well as their creation of marketplaces, allowing stable interactions. This synergy allows more complexity to be absorbed in the relational domain – for example, by growing developer communities.

Second, relational-complexity reduction seems synergetic with cognitive-complexity absorption (relationship 2 in [Figure 5](#)). Practically, reducing the number of parts in a system's architecture through the modularization mechanism allows for interpretative flexibility vis-à-vis interactive content, allowing advanced self-development solution tools between

Complexity management mechanism	Promoting openness and enhances networking	Facilitating the self-development of solutions	Providing tools to enhance collaboration	Embracing diverse resource combinations	Setting common rules and protocols	Using marketplace logic	Using modularity
Complexity management approach	Absorption	Absorption	Absorption	Absorption	Reduction	Reduction	Reduction
Complexity domain	Relational	Cognitive	Relational	Relational	Cognitive	Cognitive	Relational
Example: ThingWorx	Diverse user communities (vendors and service providers) with diverse technological knowledge	Provides tools and resources to support developers in creating and tailoring customized solutions	Supports developer-to-developer collaboration with a database of illustrative articles, technical documentation, and download support software	Connects millions of devices through interactions with business systems, such as ERP, CRM, and big-data analytics software	Allows connected-product providers to exploit a set of standards, secure, and scalable tools with configurable, role-based authorizations	Its marketplace aims to both develop and sell own-IoT applications, as well as finding market-ready solutions	Uses a modular structure, encompassing a core module that connects to all platform components
Example: MindSphere	Ecosystem characterized by broad domain expertise and several IT capabilities (app developers, system integrators, and tech partners)	Provides an environment that facilitates the development of customer applications	Incentivizes collaboration through an open-source platform that facilitates resource-sharing and library-sharing among community users	Provides partners in both operational technology (OT) and informational technology (IT) with tools to meet diverse customer needs	MindConnect suite connects physical assets (industrial devices) with standardized, secure interfaces	Third-party developers can also market their applications via the platform's digital marketplace	APIs make modular architecture and help customers develop customized applications

Table 1. Complexity-management mechanisms on our two example platforms (data sources for illustrative cases indicated in [Appendix](#))

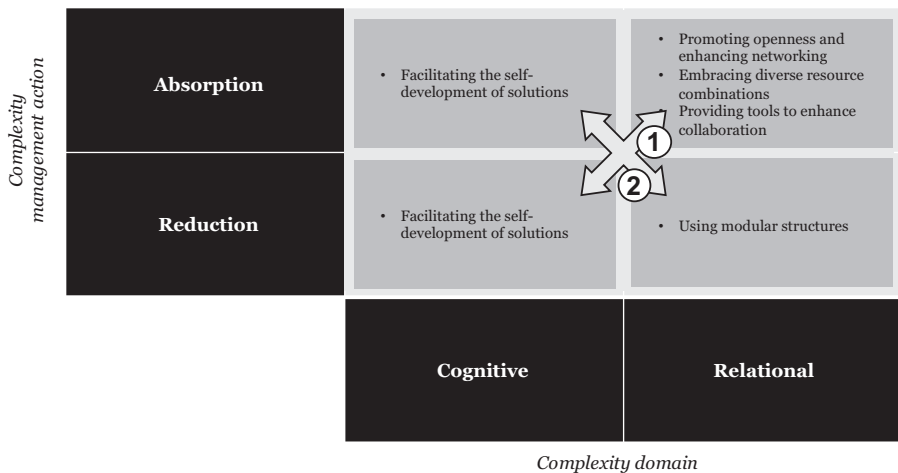


Figure 5.
The interplay between complexity-reduction and -absorption mechanisms on our example platforms

platforms' stakeholders. On ThingWorx, this effect is visible in customers' ability to combine their resources with resources from the ThingWorx community, using the platform's modular architecture. Correspondingly, MindSphere customers can leverage modularization by self-developing apps and connecting them with Siemens's apps, as well as third-party suppliers' apps.

4. Discussion

Our study provides four key contributions to the servitization literature: (1) connecting the servitization and complexity-management terminologies, (2) identifying and classifying complexity-management mechanisms in servitization, (3) conceptualizing digital platforms' role in servitization complexity management, and (4) recognizing digital platforms' complexity-management synergies.

4.1 Connecting complexity-management and servitization terminologies

Servitization researchers have addressed complexity management but their analysis has cleaved closely to the servitization context, using servitization-specific terminology. Our conceptual framework connects the servitization-research terminology with the context-agnostic terminology of the complexity-management literature. The four-field framework we presented in Figure 3 categorizes servitization-related actions into mechanisms that *reduce* complexity and mechanisms that *absorb* complexity. Furthermore, these mechanisms were also divided into the domains of *cognitive complexity* and *relational complexity*. Our terminological classification provides a direct link between the servitization and complexity-management research domains, thereby allowing servitization scholars to build more precise theoretical and empirical links between studies across the two literature streams. Thus, our research clarifies servitization research and helps develop complexity-management research.

4.2 Identifying and classifying complexity-management mechanisms in servitization

The literature has recognized that servitization increases complexity, leading to positive and negative effects (Kohtamäki *et al.*, 2020b; Raja *et al.*, 2018; Eloranta and Turunen, 2016; Valtakoski, 2017). Different ways to manage this increased complexity have been identified

(Benedettini and Neely, 2012a, b; Kohtamäki *et al.*, 2020a; Valtakoski, 2017; Kreye *et al.*, 2015; Raja *et al.*, 2018). However, little attention has been devoted to complexity absorption, and the reduction-oriented narrative has been prevalent in servitization research (Eloranta and Turunen, 2016).

The current study contributes to complexity-management servitization research by addressing both complexity-reduction and complexity-absorption. We have identified 11 complexity-management mechanisms in servitization, described and classified according to their aims (to reduce or absorb complexity) and complexity domain (cognitive or relational), as Figure 3 shows.

This study's results offer a lens through which to understand how servitizing companies can balance complexity-reduction and -absorption to achieve their desired servitization outcomes. Increased complexity must be accommodated to intensify co-creation with customers and suppliers and to decrease the competitive threat of imitation (Valtakoski, 2017). Complexity-reduction, meanwhile, is needed to maintain efficiency and companies' focus; however, excessive complexity-reduction mitigates servitization's competitive advantages (Valtakoski, 2017). Our framework provides an improved structure to analyze the tension between complexity reduction and absorption.

4.3 Conceptualizing digital platforms' role in servitization complexity management

Digitalization and technology adoption in servitization have provided unique possibilities and posed significant risks to servitizing companies (Kohtamäki *et al.*, 2019b; Sjödin *et al.*, 2020). Digital servitization increases service systems' complexity and challenges traditional complexity-management methods (Kohtamäki *et al.*, 2019b). Adaptable organizational forms are needed for companies to benefit from digital servitization (Valtakoski, 2017; Raja *et al.*, 2018). Thus, in this study, we have specifically investigated the complexity-management opportunities that platforms offer for digital servitization.

Our study provides a structural characterization of how complexity-management mechanisms are deployed on digital platforms. We identified nine different complexity-management mechanisms, which we described and classified according to their complexity management action (absorption or reduction) and domain (cognitive or relational), as Figure 4 illustrates. Thus, we offer a novel approach to investigating platforms' role in complexity management. Since our analysis has covered both complexity-absorption and -reduction approaches, our results particularly complement the works of, for example, Eloranta and Turunen (2016) and Cenamor *et al.* (2017).

4.4 Recognizing digital platforms' complexity-management synergies

This study also contributes to the servitization literature by extending complexity-management opportunities involving the synergetic interplay between complexity-reduction and -absorption mechanisms. Thus far, the literature has aimed to seek a compromise between complexity-reduction and -absorption; however, the complexity-management framework that we have applied to digital platforms (Figure 4) suggests that platforms can help achieve not only a compromise but also a synergy between complexity-reduction and -absorption. This argument aligns with Sjödin *et al.* (2020) and Gebauer *et al.* (2020a, b), but we have more precisely elaborated on this topic in the complexity-management field.

Figure 4 shows how standardizing interactions through marketplace logic, common rules, and protocols on platforms (complexity reduction in the cognitive domain) accommodates a greater reach and broader networks on platforms (complexity absorption in the relational domain). Similarly, complexity reduction in the relational domain, through modularization, accommodates greater complexity (e.g., richer interactive content between platform users) in the cognitive domain. By highlighting this interplay, we have responded to a specific call for more research on platform-based business models' relation to customized solutions,

particularly from studies on service modularity and “how to determine best approaches and combinations of service elements in different service settings in order to combine modular elements, customize and personalize the service offering effectively” (Brax *et al.*, 2017, pp. 691). We have also discussed how modularity can reduce complexity in synergy with complexity-absorption mechanisms.

This synergetic enforcement of opposing complexity-management mechanisms constitutes an advancement in the servitization literature. Particularly, this finding suggests that digital platforms provide servitizing companies opportunities to overcome a typical challenge of servitization – that is, the need to compromise between customization and efficiency. The servitization literature has shown, with empirical research, how firms have sought a level of complexity that seeks the compromise between the costs of increasing complexity with the opportunity costs of limiting complexity. Our study has shown that platforms allow greater flexibility since they can accommodate a greater variety of outcomes while, at the same time, keep complexity under control.

This finding may be especially important to digital servitization: when technological possibilities are adopted, their success is not linear but, rather, forms a U-curve (Kohtamäki *et al.*, 2020b), so companies should be able to rapidly increase added technological complexities’ value in order to overcome the lower part of this U-shape. Also, the technological investments’ value is difficult to know beforehand, companies need platforms’ flexibility and scale to explore opportunities, pivot in new directions, and learn during this process (Kohtamäki *et al.*, 2020b; Valtakoski, 2017; Sjödin *et al.*, 2020).

4.5 Limitations and avenues for future research

A limitation we face is that our study is purely conceptual – despite our use of illustrative cases to practically show our conceptual findings. Therefore, further empirical research is needed. The complexity-management synergies we have proposed through our theorizing should be further investigated since they could offer relevant advancements in the analysis of fundamental servitization paradoxes (including the infamous service paradox; Gebauer *et al.*, 2005).

Among digital platforms’ complexity-management mechanisms that we have discussed, “decentralizing governance” (Figure 4) deserves particular attention in future research. In recent years, the platform literature has explored the possibilities of increased decentralization and democratic governance to build more engagement among platform users and resilience among platforms (Chen *et al.*, 2020). The servitization literature has been mixed in this regard. Eloranta and Turunen (2016) have provided hints of governance decentralization intertwined with complexity benefits. Kohtamäki *et al.* (2019b) and Jovanovic *et al.* (2021) have also observed complexity-management benefits in promoting service ecosystems’ openness. However, Skylar *et al.* (2019a) emphasized the importance of centralized decision-making in service networks. Large-scale empirical support for each argument is lacking, and subsequent studies are needed.

Furthermore, while a qualitative research approach is the dominant *modus operandi* in servitization research, we highly recommended addressing complexity management quantitatively as well to assess complexity levels in servitized contexts and, consequently, quantitatively evaluate the identified complexity-management mechanisms’ impact. Indeed, the literature has provided methods to measure complexity in manufacturing contexts (e.g., Vrabic and Butala, 2012; Isik, 2010; Jenab and Liu, 2010). Our study did not conduct any quantitative analysis of the analyzed mechanisms’ levels of complexity or effects.

Finally, the theoretical framework that we have developed should also be confronted to identify potential additions vis-à-vis mechanisms and their interplay. While complexity management has been explored in servitization research for over a decade, in-depth

theorizing has only recently entered these discussions. The framework we have introduced in this study provides a solid foundation, but more analysis is needed.

4.6 Managerial implications

While this study has focused on theoretical development, our findings offer several implications for practitioners in servitized businesses, especially in the platform-development field. Despite the growing interest in digital technologies and platforms, awareness of platforms' impact on service processes – especially in the industrial B2B domain – remains low.

This study has identified and analyzed complexity-management mechanisms that can be implemented on platforms. Therefore, managers can more consciously develop digital platforms to support servitization strategies and develop suitable portfolios of complexity-management mechanisms. For instance, managers should know that the larger a platform's users community (e.g., the number of parties engaged in providing services to a global community of customers and third-party service providers), the greater the need to seek synergies with complexity-reduction mechanisms that simplify transactions (marketplaces) and standardize interactions between parties. On the other hand, scale and diversity within platforms' user communities call for absorption mechanisms to accommodate parties' customized needs in the cognitive-complexity domain. This accommodation, in turn, will require the adoption of complexity-reduction mechanisms to control systems' structures (modularity).

Our study's more abstract contributions are also informative for practitioners. Servitization remains challenged by the "service paradox," which reflects the difficulty of providing customized solutions to customers' needs in a cost-effective manner (Gebauer *et al.*, 2005). Digital servitization is also challenged by the "digitalization trap" (Gebauer *et al.*, 2020b) – that is, the risk of inadequate revenue increases from digitalization investments. Our conceptual framework offers practitioners tools to (1) analyze and navigate the complexities of (digitally) servitized businesses and (2) design their desired complexity-management actions. Our framework also offers a vocabulary with which to discuss the challenges of servitization at the abstract level. Such discussions may help practitioners overcome their businesses' dominant logics, which could be inhibiting their innovation of new solutions to servitization-related problems.

5. Conclusion

This study has enhanced the conceptual foundations of servitization research by establishing a theoretical connection with complexity management. Our proposed framework has provided a properly grounded foundation for analyzing complexity-management mechanisms, and their interplay, in servitization. We have identified and classified the complexity-management mechanisms that servitization has adopted to reduce or absorb complexity. Moreover, we have analyzed interpretations of these mechanisms on digital platforms, recognizing digital platforms as flexible organizational arrangements that can drive complexity-management synergies.

References

- Abhari, K., Davidson, E.J. and Xiao, B. (2017), "Co-innovation platform affordances: developing a conceptual model and measurement instrument", *Industrial Management and Data Systems*, Vol. 117 No. 5, pp. 873-895, doi: [10.1108/IMDS-05-2016-0156](https://doi.org/10.1108/IMDS-05-2016-0156).
- Adrodegari, F. and Sacconi, N. (2017), "Business models for the service transformation of industrial firms", *The Service Industries Journal*, Vol. 37 No. 1, pp. 57-83.
- Agarwal, R. and Selen, W. (2009), "Dynamic capability building in service value networks for achieving service innovation", *Decision Sciences*, Vol. 40 No. 3, pp. 431-475.

- Alghisi, A. and Saccani, N. (2015), "Internal and external alignment in the servitization journey—overcoming the challenges", *Production Planning and Control*, Vol. 26 Nos 14-15, pp. 1219-1232.
- Andreassen, T. and Lindestad, B. (1998), "Customer loyalty and complex services: the impact of corporate image on quality, customer satisfaction, and loyalty for customers with varying degrees of service expertise", *International Journal of Service Industry Management*, Vol. 9 No. 1, pp. 7-23.
- Ardolino, M., Rapaccini, M., Saccani, N., Gaiardelli, P., Crespi, G. and Ruggeri, C. (2018), "The role of digital technologies for the service transformation of industrial companies", *International Journal of Production Research*, Vol. 56 No. 6, pp. 2116-2132.
- Ardolino, M., Saccani, N., Adrodegari, F. and Perona, M. (2020), "A business model framework to characterize digital multisided platforms", *Journal of Open Innovation: Technology, Market and Complexity*, Vol. 6 No. 1, p. 10, doi: [10.3390/joitmc6010010](https://doi.org/10.3390/joitmc6010010).
- Ashby, W.R. (1956), *An Introduction to Cybernetics*, Chapman and Hall, London.
- Ashmos, D.P., Duchon, D. and McDaniel, R.R. (2000), "Organizational responses to complexity: the effect on organizational performance", *Journal of Organizational Change Management*, Vol. 13 No. 6, pp. 577-595.
- Autio, E., Nambisan, S., Thomas, L.D. and Wright, M. (2018), "Digital affordances, spatial affordances, and the genesis of entrepreneurial ecosystems", *Strategic Entrepreneurship Journal*, Vol. 12 No. 1, pp. 72-95.
- Baines, T. and Lightfoot, H. (2014), "Servitization of the manufacturing firm: exploring the operations practices and technologies that deliver advanced services", *International Journal of Operations and Production Management*, Vol. 34 No. 1, pp. 2-35.
- Baines, T., Lightfoot, H.W., Benedettini, O. and Kay, J.M. (2009), "The servitization of manufacturing: a review of literature and reflection on future challenges", *Journal of Manufacturing Technology Management*, Vol. 20 No. 5, pp. 547-567.
- Baldwin, C. and Clark, K. (2000), *Design Rules: The Power of Modularity*, MIT Press, Cambridge, MA.
- Basole, R.C. and Rouse, W.B. (2008), "Complexity of service value networks: conceptualization and empirical investigation", *IBM Systems Journal*, Vol. 47 No. 1, pp. 53-70.
- Beer, S. (1985), *Diagnosing the System for Organizations*, John Wiley, London, New York.
- Beltagui, A. (2018), "A design-thinking perspective on capability development", *International Journal of Operations and Production Management*.
- Benedettini, O. and Neely, A. (2012a), "Complexity in services: an interpretative framework", *23rd Annual Conference of the Production and Operations Management Society (POMS)*, pp. 1-11.
- Benedettini, O. and Neely, A. (2012b), "Factors influencing service complexity: the perspective of servitized manufacturers", in *International Annual European Operations Management Association Conference*, pp. 1-5.
- Birkinshaw, J. (2013), "Managing complexity is the epic battle between emergence and entropy", *Harvard Business Review*, available at: <https://hbr.org/2013/11/managing-complexity-is-the-epic-battle-between-emergence-and-entropy> (accessed 5 December 2020).
- Boisot, M. and Child, J. (1999), "Organizations as adaptive systems in complex environments: the case of China", *Organization Science*, Vol. 10 No. 3, pp. 237-252.
- Boudreau, K. (2010), "Open platform strategies and innovation: granting access vs. devolving control", *Management Science*, Vol. 56 No. 10, pp. 1849-1872.
- Brax, S.A. and Visintin, F. (2017), "Meta-model of servitization: the integrative profiling approach", *Industrial Marketing Management*, Vol. 60, pp. 17-32.
- Brax, S.A., Bask, A., Hsuan, J. and Voss, C. (2017), "Service modularity and architecture—an overview and research agenda", *International Journal of Operations and Production Management*, Vol. 37 No. 6, pp. 686-702, doi: [10.1108/IJOPM-03-2017-0191](https://doi.org/10.1108/IJOPM-03-2017-0191).

-
- Breidbach, C.F., Kolb, D.G. and Srinivasan, A. (2013), "Connectivity in service systems: does technology-enablement impact the ability of a service system to co-create value?", *Journal of Service Research*, Vol. 16 No. 3, pp. 428-441.
- Bresnahan, T.F. and Greenstein, S. (1999), "Technological competition and the structure of the computer industry", *Journal of Industrial Economics*, Vol. 47 No. 1, pp. 1-40.
- Broekhuizen, T.L.J., Emrich, O., Gijsenberg, M.J., Broekhuis, M., Donkers, B. and Sloot, L.M. (2019), "Digital platform openness: drivers, dimensions and outcomes", *Journal of Business Research*.
- Burnes, B. (2005), "Complexity theories and organizational change", *International Journal of Management Reviews*, Vol. 7 No. 2, pp. 73-90.
- Cenamor, J., Sjödin, D.R. and Parida, V. (2017), "Adopting a platform approach in servitization: leveraging the value of digitalization", *International Journal of Production Economics*, Vol. 192, pp. 54-65.
- Chen, Y., Pereira, I. and Patel, P. (2020), "Decentralized governance of digital platforms", *Journal of Management*, Forthcoming.
- Chesbrough, H. (2010), "Business model innovation: opportunities and barriers", *Long Range Planning*, Vol. 43 No. 2, pp. 354-363.
- Choi, G., Nam, C. and Kim, S. (2019), "The impacts of technology platform openness on application developers' intention to continuously use a platform: from an ecosystem perspective", *Telecommunications Policy*, Vol. 43 No. 2, pp. 140-153.
- Consoli, D. and Patrucco, P.P. (2011), *Complexity and the Coordination of Technological Knowledge: The Case of Innovation Platforms*, Edward Elgar Publishing.
- Constantiou, I., Marton, A. and Tuunainen, V.K. (2017), "Four models of sharing economy platforms", *MIS Quarterly Executive*, Vol. 16 No. 4.
- Dal Zotto, C. and Omid, A. (2020), "Platformization of media entrepreneurship: a conceptual development", *Nordic Journal of Media Management*, Vol. 1 No. 2, pp. 209-233.
- Davies, A., Brady, T. and Hobday, M. (2007), "Organizing for solutions: systems sellers vs. systems integrator", *Industrial Marketing Management*, Vol. 36 No. 2, pp. 183-193.
- Eisenhardt, K. and Piezunka, H. (2011), "Complexity theory and corporate strategy", *The SAGE Handbook of Complexity and Management*, pp. 506-523.
- Eloranta, V. and Turunen, T. (2016), "Platforms in service-driven manufacturing: leveraging complexity by connecting, sharing, and integrating", *Industrial Marketing Management*, Vol. 55, pp. 178-186.
- Fargnoli, M., Haber, N. and Sakao, T. (2018), "PSS modularisation: a customer-driven integrated approach", *International Journal of Production Research*, pp. 1-17.
- Gawer, A. (2014), "Bridging differing perspectives on technological platforms: toward an integrative framework", *Research Policy*, Vol. 43 No. 7, pp. 1239-1249.
- Gawer, A. and Cusumano, M.A. (2014), "Industry platforms and ecosystem innovation", *Journal of Product Innovation Management*, Vol. 31 No. 3, pp. 417-433.
- Gebauer, H., Fleisch, E. and Friedli, T. (2005), "Overcoming the service paradox in manufacturing companies", *European Management Journal*, Vol. 23 No. 1, pp. 14-26.
- Gebauer, H., Ren, G.J., Valtakoski, A. and Reynoso, J. (2012), "Service-driven manufacturing: provision, evolution and financial impact of services in industrial firms", *Journal of Service Management*, Vol. 23 No. 1, pp. 120-136.
- Gebauer, H., Paiola, M. and Saccani, N. (2013), "Characterizing service networks for moving from products to solutions", *Industrial Marketing Management*, Vol. 42 No. 1, pp. 31-46.
- Gebauer, H., Paiola, M., Saccani, N. and Rapaccini, M. (2020a), "Digital servitization: crossing the perspectives of digitization and servitization", *Industrial Marketing Management*, Vol. 93, pp. 382-388.

- Gebauer, H., Fleisch, E., Lamprecht, C. and Wortmann, F. (2020b), "Growth paths for overcoming the digitalization paradox", *Business Horizons*, Vol. 63 No. 3, pp. 313-323, doi: [10.1016/j.bushor.2020.01.005](https://doi.org/10.1016/j.bushor.2020.01.005).
- Gebauer, H., Arzt, A., Kohtamäki, M., Lamprecht, C., Parida, V., Witell, L. and Wortmann, F. (2020c), "How to convert digital offerings into revenue enhancement—Conceptualizing business model dynamics through explorative case studies", *Industrial Marketing Management*, Vol. 91, pp. 429-441.
- Hagiu, A. and Wright, J. (2015), "Multi-sided platforms", *International Journal of Industrial Organization*, Vol. 43, pp. 162-174.
- Hazen, B.T., Russo, I., Confente, I. and Pellathy, D. (2020), "Supply chain management for circular economy: conceptual framework and research agenda", *International Journal of Logistics Management*.
- Henneberg, S.C., Gruber, T. and Naudé, P. (2013), "Services networks: concept and research agenda", *Industrial Marketing Management*, Vol. 42 No. 1, pp. 3-8.
- Howard, M., Caldwell, N., Smith, L., Maull, R. and Ng, I.C. (2014), "Servitization and operations management: a service dominant-logic approach", *International Journal of Operations and Production Management*.
- Hurlburt, G.F. (2013), "Complexity theory: a new paradigm for software integration", *IEEE Annals of the History of Computing*, Vol. 15 No. 3, pp. 26-31.
- Isik, F. (2010), "An entropy-based approach for measuring complexity in supply chains", *International Journal of Production Research*, Vol. 48 No. 12, pp. 3681-3696.
- Jaakkola, E. (2020), "Designing conceptual articles: four approaches", *AMS Review*, Vol. 10 Nos 1-2, pp. 18-26.
- Jenab, K. and Liu, D. (2010), "A graph-based model for manufacturing complexity", *International Journal of Production Research*, Vol. 48 No. 11, pp. 3383-3392.
- Jovanovic, M., Raja, J.Z., Visnjic, I. and Wiengarten, F. (2019), "Paths to service capability development for servitization: examining an internal service ecosystem", *Journal of Business Research*, Vol. 104, pp. 472-485.
- Jovanovic, M., Sjödin, D. and Parida, V. (2021), "Co-evolution of platform architecture, platform services, and platform governance: expanding the platform value of industrial digital platforms", *Technovation*, 102218.
- Kamalaldin, A., Linde, L., Sjödin, D. and Parida, V. (2020), "Transforming provider-customer relationships in digital servitization: a relational view on digitalization", *Industrial Marketing Management*, Vol. 89, pp. 306-325.
- Kapoor, K., Bigdeli, A.Z., Schroeder, A. and Baines, T. (2021), "A platform ecosystem view of servitization in manufacturing", *Technovation*, 102248.
- Kauffman, S.A. (1992), "Origins of order in evolution: self-organization and selection", *Understanding Origins*, Springer, Dordrecht, pp. 153-181.
- Kindström, D. and Kowalkowski, C. (2009), "Development of industrial service offerings: a process framework", *Journal of Service Management*, Vol. 20 No. 2, pp. 156-172, doi: [10.1108/09564230910952753](https://doi.org/10.1108/09564230910952753).
- Kindström, D. and Kowalkowski, C. (2014), "Service innovation in product-centric firms: a multidimensional business model perspective", *The Journal of Business and Industrial Marketing*, Vol. 29 No. 2, pp. 96-111.
- Kohtamäki, M., Henneberg, S.C., Martinez, V., Kimita, K. and Gebauer, H. (2019a), "A configurational approach to servitization: review and research directions", *Service Science*, Vol. 11 No. 3, pp. 213-240.
- Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H. and Baines, T. (2019b), "Digital servitization business models in ecosystems: a theory of the firm", *Journal of Business Research*, Vol. 104, pp. 380-392.

- Kohtamäki, M., Einola, S. and Rabetino, R. (2020a), "Exploring servitization through the paradox lens: coping practices in servitization", *International Journal of Production Economics*, Vol. 226, pp. 1-15.
- Kohtamäki, M., Parida, V., Patel, P.C. and Gebauer, H. (2020b), "The relationship between digitalization and servitization: the role of servitization in capturing the financial potential of digitalization", *Technological Forecasting and Social Change*, Vol. 151, 119804.
- Kowalkowski, C., Persson Ridell, O., Rödell, J.G. and Sörhammar, D. (2012), "The co-creative practice of forming a value proposition", *Journal of Marketing Management*, Vol. 28 Nos 13-14, pp. 1553-1570.
- Kowalkowski, C., Windahl, C., Kindström, D. and Gebauer, H. (2015), "What service transition? Rethinking established assumptions about manufacturers' service-led growth strategies", *Industrial Marketing Management*, Vol. 45, pp. 59-69.
- Kowalkowski, C., Gebauer, H., Kamp, B. and Parry, G. (2017a), "Servitization and deservitization: overview, concepts, and definitions", *Industrial Marketing Management*, Vol. 60, pp. 4-10.
- Kowalkowski, C., Gebauer, H. and Oliva, R. (2017b), "Service growth in product firms: past, present, and future", *Industrial Marketing Management*, Vol. 60, pp. 82-88.
- Kreye, M.E. (2019), "Does a more complex service offering increase uncertainty in operations?", *International Journal of Operations and Production Management*, Vol. 39 No. 1, pp. 75-93, doi: [10.1108/IJOPM-01-2018-0009](https://doi.org/10.1108/IJOPM-01-2018-0009).
- Kreye, M.E., Roehrich, J.K. and Lewis, M.A. (2015), "Servitising manufacturers: the impact of service complexity and contractual and relational capabilities", *Production Planning and Control*, Vol. 26 Nos 14-15, pp. 1233-1246.
- Lightfoot, H., Baines, T. and Smart, P. (2013), "The servitization of manufacturing: a systematic literature review of interdependent trends", *International Journal of Operations and Production Management*, Vol. 33 No. 11, pp. 1408-1434.
- MacInnis, D.J. (2011), "A framework for conceptual contributions in marketing", *Journal of Marketing*, Vol. 75 No. 4, pp. 136-154.
- Manson, S.M. (2001), "Simplifying complexity: a review of complexity theory", *Geoforum*, Vol. 32 No. 3, pp. 405-414.
- Maylor, H. and Turner, N. (2017), "Understand, reduce, respond: project complexity management theory and practice", *International Journal of Operations and Production Management*.
- McKelvey, B. and Boisot, M. (2009), "Redefining strategic foresight: 'Fast' and 'Far' sight via complexity science", in Costanzo, L. and MacKay, B. (Eds), *Handbook of Research on Strategy and Foresight*, Edward Elgar, Cheltenham, pp. 15-47.
- Mourtzis, D., Vlachou, A. and Zogopoulos, V. (2017), "Cloud-based augmented reality remote maintenance through shop-floor monitoring: a product-service system approach", *Journal of Manufacturing Science and Engineering*, Vol. 139 No. 6.
- Murray, P.J. (1998), "Complexity theory and the fifth discipline", *Systemic Practice and Action Research*, Vol. 11 No. 3, pp. 275-293.
- Muzellec, L., Ronteau, S. and Lambkin, M. (2015), "Two-sided Internet platforms: a business model lifecycle perspective", *Industrial Marketing Management*, Vol. 45, pp. 139-150.
- Naik, P., Schroeder, A., Kapoor, K.K., Bigdeli, A.Z. and Baines, T. (2020), "Behind the scenes of digital servitization: actualising IoT-enabled affordances", *Industrial Marketing Management*, in press.
- Nambisan, S. (2017), "Digital entrepreneurship: toward a digital technology perspective of entrepreneurship", *Entrepreneurship Theory and Practice*, Vol. 41 No. 6, pp. 1029-1055.
- Nordin, F., Kindström, D., Kowalkowski, C. and Rehme, J. (2011), "The risks of providing services: Differential risk effects of the service-development strategies of customisation, bundling, and range", *Journal of Service Management*, Vol. 22 No. 3, pp. 390-408.

- Nylund, P.A., Brem, A. and Agarwal, N. (2021), "Innovation ecosystems for meeting sustainable development goals: the evolving roles of multinational enterprises", *Journal of Cleaner Production*, Vol. 281, 125329.
- Oliva, R. and Kallenberg, R. (2003), "Managing the transition from products to services", *International Journal of Service Industry Management*, Vol. 14 No. 2, pp. 160-172, doi: [10.1108/09564230310474138](https://doi.org/10.1108/09564230310474138).
- Opresnik, D. and Taisch, M. (2015), "The value of big data in servitization", *International Journal of Production Economics*, Elsevier, Vol. 165, pp. 174-184.
- Paiola, M., Saccani, N., Perona, M. and Gebauer, H. (2013), "Moving from products to solutions: strategic approaches for developing capabilities", *European Management Journal*, Vol. 31 No. 4, pp. 390-409.
- Paschou, T., Rapaccini, M., Adrodegari, F. and Saccani, N. (2020), "Digital servitization in manufacturing: a systematic literature review and research agenda", *Industrial Marketing Management*, Vol. 89, pp. 278-292, doi: [10.1016/j.indmarman.2020.02.012](https://doi.org/10.1016/j.indmarman.2020.02.012).
- Pekkarinen, S. and Ulkuniemi, P. (2008), "Modularity in developing business services by platform approach", *International Journal of Logistics Management*, Vol. 19 No. 1, pp. 84-103.
- Perks, H., Kowalkowski, C., Witell, L. and Gustafsson, A. (2017), "Network orchestration for value platform development", *Industrial Marketing Management*, Vol. 67, pp. 106-121.
- Perona, M. and Miragliotta, G. (2004), "Complexity management and supply chain performance assessment. A field study and a conceptual framework", *International Journal of Production Economics*, Vol. 90 No. 1, pp. 103-115.
- Phillips, M.A. and Ritala, P. (2019), "A complex adaptive systems agenda for ecosystem research methodology", *Technological Forecasting and Social Change*, Vol. 148, 119739, doi: [10.1016/j.techfore.2019.119739](https://doi.org/10.1016/j.techfore.2019.119739).
- Pirola, F., Boucher, X., Wiesner, S. and Pezzotta, G. (2020), "Digital technologies in product-service systems: a literature review and a research agenda", *Computers in Industry*, Vol. 123, 103301.
- Porter, M.E. and Heppelmann, J.E. (2014), "How smart, connected products are transforming competition", *Harvard Business Review*, Vol. 92 No. 11, pp. 64-88.
- Rabetino, R., Harmsen, W., Kohtamäki, M. and Sihvonen, J. (2018), "Structuring servitization-related research", *International Journal of Operations and Production Management*, Vol. 38 No. 2, pp. 350-371, doi: [10.1108/IJOPM-03-2017-0175](https://doi.org/10.1108/IJOPM-03-2017-0175).
- Raddats, C., Baines, T., Burton, J., Story, V.M. and Zolkiewski, J. (2016), "Motivations for servitization: the impact of product complexity", *International Journal of Operations and Production Management*, Vol. 36 No. 5, pp. 572-591.
- Raddats, C., Kowalkowski, C., Benedettini, O., Burton, J. and Gebauer, H. (2019), "Servitization: a contemporary thematic review of four major research streams", *Industrial Marketing Management*, Vol. 83, pp. 207-223.
- Raja, J.Z., Chakkol, M., Johnson, M. and Beltagui, A. (2018), "Organizing for servitization: examining front-and back-end design configurations", *International Journal of Operations and Production Management*, Vol. 38 No. 1, pp. 249-271, doi: [10.1108/IJOPM-03-2016-0139](https://doi.org/10.1108/IJOPM-03-2016-0139).
- Rajala, R., Brax, S.A., Virtanen, A. and Salonen, A. (2019), "The next phase in servitization: transforming integrated solutions into modular solutions", *International Journal of Operations and Production Management*, Vol. 39 No. 5, pp. 630-657, doi: [10.1108/IJOPM-04-2018-0195](https://doi.org/10.1108/IJOPM-04-2018-0195).
- Rymaszewska, A., Helo, P. and Gunasekaran, A. (2017), "IoT powered servitization of manufacturing—an exploratory case study", *International Journal of Production Economics*, Vol. 192, pp. 92-105.
- Salonen, A., Rajala, R. and Virtanen, A. (2018), "Leveraging the benefits of modularity in the provision of integrated solutions: a strategic learning perspective", *Industrial Marketing Management*, Vol. 68, pp. 13-24.
- Sanger, M. and Giddings, M.M. (2012), "A simple approach to complexity theory", *Journal of Social Work Education*, Vol. 48 No. 2, pp. 369-376.

- Shostack, G.L. (1987), "Service positioning through structural change", *Journal of Marketing*, Vol. 51 No. 1, pp. 34-43.
- Sjödin, D.R., Parida, V. and Wincent, J. (2016), "Value co-creation process of integrated product-services: effect of role ambiguities and relational coping strategies", *Industrial Marketing Management*, Vol. 56, pp. 108-119.
- Sjödin, D., Parida, V., Kohtamäki, M. and Wincent, J. (2020), "An agile co-creation process for digital servitization: a micro-service innovation approach", *Journal of Business Research*, Vol. 112, pp. 478-491.
- Sklyar, A., Kowalkowski, C., Tronvoll, B. and Sörhammar, D. (2019a), "Organizing for digital servitization: a service ecosystem perspective", *Journal of Business Research*, Vol. 104, pp. 450-460.
- Sklyar, A., Kowalkowski, C., Sörhammar, D. and Tronvoll, B. (2019b), "Resource integration through digitalisation: a service ecosystem perspective", *Journal of Marketing Management*, Vol. 35 Nos 11-12, pp. 974-991.
- Smith, A.C. (2005), "Complexity theory for organisational futures studies", *Foresight*, Vol. 7 No. 3, pp. 22-30.
- Smith, L., Maull, R. and Ng, I. (2014), "Servitization and operations management: a service dominant-logic approach", *International Journal of Operations and Production Management*, Vol. 34 No. 2, pp. 242-269.
- Song, W. and Sakao, T. (2017), "A customization-oriented framework for design of sustainable product/service system", *Journal of Cleaner Production*, Vol. 140, pp. 1672-1685.
- Spring, M. and Santos, J. (2014), "Servitization and process interfaces", in Lay, G. (Ed.), *Servitization in Industry*, Springer, pp. 263-275.
- Täuscher, K. and Laudien, S.M. (2018), "Understanding platform business models: a mixed methods study of marketplaces", *European Management Journal*, Vol. 36 No. 3, pp. 319-329.
- Tian, J., Coreynen, W., Matthyssens, P. and Shen, L. (2021), "Platform-based servitization and business model adaptation by established manufacturers", *Technovation*, 102222, doi: [10.1016/j.technovation.2021.102222](https://doi.org/10.1016/j.technovation.2021.102222).
- Uлага, W. and Reinartz, W.J. (2011), "Hybrid offerings: how manufacturing firms combine goods and services successfully", *Journal of Marketing*, Vol. 75 No. 6, pp. 5-23.
- Valtakoski, A. (2017), "Explaining servitization failure and deservitization: a knowledge-based perspective", *Industrial Marketing Management*, Vol. 60, pp. 138-150.
- Vandermerwe, S. and Rada, J. (1988), "Servitization of business: adding value by adding services", *European Management Journal*, Vol. 6 No. 4, pp. 314-324.
- Vrabcic, R. and Butala, P. (2012), "Assessing operational complexity of manufacturing systems based on statistical complexity", *International Journal of Production Research*, Vol. 50 No. 14, pp. 3673-3685.
- Wei, R., Geiger, S. and Vize, R. (2019), "A platform approach in solution business: how platform openness can be used to control solution networks", *Industrial Marketing Management*, Vol. 83, pp. 251-265.
- Wen, X. and Zhou, X. (2016), "Servitization of manufacturing industries based on cloud-based business model and the down-to-earth implementary path", *The International Journal of Advanced Manufacturing Technology*, Vol. 87 No. 5, pp. 1491-1508.
- Williams, J., Davey, J. and Johnstone, M.L. (2020), "Marketing system failure: revisioning layton's marketing system model", *Journal of Macromarketing*, Vol. 41 No. 2, pp. 411-426, doi: [10.1177/0276146720961454](https://doi.org/10.1177/0276146720961454).
- Windahl, C. and Lakemond, N. (2006), "Developing integrated solutions: the importance of relationships within the network", *Industrial Marketing Management*, Vol. 35 No. 7, pp. 806-818.
- Zhang, H. (2017), "Complexity absorption: a processual strategic approach to corporate entrepreneurship strategy", *Frontiers of Business Research in China*, Vol. 11 No. 1, pp. 1-20.

Appendix

Electronic sources

PTC Thingworx

- (1) <http://www.businesswire.com/news/home/20131118005503/en/ThingWorx-Launches-Marketplace-Internet-Things> (accessed 1 April 2021).
- (2) <http://www.1worx.co/the-thingworx-platform/collaboration/> (accessed 1 April 2021).
- (3) <https://marketplace.thingworx.com/> (accessed 31 March 2021).
- (4) https://support.ptc.com/help/thingworx_hc/thingworx_8_hc/en/index.html#page/ThingWorx/Help/Composer/IntegrationConnectors/ConnectorOverview.html (accessed 31 September 2021).
- (5) https://support.ptc.com/WCMS/files/174041/en/Thingworx_Deployment_Architecture_Guide.pdf (accessed 31 September 2021).

Siemens Mindsphere

- (1) <https://www.cimdata.com/en/resources/complimentary-reports-research/commentaries/item/8698-mindsphere-for-closed-loop-innovation-in-the-connected-intelligent-industry-highlight> (accessed 7 April 2021).
- (2) https://www.siemens.com/investor/pool/en/investor_relations/financial_publications/speeches_and_presentations/innodayusa/06_InnoDayUSA_MindSphere_20170327.pdf (accessed 7 April 2021).
- (3) <https://www.industriaitaliana.it/siemens-creare-valore-dai-dati-con-mindsphere/> (accessed 25 March 2021).
- (4) <https://www.plm.automation.siemens.com/global/en/topic/mindsphere-whitepaper/8683> (accessed 12 March 2018).
- (5) <https://www.youtube.com/watch?v=-zKwgui0II> (accessed 25 March 2021).
- (6) <https://www.siemens.com/global/en/home/products/software/mindsphere.html> (accessed 25 March 2021).
- (7) <https://www.youtube.com/watch?v=JJ-AceKYHYU> (accessed 24 March 2021).
- (8) <http://www.ilsole24ore.com/art/tecnologie/2016-12-10/industria-40-robot-motori-e-sensori-connessi-via-cloud-mindsphere-131622.shtml?uuid=AD80hdGC> (accessed 24 March 2021).
- (9) <https://www.plm.automation.siemens.com/store/it-it/mindsphere/mindconnect/index.html> (accessed 24 March 2021).

Corresponding author

Marco Ardolino can be contacted at: marco.ardolino@unibs.it

For instructions on how to order reprints of this article, please visit our website:

www.emeraldgroupublishing.com/licensing/reprints.htm

Or contact us for further details: permissions@emeraldinsight.com