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The emergence of smart service ecosystems—The role of socio-technical antecedents and affordances

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Abstract

As physical products are increasingly augmented with digital technology, manufacturing firms have become part of the development of so-called smart products and smart services. As such, manufacturing firms are challenged by new market participants and ecosystem partners, particularly from the software development industry, and by the dynamic nature of business relationships. While the academic literature on the distinctive characteristics of ecosystems, particularly digital ecosystems, is rich, the effect of smart service ecosystems' emergence on the foundation of smart products remains uncertain. This study reports on case study research based on 47 semi-structured interviews with four companies that participate in an industrial smart service ecosystem. Taking an affordance-theoretic perspective, we uncover the antecedents of and the process of emergent smart service ecosystems. We find that smart service ecosystems have three socio-technical antecedents: a shared worldview, structural flexibility and integrity, and architecture of participation. We explain the emergence of smart service ecosystems as the result of specialisation in shared affordances and integration of idiosyncratic affordances into collective affordances. We derive seven propositions regarding the emergence of smart services, outline opportunities for further research, and present practical guidelines for manufacturing firms.

1 | INTRODUCTION

Product-focused industrial conglomerates like General Electric and SIEMENS, and multinational automakers like Peugeot, Mercedes Benz, and Ford have been around for more than a century. Known as Original Equipment Manufacturers (OEMs), they have established supplier relationships in which single actors play a focal role in value creation by dictating standards and requirements both horizontally and vertically (Barratt, 2004; Swink et al., 2007). With the increasing digitization of physical products (Grover et al., 2018; Yoo et al., 2010) and the emergence of services that complement them (Lightfoot et al., 2013), traditional industry boundaries have blurred, and the mechanics that determine how organisations collaborate have changed. Specifically, OEMs' central role in value creation is dissolving. This development challenges product-centred industries to transform their value chains that centre on customer–supplier relationships into smart service ecosystems as focal value propositions that exist beyond industries' reach (Lusch & Nambisan, 2015; Nambisan et al., 2016; Sambamurthy et al., 2003). Recent McKinsey reports suggest that, by 2025, today's 100-plus industries and value chains will have collapsed into a low number of multi-trillion-dollar ecosystems that account for some $60 trillion in revenue, a third of the global economy (McKinsey & Company, 2017, 2020).

Consider connected in-car entertainment and navigation systems as an example: Traditionally, car-makers have controlled the entire supply chain and used proprietary devices that are expensive and had limited connectivity and imperfect usability. In contrast, today's car manufacturers open their proprietary systems to allow technology companies like Apple and Google to enter the manufacturers' automotive head unit. Since car manufacturers rely on telecommunications organisations for connectivity, these organisations provide navigation, communication, and entertainment services. While OEMs once relied on vertical integration of car components, they no longer fully govern the supplier relationships, technical capabilities, and services that technology organisations offer drivers.

The consumer example outlined above illustrates how a smart service ecosystem emerges around the automotive head unit. However, the phenomenon's implications are far greater in the industrial context. In product-intense industries like the automotive, aviation, and industrial manufacturing industries, physical products that are augmented with digital technology afford novel opportunities for organisations to create value jointly in ecosystems. The value can be packaged as smart services—the application of specialised competencies based on the material properties of smart products—that leverage both the physical and the digital properties of smart products (Beverungen et al., 2019; Grover et al., 2018; Porter & Heppelmann, 2014, 2015; Yoo et al., 2010).

To highlight the extent of change that smart products and services bring about in the industrial context, consider as another example KAESER, a German industrial compressed-air specialist that has been seen as an industry-leading OEM. The compressors are primarily used on industrial shop floors and at construction sites. KAESER has gradually moved to offer smart services in collaboration with various technology and maintenance organisations. The offerings leverage the smart product in at least two ways: by enabling accurate, usage-based billing based on how much compressed air is consumed and by enabling predictive maintenance of the compressors, thus ensuring uptime. As industrial customers become accustomed to this holistic and outcome-based service offering, KAESER might eventually transform the traditional industry of individual OEMs selling physical products to multiple actors offering smart services and collaborating in smart service ecosystems. However, providing such smart services means not only overcoming technological challenges but also requiring organisations to navigate emerging inter-organisational ecosystems effectively (Lütjen et al., 2019; McKinsey & Company, 2018; Reeves et al., 2017; Svahn et al., 2017).

These two examples show the importance of understanding the peculiarities of smart service ecosystem emergence. In expanding on the concept of smart products, the scholarly literature has started to recognise the concept of smart services (Beverungen et al., 2019), but as multiple organisations become involved in realising smart services, smart service ecosystems emerge (Barile & Polese, 2010; Beverungen et al., 2019; Huber et al., 2019; Thomas & Ritala, 2021). Although scholars have started to theorise about what ecosystems are and what distinguishes them from other forms of governance (Jacobides et al., 2018), most have assumed that a central 'hub' firm coordinates the network's formation by governing other network participants and designing value creation (Gebauer et al., 2013; Kohtamäki et al., 2019). Existing work also lacks empirical evidence on the socio-technical antecedents of smart service ecosystems and the nature of smart service ecosystem's emergence through multilateral relationships among organisations and complementary contributions (Aarikka-Stenroos & Ritala, 2017; Taillard et al., 2016; Thomas & Erkko, 2015; Thomas & Ritala, 2021). In other words, it is not known how smart service ecosystems emerge to realise (interwoven) smart services. To address this research gap, we formulate the following research question:

> How do smart service ecosystems emerge around smart products in industrial manufacturing?

To address this question, we performed a revelatory case study with four organisational ecosystem participants from a large smart service ecosystem in the German manufacturing industry: an OEM, an analytics organisation (AO), a smart product operator (SPO), and maintenance, repair, and overhaul organisation (MRO). We conducted 47 semi-structured interviews to investigate how the case organisations put smart products to use to offer smart services, leading to the emergence of a smart service ecosystem.

The remainder of this paper is structured as follows. Section 2 gives the research background, introducing both the emergence of ecosystems and affordance theory. Section 3 presents the case context and details our research design, while Section 4 presents the affordances related to smart products that the organisations in our case context perceive. Section 5 discusses our derived propositions, and Section 6 outlines their theoretical and managerial implications. Section 7 concludes this work by summarising its key findings.

2 | THEORETICAL BACKGROUND

This section introduces smart service ecosystems as the phenomenon of interest as it relates to two streams of research: the formation of ecosystems and innovation in ecosystems. Then, we introduce affordance theory as the lens through which we examine and further conceptualise the process related to the emergence of smart service ecosystems.

2.1 | Smart service ecosystems in the industrial manufacturing industry

The industrial manufacturing industry has traditionally been geared towards fabricating from raw materials products that are intended for industrial use. Modern industrial products that are augmented with digital technology are referred to as smart products (Klein et al., 2018; Porter & Heppelmann, 2015). Their material properties, which include connectivity, sensors, actuators, interfaces, computing technologies, and the ability to allow for localization and identification, enable the delivery of smart services (Beverungen et al., 2019). The value of smart products goes beyond their physical (and digital) materiality (Yoo, 2013; Yoo et al., 2012) to allow for the delivery of smart services. A smart service builds on the extended features of a smart product to provide value through such extended data-based functionalities (Beverungen et al., 2019). This convergence of information systems and physical products may be generative for combinatorial and recombinant innovation which can be referred to as smart services (Beverungen et al., 2019; Yoo et al., 2012).

Smart services spark a transformation of traditional industries into service-based industries (Barile et al., 2016; Beverungen et al., 2019; Wünderlich et al., 2013). Providing smart services requires capabilities that transcend the boundaries of single organisations or even industries, so, for example, data analytics companies collaborate with traditional industrial organisations (Lightfoot et al., 2013). Against the background of increasing industry dynamics and service orientation, ecosystems are the new organising logic for offering smart services (Barile et al., 2016). Smart services ecosystems are constituted around smart products that allow actors to co-create value in the form of smart services that are the ecosystem's focal value proposition (Adner, 2017; Barile et al., 2016; Beverungen et al., 2019; Jacobides et al., 2018; Lusch & Nambisan, 2015; Nambisan, 2013). A firm is considered an ecosystem actor if it must either change (e.g., increase its capacity) or substantially adapt its business activities (e.g., establish new work routines or extend capabilities) to contribute to an ecosystem's value propositions (Adner, 2017).

Ecosystems are self-adjusting and evolving organising structures that comprise an assemblage of loosely coupled multilateral economic actors. Digital technology enables an ecosystem's focal value propositions to materialise by uncovering where its participants complement each other (Yoo et al., 2010), and the resulting ecosystem of interacting organisations is enabled by modularity, as opposed to being hierarchically managed (Jacobides et al., 2018). Ecosystems are bound together by the inability of their collective investment to be redeployed and are defined by the alignment of the multilateral collection of partners that is required for a focal value proposition to materialise (Adner, 2017; Lusch & Nambisan, 2015). The actors contribute to value propositions (Camagni, 1993; Jacobides et al., 2018) through multilateral relationships by leveraging their complementary resources and capabilities (Jacobides et al., 2018; Lusch & Nambisan, 2015). Value propositions are the core of an ecosystem and determine its (fuzzy) boundaries (Adner, 2017). In summary, an ecosystem may be perceived as a living organism that emerges around the focal value propositions that emerge from the contributions of complementary ecosystem actors (Adner, 2017).

Our study draws on two streams of research on ecosystems that view ecosystems from different angles: the formation of ecosystems and innovation in ecosystems (Table 1).

The first stream of research on which our study draws is that on the formation of ecosystems, which focuses on governance executed by a hub, an orchestrator (Lingens et al., 2020), or a 'keystone firm' (Iansiti & Levien, 2004) as an instrument with which to regulate, design, or orchestrate ecosystem formation by recruiting, motivating, and retaining participants (Jacobides et al., 2018; Thomas & Erkko, 2015). For example, such a firm establishes contractual relationships with suppliers and outsourcing providers, distributes decision rights by guarding end customer access, and coordinates the provision of service to customers (Gebauer et al., 2013). This firm may play an orchestrating role in shaping or designing the alignment of the ecosystem, which underscores that the formation of an ecosystem is dependent on the design by an orchestrator or powerful actor in the ecosystem (Lingens et al., 2020), Although studies tend to agree that ecosystems are not fully hierarchically managed, these studies predominantly delineate the role of these central actors (Jacobides et al., 2018) and have started to describe the formation of ecosystems as having a subtle, multi-faceted, and emergent nature (Aarikka-Stenroos & Ritala, 2017; Barile & Polese, 2010; Taillard et al., 2016). However, these extant studies do not provide empirical evidence for how complementing ecosystem actors link themselves and their activities multilaterally during the emergence of a smart service ecosystem (Lyytinen et al., 2016; Taillard et al., 2016; Thomas & Erkko, 2015; Thomas & Ritala, 2021). The locus of value creation has increasingly shifted from the relationship level (i.e., the relationship between a single provider and its customers) to the network level, where multiple independent actors contribute incremental value to an overall smart service offering (Barile & Polese, 2010; Huber et al., 2019). Particularly in traditional industries like manufacturing, realising complex smart services requires new market entrants that have not yet participated in value co-creation (Barile et al., 2016; Beverungen et al., 2019; Lingens et al., 2020). Therefore, how organisations initiate multilateral relationships as an antecedent to the emergence of a smart service ecosystem and their socio-technical requirements are of particular interest to both practice and academia (Aarikka-Stenroos & Ritala, 2017; Thomas & Erkko, 2015).

The second stream of research, on which our study draws is that which addresses innovation in ecosystems or networks (cf. Autio & Thomas, 2014; Lyytinen et al., 2016). This stream of research provides useful insights into interactions between ecosystem actors (Beverungen et al., 2019) and the role of digital technologies as important drivers of collaboration and collective action in ecosystems (Autio et al., 2018). Innovation results from a diverse set of actors who contribute combinations of resources that may be assembled as or allowed by material artefacts (Lyytinen et al., 2016). Thus, because of non-linear dynamic systems and the combining role of digital technologies, product innovation can be considered to be emergent, distributed, and socio-technical in nature (Lyytinen et al., 2016; Van de Ven, 2017). In contrast to intra-organisational networks, inter-organisational innovation networks—ecosystems or not—will likely 'be dynamic, uncertain and equivocal' (Lyytinen et al., 2016, p. 51) when they build on digital technologies. Innovation is no longer bound exclusively to the physical materiality of products but requires the collective, recombinant engagement and action of economic actors (Barrett et al., 2015; Beverungen

TABLE 1 Two streams of research that are relevant to our study

	Stream of research	
Dimension	**Formation of ecosystems**	**Innovation in ecosystems**
Focus and key concepts	A focal firm that coordinates service provisioning to customers is at the centre of investigations.	Innovation is depicted as a recombinant process of a diverse set of actors with specific roles. The combination of knowledge and resources, including digital technologies, may result in the embodiment of digital innovation in material artefacts von Briel et al., (2018).
Relevance to this study	This stream of research defines the boundaries of an ecosystem, which helps to define the scope of an ecosystem. It also delineates the relevance of complementarity to ecosystem formation Jacobides et al., (2018).	In the context of smart service ecosystems, smart services are the *raison d'etre* of smart service ecosystems. We build on the extant understanding of (digital) innovation, as the resulting smart services are considered to be materialised innovations.
Operationalization	This stream of research allows us to conceptualise the scope of an ecosystem by defining its boundaries.	Our data analysis pays particular attention to the combined role of digital technology in the emergence of the ecosystem. Inspired by this angle, we propose the integration and specialisation of affordances as foundational aspects of an ecosystem's emergence.
Limitations for explaining the phenomenon of interest	Existing work lacks empirical evidence that delineates how complementary ecosystem actors link themselves and their activities multilaterally during the emergence of a smart service ecosystem Lyytinen et al., (2016), Taillard et al., (2016), Thomas and Erkko, (2015), Thomas and Ritala, (2021). We argue that a focal firm is not necessarily required for a smart service ecosystem to emerge.	Existing research on innovation in ecosystems acknowledges the emergent, distributed, and socio-technical nature of innovation; most work focuses exclusively on internal organisational processes in investigating the role of digital technologies in innovation. The extant research lacks an understanding of how the generative capacity of smart products may influence and shape value creation within inter-organisational innovation networks.

et al., 2019; Nambisan et al., 2016; Yoo et al., 2012). Lyytinen et al. (2016) call for clarification of the degree to which digital technologies (particularly smart products) and their generative capacity may influence and shape inter-organisational innovation networks, but how smart products may create, capture and distribute new value remains unclear (Lyytinen et al., 2016; Yoo et al., 2010). Consequently, many authors call for research to extend this view to an ecosystem perspective (while acknowledging the emergence of ecosystems) to explain how ecosystems' participants co-create value (propositions) or innovation in ecosystems, particularly smart services (Autio et al., 2018; Barile et al., 2016; Lütjen et al., 2019; Thomas & Erkko, 2015; Vargo & Akaka, 2012).

Combining the insights from this outline of how the concept of smart service ecosystems is discussed in the literature and how we seek to contribute, Table 2 provides a summary of the foundational concepts on which our research draws.

2.2 | An affordance-theoretic perspective on the emergence of smart service ecosystems

Although digital technology is the foundation for many innovations (Nambisan, 2013; Zittrain, 2006), an assessment of the potential value it offers (i.e., through smart services) must take into account its use context (Autio et al., 2018;

TABLE 2 Definitions of concepts used in our research

Concept	Definition	Sources
Smart product	Smart products embed connectivity, sensors, actuators, interfaces, computing technologies, and the ability to provide localization and identification. Smart products' material properties can be rooted in the concept of digitised products and their modular, layered architecture, which has a high generative capacity as a foundation for innovative services.	Beverungen et al., (2019), Yoo, (2013), Yoo et al., (2012)
Smart service	Smart services are applications of specialised competencies through deeds, processes, and performances and are based on smart product's material properties.	Beverungen et al., (2019)
Ecosystem	Ecosystems are interacting organisations, enabled by modularity, that are not hierarchically managed and are bound together by their collective investment's inability to be redeployed. They are defined by the alignment structure of the multilateral set of partners that must interact for a (focal) value proposition to materialise.	Adner, (2017), Jacobides et al., (2018), Vargo and Lusch, (2017)
Smart service ecosystem	A smart service ecosystem is an ecosystem that is based on smart products' material properties and constituted around smart services as (focal)value propositions.	Adner, (2017), Barile et al., (2016), Beverungen et al., (2019), Jacobides et al., (2018), Lusch and Nambisan, (2015)

Barile et al., 2016; Vargo & Akaka, 2012). The literature focuses primarily on the technical aspects of the technology but omits the potential of using it. Because of digital technology's malleability, smart products' functionality and uses must not be studied only as deterministic (Yoo et al., 2012, 2010), so the potential of using digital technology is studied in its context (Orlikowski, 2000). Leonardi (2011, 2013a) finds that people approach technological artefacts iteratively, forming goals and the individual or collective capacity to use (or act on) an artefact's materiality. In assuming their agency, people activate an artefact's material agency (i.e., it's capacity for enabling [inter-]action) to accomplish their collective intentions, that is, the ability to form and realise collective goals through collective action. Against this backdrop, socio-material thinking acknowledges that social and material aspects of digital technology are intertwined and enacted in practice (Leonardi, 2011; Orlikowski, 2000). Specifically, an affordance-theoretic perspective helps us to study the emergence of smart service ecosystems in context and to focus on both the organisational level and the ecosystem level.

The origins of affordance theory, which first set out to describe how animals and humans interact with objects (Leonardi, 2011), lie in the realm of perceptual psychology (Gibson, 1986). Affordances are traditionally defined as 'emergent, interactive, and dynamic as well as knowledge and communication-intense activity' (Miles, 2008, p. 117). We follow the dominant perspective of Majchrzak and Markus (2013) and Strong et al. (2014) in defining an affordance as 'the potential for behaviors associated with achieving an immediate concrete outcome and arising from the relation between an artifact and a goal-oriented actor or actors' (Strong et al., 2014, p. 12). The imperative to actualize affordances as context- and actor-dependent use potentials has gained attention in interdisciplinary research (Leonardi & Barley, 2008; Markus & Silver, 2008; Seidel et al., 2013; Strong et al., 2014; Volkoff & Strong, 2013; Yoo, 2013). Nambisan et al. (2016) characterise affordance theory as a promising lens through which to distinguish innovation outcomes from innovation processes in the context of a particular set of innovating actors.

Our motivation to draw on an affordance lens to study the emergence of smart service ecosystems is twofold, as affordance theory allows us (1) to focus on the goal-oriented use potentials of smart products and go beyond their material properties and (2) to investigate how smart products' use potentials lead to the value propositions of a smart service ecosystem at both the organisational level and the ecosystem level.

The first reason for our drawing on the affordance concept, which is relational in nature, is that it allows us to focus on smart products' goal-oriented use potentials in a specific use context so we can look beyond their pure technology. Affordance theory proposes that value arises from the relationship between the material properties of an artefact (i.e., a smart product) and its use context (Majchrzak & Markus, 2013; Markus & Silver, 2008; Volkoff & Strong, 2013). According to extant work that uses an affordance lens (Leonardi & Barley, 2008; Yoo, 2013), smart products have a physical and digital materiality. Leveraging an affordance lens allows both property categories to be subsumed under what the theory calls material properties. Whereas physical material properties refer to largely unchangeable, visible, and tangible properties, such as sensors and actuators, digital material properties refer to 'what the software incorporated into an artifact can do by manipulating digital representations' (Yoo et al., 2012, p. 1398). Affordances link an object's or technology's materiality (i.e., material properties) to its use context (Fayard & Weeks, 2014; Markus & Silver, 2008; Zammuto et al., 2007). In a business context, organisations can draw on smart products' material properties to achieve their organisational goals as well as goals that go beyond their boundaries. We use affordance theory's focus on use potentials to investigate their interplay and explain the emergence of service ecosystems.

The second reason for our drawing on the affordance concept is that it is a multi-level concept that allows us to investigate the emergence of smart service ecosystems at both the organisational level and the ecosystem level: Existing research already leverages an affordance lens to conduct investigations on multiple levels and to conceptualise level-specific classes of affordances. For instance, Leonardi (2013b) focuses on multiple levels in investigating how technology changes how individuals collaborate and how these individual-level use potentials change the practices of groups of individuals (i.e., departments in an organisation). The multi-level perspective allows investigations to be conducted at both the organisational level and the ecosystem level and to study the effects that occur between these levels (Savoli & Barki, 2016). For these reasons, this perspective allows us to explain the interplay among actor-specific affordances, affordances that are shared between actors, and affordances that are perceived collectively at a group level, which may go beyond the sum of the individual parts. By applying this multilevel theory, we can investigate the emergence of smart service ecosystems by focusing on the relationship between smart products and their use contexts across the boundaries of individual organisations and at both the organisational level and the ecosystem level.

In sum, affordance theory allows us to distinguish between the material properties of smart products and the context of their use at the organisational and ecosystem levels, to investigate the interplay of multiple actors in an ecosystem, and, thus explain the emergence of smart service ecosystems.

3 | RESEARCH DESIGN AND METHOD

As research on the emergence of smart service ecosystems is scarce (Barile et al., 2016; Jacobides et al., 2018), our strategy is to study one case in depth. Since we investigate a novel phenomenon with heretofore undefined boundaries (Silverman, 2010; Yin, 2008), we sought an archetypical smart service ecosystem that could provide a unique, rich set of empirical data on our phenomenon of interest that would help us develop an explanatory theory. We investigate organisations and their interactions in an ecosystem with 'oscillating foci' (Beirão et al., 2017; Chandler & Vargo, 2011; Vargo & Lusch, 2017), taking into account the multidimensional nature of ecosystems, that allows us to reveal how affordances emerge at both the organisational level and the ecosystem level.

We follow the principles of interpretive case study research (Klein & Myers, 1999; Walsham, 1995, 2006) to explain complex real-world phenomena in their social or organisational embedded contexts (Eisenhardt & Graebner, 2007; Orlikowski & Lacono, 2001).

Our case study is revelatory for two reasons. First, cases that study the emergence of smart service ecosystems extensively are scarce and have been called for (Barile et al., 2016; Jacobides et al., 2018; Taillard et al., 2016). The phenomenon of interest has been inaccessible to investigators because of their limited access to in-depth empirical data related to a coherent smart service ecosystem. Second, our case study is revelatory since the manufacturing industry, as our case context, is subject to change and significant transformation as a result of digitization and servitization. Digitization refers to industrial products' having become increasingly equipped with digital technology (smart products) (Beverungen et al., 2019; Grover et al., 2018; Porter & Heppelmann, 2014, 2015; Yoo et al., 2010). Servitization refers to the trend of moving from a traditional, dyadic goods-dominant logic that relies on the exchange of industrial products for cash to a service-dominant logic where multiple organisations intensify value co-creation in innovative service systems to meet their customers' needs (Klein et al., 2018; Lightfoot et al., 2013; Neely, 2013).

3.1 | Case context

This section provides detailed information on our case context. First, we describe the chief characteristics of the key players and the salient characteristics of the smart service ecosystem itself (Jacobides et al., 2018). Then, we introduce the four organisations that we selected for interviews and outline the smart products and smart services they produce.

We investigate the emergence of smart service ecosystems in the context of an archetypical smart service ecosystem in the industrial manufacturing industry. Accordingly, our unit of analysis is a smart service ecosystem consisting of four typical industrial organisations—which we name OEMCorp, MROCorp, SPOCorp, and AOCorp—that leverage two types of smart products to offer smart services to their customers (Halinen & Törnroos, 2005; Miles & Huberman, 1994). The first smart product in our case is elevators that are augmented with digital technology in the form of sensors and actuators and the second is forklift trucks that are connected to a central big data analytics platform via mobile connectivity. In line with prior research (Becker et al., 2013; Gebauer et al., 2013; Meyer et al., 2011), the case organisations have typical industrial actors that include OEMs, SPOs, and MRO organisations. As our ecosystem relates to smart products and since previous focus groups with practitioners highlight the value of a dedicated AO as an organisational actor, we add the role of an AO.

- OEMs are mainly responsible for building industrial products. Their organisational structure is product-focused, and their traditional focus is the engineering and manufacture of industrial products. OEMs' organisational goals prioritise a product's beginning of life by providing high-quality products at competitive prices (Gebauer et al., 2013).
- SPOs are the main beneficiaries of the smart service ecosystem. However, the purchase of industrial products does not satisfy their need to gather resources to co-create value with their customers. SPOs' key goals are to maximise the smart products' productivity, create transparency between industrial products and processes, and pass this information on to customer organisations.
- MRO organisations play important roles in traditional industrial contexts because of industrial products' long life cycles. MRO organisations typically have a global footprint, although they are structured as regional entities. Their key objectives are to ensure fault-free and safe operations and to reduce downtime in industrial products. Despite their traditional mindset, MRO organisations recognise the benefits of leveraging digital technology to increase operational efficiency in delivering their services to SPOs. MRO organisations build strong ties with SPOs because they accompany industrial products throughout their lifecycles. MRO organisations' primary goals are to provide efficient activities and to differentiate themselves from their competitors by providing innovative smart services that address the industrial products' operations phase.
- AOs are actors that have the resources to deal with operational data in the context of industrial manufacturing. With the rise of smart products and the operational product data that results, the established roles in the industrial manufacturing industry face increasing difficulty processing that voluminous data efficiently. As players that play an emerging role in the industrial smart service ecosystem, AOs address this issue by providing dedicated

resources for the collection, storage, and analysis of vast amounts of operational product data. AOs' competencies include real-time data-streaming and big data analytics. Their organisational culture tends to be open-minded towards innovation and digital technology.

The ecosystem we investigate in our study has all four types of industrial actors: OEM, SPO, MRO, and AO. It is an ecosystem in the industrial manufacturing sector in Germany that involves around 50 networked firms and organisations. We applied purposeful sampling (Coyne, 1997; Patton, 1990) to select a subset of four organisations that represent the four roles; the result is a typical set of actors representing a smart service ecosystem in the industrial space. This smart service ecosystem is uniquely suited to our research objectives because each of its industrial organisations plays characteristic roles in a smart service ecosystem in the industrial manufacturing industry. Following Adner (2017), we determined the boundaries of our ecosystem based on the changes in the firms' activities that allowed them to take part in providing smart services. Figure 1 provides an overview of our archetypical smart service ecosystem, which consists of the four organisations in our case ecosystem: OEMCorp, MROCorp, SPOCorp, and AOCorp.

We briefly characterise each organisation:

- *OEMCorp* is a multinational conglomerate that focuses on industrial engineering of standardised intralogistics products like elevators and escalators. OEMCorp also manufactures more extensive customised industrial solutions, such as power plants and production facilities. The company employs around 160 000 people and generates annual revenue of more than €40 billion. In our case ecosystem, OEMCorp does not perform the responsibilities of an 'orchestrator' or exercise more power than other actors in the network does.
- *SPOCorp* is a global steel-processing company in the business of global material processing and distribution, with around €14 billion in annual revenue, 20 000 employees, and 500 sites worldwide. Their services include slitting, shearing, laser cutting, sawing, drilling, milling, and coating of the materials they sell. To provide these services, they operate a range of intralogistics equipment and moving assets, such as forklift trucks and stationary equipment.[1] Other equipment includes conveyor belts, high-precision laser-cutting machines, and packaging machines.
- *MROCorp* is a leading multinational intralogistics and materials-handling organisation that focuses on moving assets in intralogistics. In 2018, MROCorp generated revenues exceeding $4 billion with a workforce of around 20 000 employees. The MRO portion of the business, which comprises more than half of the staff, is organised regionally and is responsible for more than 45% of total revenue.
- *AOCorp*, a concrete-manufacturing AO that focuses on Industrial Internet of Things (IIoT) use cases, offers a data platform that supports the cloud-based prediction of anomalies using digital twins. This technology supports a range of industrial assets, including moving equipment like forklift trucks and fixed assets like elevators. As AOCorp has a close and stable relationship with one of the biggest industrial OEMs in Germany, it has profound domain knowledge and expertise in the operational data of industrial products.

Our case organisations provide smart services that, collectively, materialise into (focal) value propositions. Table 3 provides examples of smart services in our case study's smart service ecosystem.

In line with Jacobides et al. (2018), our case ecosystem differs from other business constellations in that 'interacting organizations [are] enabled by modularity, not hierarchically managed, [and] bound together by the nondeployability of their collective investment elsewhere' (Jacobides et al., 2018, p. 2255). When selecting the case ecosystem, we ensured that its participants have the three crucial attributes of being enabled by modularity, not hierarchically managed, and bound together by their inability to deploy their collective investment elsewhere. Our case organisations are enabled by modularity in that they are distinct parts of the ecosystem, with each organisation having distinct organisational goals and value propositions for its customers. Since our case organisations are both separate organisational entities and not deeply bound by contractual agreements, we can confirm that they are not hierarchically managed. When selecting the four case organisations, we ensured that they are independent yet

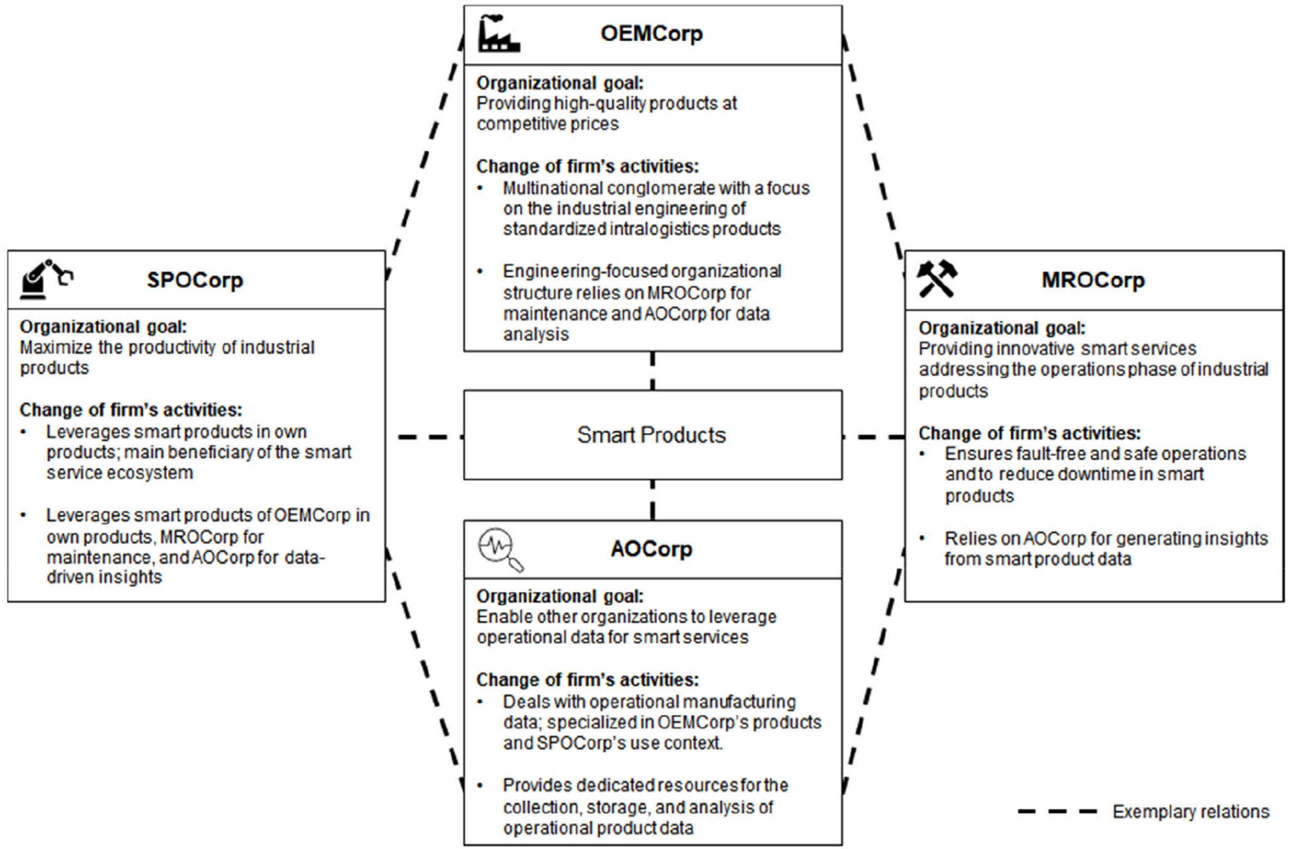

FIGURE 1 Overview of the four organisations in our smart service ecosystem

TABLE 3 Examples of smart services identified in our case ecosystem

Sample smart service	Description	Sample quotations
Triggering maintenance activities for elevators based on analysis of historic data	Historic data of an elevator's door movements can be tracked at each level. Individual elevators' patterns can be compared with the historic data of a single piece of equipment and the entire installation. Anomalies can trigger maintenance activities.	'We operate four seasons a year, and I hear from my team that [the elevators] have a higher failure rate in the summer when it's hot […] than in winter. Traditional service is not able to address this, but with continuous data streams, we are able to see these connections. […] Humidity in different continents is another thing for the bearings and hoists.' (*Director of Operations*, *SPOCorp*)
Diagnosing and solving elevators' technical problems remotely	Using digital technology like sensors and actuators that are integrated into the elevator on each floor and the drive system, as well as a capable infrastructure, makes diagnosing the root cause of technical problems possible. Spare parts can be pre-ordered accordingly, and on-site service visits can be scheduled. Software problems can be solved remotely by changing parameters or updating the elevator's software.	'We have the ability to reset the elevator remotely or move it around safely. […] Such remote activities also eliminate on-site trips.' (*Vice President*, *Field Service*, *MROCorp*) 'We want to be able to update the software on the products remotely.' (*Global Head of IT Operations*, *OEMCorp*)
Benchmarking production facilities' performance	Operational data of machinery and production facilities in the process industry like paper production, water treatment, steel processing, and chemical production can be used to benchmark throughput and production facilities.	'We focus on instrumentation and control technology. What might interest an operator of a paper production facility? […] What does he want? For sure, he wants optimal efficiency and utilization. […] In the end, it is resource efficiency and profitability.' (Service Line Manager, Plant Cloud Services, AOCorp)
Renting intralogistics equipment based on actual usage	Instead of selling or leasing forklift trucks, they can be offered as a service based on their actual usage, which includes wear and tear, as well as maintenance and repair activities that involve the MRO organisation.	'For us, flexible pricing means leveraging seasonal use—for instance, seasonal complementing dynamic scaling of the farmers' truck fleet in northern and southern Italy—as well as solving the financing problems of forklift truck operators. Usage-based pricing is a huge topic with many smaller sub-use cases.' (*Managing Director*, *Innovation Management*, *OEMCorp*)
Managing and optimising material flows and intralogistics processes for customers	Instead of selling or leasing forklift trucks, this service offering assumes overall responsibility for material flows at the customer site and optimises intralogistics processes for customers.	'If we establish a partnership with both our customers and [AOCorp], we can go beyond just offering forklift truck control systems and actually manage our customers' processes and operations for them.' (*Director*, *After-Sales and Customer Service*, *MROCorp*)
Auto-levelling for elevators	In the past, periodic on-site maintenance activities were necessary on each floor to adjust where the elevators stop. Now, using both sensing and responding capabilities, this adjustment can be done as an automatic service.	'Precision monitoring and leveling is a quick win. It could be accomplished through continuous measuring. The added value for the operator and the user is the increased safety, the prevention of accidents, and a reduced number of liability losses.' *(Director*, *Sales Region A*, *OEMCorp)*

interdependent, such that a clearly defined value proposition for the ecosystem's customers is present. Further, in line with Adner (2017), we selected case organisations whose business activities changed or were substantially modified to allow the defined value proposition to be generated. Hence, we can confirm that coordination is governed without full hierarchical fiat. Finally, we consider our case ecosystem to be a smart service ecosystem, as its participating actors are tied together around a set of smart products that require domain expertise in the moving assets and intralogistics industry and could not be deployed elsewhere.

The smart products themselves are the cornerstone of the smart service ecosystem. Following the affordance theory, the material properties that characterise both forklift trucks and elevators as smart products in our focal ecosystem provide the foundation for smart services. To structure the individual modules' material properties, we draw on the layered modular architecture Yoo et al. (2012) introduced, which consists of four layers: the device layer, the network layer, the service layer, and the contents layer.

In the context of our case, industrial products like elevators and forklift trucks must be augmented with sensors and actuators to protect against on-site fraud and manipulation on the *device layer*. Bi-directional, reliable, and secure product connectivity with sufficient bandwidth is established in the network layer to transmit various kinds of sensor data securely to a data platform in the service layer. (We identify standardised interfaces and protocols like MQTT and OPCUA.) After transmission to a data platform, operational product data can be stored and analysed in the service layer. To analyse the data in the service layer in such a way as to obtain insights and make sound decisions based on the operational product data, data-analytics technology that can handle enormous amounts of data must be in place. It can be distinguished between two modes of data analysis: prompt analysis of incoming data using complex event processing engines and messaging buses so the firm can react to unforeseen events, and pattern detection, advanced statistical analysis, and machine learning to analyse the substantial amounts of historic data on the data platform and on the smart products themselves. (Apache Spark and Hadoop are good examples.) Finally, the content layer involves data received from industrial products. The data must be consistent and comparable throughout the installed base and provide a comprehensive reflection of the industrial production in the field. (Practitioners refer to this reflection as a ‘thing shadow’ or a ‘digital twin.’) Table 4 provides an overview of the material properties of the digital technology attached to industrial intralogistics equipment as the nexus of our case ecosystem.

We chose the industrial manufacturing industry for our study of the emergence of smart service ecosystems for three reasons (Barile et al., 2016; Tuunanen, 2012). First, innovation in industrial manufacturing is no longer bound exclusively to the physical materiality of products or a single organisational actor but requires the involvement of multiple ecosystem participants (Barrett et al., 2015; Nambisan et al., 2016). Services in the industrial manufacturing industry are geared towards the long lifecycles of industrial products (Fain et al., 2017; Lightfoot et al., 2013), adding stability to our case context in terms of the ecosystem's primary usage. Second, industrial manufacturers proliferate digital technology for smart products rapidly, increasing the creation of collective smart services by participants in ecosystems (Barile et al., 2016; Nambisan et al., 2016). Third, because of the long life cycles of and high investment in industrial products, the industrial manufacturing industry is transitioning to smart service ecosystems that leverage digital technology for smart products (Barile et al., 2016; Fain et al., 2017; Lightfoot et al., 2013). Hence, our case ecosystem allows us to determine whether the prevalent perspective of a hub enterprise in the industrial manufacturing industry should be deemed ‘out-of-date industrial or manufacturing logic’ (Barile et al., 2016, p. 666).

3.2 | Data collection

The focus of our data collection was on information about how smart service ecosystems emerge. We conducted 47 interviews at a large German smart service ecosystem in the industrial space, involving all four types of industrial actors. Using snowball sampling, we collected data from four industrial organisational perspectives–those of the OEM, the SPO, the MRO, and the AO (Myers & Newman, 2007). Interviews were conducted between March 2014 and March 2018 as the primary method of data collection. Two researchers conducted semi-structured interviews

TABLE 4 Material properties of smart products as shared digital technology

Material property	Sample quotations
Physical products augmented with tamper-proof sensors and actuators	'You may want to monitor that particular piece of equipment, which is another functionality of what [internal project name] can provide, and you need to utilize either serial connections or sensors, which are independent of the control system. This imposes limits on what you can do remotely.' (*Group Chief Technology Officer and Head of Group R&D, OEMCorp*) 'Hardware security is super-important. […] We do not have any interest in a third party accessing that raw operational product data in any manner.' (*Head of Product Marketing, OEMCorp*)
Bi-directional, reliable, and secure product connectivity with sufficient bandwidth	'We use various technologies to ensure reliable connectivity […]. Wireless network and Bluetooth are two options […], but the most widespread technology is 3G. More than 12 000 connected products result in around 350GB of compressed mobile traffic per year.' (*Head of Competence Center IoT Platform Architecture, OEMCorp*)
Standardised interfaces, protocols, and data structures	'Technical standards like OPCUA that allow us to communicate directly with the cloud infrastructure or MQTT […] are relevant for interoperability and the development of data-driven services.' (*Service Product Manager, Out of the Box Analytics, AOCorp*)
Data storage and retrieval	'An IoT software platform must be able to store operational product data, irrespective of the age and configuration of the capturing device. Since we are obliged to meet statutory storage policies, we might need to save collected individual measurement values for 15 years. This requirement can only be addressed by a central platform. (*Vice President, Business Development and Operational Excellence, POCorp*)
Incoming data-stream processing and timely alerts and notification	'When I get an error, I can immediately tell the customer to stop the operations to prevent damage.' (*Director, After-Sales Region A, MROCorp*)
Descriptive data analytics based on historic data	'The machine is not just a simple transmitter of data; there is a lot of inbuilt intelligence and computing power. For example, the product doesn't continuously send data but systematically connects to a central platform after aggregating and validating data.' (*Head of Competence Center IoT Platform Architecture, OEMCorp*)
Predictive data analytics based on historic and current data	'The goal of predictive maintenance is to predict when a component will break down and then replace it during a regular service interval, such as at night, before a failure happens, so we can increase the overall availability of the product.' (*Vice President, Field Service, MROCorp*)
Digital product twin and integration of product master data	'Today, we can build digital twins that simulate and synchronize the characteristics and behavior of the real machine.' (*Head of Managed Service Analytics, AOCorp*)
Consistency of operational product data throughout the installed base	'We need to establish a single point of truth and create an unambiguous data record over the product's whole lifecycle.' (*Managing Director, Innovation Management, OEMCorp*) '[Irrespective of the final use cases], we aim at digitizing products in a highly standardized and scalable way. This includes hardware, sensors, software components, data management, data analysis, and the generation of insights.' (*Service Line Manager, Asset Analytics Services, AOCorp*)

with executives from the IT department, with chief technology officers, and with managers responsible for a service business, service innovation, and product digitization until we reached data saturation (Corbin & Strauss, 2008).

Our open-ended interview questions focused on five areas: the organisational context, including the job position of the interviewee and the competitive situation of organisation; descriptions of smart products and use cases; key features and participants of the ecosystem and collaboration with other organisations; process and activities related to how the ecosystem was formed; and complementarity and value propositions for the end customer. To obtain a holistic, unbiased view and balance the breadth and depth of the four perspectives to meet the requirements of validity and reliability, we followed Eisenhardt and Graebner (2007) in recruiting interviewees from multiple hierarchical levels, organisational roles, and locations (Bryman & Bell, 2015; Easterby-Smith et al., 2012). We designed the interviews to reveal how smart products are harnessed in both an organisational context and an ecosystem context, so we structured them based on the theoretical concepts and frameworks discussed in Section 2. The average duration of the interviews was 72 min. All interviews were recorded and transcribed, resulting in 864 pages of text.

We sought to develop a clear chain of evidence by considering multiple data sources, so in addition to interviews, we performed supplemental activities like full-day innovation workshops, focus groups (Tremblay et al., 2010), and conference calls. We also reviewed internal documentation, presentations, and other archival data from the organisations we interviewed. Then we compiled actor-specific summaries for all activities other than the semi-structured interviews. These activities gave us additional or broadened insights and triangulated the findings obtained from the interviews (Yin, 2008). Appendix A presents an overview of the data gathered and their sources.

3.3 | Data analysis

To mitigate interpretive research's risk of low generalizability, we applied Gioia et al.'s (2013) rigorous analysis approach to concept development. This approach pays particular attention to linking the empirical case and the idiographic findings to the existing body of knowledge as a way to balance the generation of novel theory and identification of theoretical precedents.

Two researchers discussed and analysed the collected data line by line and in an iterative manner using an interwoven three-stage process of *open*, *axial*, and *selective* coding. In addition to employing Gioia et al.'s (2013) recommendations, the data analysis is rooted in Corbin and Strauss's (1990) and Strauss and Corbin's (1997) recommendations and in grounded theory (Glaser & Strauss, 2009). We sought to identify first-order concepts (informant-centric concepts and themes), second-order concepts (research-centric concepts and themes), and their distillation into aggregate dimensions (Gioia et al., 2013). Appendix B provides an overview of the data structure we derived from open, axial, and selective coding. Following Strauss and Corbin (1990, p. 94), we 'never impose [d] anything on the data' while also applying their principle of theoretical sensitivity, which encourages the use of analytic tools like the affordance theory to allow insights to emerge. We were aware that using analytical tools like existing theory could carry the risk of forcing the data in preconceived ways, possibly leading to confirmation bias.

In the open coding stage, we identified recurring codes in the data to address the concepts that guided us when we compiled the interview guideline (Van Maanen, 1979) while remaining open to identifying other salient concepts from the data (Gioia et al., 2013). We compared the codes as they emerged to identify common first-order concepts based on our set of empirical data. Appendix B lists the final 39 first-order concepts.

In the axial coding stage, we condensed first-order concepts into themes by drawing on the theory of affordances to distinguish between smart products' material properties and the use context at the organisational and ecosystem levels (Chandler & Vargo, 2011). By harnessing the full strength of human sense-making, we could explore the qualitative relational nature of affordances in an archetypical smart service ecosystem (Leonardi, 2011; Pozzi et al., 2014). Appendix B lists the 17 final second-order concepts.

Having first derived a workable set of first-order concepts and second-order themes (Gioia et al., 2013), we used an integrated perspective in the selective coding stage to distill the second-order themes further into 'aggregate dimensions.' When we stabilised our coding structure at the beginning of the selective coding stage, we compiled a coding scheme that was evaluated in two focus group workshops with practitioners who had not participated in the interviews and an interdisciplinary panel of senior researchers, respectively (Tremblay et al., 2010). The evaluation workshops led to simplifying the initial coding scheme to enhance clarity and allow for exploratory findings.

While interpretative research typically does not take into account assessments of intercoder agreements, we wanted to see whether we had convergence on key aspects of our coding scheme. Complementing the methodology proposed by Gioia et al. (2013), similar to other studies (Anand et al., 2007; Clark et al., 2010; Gioia et al., 2010; Nag et al., 2007), we sought to increase trustworthiness and credibility and bolster our confidence in our interpretations' plausibility by asking two additional researchers who were not involved in this project to code an initial sample of 11 interviews in two iterations. After each iteration, we assessed inter-coder reliability using Cohen's kappa, a coefficient that measures whether the inter-rater proportion of agreement is greater than would be expected by chance (Rust & Cooil, 1994). After the first round, Cohen's kappa was 0.51. We discussed the major inconsistencies in coding with independent coders and revised the coding scheme for enhanced clarity and more consistent coding results. After the second round of coding using these changes, Cohen's kappa increased to 0.77, which is substantially higher than the threshold level of 0.60, indicating significant results (Moore & Benbasat, 1991). This step increased the rigour of our study. Coding the entire data set using the coding scheme (Appendix B) resulted in 2611 codes. We used NVivo 11, a computer-assisted qualitative data analysis tool, to analyse the interview transcripts and internal documents.

Finally, to scale up and integrate our emerging theory theoretically into other theories in the research field (Urquhart et al., 2010), we paid close attention to nascent themes in the literature that are related to the emergence of ecosystems, smart services, and digital innovation (Gioia et al., 2013) and that are either not referred to or discussed only conceptually or that allow theoretical knowledge to be incorporated into our first-order concepts. An iterative process of relating our aggregate dimensions to the body of knowledge allowed us to distill propositions that describe the relationships among our second-order concepts and the concepts of the extant body of knowledge on ecosystems (Lusch & Nambisan, 2015), as Gioia et al. (2013) suggest. In doing so, we focused on exploring the mechanisms at play in ecosystems' emergence. We refer to mechanisms as 'an intermediary level of analysis in-between pure description and storytelling on the one hand, and universal social laws on the other' (Hedström & Swedberg, 1996, p. 281). The concept of mechanisms allows the processes that underlie cause-effect relationships to be described (Gross, 2009). Mechanism-based theorising has proven valuable in qualitative research that focuses on the emergent nature of digital phenomena (Henfridsson & Yoo, 2014; Huang et al., 2017).

4 | RESULTS

This section describes the affordances related to smart products that the organisations in our case context perceive. While we focus on the organisational and ecosystem levels, we identify three classes of affordances: shared affordances, idiosyncratic affordances, and collective affordances. Appendix C provides a detailed overview of the affordances we identified and their relationships. In what follows, we describe the affordances we identified and their relationships.

4.1 | A shared worldview manifests in shared affordances

Shared affordances are those that all participants in a smart service ecosystem perceive. Our study suggests that shared affordances arise through a *shared worldview*, as the subject matter experts we interviewed reported a shared set of business assumptions and at least partly aligned organisational goals, which they considered an important prerequisite for developing smart products and services.

> In the worst case, you talk to people from other organizations, and you notice that they have no clue about how smart industrial equipment transforms our business. A shared perspective and a shared language are mandatory. (Head of Managed Service/Analytics, AOCorp)

The shared affordances the participants identified are perceived equally by all case companies since they are tied to the common denominator of organisations' goals for creating transparency and visibility while also controlling the

TABLE 5 Overview of shared affordances

ID	Shared affordance (*code frequency*)	Sample quotations
SA #01	Sensing equipment state (*42*)	'It would be valuable for us to have [...] transparency to see the condition and capacity use of all of our machines.' (*Head of Logistics and Process Performance, OEMCorp*) 'As we monitor assets, we can tie down a mean time between failures in specific equipment types and specific equipment configurations that will help us understand what requires more maintenance and what doesn't.' (*Director, Service Operations, MROCorp*) 'Operational machine data is very interesting to us, as we can deduct performance measures [...], and then we obtain visibility on how efficiently this equipment is actually used.' (*Director of Operations, POCorp*)
SA #02	Actuating equipment state *(13)*	'Actuators could be added to the building infrastructure in large warehouses. A specific example would be controlling rapid action doors based on the speed of approaching forklift trucks. Connected actuators would ensure that the doors open just in time to avoid emergency braking and loss of load.' (*Director, New Business and Product Digitization, OEMCorp*)

equipment state. Table 5 provides an overview of the two shared affordances identified: 'Sensing equipment state' (SA #01) and 'Actuating equipment state' (SA #02).

Subject matter experts in all four companies of our case ecosystem acknowledged the affordance of 'Sensing equipment state' (SA #01) so visibility and the state of operations is an underlying concern for all participants. One consideration is that technological distance negatively affects inter-organisational innovation, and shared affordances signal the potential for joint smart service innovations in the case ecosystem. Subject matter experts from the four companies exhibited similar mental frameworks when they described the shared affordances of smart products. For example, OEMCorp's Head of Logistics and Process Performance spoke of the '*transparency to see machine conditions*,' the MROCorp's Director of Service Operations mentioned the ability to '*monitor assets*,' and POCorp's Director of Operations talked about the potential of '*obtaining visibility*.'

Apart from a shared mental framework, shared affordances manifest a shared situational awareness of technologies' affordances, which is the foundation for capitalising on inter-organisational synergies. In other words, shared affordances motivate the participants in an ecosystem to mobilise and integrate their diverse capabilities. A service manager at AOCorp explained how a shared affordance leverages the ecosystem's synergies:

> If we can observe systemic phenomena in the installed base, they can draw CAPEX/OPEX decisions based on our system. This allows the MRO organization to work on strategic topics, the OEM to work on engineering better products, and operators to optimize the setup of their installed base and utilization. (Service Manager, Out of the Box Analytics, AOCorp)

We conclude that the shared worldview of the four organisations participating in the smart service ecosystem manifests in the smart products' shared affordances that all participants perceived.

4.2 | Structural flexibility and integrity manifest in idiosyncratic affordances

Idiosyncratic affordances are actor-specific affordances of smart products that depend on an organisation's context, unique goals, and capabilities. Data from our case ecosystem indicates that idiosyncratic affordances emerge through a process of actors' drilling down or into or 'specialising' in shared affordances to pursue the goals that are specific to their respective organisations. This sequential process of specialisation by relying on shared affordances to build idiosyncratic affordances is reflected in our data:

> The real challenge is that you have to see these general benefits through the eyes of your organization. The benefits that we see as a manufacturer are different from what the insurance industry comes up with. Compared to us, they will feed their insurance models and algorithms with this [operational visibility]. For them, this leads to fantastic risk evaluations. (Service Manager, Out of the Box Analytics, AOCorp)

We refer to this process of elaborating idiosyncratic affordances that uniquely fit the individual organisation's resources and objectives as specialisation. In other words, organisations leverage shared affordances to work towards achieving their individual organisational goals. Table 6 provides an overview of the idiosyncratic affordances we identified.

For example, AOCorp leverages data to generate performance insights (AO #01).

> It starts with simple benchmarking topics—that is, comparisons between performances over time. This extends to more sophisticated issues. (Service Line Manager, Asset Analytics Services, AOCorp)

However, OEMCorp identifies misuse of its products by leveraging insights that are based on domain knowledge that is idiosyncratic to its business (OEM #03).

> What are the environmental conditions of our products? Temperature? Dust and degree of air pollution? Because we want to earn more money from our customers in a fair way, we have to measure the environmental factors of product operations. (Managing Director, Innovation Management, OEMCorp)

Based on the misuse it identifies, MROCorp manages product operations so it can guarantee product uptime (MRO #04):

> We want to sell service contracts that say that we take care of the customer's machine so the customer can focus on his core business. (Head of MRO Service, MROCorp)

Finally, SPOCorp leverages industrial equipment with guaranteed uptime by providing enhanced operational transparency (SPO #02):

> We can use the new data to provide our customers with more transparency and information about the state of their orders. (Head of Logistics and Process Management, SPOCorp)

The formation of a broad set of idiosyncratic affordances by the participants in the smart service ecosystem requires considerable *structural flexibility* because these affordances represent numerous opportunities for joint innovations and flexible adaptation to environmental conditions. For example, SPOCorp's affordance of providing transparency to customers complements MROCorp's affordance of managing industrial equipment operations to guarantee product uptime (MRO #04). MROCorp's offering, which affords SPOCorp more reliable planning of operational processes, also complements to OEMCorp's affordance of identifying product misuse (OEM #03), because guaranteeing uptime requires ensuring that industrial equipment operation complies with agreed terms of use. As a third example, MROCorp's affordance (MRO #04) is further supported by AOCorp's affordance of performance

TABLE 6 Overview of idiosyncratic affordances

ID	Idiosyncratic affordance (*code frequency*)	Sample quotations
Idiosyncratic Affordances of Analytics Organisation (AOCorp)		
Organisational goal(s) of AOCorp: Provide scalable data-driven support and enable value co-creation in industrial smart service ecosystems (16)		
AO #01	Performance benchmarking (*14*)	'It starts with simple benchmarking topics—that is, comparisons between performances over time. This extends to more sophisticated issues.' (*Service Line Manager, Asset Analytics Services, AOCorp*)
AO #02	Event triggering (*36*)	'[One of our service offerings] just triggers machine halts or switching parameters between A and B. Customers can do this manually based on the insights that we provide, or they can trust our system. I think that this will start small: When introducing such a system, an employee will have to confirm 'OK,' 'OK,' 'OK.' When he has pressed 'OK' for two years, and the decisions were good, he will finally let our system take over.' (*Service Line Manager Energy Management, AOCorp*)
AO #03	Insights provisioning (*40*)	'We aimed at providing value services instead of hotlines or support for problems. Therefore, we have established various service lines that provide insights and various kinds of value to customers.' (*Service Line Manager, Plant Cloud Services, AOCorp*) 'We need a system that allows us to address data-sharing topics in a goal-oriented way.' (*Service Line Manager, Process Data Analytics, AOCorp*)
Idiosyncratic Affordances of Original Equipment Manufacturer (OEMCorp)		
Organisational goal(s) of OEMCorp: Engineer safe, superior industrial products at a competitive price (25); offer product-complementing services (48)		
OEM #01	Product mix (*117*)	'We offer to optimize the product mix for the customer organization considering the tasks that need to be accomplished with our products.' (*Managing Director, Product Marketing and Communication, OEMCorp*)
OEM #02	Product usage insights (*45*)	'It would be valuable for us to have a platform where we have this transparency to see the capacity use of all of our machines.' (*Head of Logistics and Process Performance, OEMCorp*) 'If we know exactly how our products are used and where issues occur, then we can improve future products or design upgrade kits to fix existing products.' (*Managing Director, Product Marketing and Communication, OEMCorp*)
OEM #03	Identifying product misuse (*36*)	'What are the environmental conditions of our products? Temperature? Dust and degree of air pollution? Because we want to earn more money from our customers in a fair way, we have to measure the environmental factors of product operations.' (*Managing Director, Innovation Management, OEMCorp*)
OEM #04	Product-complementing services (*72*)	'Based on a cross-functional innovation initiative, our goal is to offer entirely new services. [...] Today, we can barely imagine the potential of our products when they are augmented with digital technology.' (*Director, Industrial Services, OEMCorp*) 'We need to get rid of this thinking in terms of steel and iron. We need to sell more services instead of machines. We need to address our customers' needs.' (*Director, New Business and Product Digitization, OEMCorp*)

TABLE 6 (Continued)

ID	Idiosyncratic affordance (*code frequency*)	Sample quotations
Idiosyncratic Affordances of Maintenance, Repair, and Overhaul Company (MROCorp)		
Organisational goal(s) of MROCorp: Ensure error-free operations of industrial products in an efficient and effective manner (*98*)		
MRO #01	Triggering MRO activities (*31*)	'The goal of predictive maintenance is to predict when a component will break down and then replace it during a regular service interval, such as during the night before a failure happens, so we can increase the overall availability of the product.' (*Vice President*, *Field Service*, *MROCorp*)
MRO #02	Empowering & optimising field service activities (*93*)	'Currently, all technicians have a mobile device […] to manage and control their work. […] We need information on these devices from each product instance—real-time information, historical information, fault logs, […].' (*Vice President*, *Service Support*, *MROCorp*)
MRO #03	Establishing remote online diagnosis (*31*)	'An organizational function exists focusing on diagnosing and resolving problems remotely to replace field visits, or if the field service agent is not able to solve it, he or a smart algorithm finds the cause of the problem and recommends a potential solution.' (*Director*, *Field Service and MRO*, *MROCorp*)
MRO #04	Managing product operations and guaranteeing product uptime (*32*)	'The customer, at a certain point in time, says, 'Okay, you take care of it. I just want my truck to run, to work properly, and to have no downtime,' and that's fine.' (*Director*, *Sales Region A*, *MROCorp*) 'We want to sell service contracts that say that we take care of the customer's machine so that the customer can focus on his core business.' (*Head of MRO Service*, *MROCorp*)
Idiosyncratic Affordances of Smart Product Operator Company (SPOCorp)		
Organisational goal(s) of SPOCorp: Integrate industrial products into own value co-creation (*45*); gain operational transparency on value co-creation processes that utilize smart products *(54)*		
SPO #01	Gaining transparency on internal processes to manage work orders based on actual capacity *(65)*	'It would be valuable for us to have timely machine data, which would allow the foreman to see the status of work orders, such as the current processing speed, estimated time of completion of the work order, and disruptions in our production processes. We leverage product data to derive our output and performance. Conclusions about product use would also be great.' *(Director of Operations, SPOCorp)* 'Besides asset data, contextual information such as 'What are the workers doing?' or 'Why are the machines not [operating] right now?' is needed.' *(Senior Manager*, *Maintenance and Facility Engineering*, *POCorp)* 'We have an antiquated Enterprise Resource Planning system that's more of an inventory system. […] We feed some operational data on equipment operations into that system. Pairing some of that data with the data from the equipment would help us see the whole picture of what has occurred to that equipment over time.' *(Vice President*, *Operations*, *Region B*, *POCorp)*
SPO #02	Providing transparency on operations and processing of orders to customers (*48*)	'We can use the new data to provide our customers with more transparency and information about the state of their orders.' (*Head of Logistics and Process Management*, *SPOCorp*)

benchmarking (AO #01), because operating industrial equipment as a service relies on the ability to manage operations efficiently. In summary, then, the formation of a broad set of idiosyncratic affordances leads to opportunities for joint service innovations within the smart service ecosystem that can be exploited, depending on the specific environmental conditions.

The formation of idiosyncratic affordances also generates and strengthens ties between organisations. Inter-organisational ties relate to reciprocal dependencies, whose strategic role in providing smart services several interviewees emphasised:

> Real partnerships arise from reciprocal dependence. […] I think that we need to collaborate in such a way [that] reciprocity is a continuous balancing act. (Managing Director, Innovation Management, OEMCorp)

Structural integrity results from value propositions that participants in an ecosystem provide each other based on their unique and complementary competencies. Our data indicate that the companies are aware of these complements, through which novel smart service opportunities may emerge. For example, OEMCorp relies on an AO's data analytics competency:

> [OEMCorp] owns the (proprietary) connectivity to our products. However, the balance of power in the ecosystem looks very different when we go one level above and look at analytical capabilities. This means that other actors provide information like 'Caution, this machine is most likely to go down.' (Service Product Manager, Out of the Box Analytics, AOCorp)

We conclude that a smart service ecosystem's structural flexibility and integrity manifest in idiosyncratic affordances that are actor-specific and depend on the individual organisation's context and the organisational actor's goals.

4.3 | The architecture of participation manifests in collective affordances

Collective affordances are those use potentials of smart products that are enacted by a group of participants in a smart service ecosystem and result in joint provisioning of smart services. Our data indicate that collective affordances are formed through the integration of various actors' idiosyncratic affordances. The mechanisms that collective affordances build on top of idiosyncratic affordances are also reflected in our empirical data:

> Yes, I am talking about this interconnectedness spanning organizational boundaries. Take the example of the port of [City anonymized], with its smart and interconnected parking lots, cranes, and piers. Individual organizations must first realize their use cases and benefits before they exchange information, resulting in greater benefits beyond individual organizational boundaries. (Service Product Manager, Out of the Box Analytics, AOCorp)

We identify two collective affordances that relate to two smart services: 'Managing and optimizing product operations' (CA #01) and 'Performance-based contracting.' (CA #02). Table 7 provides an overview of these two collective affordances.

The affordance of 'Managing and optimizing product operations' (CA #01) integrates a set of idiosyncratic affordances of various organisations. Specifically, CA #01 integrates 'Event triggering' (AO #02) from AOCorp; 'Product usage insights' (OEM #02), 'Identifying product misuse' (OEM #03), and 'Product-complementing services' (OEM #04) from OEMCorp; 'Triggering MRO activities' (MRO #01), 'Manage product operations and guarantee

TABLE 7 Overview of collective affordances

ID	Collective affordance (*code frequency*)	Sample quotations
Collective affordances within the entire smart service ecosystem		
CA #01	Managing and optimising product operations (*27*)	'If we establish a partnership with both our customers and [AOCorp], we can go beyond just offering forklift truck control systems and actually manage our customers' processes and finally manage their operations for them.' (*Director, After-Sales and Customer Service, MROCorp*)
CA #02	Performance-based contracting (*32*)	'Flexible pricing means for us to leverage seasonal utilization—for instance, seasonal complementing dynamic scaling of farmers' truck fleets in northern and southern Italy as well as solving financing problems of forklift truck operators. Usage-based pricing is a huge topic with many smaller sub-use cases.' (*Managing Director, Innovation Management, OEMCorp*)

product uptime' (MRO #05) from MROCorp; and 'Gaining transparency on internal processes to manage work orders based on actual capacity' (SPO #01) from SPOCorp. To manage and optimise product operations, events like maintenance and repair activities must be triggered based on the industrial equipment's idiosyncratic conditions. OEMCorp supports the optimization of product operations by relying on the data and identifying misuse.

Our data suggest that these collective affordances create mechanisms through which the ecosystem participants' contributions are coordinated, integrated, and synchronised. Collective affordances represent a shared and agreed logic for the integration of the individual ecosystem participants' value propositions to produce super-additive value in the form of smart services, as shown in the example of the collective affordance 'Managing and optimizing product operations' (CA #01). Such an *architecture of participation* is necessary because developing smart services (i.e., collective affordances) across organisational boundaries requires more substantial coordinated efforts than service innovation within a firm's internal boundaries (i.e., idiosyncratic affordances) does:

> We are constantly in search of smart, innovative services. However, in ecosystems, this is a little more complicated than developing new products or increasing the internal efficiency of technical customer service. (Managing Director of Product Marketing and Communication, OEMCorp)

Collective affordances require transparent rules for the exchange of resources and capabilities between actors. For example, for the collective affordance 'Managing and optimizing product operations,' all of the actors involved share a common understanding of each other's contributions to the value proposition:

> The customer will be able to be more effective and have to deal with less equipment because of the products' increased uptime. Digital solutions like wearing sensors, as well as localization, will help to increase the product's efficiency and lower the number of machines needed (Director of Industrial Services, OEMCorp)

The ecosystem's participants also agree on how these value propositions are interconnected to provide value to SPOCorp:

> We draw on the expertise of various partners from different areas of expertise. We understand this effort as a team effort and embrace participation in a regular innovation process. (Managing Director, Innovation Management, OEMCorp)

Finally, the ecosystem parties must be aware of the multilateral connections required to produce super-additive value to SPOCorp:

> We consider this an ecosystem with multiple organizational actors who are all working on the same challenge. I believe that organizational borders are blurred. (Service Product Manager, Out of the Box Analytics, AOCorp)

Hence, we conclude that a smart service ecosystem's architecture of participation manifests in the collective affordances of smart products that are enacted by a group of participants in an ecosystem and result in the joint provisioning of smart services.

The three types of affordances we identified help us to explain how the case's smart service ecosystem emerged. Specifically, we revealed two *shared* affordances that relate to the properties of smart products that allow their operational states to be sensed and are jointly perceived by all ecosystem participants. Thirteen *idiosyncratic* affordances are role-specific and depend on the goals the respective organisation associates with the material properties of smart products. Finally, two *collective* affordances describe the ultimate affordances of smart products that are jointly enacted by a group of ecosystem participants and result in the joint provisioning of smart services.

5 | DISCUSSION

This section describes the results we found in the data in light of the extant literature. We develop a model that explains the emergence of smart service ecosystems, as presented in Figure 2. We explain and discuss this model in detail and derive propositions that conceptualise the relationships shown in the model.

Based on the material properties of smart products, smart service ecosystems emerge through *specialising* shared affordances, *integrating* idiosyncratic affordances, and jointly *establishing* collective affordances. Our data reveals three socio-technical antecedents of smart service ecosystem emergence: a *shared worldview*, *structural flexibility and integrity*, and *architecture of participation*. These antecedents manifest in the three classes of affordances and generate value propositions of smart service ecosystems.

The first antecedent, a shared worldview, manifests in shared affordances because, when participants in an ecosystem perceive shared affordances in a smart product, these participants exhibit low technological distance and shared situational awareness. The literature on firm alliances uses the term 'technological distance,' which refers to how organisations differ in terms of their perceptions and understanding of their technology profile's role in comparison to their partners in the ecosystem (Gilsing et al., 2008; Nooteboom et al., 2007; Wuyts et al., 2005). We argue that a shared worldview reduces the technological distance among participants in an ecosystem and increases their shared situational awareness of possibilities for the integration and exchange of resources. Sharing information in a smart service ecosystem also increases shared situational awareness among its participants. Consequently, we formulate proposition 1a as follows:

Proposition 1a. A shared worldview manifests in shared affordances.

The second antecedent, structural flexibility and integrity, leads organisations to determine what their unique contributions to an emerging smart service ecosystem might be, recognising that they might have to alter how they do things and collaborate with others to allow for flexible formation of configurations of actors and complementary idiosyncratic affordances. Therefore, we argue that idiosyncratic affordances require a considerable degree of structural flexibility and integrity. The ecosystem literature also mentions that organisations 'need to develop strategies that recognize and manage indirect links is one of the key distinctions between traditional strategy and ecosystem strategy' (Adner, 2017, p. 44). Through structural flexibility, an ecosystem's participants can react to external

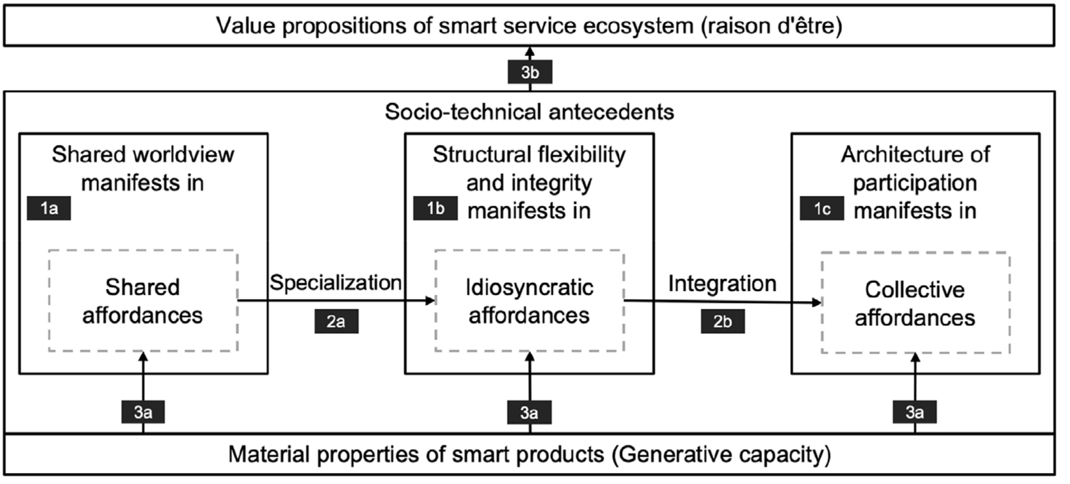

FIGURE 2 Theoretical model explaining the emergence of smart service ecosystems based on material properties of smart products and socio-technical antecedents

conditions by forming dynamic, cooperative constellations (Adner, 2017; Moore, 1997). In our case ecosystem, MROCorp's organisational goal is to ensure error-free operations of industrial products in an efficient and effective way, while OEMCorp's goal is to engineer safe, superior industrial products and complementary services for a competitive price. Through structural integrity, strong ties are formed that hold the ecosystem participants together (Lusch & Nambisan, 2015). For example, MROCorp's and OEMCorp's idiosyncratic affordances are complementary to SPOCorp's idiosyncratic affordances. Therefore, we state proposition 1b:

Proposition 1b. Structural flexibility and integrity manifest in idiosyncratic affordances.

The third antecedent, architecture of participation, ensures collaboration across the ecosystem by providing mechanisms to ensure coordination, integration, and synchronisation of the ecosystem's participants (Lusch & Nambisan, 2015, p. 165). Collective affordances determine how to coordinate, integrate, and synchronise the contributions of the ecosystem's participants to realise complex smart services, thus specifying an architecture of participation. Our case ecosystem's architecture of participation fosters collaborative development of joint value propositions for the end customer. For example, the affordance ‘Performance-based contracting’ (CA #02), allows industrial products like forklifts to be billed by the amount of use they deliver (e.g., the number of tonnes they move within a settlement period, including wear and tear and maintenance). According to the Managing Director, Innovation Management of OEMCorp, ‘partners from different areas of expertise [collaborate and] understand this effort as a team effort and embrace participation in a regular innovation process.’ Accordingly, architecture of participation allows an ecosystem's participants to operate in unison without hierarchical structures or control mechanisms (Lusch & Nambisan, 2015). An architecture of participation is characterised mainly by an ecosystem's institutional arrangements, such as rules, norms, and practices used by actors to coordinate actions (Lusch & Nambisan, 2015). These rules, norms, and practices are a result of the non-fungibility of ecosystem actors' investments in connecting to a smart service ecosystem (Jacobides et al., 2018), bringing us to proposition 1c.

Proposition 1c. An architecture of participation manifests in collective affordances.

Our data also shows that the emergence of a smart service ecosystem is a process of affordance specialisation and integration that leads to joint value propositions. Organisational actors draw on shared affordances to form idiosyncratic affordances through *specialisation*, taking into account their organisations' goals and capabilities. Specialisation refers to the actors' differing perspectives on which smart products can be used as complements because of their generative nature or capacity (Cennamo & Santaló, 2019; Yoo et al., 2012). In our case, each ecosystem actor builds on shared affordances to come up with their specialised idiosyncratic affordances. For example, OEMCorp specialises in 'Product-complementing services' (OEM #04) by drawing on both 'Sensing equipment state' (SA #01) and 'Actuating equipment state' (SA #02). With the example of an elevator as a smart product, a product-complementing service could be a continuous overweight check (drawing on 'Sensing the equipment state') that would avoid damaging the elevator by preventing it from moving (drawing on 'Actuating equipment state') if overweight is detected. A maintenance organisation like MROComp might build on these two affordances in a different way, such as by identifying misuse that might void the warranty.

Idiosyncratic affordances build on the recombinant and generative innovation potential of shared affordances' laying the foundations for materialising joint value propositions—that is, complex smart services in a smart service ecosystem (Cennamo & Santaló, 2019; Lyytinen et al., 2016; Thomas & Ritala, 2021; Yoo et al., 2012). As such, our notion of idiosyncratic affordances supports the rationale for a set of an ecosystem's actors' multilateral relationships that are due to these actors' complementarities (Adner, 2017; Jacobides et al., 2018; Shipilov & Gawer, 2020).

In summary, based on our data, we argue that the emergence of a smart service ecosystem depends on socio-technical antecedents. Further, the multilateral linking of an ecosystem's participants builds on the specialisation of the actors' activities, specifically their adoption of shared affordances (Adner, 2017). In this process of specialisation, a participant in an ecosystem establishes its position in the flow of the ecosystem's activities that materialise focal value propositions (Adner, 2017). This logic leads us to proposition 2a.

> **Proposition 2a.** Idiosyncratic affordances are the result of a process in which actors specialise shared affordances to pursue idiosyncratic organisational goals.

Collective affordances arise through the *integration* of idiosyncratic affordances; that is, the integration of idiosyncratic affordances related to a smart product is a decentralised, emergent process that results in the collective affordances that underlie ecosystems' joint value propositions. For example, the collective affordance 'Performance-based contracting' (CA #02) requires the actors in our case's smart service ecosystem to integrate 'Product usage insights' (OEM #02) and 'Managing product operations and guarantee product uptime' (MRO #04). As the Managing Director of Innovation Management at OEMCorp observed, this collective affordance results from integrating a set of idiosyncratic affordances from various actors in the ecosystem:

> Usage-based pricing is a huge topic with many smaller sub-use cases. (Managing Director, Innovation Management, OEMCorp)

Demarcating three classes of affordances and the mechanisms of specialisation and integration highlights the role of the collective affordances that underlie the realisation of joint focal value propositions as the ultima ratio or *raison d'être* of a smart service ecosystem. While the process of specialisation allows a participant in the ecosystem to position itself in the flow of activities, the process of integration culminates in multilateral ties that are bound by a smart products' capacity for action (Adner, 2017). Consequently, we formulate proposition 2b:

> **Proposition 2b.** Collective affordances are the result of a convergence process in which actors integrate the idiosyncratic affordances that lead to an ecosystem's joint focal value propositions.

Our results indicate that the emergence of a smart service ecosystem relies on the generative nature of smart products' material properties—that is, their generative capacity for action and allowance for non-designed use—and convergence properties, referring to merging formerly separate entities (Beverungen et al., 2019; Cennamo & Santaló, 2019).

Generativity results from the combination of 'information available about the product, product environment or the network to which the product is connected to stimulate the co-production of new ideas' (Lyytinen et al., 2016, p. 53). Our results highlight the role of smart products' material properties (Table 3) in smart service ecosystems' emergence. As such, an organisation's ability to sense and develop affordances related to smart products sets the foundation for a firm's participation in a smart service ecosystem. Smart products' generative nature and digital connectivity (Lyytinen et al., 2016) result in shared affordances for an ecosystem's actors. Relying on these generative, shared affordances, these actors contribute their resources and capabilities to build idiosyncratic affordances as complements to those of other actors in the ecosystem (Cennamo & Santaló, 2019; Thomas & Ritala, 2021). The idiosyncratic affordances can be integrated into the collective affordances that underlie the realisation of a smart service ecosystem's joint value propositions, which are its *raison d'être*. Following this line of reasoning, linking multilateral ecosystem participants and positioning their idiosyncratic activities (Adner, 2017) are based on a smart product's generative capacity for action—in other words, shared, idiosyncratic, and collective affordances. We formulate proposition 3a as follows:

> **Proposition 3a.** A smart product's generative capacity allows for the emergence of a smart service ecosystem by giving rise to shared, idiosyncratic, and collective affordances.

Finally, the process of affordance specialisation and integration has given the three social-technical antecedents is a form of digital convergence, as 'diverse information is transformed into a unified digital format that connects previously unrelated knowledge in ways that can be manipulated and analysed' (Lyytinen et al., 2016, p. 53). Our results show how the mechanisms of specialisation of shared affordances and integration of idiosyncratic affordances result in collective affordances that span individual organisations and give rise to smart service ecosystems. All of these factors rely on the socio-technical antecedents of a shared worldview, structural flexibility and integrity, and architecture of participation, as well as the generative capacity of smart products. Therefore, we set proposition 3b as:

> **Proposition 3b.** The convergence towards a smart service ecosystem's focal value propositions requires the mechanisms of affordance specialisation and integration and the three socio-technical antecedents of a shared worldview, structural flexibility and integrity, and architecture participation.

In summary, we reveal the mechanisms of specialisation (Proposition 2a) and integration (Proposition 2b) as driving forces of the multiple actors' cooperation in ecosystems and address the lack of research on the emergence of smart service ecosystems based on a shared worldview (Proposition 1a), structural flexibility and integrity (Proposition 1b), and architecture of participation (1c). This process is highly influenced by the material properties of the underlying smart products and the smart services that they afford (Proposition 3a). Therefore, we posit that shared affordances act as conduits for the collective action that facilitates specialisation into idiosyncratic affordances and a distinct set of roles in an ecosystem. This enables the recombination and convergence of affordances into a joint focal value proposition (a collective affordance), the anchoring point, and *the* ultima ratio of an ecosystem (Proposition 3b).

6 | IMPLICATIONS

Our study contributes to both theory and practice. With a scholarly audience in mind, we iterate through the three research areas in our research model and outline related avenues for further research. As for practitioners, our results offer support in making effective decisions when collaborating across organisational boundaries to leverage smart products in smart service offerings and when navigating smart service ecosystems.

6.1 | Theoretical implications

Our results have several implications for the theory that may serve as starting points for further research. We explain the emergence of smart service ecosystems by identifying three classes of affordance that are based on the foundations of socio-technical antecedents and the generative capacity of smart products. We also identify *specialisation* and *integration* as driving forces in the emergence of smart service ecosystems and in smart service ecosystem participants' joint journey to materialising their ecosystems' value propositions. Finally, our propositions prepare future research to develop measurement instruments to determine when and why smart service ecosystems emerge. Table 8 summarises suggested avenues for further research on the emergence of smart service ecosystems based on the theoretical implications of the work at hand.

Specifically, we extend the current body of knowledge on smart service ecosystems' emergence in three ways:

a. We explain the role of the socio-technical antecedents and the resulting three affordance classes in the emergence of smart service ecosystems.
b. We clarify the roles of ecosystem actors' multilateral relationships and smart products through *specialisation* and *integration* of affordance classes in forming smart services.
c. We conceptualise emergence as the materialisation of smart service ecosystems' focal value propositions through the collective action of complementary ecosystem actors based on smart products' generative capacity.

6.1.1 | Understanding socio-technical antecedents and the foundations of smart service ecosystems' emergence

The first way in which we extend the current body of knowledge on smart service ecosystems' emergence is by providing an empirical account of the socio-technical antecedents of smart service ecosystems' emergence. The ecosystem literature does not adequately explain the circumstances under which actors assemble to co-create value in ecosystems constituted around smart products and how actors' contributions lead to the realisation of complex smart services as joint value propositions (Aarikka-Stenroos & Ritala, 2017; Autio & Thomas, 2020; Barile et al., 2016). Our results identify the foundations of a smart service ecosystem's emergence and the materialisation of its focal value proposition as a *raison d'être*. We provide empirical evidence for arguments, once only conceptual, that the emergence of a smart service ecosystem depends on a *shared worldview*, *structural flexibility and integrity*, and *architecture of participation* (Lusch & Nambisan, 2015; Taillard et al., 2016).

Our data reveals that these foundational characteristics of smart service ecosystems are evident in the three affordance classes as stepwise elements that lead to the emergence of smart service ecosystems: Shared affordances require that actors have a shared worldview, idiosyncratic affordances require structural flexibility and integrity, and collective affordances require an architecture of participation.

By providing empirical evidence for these antecedents and their corresponding classes of affordances, we contribute to Jacobides et al.'s (2018) conceptual arguments on modularity and complementarity and the required (pre)-conditions—that is, socio-technical antecedents—of the emergence of smart service ecosystems. Our case clarifies that organisations' investments are rooted in three socio-technical antecedents and will not easily be redeployed elsewhere (cf. Jacobides et al., 2018; Thomas & Ritala, 2021). Jacobides et al. (2018) propose types of complementarities with which to classify ecosystems conceptually by distinguishing among the roles of generic, unique, and supermodular complementarities in the creation of an ecosystem's value proposition. Our notion of affordances resembles this classification, as shared, idiosyncratic, and collective affordances parallel generic, unique, and supermodular complementarities, respectively. By providing empirical evidence for ecosystems' specific socio-technical antecedents and the resulting three affordance classes, we extend the current body of knowledge and its conceptual reasoning (Taillard et al., 2016; Thomas & Erkko, 2015).

TABLE 8 Potential research avenues on smart service ecosystem emergence

Implications for theory	Areas relevant for IS research	Potential research avenues
1. Understanding of the socio-technical antecedents and the resulting three affordance classes of smart service ecosystem emergence.	Corroborate the application of affordance theory in a multi-level setup Strong et al., (2014)	Validate affordances identified in the context of industrial manufacturing
	Stakeholder theory Freeman et al., (2010), stakeholder alignment, and speed of digital business strategies Bharadwaj et al., (2013)	Reconceptualization of supply chains towards service networks
	Service innovation and service-Dominant logic Lusch and Nambisan, (2015), Vargo and Lusch, (2008, 2017)	Smart service ecosystem design, classification of smart service ecosystems, smart service ecosystem design patterns
	Ecosystem design Jacobides et al., (2018)	Ecosystem transformation and change management
2. Role of multilateral relationships of ecosystem actors and smart products through *specialisation* and *integration* of affordance classes to form smart services	Organisational and inter-organisational change and resource integration Sklyar, Kowalkowski, Tronvoll, & Sörhammar, (2019)	Affordance actualization interdependence within organisations
	Actor complementarity and alignment of individuals' firms' business models in the context of smart service ecosystems Kohtamäki et al., (2019)	Boundaries of smart service ecosystems and industry convergence
	Dependencies between affordances and affordance classes Strong et al., (2014)	Collective affordance actualization paths within ecosystems
3. Emergence as the materialisation of focal value propositions of a smart service ecosystem through the collective action of complementing ecosystem actors based on the generative capacity of smart products.	Business model generation and value realisation mechanisms	Identification of value realisation patterns
	Ecosystem governance and regulation Jacobides et al., (2018)	Generic mechanisms to recruit (and retain) ecosystem participants
	Smart products as technology platforms Yoo et al., (2012)	Generative design and design principles of smart products

Against this backdrop, future research may validate and corroborate the affordance classes identified in the context of industrial manufacturing and their socio-technical antecedents. The resulting corroborated findings might help research to favour the concept of smart service ecosystems over that of supply chains to conceptualise cross-industry collaboration in the context of smart products and work on stakeholder alignment and digital business strategies (Bharadwaj et al., 2013). Further work in this area will also advance affordance theory by investigating affordances at both an organisational and ecosystem level to confirm the theory's use in a multi-level setup. Minting smart service ecosystems' design principles and their respective design patterns could be an additional opportunity to explain service innovation in a more generic way and to contribute to the scholarly discussion (Lusch & Nambisan, 2015; Vargo & Lusch, 2008, 2017).

6.1.2 | Specialisation and integration of smart products' affordances by ecosystem actors

The second way in which we extend the current body of knowledge on smart service ecosystems' emergence is to clarify the roles of ecosystem actors' multilateral relationships and smart products through the mechanisms of specialisation and integration. The three affordance classes identified in our study delineate the path of specialisation and integration. Our work proposes that specialising shared affordances and integrating idiosyncratic affordances culminate in the realisation of collective affordances. This logic enriches Adner's (2017) structuralist perspective and allows for an analytically distinct acknowledgement of activities conducted through integration and specialisation and the intertwining of multilaterally related ecosystem participants through shared, idiosyncratic, and collective affordances. In using this logic, we avoid an analytically reductive approach (Barile & Polese, 2010) for illuminating the complex, multi-agent process of smart service ecosystems' emergence (Thomas & Ritala, 2021).

The extant research focuses mainly on ecosystems' structure and argues for fuzzy or even boundaryless ecosystems, while Adner (2017) proposes that boundaries may be determined by the required activities of firms to allow for their value propositions to materialise. Our proposals regarding the specialisation and integration of affordances extend this view and account for these activities. In other words, specialised and integrated affordances result in interlinked ecosystem participants. Thus, we substantiate previous findings regarding the shift towards distributed innovation networks changing how value is traditionally created in the industrial space (Barile & Polese, 2010; Lütjen et al., 2019). Our work highlights the role of smart products for industry convergence and proposes smart service ecosystems as an organising logic and a new form of innovation network that affords previously unforeseeable smart services (Autio & Thomas, 2020; Lyytinen et al., 2016; Zammuto et al., 2007).

For future research, we provide concepts and conditions under which unprompted, unpredictable, innovative, and recombinant contributions by distinct sets of actors may converge into smart service ecosystems and emphasise the roles of digital technology, joint goals, and socio-technical antecedents in the emergence of ecosystems (Autio & Thomas, 2020; Lyytinen et al., 2016; Thomas & Erkko, 2015; Thomas & Ritala, 2021; Yoo et al., 2012). Future research could also focus on the actualization of idiosyncratic affordances by taking an organisational change perspective to investigate patterns of resource integration at the organisation level (Sklyar, Kowalkowski, Sörhammar, & Tronvoll, 2019). Besides investigating the change processes in an organisation that are required to harness smart products' affordances (Sklyar, Kowalkowski, Tronvoll, & Sörhammar, 2019), the alignment of firms' business models in the context of a smart service ecosystem (Kohtamäki et al., 2019) should be investigated to improve our understanding of affordance specialisation and integration. Researchers may also build on the three affordance classes, as well as affordance specialisation and integration, to clarify the boundaries of the smart service ecosystem. In addition, we suggest theory-building research on the extension of smart service ecosystems' boundaries that results in industry convergence or even replacement. Investigating these movements could be especially useful in manufacturing and other industries that are transforming. Future research in this area may shed light on which characteristics of smart service ecosystems make the ecosystem a favourable place for potential participants other than new ways of economic exchange and collaboration to actualize collective affordances.

6.1.3 | Emergence as the materialisation of a smart service ecosystem's value propositions

Finally, the third way in which we extend the current body of knowledge on smart service ecosystems' emergence is to reveal how organisations jointly turn smart products into corresponding smart services as the value propositions of a smart service ecosystem (Barile et al., 2016; Beverungen et al., 2019; Vargo & Akaka, 2012). Specifically, we identify smart products' generative capacity as the origin of three classes of affordances. Smart products' generative capacity inspires participants in smart service ecosystems to make complementary contributions that are in line with their individual or aligned organisational goals and eventually build collective affordances from those contributions (Cennamo & Santaló, 2019; Thomas & Ritala, 2021). Whether an organisation can position itself successfully in a smart service ecosystem depends on its ability to exploit a smart product's generative capacity and enter into a shared value proposition. As such, our work is the first to show that smart products' material properties are common ground for actors' collaboration and coordination that stimulate new links to previously unconnected nodes and economic actors (Autio & Thomas, 2014; Lütjen et al., 2019; Lyytinen et al., 2016). In doing so, our work explains how a smart service ecosystem's actors may gather to provide smart services as value propositions by unbundling the role of smart products (Aarikka-Stenroos & Ritala, 2017; Barile & Polese, 2010; Shipilov & Gawer, 2020) as the starting point for a smart service ecosystem to emerge.

Generally, emergence is understood as the process of generating from pre-existing material unanticipated new entities, structures, totalities, and/or concepts that are more than the sum of their parts (Bhaskar, 2008; Taillard et al., 2016). The ecosystem literature defines ecosystems as non-hierarchical coordination and collaboration while acknowledging that they do not emerge entirely spontaneously (Jacobides et al., 2018; Lingens et al., 2020; Thomas & Erkko, 2015). However, that literature does not provide detailed concepts regarding ecosystems' emergence, such as rules for membership and the complementarity of ecosystem actors' contributions that are founded on material properties or smart products (Cennamo & Santaló, 2019; Jacobides et al., 2018; Lyytinen et al., 2016; Thomas & Ritala, 2021). The literature also lacks empirical evidence on the phenomenon of emergence (Barile et al., 2016; Jacobides et al., 2018).

While we draw on an empirical case, we conceptualise emergence as the materialisation of a smart service ecosystem's value propositions. We argue that the emergence of a smart service ecosystem is not fully determined by a hub firm's execution of governance, design, or orchestration and does not always follow a formation 'by design.' Instead, its emergence depends heavily on the participation of multiple actors, which requires shared intentions that result from and foster the actors' interdependence (Taillard et al., 2016; Thomas & Ritala, 2021).

Our study shows that a smart service ecosystem's value propositions result from complementary contributions by multiple actors whose complementary contributions can be integrated into a (focal) value proposition—the *raison d'être* of a smart service ecosystem. With this understanding, we substantiate Thomas and Ritala's (2021, p. 4) conceptual argument that 'collective action among different ecosystem participants enables an emerging ecosystem.'

As a (focal) value proposition that draws on smart products can be seen as the nexus of a smart service ecosystem, future work should abstract from single ecosystems to investigate a phenomenon of interest in a more generalised way. One approach could be to identify patterns in smart service ecosystems (Storbacka et al., 2016) or generic mechanisms used to recruit and retain participants. We ask for further research, informed by the contributions of this paper, to address the implications of smart products' generative design and their modularity on the emergence of the smart service ecosystem (Jacobides et al., 2018). Examples of generative design and modularity are openness and accessibility of technology for potential new actors in an ecosystem, such as the relationship between the Advanced Programmable Interface (API) design of smart products and the emergence of smart service ecosystems, as is done in platform research (Wulf & Blohm, 2020). In performing such research, researchers could benefit from how we applied the affordance theory to shed light on how smart products' materiality and design may determine a smart service ecosystem's viability (Thomas & Ritala, 2021). In addition, we hope that identifying the socio-technical antecedents and the affordances classes will inform future research on value creation and capture, on how smart products act as conduits for coordination of ecosystem participants' business activities, and on how ecosystem participants may design their roles in an ecosystem that is not under their control (Jacobides et al., 2018).

6.2 | Managerial implications

Our findings provide insights for practitioners that support them in navigating smart service ecosystems and making effective decisions when collaborating across organisational boundaries to leverage smart products in smart service offerings. These insights are especially valuable for decision-makers in traditional product-oriented industries, where collaboration across organisational boundaries has traditionally been characterised by dominant positions and controlling supply chains instead of collaborating in diverse ecosystems across industries (Porter, 1985; Stabell & Fjeldstad, 1998). Today's product-oriented organisations cannot dictate to suppliers and partners how they should harness the benefits of smart products (Porter & Heppelmann, 2014). Our work indicates that smart service ecosystems require generic affordances, rather than features designed for use only in a particular context or industry, and organisations' participation and specialisation in co-creating value (i.e., smart services) in the context of smart services in ecosystems.

The first of these requirements, that smart service ecosystems demand is that organisations build on smart products' generic affordances, and places smart products as cornerstones in smart service ecosystems that cannot be designed and fabricated by a single organisation that prescribes each use scenario or dictates the roles of other actors in the ecosystem. As illustrated by our first example in the introduction, the proprietary design of multimedia interfaces by car manufacturers featuring a fixed set of functionalities, such as offline navigation with static maps, music playback, or radio stations, is such a 'by design' approach, which results in pre-defined and limited affordances and limited value for the end user. Instead, OEMs could focus on establishing what we call socio-technical antecedents. As already Jacobides et al. (2018) indicate, actors in ecosystems must build on open, modular standards if smart service ecosystems are to emerge. Examples are common technical standards to connect mobile phones to cars and standardised architectures like OPC UA in the industrial space. Such standards allow actors from inside or even outside the industry to identify how they might contribute to an ecosystem's overall value proposition. Therefore, we encourage industrial and product-oriented organisations to create or participate in working groups to define technical reference architectures, industry standards, and open interfaces that establish common ground so as to expedite the process of developing smart services. Instead of safeguarding smart products' material properties from other actors, industrial organisations should seek to achieve maximum exposure so potential collaborators will emerge and unleash their smart products' generative capacity. Practitioners have coined the term 'frenemies' to refer to organisations with which they collaborate and whose competition they fear. From a legal perspective, cross-licensing agreements help to overcome practical challenges by making it possible to grant competitors the right to use a smart product (or its functionality) in a controlled manner while at the same time shielding its use from other organisations (Zhao et al., 2021). Further, organisations that are considering exploiting a smart product should clarify its obvious benefits that can be accessible to multiple industry roles. Sensing the equipment state of a smart industrial product is a shared affordance with which multiple actors may engage to provide added value (e.g., through outcome-based business models). Accordingly, organisations should identify the value that aligns with their goals by specifying the smart products' affordances in the organisation's specific context. While doing so, organisations should be aware of the potential complementarities that could arise from establishing connections with other participants in their existing or emerging smart service ecosystems (Beirão et al., 2017). They must co-specialise to identify a niche that is relevant to other actors in the smart service ecosystem while evaluating smart products and the surrounding ecosystem as a platform for new affordances.

The second requirement of smart services ecosystems is that companies detect and exploit super-additive value propositions that emerge from integrating actors' affordances into a joint value proposition that benefits the organisations in the ecosystem. Shifting from purely technical 'proofs-of-concept' to more holistic 'proofs-of-value' helps organisations prototype and tweak setups. We also encourage organisations to start open conversations and working groups with potential partners in an effort to form a shared vision from the perspective of end customers. Traditional product-oriented organisations often fear losing power and authority to technology organisations. To align with and influence technology organisations, automakers and other industrial organisations often form alliances with technology organisations as converging actors entering the industry when a smart service ecosystem emerges. Such strategic partnerships and alliances may be seen as examples of the socio-technical antecedents we identified: a shared worldview, structural flexibility and integrity, and an architecture for participation. To return to our first example from the introduction, we showed how technology organisations like *Google* and *Apple* entered the automotive industry with offerings like *Android Auto* and *Apple Car* to provide smart services related to car-users' entertainment and navigation needs. In the past, carmakers developed well-designed and highly proprietary head units as closed systems, but today, strategic partnerships that cut across industry boundaries serve as the common ground for aligning shared intentions, building on sophisticated and modular architectures, and paving the way to the future. *Daimler Truck*, cooperating with Google's *Waymo* on autonomous driving, is a recent example of this type of industry-converging alliance.[2] Building in-house capabilities that traditionally reside outside the industry or filling capability gaps through acquisitions for the sake of full control seem to be doomed to failure. In particular, new enabling technology innovations like the Internet of Things, Machine Learning, and the convergence of the material and social worlds demand highly specified capabilities that are impossible to manage through arm's-length relationships and hierarchically managed supply chains or contractual alliances, as it would be impossible to manage customised contractual agreements and technical interfaces with each partner to satisfy each use case.

Initial industry-specific business cases require complementing other industries' ecosystem actors by specialisation and integration of smart products' abilities, assets, competencies, and knowledge that do not reside within the reach of industry incumbents. Until now, policy-makers, regulators, and antitrust authorities have thought only about competitive markets, which are much narrower than ecosystems. Practices like tying and bundling, which are typically prosecuted by focusing on individual organisations, must be reconsidered in light of emerging smart service ecosystems.

In summary, the research at hand identifies mechanisms that enable organisations to join forces, sparking the emergence of a smart service ecosystem around smart products in the context of the industrial manufacturing sector. In this context, smart products are the cornerstones of emerging smart service ecosystems, and these products' generative capacity is the starting point for the collective activities in a smart service ecosystem that lead to smart services.

7 | CONCLUSION

Until now, scholars have mostly postulated that smart service ecosystems are engineered 'by design' and that a central 'hub' firm coordinates value creation related to smart products by governing other network participants and designing value creation. By taking an affordance-centric perspective, this empirical study explains the phenomenon of smart service ecosystems' emergence by conceptualising three classes of organisational affordances—shared, idiosyncratic, and collective—and derives propositions that detail the socio-technical antecedents of smart service ecosystems' emergence. The results of this study help to understand how organisations can tap into the value potential of smart products by establishing their niche during the emergence of ecosystems. The theoretical implications of this research are threefold.

First, this research provides an understanding of the socio-technical antecedents of smart service ecosystems' emergence and therefore is able to explain the circumstances under which actors are able to co-create value in smart services as joint value propositions. Specifically, a shared worldview, structural flexibility and integrity, and an architecture of participation are needed as antecedents to develop shared, idiosyncratic, and collective affordances as stepwise factors in moving smart services into smart service ecosystems. Second, the identified mechanisms of specialisation and integration of smart products' affordances by ecosystem actors clarify the roles of ecosystem actors' multilateral relationships as well as of the generative capacity of smart products as they are ultimately the driving forces behind the emergence of smart service ecosystems. Specialisation is the process of elaborating idiosyncratic affordances that uniquely fit the idiosyncratic organisation's objectives and resources. Drawing on these various actors' idiosyncratic affordances, the integration mechanism depicts the forming of collective affordances as focal value propositions of the ecosystem. Third and consequently, we establish an understanding of emergence as the materialisation of a smart service ecosystem's value propositions. The smart service ecosystem's value propositions result from complementary idiosyncratic contributions by multiple actors that are integrated into focal value propositions—the raison d'être of a smart service ecosystem.

For managerial decision makers, this paper is especially valuable as it provides guidance on which aspects to focus on when having a vested interest in the success of an emerging smart service ecosystem. The case at hand illustrates how it is no longer feasible for single decision-makers and organisations to design the entire value creation around physical products by themselves. Our theoretical model as well as the discussed implications help to prioritise key elements for decision-makers in traditional product-oriented industries and illustrate how collaboration across industries is required. Taking decisions with regards to the material properties of smart products as an example, practitioners should focus on generative designs, for example, through modularity and openness to safeguard accessibility of technology for potential new actors in an ecosystem. Appropriate APIs design and Software Development Kits are examples of an architecture of participation that allow the collaboration of organisational actors—even across industrial boundaries.

This study is not without limitations. The study's unit of analysis is a smart service ecosystem in the context of smart products in the industrial manufacturing industry. Although the case ecosystem can be characterised as typical, configurations of actors in other industries may differ from the study's setting and lead to other results. Other affordances could also arise in other organisational settings or industries. As the industrial context that the study at hand focuses on is characterised by long product life cycles, the dynamics of ecosystem emergence, as well as intermediate actor configurations, might be more stable and explicit compared to other contexts such as in fast-paced consumer-focused industries. On the one hand, this study might have benefited from the slower-paced, more explicit nature of change in an industrial setup as it allowed us to study underlying mechanisms and processes more diligently. On the other hand, the permanence of the industry might distort the way how ecosystems emerge compared to other contexts. In consumer-focused industries, on the contrary, customer needs change more rapidly resulting in more dynamic ecosystem configurations and more transient ecosystem participants. Traditional industry boundaries might blur a lot faster and the OEMs' central role in value creation might be even more dissolving. At the same time, shorter life cycles of the smart products as the ecosystems' centres result in more frequent opportunities to change their material properties and hence actualize an altering set of affordances. As such, we hope that our theoretical model with the three socio-technical antecedents and their respective affordances classes can serve as a valuable framework and springboard for future, more detailed investigations in other industries and contexts. Additional research should focus on investigating how more dynamic contexts influence the emergence of ecosystems around smart products.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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ENDNOTES

[1] Depending on the industry, practitioners sometimes use the terms (industrial) *equipment* or *assets* to refer to (industrial) *products*. Therefore, we use the terms product, equipment, and asset interchangeably.

[2] https://techcrunch.com/2020/10/27/daimler-trucks-partners-with-waymo-to-build-self-driving-semi-trucks/,27.10.2020

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APPENDIX A: Overview of collected and analysed empirical data among archetypical actors

Org. actor	Data source	General information	Detailed information	Duration
OEMCorp	Semi-structured interviews	15 interviews • $\sum$ 15:56 h • μ: 1:04 h • σ: 20:12 min 267 pages of text	Group Chief Technology Officer and Head of Group R&D	51 min
			Managing Director, Innovation Management	40 min
			Head of IT-Architecture, Standards, and Innovation	46 min
			Managing Director, Product Marketing and Communication	84 min
			Head of Digital Business Development	52 min
			Director, Industrial Services	91 min
			Technical Lead Product Digitization	22 min
			Head of Competence Center IoT Platform Architecture	83 min
			Director, New Business and Product Digitization	63 min
			Managing Director, Technology	84 min
			Director, Sales Region A	83 min
			Head of Global Software Development	64 min
			Global Head of IT Operations	64 min
			Head of Product Marketing	49 min
			Head of R&D Electrical Engineering and Automation	80 min
	Focus group workshops and meetings	4 full-day workshops and 2 meetings	Smart equipment 2.0 proof-of-concept kickoff workshop	Full day
			Milestone review workshop I	Full day
			Milestone review workshop II	Full day
			Smart service systems innovation workshop	Full day
			Six 1-hour 1:1 meetings on smart services	6 hours
			Foresight workshop on flexible pricing models and outcome-based offerings	2 hours
	Internal documents and archival data	Strategic service innovation concepts, technical documentation	Presentation on strategic service innovation clusters; 2 x innovation board status presentations: project brief on business model transformation project (usage-based industrial equipment offerings and servitization), Internet of Things/ telematics platform architecture proposal, sensor data payload calculations, target data model: operational industrial product data, network, and connectivity requirements documentation	–
SPOCorp	Semi-structured interviews	10 interviews • $\sum$ 11:46 h • μ: 1:11 h • σ: 11:46 min	Head of E-Commerce and Digitization	80 min
			Senior Manager, Maintenance and Facility Engineering	82 min

Org. actor	Data source	General information	Detailed information	Duration
		157 pages of text	Head of Internet of Things and Operations	59 min
			Manager, Organizational Design, Processes and Change	69 min
			Head of Logistics and Process Performance	74 min
			Vice President, Operations Region A	64 min
			Vice President, Operations Region B	59 min
			Director of Operations	54 min
			Vice President, Technology and Equipment	74 min
			Vice President, Business Development and Operational Excellence	91 min
	Focus group workshops and meetings	2 full-day workshops and 34 status calls	Two full-day workshops with interdisciplinary staff ranging from management to blue-collar positions (shift supervisor) to identify use potentials of digitising existing proprietary installed base to optimise productivity/uptime of products and optimise internal processes and various status calls in implementation status	2x full day
	Internal documents and archival data	Operational process models and documentation, emails	Process documentation, internal documents on digitization potentials and strategic decisions in planning and running smart initiatives, emails and documents exchanged between digitization consultants and internal management	-
MROCorp	Semi-structured interviews	15 interviews • $\sum$ 17:10 h • μ: 1:09 h • σ: 21:12 min 279 pages of text	Director, Service Operations	74 min
			Director, After-Sales Service Region A	78 min
			Director, Technical Customer Service	75 min
			Head of MRO Service	36 min
			Executive Director Service	40 min
			Director, After-Sales and Customer Service	108 min
			Head of Business Development	38 min
			Head of Full Service Business	53 min
			Vice President, Service Support	63 min
			Manager, Business Development & Digital Transformation	54 min
			Head of Technical Service	96 min
			Vice President, Field Service	83 min
			Head of Industrial Service	75 min
			Director, Field Service and MRO	85 min
			Director, Service Standards	72 min
	Focus group workshops and meetings	1 full-day service design thinking workshops and 7 smart services identification sessions	One-day service innovation and digitization workshop leveraging elements from the design thinking methodology, Seven smart service expert sessions to brainstorm potential smart services and use/revenue potentials for harnessing	Full day 7 a 60 mins

(Continues)

Org. actor	Data source	General information	Detailed information	Duration
			smart products in the context of the industrial MRO business	
	Internal documents and archival data	Strategic service innovation concepts, technical documentation	Strategic documents on innovation in the context of MRO and service business	–
AOCorp	Semi-structured interviews	7 interviews ∑ 10:30 h • μ: 1:30 h • σ: 21:03 min 152 pages of text	Service line manager, plant cloud services	85 min
			Service product manager, out of the box analytics	96 min
			Head of managed service/analytics	131 min
			Head of analytical service development	96 min
			Service line manager, asset analytics services	73 min
			Service line manager, process data analytics	67 min
			Service line manager, energy data management	82 min
	Focus group workshops and meetings	Full day	Full-day workshop to elicit potential business models	Full day
	Internal documents and archival data	Business concept and strategic presentations	Internal documents and strategic presentations on business concepts to provide data-driven services in the industrial manufacturing industry	–

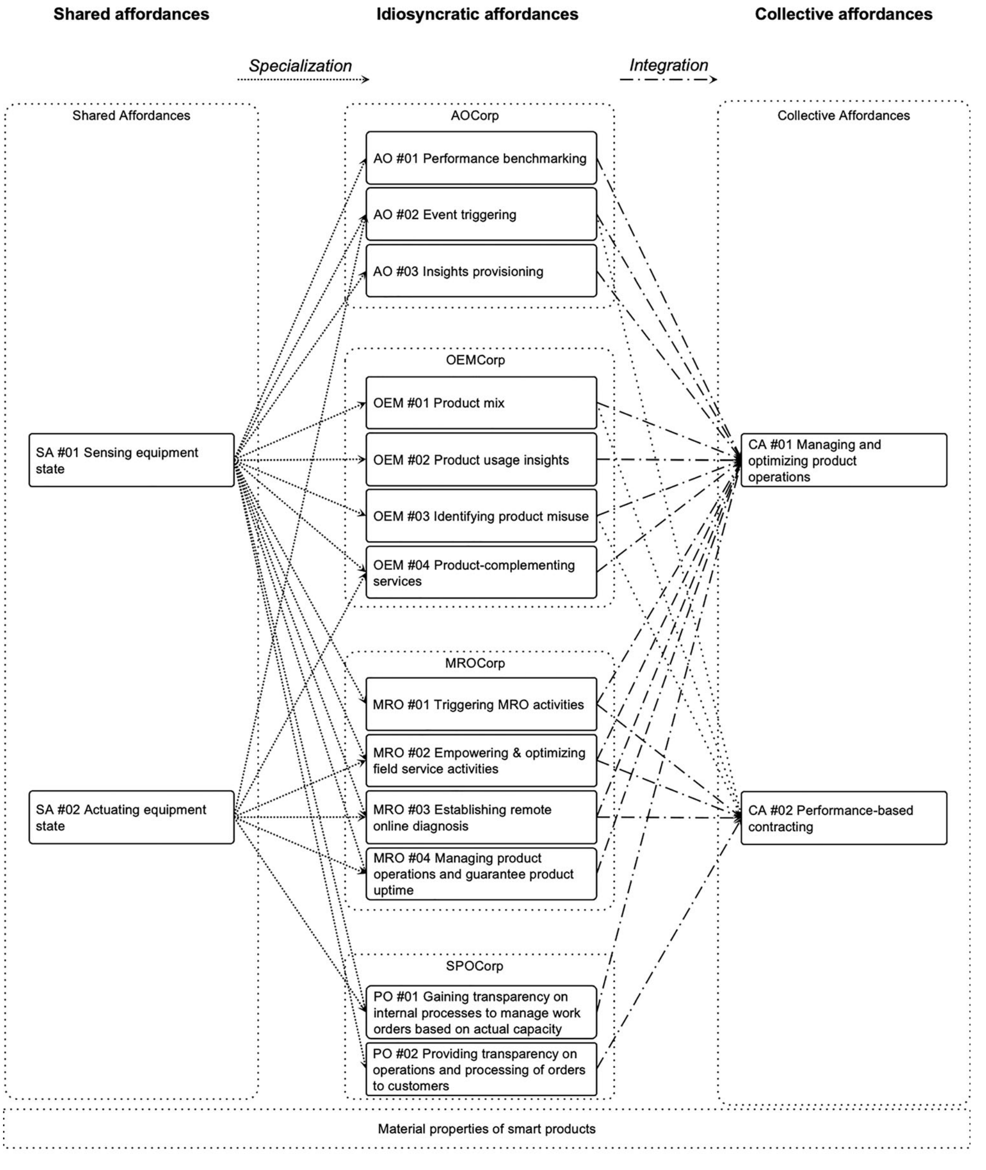
APPENDIX B: Data structure derived from open, axial, and selective coding

1st order concepts	2nd order themes	Aggregate dimensions
• Value of operational product information and condition • Sharing of operational product information across organisations • Operational transparency through monitoring industrial products (i.e., Digital Twin)	Sensing equipment state	Shared affordances
• Influencing the state of smart products remotely • Controlling equipment based on contextual conditions of 3rd party equipment	Actuating equipment state	
• Performance comparisons of individual organisations with competitor data • Visibility into effectiveness and efficiency comparisons to industry • Operational intelligence and the ability to compare operational effectiveness	Performance benchmarking	Idiosyncratic affordances of AOCorp
• Trigger events or business processes based on operational data • Recommendations for field service activities	Event triggering	
• Sharing data-driven insights on operations based on operational data • Sharing data-driven insights on machine state or condition based on operational data	Insights provisioning	
• Making available the right products at the right place at the right time	Product mix	Idiosyncratic affordances of OEMCorp
• Leverage operational product data to engineer better products • Consistency of operational product for meaningful usage insights • Unified perspective on machinery/shop floor capacity	Product usage insights	
• Awareness of product operations context and environment • Warning for product usage outside of authorised parameters • Make products safer to use	Identify product misuse	
• Additional services that make the life of operators easier • Data-driven set-up services for product operations	Product-complementing services	
• Historic operational product data as service trigger • MRO activities based on data patterns • Predictive maintenance • Identifying typical mean time between failures	Triggering MRO activities	Idiosyncratic affordances of MROCorp
• Classifying and coding maintenance jobs • Field Service Technicians have access to operational product data (mobile devices) • Data-driven cost optimization for service activities • Managing spare parts supply based on operational data	Empowering & optimising field service activities	
• Login to the smart product from headquarters • Understand what is going on with smart products in the field remotely	Remote online diagnosis	

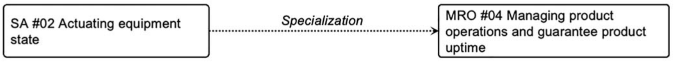
(Continues)

1st order concepts	2nd order themes	Aggregate dimensions
• Diagnosing errors and minor technical problems remotely • Reset products remotely • Remote control products in maintenance mode • Update software of smart products • Outsourcing responsibility for product operations	Manage product operations and guarantee product uptime	
• Pre-shift inspection • Live capacity and work order data to optimise operations • Feed operational data into other IT systems (e.g., Enterprise Resource Planning System)	Gaining transparency on internal processes to manage work orders based on actual capacity	Idiosyncratic affordances of SPOCorp
• Share insights on the status and estimated time of arrival to end-customers • Keeping shop floor employees up-to-date and informed about production status	Providing transparency on operations and processing of orders to customers	
• Partnerships with third parties for effective operations • Staying use-case agnostic allows enabling future use cases • Interconnectedness spanning organisational boundaries • Selling operational information for collective use cases • Realise the combination of benefits for the end-customer across organisational boundaries	Managing and optimising product operations	Collective affordances
• Renting product based on actual usage (flexible pricing) • Giving away product for free, revenue based on usage • Seasonal rates based on usage • CAPEX/OPEX optimization	Performance-based contracting	

APPENDIX C: Overview of shared, idiosyncratic, and collective affordances and their interdependencies



Exemplary explanation of the relationship between affordances in different affordance classes



To manage product operations and guarantee product uptime (MRO #04), it is not enough to just sense the state of a smart product, which is described through *SA #01 Sensing equipment state*. In fact, the ability to control and modify the state of the smart product is required to actively manage product operations. An example would be that an MRO organization would intervene in operations of a forklift truck in case of safe operations can no longer be guaranteed. A specific example would be to slow down a truck to still ensure basic operations (i.e., uptime) until a field service technician arrived at the site to fix an underlying safety issues avoiding a full outage of the truck.