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RESEARCH PAPER

Configurations of digital platforms for manufacturing: An analysis of seven cases according to platform functions and types

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Abstract
We analyze organizational configurations of digital platforms for manufacturing according to two dimensions: platform functions and platform types. Platform functions refer to the organizational functions of platforms: manufacturing, data sharing, market making, and innovation. Platform types refer to a typology of how platforms are organized: as internal, supply chain, or industry type. We combine those dimensions into a framework and use that to analyze seven cases of digital platforms from the manufacturing sector. Our research answers calls for conceptual clarity and scoping of the digital platform concept and mends relative lack of attention toward digital platforms for the manufacturing sector. We find that digital platforms for manufacturing come in different, partly unexpected, configurations: (1) not all functions are necessarily organizationally part of the platform, (2) not all functions are necessarily organized according to the same platform type, but (3) also not all random configurations of platform types and functions seem to be possible. This complexity highlights the importance of the innovation function for exploring effective configurations of digital platforms for manufacturing.

Keywords Digital platforms · Platforms · Platform innovation · Manufacturing · Digitalization

JEL classification M1 · L1 · L6

Introduction

The digital platform concept is increasingly used in business practice and in management, strategy, innovation, and information systems literature (e.g., De Reuver et al., 2018; Evans & Schmalensee, 2016; Gawer, 2014; Gawer & Cusumano, 2014; Hein et al., 2020; Jovanovic et al., 2022; Parker et al., 2016; Rai et al., 2006; Thomas et al., 2015; Tilson et al., 2010; Tiwana, 2015; Yoo et al., 2010). Digital platforms can be related to any combination of the provisioning of hardware, software, and services. Digital platforms have made a huge impact on software, services, and retail sector structures. The examples of Amazon, Uber, Airbnb, "Software as a Service," and "Cloud services" are well-known. In the words of Cusumano et al. (2020, p.11), "Unlike in the traditional economy, where companies require expensive physical investments to build out their business models, in the digital world, companies can grow rapidly with a clever combination of data, software and ecosystem strategies." And yet, despite a generic shift from physical products toward digital products and "as-a-service" offerings, physical products still need to be developed, produced, and transported. Therefore, manufacturing remains important and "expensive physical investments" in manufacturing facilities are still needed. Because digitalization also affects the manufacturing sector, technical and organizational investments and changes are needed to create digital platforms for manufacturing. Yoo et al. (2010) already called for specific research on digital platforms related to physical products, though such research has been relatively scarce

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(Hanelt et al., 2020; Nischak & Hanelt, 2019; Riasanow et al., 2021). We intend to contribute by focusing on digital platforms in the manufacturing sector.

Existing research suggests that the development of digital platforms in the manufacturing sector is subject to specific dynamics and challenges (Björkdahl, 2020; Culot et al., 2020; Hanelt et al., 2020; Riemensperger & Falk, 2020; Riasanow et al., 2021; Shree et al., 2021). Examples from business practice show that digital platforms for manufacturing are not necessarily digitalized versions of traditional value chains. For example, 3D Hubs is a platform that connects supply and demand for 3D printing but does not manufacture anything itself. Sculpteo is a 3D printing platform with similar functionality but with a shared manufacturing function. This means that creating digital platforms for manufacturing is not just a technical, but rather an organizational challenge. Recent research suggests that digital platforms may consist of loosely coupled complementary modules rather than functional layers that mirror each other (Baskerville et al., 2020; Colfer & Baldwin, 2016; Constantinides et al., 2018). We therefore use the term "digital platforms for manufacturing" rather than "digital manufacturing platforms" to avoid the suggestion that such platforms are always fully integrated organizations. We intend to address this organizational question by analyzing the configurations of digital platforms currently used in the manufacturing sector. By providing an analytic framework to do so, we also intend to answer calls for conceptual clarity and better scoping of digital platforms for manufacturing (De Reuver et al., 2018; Yoo et al., 2010).

Our research question is therefore: "What are different organizational configurations of digital platforms for manufacturing?"

We answer this research question by first developing a framework to analyze such platforms on two dimensions: platform functions and platform types. Regarding organizational functionality, we distinguish four platform functions: manufacturing, data sharing, market making, and innovation. Early information systems literature has emphasized the manufacturing function and the data sharing function of platforms (e.g., Rai et al., 2006; Rayport & Sviokla, 1995; Yoo et al., 2010). Literature from economics and business strategy has emphasized the market making function of platforms (e.g., Evans & Schmalensee, 2016; Rochet & Tirole, 2003; Spulber, 1996a, b). Platforms are new organizational forms (McIntyre et al., 2021) and it is therefore not always clear how they should be configured, i.e., which configurations will yield lowest transactions costs and/or generate the desired network effects, and which actor will benefit from the value that is created (McIntyre et al., 2021; Wallbach et al., 2019; Yablonski, 2018). We argue that, therefore, digital platforms for manufacturing need an innovation function to explore possible configurations (e.g., Alt, 2022; Yablonski, 2018). This innovation function is about innovation *of* the platform, not innovation *on* the platform. It exists for platform leaders or platform consortia to learn about possible platform configurations, to imagine them, to design them, and to experiment with them. Regarding platform types, we distinguish internal, supply chain, and industry platform types, following the seminal typology of organizing platforms (Facin et al., 2016; Gawer, 2014; Thomas et al., 2015).

We use the framework to analyze seven cases of digital platforms used in the manufacturing sector. Subsequently, we describe our findings and we provide conclusions, implications, and recommendations for further research.

Theoretical background

Platforms as organizational configurations

Digital platforms for manufacturing are a subset of platforms. Platforms are modular architectures that enable loose coupling and mixing and matching of modules (Baldwin & Woodard, 2009; Richard & Devinney, 2005; Staudenmayer et al., 2005). As Kolloch & Dellermann (2018) state: "This allows an effective division of labor among different actors during the design and production of complex systems ..." (p.255). Platforms allow for horizontal and vertical disintegration and reintegration. They enable configurations that depart from existing integrated firms or supply chains, and that evolve into business ecosystems, and two- or multi-sided markets. When multiple companies operate or participate in a platform, they must agree on at least the interfaces, to be able to work together. This means, for example, to agree on standardized inputs and outputs of modules and on standardized communications (see also Kapoor et al., 2022). For addressing market demands, they also must consider which modules are necessary and how the interactions between the modules are shaped. Finally, they must find a mode of innovating the platform by renewing modules and interfaces. A platform is therefore mainly an organizational entity. Gawer's (Gawer, 2014, p.1240) definition of a platform captures this organizational aspect: "… evolving organizations or meta-organizations that: (1) federate and coordinate constitutive agents who can innovate and compete; (2) create value by generating and harnessing economies of scope in supply or/and in demand; and (3) entail a modular technological architecture composed of a core and a periphery." We adopt this definition for digital platforms for manufacturing, especially to determine what is organizationally part of the platform and what is not.

Platform functions

Any platform will need to fulfill a number of organizational functions. The most basic ones, manufacturing and data sharing, have been identified in early platform literature. Later, platform literature has added market making and innovation functions.

The manufacturing function is perhaps the most obvious one in a digital platform for manufacturing. Whether it is called physical value chain (Rayport & Sviokla, 1995), supply chain process (Rai et al., 2006), contents layer (Yoo et al., 2010), or production logic (Thomas et al., 2015), it refers to a function where physical products are made in manufacturing facilities. This function may emphasize the product, e.g., in the form of shared development or parts procurement, or the production process, e.g., in the form of sharing production assets, or control and maintenance. An example is Sculpteo (discussed in the "Sculpteo" section), a platform provider focused on 3D printing services. Customers can upload a 3D design into their online platform for further design and analysis. Sculpteo has fulfillment centers with large numbers of 3D printers with different capabilities to produce the required 3D printed component. Depending on the partners involved, the manufacturing function can be executed and managed within one firm, across partners in a supply chain, or across partners in the wider industry.

The data sharing function provides the necessary technical and organizational capabilities to arrange data sharing between and within manufacturing firms and other platform partners. It does so by registering, aggregating, or sharing data. This is true whether it has been called virtual value chain (Rayport & Sviokla, 1995) or information flow (Rai et al., 2006) or whether it has been split into different sublayers including IT networks and devices (Yoo et al., 2010). The data sharing function involves reference architectures for data sharing to achieve interoperability. Standards play an important role in this. An example is the International Data Spaces Association (discussed in the "International Data Spaces Association (IDSA)" section). It provides a reference architecture for setting up data spaces and the creation of smart data applications in various sectors. It is managed as an open standard by users and technology providers. Depending on the partners involved, the data sharing function can be used and defined within one firm, across partners in a supply chain, or across partners in the wider industry.

The market making function has been long emphasized by literature from economics and business strategy under the labels of market making (Spulber, 1996a), intermediation (Spulber, 1996b), and two-sided markets (Rochet & Tirole, 2003). In platform literature, it has been called transaction logic (Thomas et al., 2015) or transaction platforms (Evans & Schmalensee, 2016). It connects interdependent user groups, e.g., customers and manufacturing firms, but not limited to those, by playing an intermediation or a matchmaking role (Evans & Schmalensee, 2016). The function is especially relevant where the market is so complex that customers and manufacturers have difficulties finding each other. An example is 3D Hubs (discussed in the "3D Hubs" section), a platform that connects supply and demand for 3D printing. As a market maker, 3D Hubs provides guidelines to customers and suppliers that they connect via their platform. The actual manufacturing of products is carried out by local (independent) 3D printing partners connected to the 3D Hubs platform. A market making function can refer to a kind or internal market within a firm, to multiple partners in a supply chain (forming supply and demand) yet based on rules set by a focal firm, or to multiple partners in a wider industry with community-defined rules.

An innovation function is necessary to conceive the possible configurations of digital platforms for manufacturing (e.g., Alt, 2022). It is a vehicle to think about, develop, pilot, test, experiment with, implement, execute, and manage innovation of digital platform configurations, while ensuring that physical manufacturing investments will continue to pay off. We can see firms executing and managing innovation processes internally, or across existing supply chains, but we also see firms and other partners cooperating in public-private triple or quadruple helix partnerships, including knowledge institutes, governments, and education institutes. Such innovation hubs provide the necessary business and financial support to explore innovation of the platform, i.e., of its technical and social structures. An example is Smart Connected Supplier Network (discussed in the "Smart Connected Supplier Network (SCSN)" section) that aims to innovate the manufacturing value system. Depending on the partners involved, the innovation function can thus be executed and managed within one firm, across partners in a supply chain, or across partners in the wider industry.

For reasons of socio-technical inertia (Schmid et al., 2017), digitalization in manufacturing has often been the digital equivalent of existing analog functionality (Tilson et al., 2010). Following this thinking, digital platforms have been conceptualized as modular, layered architectures, where the (functional) layers "mirror" each other (e.g., Rai et al., 2006; Rayport & Sviokla, 1995; Yoo et al., 2010). For example, a (physical) product manufacturing layer on top of a digital (data) infrastructure (Constantinides et al., 2018; Yoo et al., 2010). Alternatively, digital platforms have been conceptualized as logically connected architectures, where all platform functions co-evolve (Jovanovic et al., 2022; Thomas et al., 2015).

Platform types

Existing literature suggests that platforms come in different organizational types: by firms internally, by different

Table 1 Analytical framework for platform configurations

Platform function	Platform type	Description	References
Manufacturing	Internal	Manufacturing executed and managed within the firm	Rayport and Sviokla (1995); Rai et al. (2006); Yoo et al. (2010); Thomas et al. (2015); Gawer (2014)
	Supply chain	Manufacturing executed by different partners, managed by a focal partner	
	Industry	Manufacturing executed by different partners, managed by community of partners	
Data sharing	Internal	Data sharing system used and defined within the firm	Rayport and Sviokla (1995); Rai et al. (2006); Yoo et al. (2010); Gawer (2014)
	Supply chain	Centralized data sharing system, used by different partners, with interfaces defined by a focal partner	
	Industry	Decentralized data sharing system, used by different partners, with community-defined	
Market making	Internal	Internal market within the firm (e.g., between subsidiaries within a firm)	Spulber (1996a, b); Rochet and Tirole (2003); Gawer (2014); Thomas et al. (2015); Evans and Schmalensee (2016)
	Supply chain	Market with different partners (supply/demand), with rules determined by a focal partner	
	Industry	Market with different partners (multi-sided) with community-defined rules	
Innovation	Internal	Innovation executed and managed within the firm	Gawer (2014); Yablonski (2018); Alt (2022)
	Supply chain	Innovation executed by different partner, managed by a focal partner	
	Industry	Innovation executed by different partners, managed by community of partners	

partners in a supply chain, or by conglomerates of partners in the wider industry (Facin et al., 2016; Gawer, 2014; Gawer & Cusumano, 2014; Thomas et al., 2015). The types are consistent in themselves, i.e., platforms and everything related to them, such as partners, functions, and governance, are either of internal, or supply chain or industry type, but not mixed.

Internal platforms are firm-specific modular architectures, often used for providing a series of products. The concept builds strongly on modular product platform concepts as discussed by Wheelwright and Clark (1992) and Baldwin and Clark (2000). An example of internal platforms can be found in the automotive sector where a single architecture of modules is often used to produce a variety of car models.

Supply chain platforms extend the internal platform concept to a network of partners in a supply chain. The different modules of the product are no longer only designed and manufactured by one firm, but by multiple partners (see, e.g., Gawer, 2014). This puts high demands on the platform architecture because the modules are not fully under control of a single firm. Agreement needs to be reached between the supply chain partners on how the modules fit, what the (technical) interfaces are, what to do in case of deviations, and how the product and its modules can be innovated. The number of supply chain partners may be small or large, but it is contractually clear who is involved and who is not, and it is clear to every partner for which module(s) they are responsible. Examples of supply chain platforms can also be found in the automotive sector where modules applied in cars are often developed and produced by specialized suppliers who have a formal, contractual relationship with the OEM.

Industry platforms extend the concept even further to include external partners that do not necessarily have a formal contractual relationship with other firms on the platform (see also Cusumano & Gawer, 2002; Jacobides et al., 2018). Often the purpose of industry platforms is to attract as many partners as possible to ensure positive network effects. Examples of such platforms can be found in computer or smartphone operating systems that allow many companies to manufacture and supply core or complementary hardware and software. The number of potential partners depends on the openness of the platform. Industry platforms entail system governance questions about platform architecture, interfaces, and platform change (Hein et al., 2020; Jovanovic et al., 2022; Tilson et al., 2010). Such governance can be provided by a "platform leader" (Cusumano & Gawer, 2002) or by a consortium of partners that "orchestrates" the system. Unlike a supply chain platform, there is no central control over the full scope of the end-products that are delivered by the industry platform.

Analytical framework and expectations

Based on the discussion above, we propose to analyze the organizational configurations of digital platforms for manufacturing according to the framework presented in Table 1. For every platform, it is first determined which platform functions are organizationally part of the platform: manufacturing, data sharing, market making, and innovation. Then, per function, it is assessed of which platform type this function is—internal, supply chain, or industry—based on where and by which actor(s) the function is managed and/or executed.

Building on existing literature, we can formulate two expectations for what such configurations may look like. First, if platform functions are organized as layers or logics (e.g., Rai et al., 2006; Rayport & Sviokla, 1995; Yoo et al., 2010), then all platform functions should be directly linked to each other, and we expect to see all four functions as organizationally part of the platform. Second, because platform type literature tells us that platforms are internally consistent (Facin et al., 2016; Gawer, 2014; Gawer & Cusumano, 2014; Hein et al., 2020; Jovanovic et al., 2022; Thomas et al., 2015), we expect all functions of a platform to be of the same type: either internal, supply chain, or industry, but not mixed.

However, the developments in information systems lead us to question those expectations: modern information systems can be loosely coupled, do not necessarily follow physical reality, but can shape physical reality (see, e.g., Colfer & Baldwin, 2016; Constantinides et al., 2018). Baskerville et al. (2020) speak of "ontological reversal": whereas in the past, it was the physical reality that dictated what information systems would look like, it may presently be the reverse. The consequences are that "… digitizing has the potential to remove the tight couplings between information types and their storage, transmission, and processing technologies—potentially shattering the dominant service model and the stability of the industrial organization" (Tilson et al., 2010, p.749). This gives rise to many possible platform configurations. We might therefore encounter digital platforms for manufacturing that do not have all functions on the platform and/or where not all functions are organized according to the same platform type.

Data and methods

We analyze the configurations of seven cases of digital platforms in the manufacturing sector: (1) Sculpteo, (2) MindSphere, (3) International Data Spaces Association (IDSA), (4) 3D Hubs, (5) Skuchain, (6) Nimble, and (7) Smart Connected Supplier Network (SCSN). We use these cases to gain insight (e.g., Mintzberg, 1979) into their organizational configurations only, and not to gain deep insights into the individual platforms, though that may be a fruitful avenue for further research. We strive to meet the criteria for case study research in innovation management as provided by Goffin et al. (2019). Specifically, we explain the reason for choosing our approach and the theoretical sampling. Cases are based on multiple sources of data and coded by multiple investigators. We combine rich textual descriptions of each platform's types and functions. We show the trail of evidence by scoring each platform in our framework (see Appendix Tables 5, 6, 7, 8, 9, 10 and 11). This enables us to interpret case results on a case-by-case and on a cross-case basis. We provide a reflection on the method in the final section of this paper.

We selected the cases based on three criteria: (1) the domain, the digital platform should be recognized to be used in or for manufacturing firms, supply chains or industries (European Union, 2017); (2) the platform functions, the digital platform should cover at least two of four platform functions (manufacturing, data sharing, market making, and/or innovation); and (3) the availability of recent data.

We used the data sources as shown in Table 2 to write up the initial case. We systematically analyzed the cases using the framework presented in Table 1. This ensures replicability. First, we assessed the presence or absence of the functions. Because we used a strict interpretation of the Gawer (2014) definition to decide whether a function is on the platform, some of the outcomes seemed counterintuitive at first. Then, using the typology of Gawer (2014), we scored each function according to platform type. To validate these scores, we also scored each function according to Gawer's (Gawer, 2014) sub-dimensions of the platform types: level of analysis, constitutive agents, technological architecture, interfaces, accessible innovative capabilities, and coordination mechanisms (see Appendix Tables 5, 6, 7, 8, 9, 10, and 11).

Two co-authors independently scored each case, then discussed the outcomes with each other, and, when relevant, revised their judgements until they reached consensus. Subsequently, those co-authors discussed their scores with the other co-authors. Based on questions and remarks from those discussions, they again revised their judgements when relevant. These two processes—scoring and discussion—were repeated for multiple rounds until full consensus was reached on each case.

Case descriptions

In this section, we present descriptions of seven case examples of digital platforms for manufacturing according to the function that is most visible in this platform (see Table 3). We start with a platform in which the manufacturing function is most visible (Sculpteo), followed by two platforms in which the data sharing function is most visible (MindSphere and IDSA), two platforms in which the market making function is most visible (3D Hubs and Skuchain), and we conclude with two platforms in which the innovation function is most visible (Nimble and SCSN).

Sculpteo

Sculpteo is a French platform (firm) focused on providing 3D printing services, not unlike 3D Hubs. Customers can upload a 3D design onto the online platform for further design and

Table 2 Data sources

Case	Internet sources	Literature sources	Interview sources
Sculpteo	www.sculpteo.com	Elam (2016, practice) Rayna and Striukova (2016, academic)	Expert interview as part of the EU-H2020 DIMOFAC project
MindSphere	www.plm.automation.siemens.com/global/en/products/mindsphere/	European Union (2017, practice)	-
International Data Spaces Association	https://internationaldataspaces.org	European Union (2017, practice) Otto and Jarke (2019, academic)	Expert working at IDSA consulted for the EU project enhancing the use of data in Europe
3D Hubs	www.hubs.com	-	Expert working at 3D Hubs
Skuchain	www.skuchain.com	-	-
Nimble	www.nimble-project.org/	Tock et al. (2020, practice)	-
Smart Connected Supplier Network	www.smart-connected.nl www.market40.eu www.brainportindustriescampus.com	Stolwijk and Berkers (2020, practice)	Expert involved in SCSN

analysis. An important difference with 3D Hubs is that Sculpteo owns several fulfillment centers with large numbers of 3D printers with the capabilities to print the required 3D component. This means that the manufacturing function is an internal platform. Sculpteo fulfills the innovation function by setting up and improving the functionalities of the platform by itself. Innovation is therefore also classified as an internal platform because other partners do not have a defined role in this. The data sharing function can be classified as a supply chain platform because Sculpteo fully determines how customers can interact with the platform. The platform does not have a market making function since it does not fulfill a match making role between buyers and suppliers.

MindSphere

MindSphere is an Internet-of-Things platform, initiated and developed by Siemens, an established firm in factory automation. It connects products, plants, systems, and machines inside the factory, fulfilling the data sharing function. Other vendors of equipment and software can connect to MindSphere but they need to apply the standards and interface specifications defined by Siemens, classifying the data sharing function as a supply chain platform. Siemens fulfills the innovation function by setting up and improving the functionalities of MindSphere by itself. The innovation function is therefore classified as an internal platform. MindSphere itself does not have a market making or manufacturing function. Nevertheless, it can be used as a constituent of another platform, e.g., an equipment manufacturer using MindSphere to collect maintenance data of its customers' equipment. As such, MindSphere can become part of a bigger digital platform for manufacturing. Depending on the choices of this bigger platform, the classifications of the market making and manufacturing functions can vary, though they are not *on* the MindSphere platform. The innovation and data sharing functions are tied to MindSphere/Siemens.

Table 3 Case examples

Platform	Most visible platform function	Platform founding year	Platform founding location	Section
Sculpteo	Manufacturing	2009	EU (France)	"Sculpteo" section
MindSphere	Data sharing	2018	EU (Germany)	"MindSphere" section
IDSA	Data sharing	2018	EU (Germany)	"International Data Spaces Association (IDSA)" section
3D Hubs	Market making	2013	EU (Netherlands)	"3D Hubs" section
Skuchain	Market making	2014	USA	"Skuchain" section
Nimble	Innovation	2016	EU (multiple countries)	"Nimble" section
SCSN	Innovation	2015	EU (Netherlands)	"Smart Connected Supplier Network (SCSN)" section

International Data Spaces Association (IDSA)

The International Data Space Association was set up by several industrial and research partners to develop a reference architecture for data spaces. In a data space, different partners can share data in a trusted and controlled way (Otto & Jarke, 2019). The IDSA Reference Architecture Model describes which technical components should be used in a data space and which interface specifications the components should adhere to. In addition, the association provides mechanisms to certify commercial or open-source implementations of these specifications. Together, they provide generic functionality for setting up data spaces in many different domains (Otto & Jarke, 2019). IDSA works together with many different sector-specific initiatives that apply the standards in their data sharing schemes. There are also different technology providers who implement the specifications of IDSA. In both cases, they work on top of the IDSA Reference Architecture Model. SCSN is an example of such an initiative. In this way, IDSA implements an innovation and data sharing function. Both functions can be classified as an industry platform, because the standards are developed in cooperation with all involved partners, including sector representatives and technology providers.

3D Hubs

3D Hubs is a platform that connects supply and demand for 3D printing, e.g., of food and health care products, and thus fulfills a market making function. It was initiated by a start-up in the Netherlands also called 3D Hubs. The start-up decided on innovations of the platform and in 2018 changed it from a B2C platform into a B2B platform. The innovation function is therefore classified as an internal platform. 3D Hubs as market maker provides the guidelines to the customers and suppliers they connect via their platform, meaning that the market making function of this platform is classified as a supply chain platform. 3D Hubs maintains interfaces with other platforms for the data sharing and manufacturing functions. The data sharing function is implemented through Amazon Web Services, a commercial cloud platform used by 3D Hubs to store and exchange orders and design data. The actual manufacturing of products is carried out by local independent 3D printing firms, connected to 3D Hubs. Initially, this was a peer-to-peer business (industry platform). In 2018, 3D Hubs decided to introduce a "fulfilled by 3D Hubs" program in which the actual manufacturing shifted to a dedicated 3D Hubs-contracted manufacturing partner. This means that the manufacturing function is currently classified as a supply chain platform. In the old model, any qualifying manufacturer could connect. The market making function has therefore shifted from an industry to a supply chain platform.

Skuchain

Skuchain is a platform founded by a start-up in the USA to empower stakeholders in a global value chain to enable supply chain cooperation and inventory management. Skuchain is active in a wide range of manufacturing sectors, such as aerospace, automotive, and electronics. In addition, it is active in the energy sector, mining and minerals, food and agriculture, financial services, insurance, and commodity industries. The platform brings together customers and suppliers; hence, it has a form of market making function. This is classified as an industry platform because the transaction is directly between two individual businesses. It does not have a manufacturing function on the platform. The start-up fulfills the innovation function by setting up and improving the functionalities of the platform by itself; hence, it is classified as an internal platform. The underlying blockchain technology of the platform enables the data sharing function. Even though from a technical point of view this architecture is highly decentralized, it is classified as a supply chain platform, because Skuchain maintains the interface specifications for all users of the blockchain-enabled platform.

Nimble

Nimble started as a European project with a consortium of partners that set up a cloud-based platform on which European manufacturing firms can register, publish machine-readable catalogs for products and services, search for useful supply chain partners, negotiate contracts, and supply logistics. The platform was released in April 2020 and is being used in furniture manufacturing and sales. The data sharing function is classified as a supply chain platform. The Nimble consortium defines how users can connect to the platform and share data through it; this platform has a centralized technical architecture. Nimble was developed as a consortium-led project of different partners. The innovation function is therefore also classified as a supply chain platform. Buyers and suppliers can work together on the Nimble platform. However, the Nimble consortium has no role in the decision-making process between buyers and suppliers. That means that the market making function is an industry platform since the decision-making process for market making is completely in the hands of the buyers and suppliers. The manufacturing function is executed by the individual firms using the platform. There is no collaborative physical manufacturing process.

Smart Connected Supplier Network (SCSN)

The partners of the Smart Connected Supplier Network (SCSN) public-private partnership developed a standard for data sharing between partners in high-tech supply chains (Stolwijk & Berkers, 2020). The initiative was set up by

Table 4 Summary of the findings

Case example	Platform type of …				Functions organized according to the same platform type?
	Innovation function	Data sharing function	Market making function	Manufacturing function	
Sculpteo	Internal	Supply chain	Not on platform	Internal	No
MindSphere	Internal	Supply chain	Not on platform	Not on platform	No
IDSA	Industry	Industry	Not on platform	Not on platform	Yes
3D Hubs	Internal	Supply chain	Supply chain (previously Industry)	Supply chain (previously Industry)	No
Skuchain	Internal	Supply chain	Industry	Not on platform	No
Nimble	Supply chain	Supply chain	Industry	Not on platform	No
SCSN	Industry	Industry	Industry (developing)	Industry (developing)	Yes
Cross-case finding	*On the platform, dominantly internal*	*On the platform, dominantly supply chain or industry*	*Market making not necessarily on the platform*	*Manufacturing not necessarily on the platform*	*Functions mostly not organized according to the same platform type*

Brainport Industries, a sector organization representing approximately 100 manufacturers, and TNO, a research and technology institute in the Netherlands. They brought together a representative group of manufacturing companies and their software providers. SCSN fulfills the innovation function: jointly defining the capabilities of the network through working groups of members. We therefore classify the innovation function as an industry platform. Technically, the data sharing is achieved through the standard provided by the International Data Spaces Association (IDSA, discussed in the "International Data Spaces Association (IDSA)" section). Each partner in the network can decide which data is shared with which other organization. Examples of data include orders, logistics data, forecasts, and data used for the lifecycle management of products. Each connecting organization implements its own "connector," through which data is being shared. Each organization has full data sovereignty: they can decide with which organizations they will share data. We therefore classify the data sharing function also as an industry platform. Although there is no central platform, all connectors are interoperable. This provides organizations with the ability to communicate with all other organizations through a single connection, providing strong network externalities as SCSN is growing. This has caused SCSN to be increasingly being used as a platform for new solutions, with companies deciding to build new "apps" and services on top of SCSN. For example, the market making function—not provided through the SCSN foundation—is provided by third parties using SCSN as a basis. They use the data sharing function of SCSN to enable new collaboration scenarios. In addition, the Brainport Industries association has started the development of a campus to physically house several partners of the high-tech supply network under one roof whereby these companies are digitally connected through SCSN. This can be regarded as the addition of a manufacturing function to the platform.

Discussion of the findings

We analyzed the configurations of seven digital platforms for manufacturing. The results (see Table 4) show three main findings: (1) not every digital platform for manufacturing has all the functions as part of the platform, (2) not all functions are necessarily organized according to the same platform type, and (3) not all random combinations of functions and types seem to be possible. We discuss these findings below.

Not all functions as part of the platform

A main assumption in the literature is that platforms are organized according to layers or logics (e.g., Rai et al., 2006; Rayport & Sviokla, 1995; Yoo et al., 2010). We therefore expected that all digital platforms for manufacturing would comprise the four functions—manufacturing, data sharing, market making, and innovation—because they would be directly linked. Unexpectedly, we see that not every digital platform for manufacturing has all these functions. A number of the digital platforms we analyzed do not have a manufacturing function organizationally as part of the platform. While the platform can always be used for manufacturing in firms or supply chains, such use is sometimes independent of the platform itself, i.e., not integrated into the platform. Hence "digital platforms for manufacturing" and not "digital manufacturing platforms." When the manufacturing function is not on the platform, it is not coordinated with the platform partners, and, as a manufacturing function, it does not benefit from the main value as generated by the platform: the network effects, the economies of scope, and the modular technological architecture (see also Björkdahl, 2020; Ghosh et al., 2022; Wallbach et al., 2019). This has the advantage of keeping the manufacturing function as it is, not requiring new investments or extensive coordination, but it also entails the danger of becoming no more than an exchangeable module of digital platforms shaped by non-manufacturing players.

Like we found platforms without a manufacturing function, we also find platforms without a market making function. These platforms may be selling goods or services, but they do not fulfill a matching role by bringing buyers and suppliers together. In some cases, like MindSphere or IDSA, this may be because the focus of the platform is not on the market for end-products but rather on facilitating processes. In other cases, the lack of market making may open the vulnerability for manufacturing firms and platforms to see their (very efficiently made) products traded on market making platforms started by new digital players, who may appropriate a significant share of the value created.

Our findings contradict literature in which digital platforms have been conceptualized as layered architectures (e.g., Rai et al., 2006; Rayport & Sviokla, 1995; Yoo et al., 2010), where the digital aspects "mirror" the physical reality or as architectures where the functions logically go together (e.g., Jovanovic et al., 2022; Thomas et al., 2015), for, in both cases, we would expect to see all functions as part of the platform organization, and not absent or organized in a different way. Our findings instead tie in with the notion that organizational configurations may be loosely coupled and not necessarily dictated by physical reality (e.g., Baskerville et al., 2020; Colfer & Baldwin, 2016; Constantinides et al., 2018).

Not all functions organized according to the same platform type

Following the seminal conceptual and review articles (Facin et al., 2016; Gawer, 2014; Gawer & Cusumano, 2014; Hein et al., 2020; Jovanovic et al., 2022; Thomas et al., 2015), we expected digital platforms for manufacturing to be either one of three types: internal, supply chain or industry platforms, and that all functions are aligned within that type. Our cases show that the functions of a digital platform for manufacturing are not necessarily organized according to the same platform type. This finding partly contradicts findings by Thomas et al. (2015) who find that platforms are governed by a logic and by Jovanovic et al. (2022) who find that the different aspects of platform architecture development are co-evolving and are expected to be aligned. Here, too, our findings support the notion that digital platforms for manufacturing may not necessarily be integrated systems but may be loosely coupled (Baskerville et al., 2020; Colfer & Baldwin, 2016; Constantinides et al., 2018). Therefore, digital platforms for manufacturing do not necessarily conform to existing, known, OEM-determined industry structures (see also Kapoor et al., 2022).

In our study, we did not investigate platform evolution, and we can therefore not confidently state that alignment of all functions into the same platform type is not necessary in the longer run, but we can also not confirm that such alignment is necessary. A lack of alignment at the current moment may be a sign of platform partners searching for the right platform configurations, but not having succeeded in fully determining what those configurations should be. Given that our case examples are all recent, and may still be searching for effective configurations, we think that it is "too early to tell."

The possibility of more complex configurations is an addition to the typology as presented by Gawer (2014), Thomas et al. (2015), and Facin et al. (2016), which assume that the platform is a unity. If we dive deeper into the *aspects* of the platform types as provided by Gawer (2014), we see that, with very few exceptions, they always align with the overall assessment of the platform type per function (see Appendix Tables 5, 6, 7, 8, 9, 10, and 11). This provides confidence in Gawer's (Gawer, 2014) typology, and in our own findings, they are not likely to be due to a mistake in the typology or in the analysis, but rather to the complexity of current real-world digital platform configurations in manufacturing.

Not all configurations seem possible

Nuancing the previous findings, our case analysis seems to show that not all random configurations of functions across platform types will be found in practice, although more research is required to substantiate that. Apparently, some logic is necessary, though not in a way that may be immediately obvious to manufacturing partners or to researchers.

Considering the functions, in our set of seven cases, all of them comprise both data sharing and innovation functions, whereas the manufacturing or market making functions are sometimes missing. At first glance, it seems strange that in digital platforms for manufacturing, the manufacturing function itself can be missing. At second glance, this can be understood: the platform can bring partners with different functions together, but that does not necessarily imply that all those functions need to be organizationally part of the platform itself. In contrast, bringing partners with different functions together almost inevitably means that data needs to be shared by those partners and hence data sharing is always an integral part of the platform. This seems to be in line with the notion that the data sharing function is dominantly organized as supply chain type or industry type: across rather than within partner firms.

It is interesting to explore why the innovation function is part of the platform in all cases. Is there a reason for that finding or is our set of cases simply too small to have a case without an innovation function? We defined the innovation function earlier on as a vehicle to think about, develop, pilot, test, experiment with, and implement innovation of digital configurations, while ensuring that physical manufacturing investments will continue to pay off. This seems to imply that the innovation function is important in the early stages of the platform formation and operation. The emerging nature of digital platforms for manufacturing is therefore a possible explanation for the fact that all cases contain an innovation function.

In sum, given the current stage of development of platforms in the manufacturing sector, many possible configurations may exist, though it is too early to tell which ones will prove to be effective and sustainable. Finding that out is quite a difficult, multi-dimensional task, as Kapoor et al. (2022) show in their research. The implication is that the platform innovation function is important to explore the different possible configurations of digital platforms for manufacturing and to think about, develop, pilot, test, experiment with, and implement innovation of digital configurations.

Conclusions, implications, and future research

Conclusions

Our research question was "What are different organizational configurations of digital platforms for manufacturing?" The answer is that they come in different, partly unexpected, configurations. This finding has three sub-findings.

First, we find, unexpectedly, that digital platforms for manufacturing do not always include a manufacturing function or market making function. This supports notions from practitioners that digital platforms for the manufacturing sectors may be different from those in consumer sectors (Riemensperger & Falk, 2020). It may also indicate that the manufacturing sector uses digital platforms in a limited way, benefiting only partially from the value they can provide (see also Björkdahl, 2020;Culot et al., 2020 ; Hanelt et al., 2020). The implication for theory is that, while platforms may still be regarded as organized in layers or according to a certain logic (this may be, after all, only a way of looking), we have to be careful not to infer that the layers, aspects, or functions are by definition "mirrored" or "hard wired," but keep an open mind on how the functions are related (see Baskerville et al., 2020;Colfer & Baldwin, 2016 ; Constantinides et al., 2018).

Second, we find that the functions of digital platforms for manufacturing are not necessarily aligned within the same platform type. This partly contradicts earlier concepts and findings (e.g., Facin et al., 2016; Gawer, 2014; Gawer & Cusumano, 2014; Hein et al., 2020; Jovanovic et al., 2022; Thomas et al., 2015), but it provides support for the notion that digital platforms are loosely coupled architectures, as opposed to (fixed) layered architectures (Colfer & Baldwin, 2016; Constantinides et al., 2018). The implication for theory is that the typology of internal, supply chain, and industry platforms should be understood indeed as a typology, where in-between or transitory cases are possible, and not as a fixed classification.

Third, we find that, despite the complexity suggested by our other findings, not all random configurations of platform functions and types seem to be possible. Some configurations seem more preferred or "logical" than others. Specifically, all digital platforms for manufacturing seem to incorporate an innovation function, likely because there is a clear need to explore new and unknown platform configurations, and their consequences for cost, network effects, and value creation (Kapoor et al., 2022; McIntyre et al., 2021; Wallbach et al., 2019; Yablonski, 2018). The implication may be that the development of digital platforms in the manufacturing sector is still in relatively early stages and that configurations have not yet crystallized and that further research regarding their evolution is necessary.

Our research contributes to the literature on platforms in three ways. First, we mend a relative scarcity of research digital platforms in the manufacturing sectors. Second, we answer the calls for conceptual clarity on digital platforms (De Reuver et al., 2018) and for digital platforms related to physical products (Yoo et al., 2010). Third, we analyze configurations of platforms according to their types and functions and we find that these configurations seem to be more complex than existing literature would lead us to expect.

Managerial and policy implications

Despite the prominence of the services sector in advanced economies, the manufacturing sector is still important. In the transition from internal and supply chain to industry platform configurations, the manufacturing sector has been relatively lagging. Traditionally, manufacturing platforms have been internal to the firm or at best supply chain type. Initially, the main challenge for manufacturing seemed to be technical: starting from the manufacturing function, to design integrated platforms by logically adding a data function and, more recently, a market making function. Our research suggests a major organizational challenge: digital platforms for manufacturing come in different, partly unexpected, configurations. It is important for players in the manufacturing sector to understand these complexities and whether they are by design or by accident. These complexities may stem from technological developments that allow platforms to be loosely coupled organizations rather than "hardwired" integrated organizations, or from the relative lagging of the manufacturing sector in adopting digital platforms, or a combination of both.

The apparent complexity is both good and bad news for manufacturing firms. The good news is that they will have more opportunities to participate in various complex platform configurations and that those platforms can be more easily reconfigured and extended. Such reconfiguration and extension does not happen by itself; it needs to be organized. This is what happens in the *innovation function*: not only the technical modules need to be reconfigured but the organizational structures such as governance, coordination, and contracts as well (see also Jovanovic et al., 2022).

The bad news is that manufacturing firms are not by definition in the driving seat of this process. Culot et al. (2020) signal uncertainties, such as increasing dependencies on data providers, more co-creation by customers, replacement of traditional intermediaries, entry of new competitors (e.g., from related sectors, new digital players, or software or IT services providers), and deep changes in the relations between partners in value networks (Culot et al., 2020; Hanelt et al., 2020). In addition, lessons can be drawn from digital platform-related transformations in the software, services, and retail sectors. This makes the innovation function a crucial one for manufacturing platforms, because if manufacturing firms do not actively take initiative in innovating toward their own digital platforms, they may either remain stuck in improving their existing configurations or they may become no more than exchangeable modules in platforms shaped by new digital players. Manufacturing firms need to actively initiate platform innovation and/or participate in supply chain or industry innovation partnerships, to explore new configurations of digital platforms for manufacturing.

If they succeed in doing this, digital platforms for manufacturing can potentially create huge economies of scope and network effects. Therefore, digital platforms are becoming mission critical for the competitiveness of the manufacturing sector. A possible outcome of the positive feedback effects of economies of scope and network effects, however, is the "winner-take-all" effect: one or a few major players may come to dominate certain platform functions and/or one or a few platforms may come to dominate a sector. Governments could therefore stimulate the initiation of platforms based on decentralized architectures, and with shared control over platform functions by several partners, to avoid the negative consequences of such winner-takes-all effects. The innovation function of digital platforms for manufacturing, especially when shaped by public-private partnerships, seems to be a good vehicle to govern such platforms, as can be seen from the examples of International Data Spaces Association (IDSA) and Smart Connected Supplier Network (SCSN).

Future research

Our findings provide promising directions for future research, either through in-depth case studies or larger-sample overview studies. While observing the requirements for case study research in innovation management (Goffin et al., 2019), in this paper, we limited ourselves to seven cases. Our approach limits our ability to clearly confirm or disconfirm what digital platforms for manufacturing will or should look like and limits our ability to generalize. Recently, several interesting studies appeared that point the way for more empirical research, notably Riasanow et al. (2021), identifying clusters in platform ecosystems; Ghosh et al. (2022) identifying dynamic capabilities; Jovanovic et al. (2022), identifying co-evolution of platform aspects; and Kapoor et al. (2022), Hein et al. (2019), and Tian et al. (2022), identifying how platforms should be organized for servitization.

Further case study research could focus on the inner workings of the innovation function, asking, for example, "How do manufacturing players participate in exploring the different possible configurations of digital platforms for manufacturing?" or "How do they develop, pilot, test, experiment with and implement platform innovations?" Longitudinal case research could focus on the evolution or transition of platform functions and types over time (see, e.g., Sandberg et al.'s, 2020 case study on the evolution of ABBs platforms). We already saw such an evolution for 3D Hubs, which shifted its market making function from an industry type to a supply chain type of platform, and for SCSN, which develops market making and manufacturing functions. Insights in evolution will help answering questions such as "Should platform functions be organizationally aligned with each other? If so, how?" (see, e.g., Jovanovic et al. (2022) and the discussion in the "Not all functions organized according to the same platform type" section); "Are platforms typically starting from one function? Is that the innovation function, or can they start from other functions as well?", "Are digital platforms for manufacturing developing from existing firms or supply chains into industry platforms, or can they be newly conceived as industry platforms?", "Are some of those developments better or worse?", "What do such developments depend on?", "Will digital platforms for manufacturing develop toward having all four functions or will platforms with two or three functions also remain feasible?", and "Will digital platforms for manufacturing converge into a limited number of dominant 'winner-take-all' platforms, as observed in some social media and retail examples?"

As more theory on digital platforms for manufacturing becomes available, it will be productive to conduct larger-sample studies. Such studies could focus on which configurations of platform functions and types are possible, occur frequently, and/or are successful. Relevant questions may include "Are there 'ideal types' of sustainable configurations of digital platforms for manufacturing?", "Which configurations are 'better' or 'worse', and under which conditions?", and "Can configurations be ranked in complexity, and under which conditions would they need to be more complex or less complex?"[1] As reality unfolds, such longitudinal and large-sample studies will become increasingly feasible.

[1] We thank an anonymous reviewer for bringing this to our attention. A ranking criterion for complexity could be the number of platform types per platform, in which case Skuchain would rank as "high complexity"; 3D Hubs, Nimble, MindSphere, and Sculpteo as "medium complexity"; and IDSA and SCSN as "low complexity."

Appendix

We first scored each case according to our framework. See the top part of each table behind "platform type." In addition, to validate the scores of internal, supply chain, or industry platform type, we scored each function according to the *sub-dimensions of the platform types* as mentioned by Gawer (2014): level of analysis, constitutive agents, technological architecture, interfaces, accessible innovative capabilities, and coordination mechanisms. The tables below show the results. They specifically show that in every case, all the sub-dimensions score in the same platform type as the overall scores. This validates our scores of the cases, and it confirms the validity of the Gawer (2014) framework.

Table 5 Sculpteo

		Functions			
		Innovation	Data sharing	Market making	Manufacturing
Platform type	Internal platform	V			V
	Supply chain platform		V		
	Industry platform				
Sub-dimensions					
Level of analysis	Firm	V			V
	Supply chain		V		
	Industry ecosystems				
Platform constitutive agents	One firm	V			V
	Assembler				
	Platform leader		V		
Technological architecture	• Modular design • Core and periphery	V	V		V
Interfaces	Closed interfaces	V			V
	Selectively open		V		
	Open interfaces				
Accessible innovative capabilities	Firm capabilities	V			V
	Supply chain capabilities		V		
	Unlimited pool of externalities				
Coordination mechanisms	Managerial hierarchy	V			V
	Contractual relations		V		
	Ecosystem governance				

Table 6 MindSphere

		Functions			
		Innovation	Data sharing	Market making	Manufacturing
Platform type	Internal platform	V			
	Supply chain platform		V		
	Industry platform				
Sub-dimensions					
Level of analysis	Firm	V			
	Supply chain		V		
	Industry ecosystems				
Platform constitutive agents	One firm				
	Assembler				
	Platform leader	V	V		
Technological architecture	• Modular design • Core and periphery	V	V		
Interfaces	Closed interfaces	V			
	Selectively open		V		
	Open interfaces				
Accessible innovative capabilities	Firm capabilities	V			
	Supply chain capabilities		V		
	Unlimited pool of externalities				
Coordination mechanisms	Managerial hierarchy	V			
	Contractual relations		V		
	Ecosystem governance				

Table 7 International Data Spaces Association

		Functions			
		Innovation	Data sharing	Market making	Manufacturing
Platform type	Internal platform				
	Supply chain platform				
	Industry platform	V	V		
Sub-dimensions					
Level of analysis	Firm				
	Supply chain				
	Industry ecosystems	V	V		
Platform constitutive agents	One firm				
	Assembler				
	Platform leader	V	V		
Technological architecture	• Modular design • Core and periphery	V	V		
Interfaces	Closed interfaces				
	Selectively open				
	Open interfaces	V	V		
Accessible innovative capabilities	Firm capabilities				
	Supply chain capabilities				
	Unlimited pool of externalities	V	V		
Coordination mechanisms	Managerial hierarchy				
	Contractual relations				
	Ecosystem governance	V	V		

Table 8 3D Hubs

		Functions			
		Innovation	Data sharing	Market making	Manufacturing
Platform type	Internal platform	V			
	Supply chain platform		V	V	V
	Industry platform			(V)	(V)
Sub-dimensions					
Level of analysis	Firm	V			
	Supply chain		V	V	V
	Industry ecosystems			(V)	(V)
Platform constitutive agents	One firm	V			
	Assembler			V	V
	Platform leader		V	(V)	(V)
Technological architecture	• Modular design • Core and periphery	V	V	V	V
Interfaces	Closed interfaces	V			
	Selectively open		V	V	V
	Open interfaces			(V)	(V)
Accessible innovative capabilities	Firm capabilities	V			
	Supply chain capabilities		V	V	V
	Unlimited pool of externalities			(V)	(V)
Coordination mechanisms	Managerial hierarchy	V			
	Contractual relations		V	V	V
	Ecosystem governance			(V)	(V)

V current situation, *(V)* old situation

Table 9 Skuchain

		Functions			
		Innovation	Data sharing	Market making	Manufacturing
Platform type	Internal platform	V			
	Supply chain platform		V		
	Industry platform			V	
Sub-dimensions					
Level of analysis	Firm	V			
	Supply chain		V		
	Industry ecosystems			V	
Platform constitutive agents	One firm	V			
	Assembler				
	Platform leader		V	V	
Technological architecture	• Modular design • Core and periphery	V	V	V	
Interfaces	Closed interfaces	V			
	Selectively open		V		
	Open interfaces			V	
Accessible innovative capabilities	Firm capabilities	V			
	Supply chain capabilities		V		
	Unlimited pool of externalities			V	
Coordination mechanisms	Managerial hierarchy	V			
	Contractual relations		V		
	Ecosystem governance			V	

Table 10 Nimble

		Functions			
		Innovation	Data sharing	Market making	Manufacturing
Platform type	Internal platform				
	Supply chain platform	V	V		
	Industry platform			V	
Sub-dimensions					
Level of analysis	Firm				
	Supply chain	V	V		
	Industry ecosystems			V	
Platform constitutive agents	One firm				
	Assembler	V	V		
	Platform leader			V	
Technological architecture	• Modular design • Core and periphery	V	V	V	
Interfaces	Closed interfaces				
	Selectively open	V	V		
	Open interfaces			V	
Accessible innovative capabilities	Firm capabilities				
	Supply chain capabilities	V	V		
	Unlimited pool of externalities			V	
Coordination mechanisms	Managerial hierarchy				
	Contractual relations	V	V		
	Ecosystem governance			V	

Table 11 Smart Connected Supplier Network

		Functions			
		Innovation	Data sharing	Market making	Manufacturing
Platform type	Internal platform				
	Supply chain platform				
	Industry platform	V	V	developing	developing
Sub-dimensions					
Level of analysis	Firm				
	Supply chain				
	Industry ecosystems	V	V	developing	developing
Platform constitutive agents	One firm				
	Assembler				
	Platform leader	V	V	developing	developing
Technological architecture	• Modular design • Core and periphery	V	V	developing	developing
Interfaces	Closed interfaces				
	Selectively open				
	Open interfaces	V	V	developing	developing
Accessible innovative capabilities	Firm capabilities				
	Supply chain capabilities				
	Unlimited pool of externalities	V	V	developing	developing
Coordination mechanisms	Managerial hierarchy				
	Contractual relations				
	Ecosystem governance	V	V	developing	developing

Data Availability Case data from the tables in this paper can be acquired from the corresponding author upon request.

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