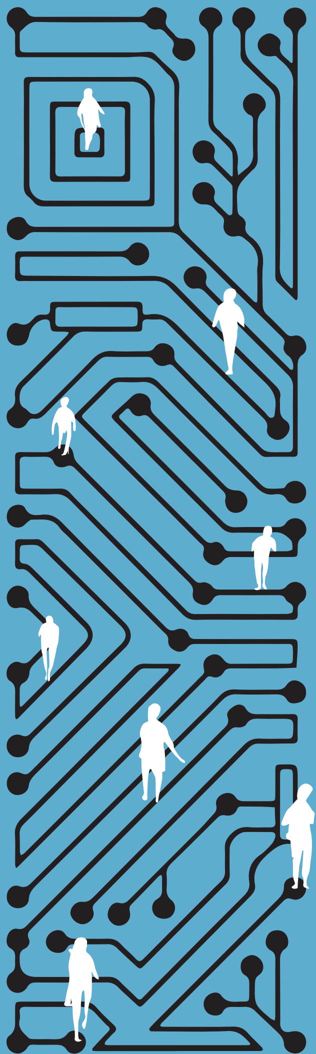
Understanding digital innovation processes in manufacturing SMEs:

Crossing organizational boundaries to address managerial challenges



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Understanding digital innovation processes in manufacturing SMEs: Crossing organizational boundaries to address managerial challenges

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geboren op 20 november 1995
te Valkenburg aan de Geul

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from Radboud University Nijmegen
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according to the decision of the Doctorate Board
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by

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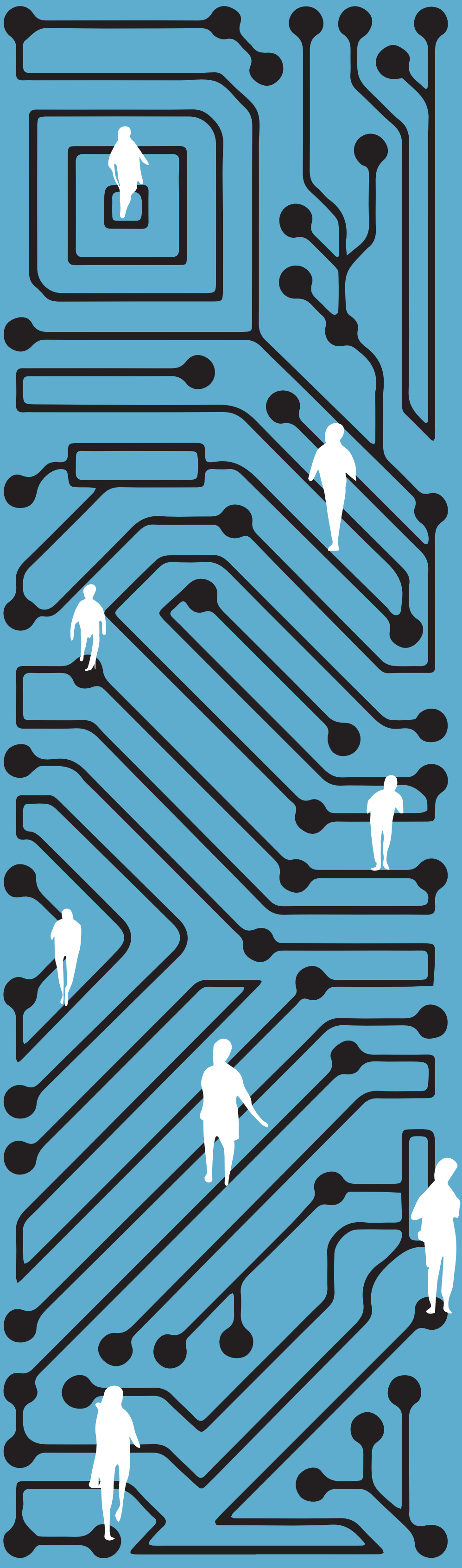


1.

Introduction

"The intermediary approached us with the idea of establishing a field lab focused on digital twinning some time ago already. The capabilities of this emerging technology can help us to further digitize and optimize our manufacturing processes and products. While we can choose to do this independently, I believe that by working together we can accelerate our digitalization efforts by learning from one another" (CEO of Medcorp, SME participating in field lab, December 2021).

"The senior managers of Truckcorp and Minecorp are uncertain about how to proceed with the development of digital twinning applications within the field lab. Truckcorp's manager expresses that he faces difficulties in generating enthusiasm among colleagues, as many prefer to stick to business as usual and do not see the urgency of the digital twinning project. Minecorp's senior manager shares this sentiment: *We run into similar issues, developing an actual digital twin of our product seems something for the long-term future".* They are interrupted by the senior managers of Medcorp and Bikecorp, who advocate that sharing experiences, good or bad, is useful for learning from each other." (field notes on field lab, November 2022).

The above two data excerpts illustrate that while crossing organizational boundaries may be valuable for actors in manufacturing SMEs pursuing digital innovation, for example by participating in a field lab as described above, it can also add another layer of complexity in doing so. For example, actors need to coordinate how they collaborate in such a setting, develop fruitful knowledge or resource sharing practices, while at the same time connecting to what is going on in their internal organization. Thus, in crossing their organizational boundaries, actors representing manufacturing SMEs not only have to navigate technical challenges that are associated with exploring new opportunities offered by emerging digital technologies, but also navigate social challenges that may originate from collaborating in a complex setting like a field lab or dealing with potential resistance to change in the internal organization.

In the Dutch context, SMEs digital innovation is generally considered an important driver for these firms to remain competitive (Ministry of Economic Affairs and Climate Policy, 2023; Smart Industry Netherlands, 2022). SMEs in the Netherlands are performing better than the European Union average in terms of the use of basic digital technologies.

However, in terms of more advanced digital technologies, like digital twinning described in the example above, SMEs still require additional support in accessing and implementing these (European Commission, 2023a). Dutch national and regional governments attempt to create awareness among SMEs on the opportunities digital technologies can provide through various initiatives, for example by sponsoring field labs and European Digital Innovation Hubs (Ministry of Economic Affairs and Climate Policy, 2023). These are designed for offering manufacturing firms advice and knowledge transfer regarding specific digital technologies, and to contribute to partnership development more broadly (Stolwijk & Seiffert, 2016; Stolwijk & Willems, 2019). However, despite these efforts, evaluations of these government-sponsored initiatives, like field labs, have shown that while potentially increasing SME awareness about digital technologies' potential for innovation, the actual realization of smart products or digital factories, as outcomes of digital innovation, remains limited.

Despite increased attention to this phenomenon in both research and practice, the above shows that there is still a long road to travel concerning manufacturing SMEs' digital innovation journeys. As SMEs may face resource constraints and are mostly taken up by demands of the day-to-day business, there is often less room for innovation (Horvath & Szabo, 2019; Muller et al., 2018). As a result, it is generally acknowledged that manufacturing SMEs struggle to implement digital technologies and embrace digital innovation. Taken together, this doctoral thesis is written from the desire to get a better understanding of how actors in manufacturing SMEs pursue digital innovation. Following a phenomenon-driven and explanatory approach, I pay specific attention to how crossing organizational boundaries can potentially alleviate internal resource constraints. Using different vantage points to better understand this complex phenomenon, I complement digital innovation literature with perspectives paying attention to resources or that have a practice orientation, or both. By the end, this thesis will hopefully have provided a better understanding of how actors navigate the crossing of their organizational boundaries to support digital innovation initiatives inside their manufacturing SMEs.

SME digital innovation in the Industry 4.0 context

The term Industry 4.0 stems from a German strategic initiative, announced in 2013 to take a pioneering role in industries which are currently revolutionizing the manufacturing sector (Kagermann et al., 2013). It symbolizes the beginning of the Fourth Industrial Revolution (Liao et al., 2017). In Industry 4.0, through digital technologies, the virtual space is integrated with the physical world (Vial, 2019; Xu et al., 2018). Over the last few years Industry 4.0 has emerged as a promising paradigm on which organizations rely to integrate and extend manufacturing processes as well as products at both intra- and inter-organizational levels (Dąbrowska et al., 2022).

Within the context of Industry 4.0, I am particularly interested in digital innovation, which has rapidly gained prominence across industries and sectors (Christensen et al., 2018; Downes & Nunes, 2013; Ozalp et al., 2018). Keeping up with these Industry 4.0 developments is considered a new imperative (Urbinati et al., 2022), in particular for firms in the manufacturing industry. Digital innovation involves the creation of or changes in market offerings, business processes, or models driven by the uptake of digital technologies like robotics, additive manufacturing, and augmented- and virtual reality (Blichfeldt & Faullant, 2021; Nambisan et al., 2017; Urbinati et al., 2022). Scholars suggest that digital innovation unfolds differently compared to other forms of innovation, mainly due to its core distinguishing characteristics of convergence and generativity (Nambisan et al., 2019; Yoo et al., 2010). Generativity considers digital technologies' capacity "to produce unprompted change driven by large, varied, and uncoordinated audiences" (Zittrain, 2006, p. 1980). As a result, it contributes to the proliferation of new technology-enabled products, processes, services, and business models (Tilson et al., 2012). Convergence refers to digital technologies coevolving with a myriad of interdependent technologies due to their connectedness and embeddedness across platforms and ecosystems (Gawer, 2021; Lyytinen, 2022; Yoo et al., 2010). It brings together previously separate products, entities, and industries, by allowing participation from multiple parties and by accumulating information from multiple sources (Yoo et al., 2012). Furthermore, due to the distributed nature of digital innovation, the need for actors to cross organizational boundaries during the innovation process increases (Ghezzi & Cavallo, 2020), while actors should also address trade-offs between internal and external collaboration (Moschko et al., 2023; Svahn et al., 2017). This requires scholars to broaden their scope beyond single organizations (Benitez et al., 2020) and consider how actors cross organizational boundaries, as manufacturing firms may lack the required resources and competences to engage in digital innovation on their own (Sestino et al., 2020).

Against this background, SMEs hold a special place, and may face specific challenges in pursuing digital innovation. For example, they are often taken up by the demands of day-to-day business (Muller et al., 2018), which makes identifying digital innovation opportunities more difficult (Benitez et al., 2020; Horvath & Szabo, 2019). Furthermore, they are generally more limited in their internal resources, for instance due to financial constraints (Chiappini et al., 2022; Mittal et al., 2018) or a lack of digitally skilled employees (Müller & Voigt, 2017), making it crucial for them to cross organizational boundaries – accessing complementary resources to support their digital innovation initiatives (Muller et al., 2018). A limited number of previous studies started exploring the value of crossing organizational boundaries for manufacturing SMEs to tap into complementary resources, for instance considering types of useful collaboration partners (e.g., Agostini & Nosella, 2019; Ricci et al., 2021) or proposing that engaging in intermediary-based collaboration is particularly useful (e.g., Caloffi et al., 2023). However, we lack an in-depth understanding of *how* actors cross organizational boundaries to attract, develop, and internalize required resources to pursue digital innovation. It is imperative to develop a better understanding of how crossing organizational boundaries can support manufacturing SMEs in pursuing digital innovation, since digital innovation initiatives do not always flourish (Ghobakhloo & Iranmanesh, 2021), but open up the potential for manufacturing firms to become more sustainable and competitive (Liu et al., 2023). Therefore, the general research objective for this dissertation is *to provide a deeper understanding of how actors in manufacturing SMEs cross organizational boundaries to pursue digital innovation.*

Theorizing complex phenomena

I aim to fulfill this research objective through a phenomenon-driven and explanatory approach relying on different vantage points (Cornelissen et al., 2021; Cornelissen & Kaandorp, 2022; Cornelissen, 2023). In line with a growing recognition of the limitations of exclusively applying separate approaches to theorizing, like the predominant propositional approach (Colquitt & Zapata-Phelan, 2007; Makadok et al., 2018), 'theoretical pluralism' (Cornelissen et al., 2021) has been forwarded to explain complex phenomena from different vantage points and is gaining traction across social sciences (Gelman & Imbens, 2013; Heckman & Singer, 2017; Pearl & Mackenzie, 2018). Following this dissertation's objective to develop a deeper understanding of a complex, real-world phenomenon – manufacturing SMEs' crossing organizational boundaries to pursue digital innovation –, I rely on multiple forms of theorizing and their related 'theoretical grammars' (Cornelissen, 2023) and corresponding research methods, which can each play distinct roles and complement each other in explaining phenomena (Cornelissen et al., 2021; Cornelissen & Kaandorp, 2022; Sandberg & Alvesson, 2021; Shaver, 2020). I move away from propositional theorizing that, while resulting in valuable insights, has been criticized to overly simplify these complex phenomena in its theorizing (e.g., Cornelissen, 2023; Tsoukas, 2017). These simplified theories may be detached from what practitioners are experiencing in the real world (Petriglieri, 2020; Weick, 2003), for example by taking away context, process, and time (Tsoukas, 2017), which makes practitioners complain about the irrelevance of management theory (Tsoukas, 2017; Weick, 2003; 2007). This ties into the ongoing scholarly debate that developments in management theory are stagnating or even banal (Alvesson & Sandberg, 2011; Cronin et al., 2021; Delbridge & Fiss, 2013). Hence, I combine configurational and process theoretical grammars instead of relying on the predominant propositional theorizing approach. Fitting my phenomenon-driven and explanatory approach, I aim to 'hunt for causes' (configurational and process theorizing) instead of 'using causes' (propositional theorizing) to further explain digital innovation in manufacturing SMEs (in line with Cornelissen & Kaandorp, 2022)

Management researchers have recently started experimenting with ways to coherently and effectively combine multiple forms of theorizing. For example, by combining process and configurational approaches (Cloutier & Langley, 2020) or by combining all three grammars inherent to explanatory theorizing (Slager et al., 2023). These few illustrative studies practiced theoretical pluralism mostly by combining grammars into a singular mixed-methods study (Cornelissen, 2023). Theoretical pluralism can also involve combining grammars as part of a program of research on a phenomenon (Cornelissen, 2023; Cronin et al., 2021; Post et al., 2020; Shaver, 2020).

Applying the latter approach, I relied on configurational and process theorizing in three separate empirical studies. This offered me different vantage points on the phenomenon under study, and enabled me to develop a deeper explanation of manufacturing SMEs crossing organizational boundaries for digital innovation. In particular, through a configurational approach, I explored multiple combinations of internal and external resources and contexts that are supportive or not for SMEs digital innovation initiatives (study 1); while by following processual approaches I analyzed how actors identify, develop, and internalize these external resources in the course of the innovation process (study 2); and developed a more detailed understanding of the practices in intermediary-based collaborations, a specific type of crossing organizational boundaries, that support or hamper participating SMEs' digital innovation initiatives.

Resource bundles, resourcing, and sociomaterial practices for digital innovation

In this dissertation, I examine different sub phenomena related to how SMEs cross organizational boundaries for digital innovation in three empirical studies. Since I zoom in on different parts of this phenomenon in the three empirical chapters, I also used different theoretical lenses that align with the part of the phenomenon I investigated. Together, this provided a more layered understanding of the phenomenon of crossing organizational boundaries for digital innovation by manufacturing SMEs. As theoretical lenses, I draw on theories with a practice orientation or a focus on resources, or both.

In particular, in the first study I draw on resource-based view (RBV) logic, aligning well with the configurational approach I took, which supported me in exploring which resource bundles are supportive to or can hamper SMEs digital innovation initiatives. In the second study, I switch to a resourcing perspective, matching my (retrospective) processual approach, which supported developing an understanding of how actors identify, develop, and integrate external resources to pursue digital innovation. In the third empirical chapter, in contrast to the first two in which I more broadly explored resources and the development of resources supporting digital innovation in SMEs, I zoomed in on a specific type of crossing organizational boundaries: intermediary-based collaborations. In these collaborations SMEs can seek advice and rely on a network regarding specific digital technologies. Yet as most SMEs are only to a limited extent familiar with these technologies, I draw on a perspective that pays attention to how social actors and technology intertwine over time in practice: sociomateriality.

Hence, to understand different pieces of the digital innovation puzzle in SMEs, I draw on different theoretical perspectives that each align with my research approach and sub phenomenon under study. Together, these explanations contribute to a more layered and holistic understanding of how actors in SMEs cross organizational boundaries to support digital innovation initiatives. Below I further outline the suitability of each of the theoretical perspectives related to the sub phenomena, as well as providing definitions of core concepts for each of these perspectives.

The objective of the first study was to explore which bundles of internal and external resources contingent on specific contexts are supportive to or can hamper SMEs digital innovation initiatives. I draw on resource-based view (RBV) logic (Barney, 1991; Penrose, 1959), particularly on Penrose (1959) who was one of the first to draw attention to these resource *bundles*. She defined these as combinations of different types of resources. This RBV logic further suggests that the value of these resource bundles is contingent on contextual conditions (Brush & Artz, 1999; Miller & Shamsie, 1996). Translating this to the manufacturing SME context, this implies that certain resource bundles may be productive in one context, for instance a specific region or industry, and unproductive in another. Previous studies along this line have shown that implementing advanced digital technologies is a complex and resource-intensive endeavor (Ghobakhloo & Iranmanesh, 2021), which can be further supported or constrained by a firm's context (Chen & Tian, 2022). In this light, these prior studies discussed both internal and external resources that SMEs may need in pursuing digital innovation, such as human and technical resources (Marrucci et al., 2023; Müller &

Voigt, 2017), and external social resources (i.e., relationships) by collaborating directly with external actors or indirectly through intermediaries (Agostini & Nosella, 2019; Ricci et al., 2021; Rossi et al., 2022). Yet, SMEs often face resource constraints (Horvath & Szabo, 2019; Mittal et al., 2018), which makes it likely that they do not have access to all the required resources internally, for instance through a lack of digitally skilled employees (Müller & Voigt, 2017; Muller et al., 2018). Hence, a perspective focused on resource *bundles,* in which resources may be able to complement (i.e., reinforce) or substitute (i.e., replace) each other (Ennen & Richter, 2010; Pahnke et al., 2023) holds value in exploring how SMEs can implement advanced digital technologies for pursuing digital innovation, despite facing resource constraints.

By combining a configurational approach and RBV logic in the first study, I could reveal complex causal dynamics at play which resulted in the identification of diverse resource bundles with specific contexts associated with advanced and not advanced digital technology use in manufacturing SMEs. SMEs that used more advanced digital technologies always accessed external resources, albeit in different ways: through broad and deep interorganizational collaborations and/or intermediary-based collaborations.

While the first study focused on developing a valuable, yet relatively static overview of productive resource bundles for SMEs in the digital innovation context, the second and third studies emphasized developing a processual understanding of how actors identify, develop, and integrate external resources to pursue digital innovation. In the second study I drew on a perspective with both a resource and process sensitivity: resourcing (Feldman, 2004; Feldman & Worline, 2011). As an application of practice theory (Feldman & Worline, 2016), the resourcing perspective pays attention to the specific actions through which resources gain their value (Feldman & Worline, 2011). This perspective departs from earlier perspectives on resources, such as resource dependence theory (Salancik & Pfeffer, 1978), by emphasizing how the value of a resource arises from its meaning in interrelated practices (Feldman & Worline, 2016). Thus it tries to address the criticism of these earlier perspectives as a static conceptualization that foregrounds innate qualities of resources without explaining how these gain their value (Kraaijenbrink et al., 2010). To illustrate this notion of resourcing, Feldman and Worline (2011) describe the historical example of breadcrumbs during World War II. On their own, breadcrumbs have no inherent use or meaning, as they can be used in many ways to achieve different objectives. However, in WWII, people turned breadcrumbs into a resource by using them to prepare meatballs, as meat was scarce. Adding breadcrumbs allowed them to conserve meat resources and still prepare a tasty family dinner. To the family adapting their meatball recipe to save money, breadcrumbs are, through this action, turned into a valuable resource. Thus, resourcing theory emphasizes that, as illustrated by the meatballs example, action is necessary to access potential resources' innate qualities. Without action, a potential resource is not useful and does not become a resource-in-use. This resourcing perspective was particularly valuable in the digital innovation context, because, although external resources are crucial for pursuing digital innovation, the process of resourcing them is particularly challenging when complementary external resources are relatively distant and unfamiliar. This means they often need to be identified and developed in an iterative fashion, including instances of reorientation and trial-and-error (Deken et al., 2018). Combining this with the specific managerial challenges SMEs face in pursuing digital innovation applying a resourcing perspective was particularly valuable. These challenges relate to, for instance, limited experience in identifying opportunities (Benitez et al., 2020) and managing structured innovation processes (Giotopoulos et al., 2017; Pessot et al., 2023), and their limited internal resources (Chiappini et al., 2022; Mittal et al., 2018). The resourcing perspective allowed me to assess, by focusing on specific activities of attributing value to resources (Feldman & Quick, 2009), whether and how micro-level instances of external resourcing are developed in a certain direction to energize a more extensive digital innovation process.

In the third study I zoomed in on a specific type of boundary crossing: by participating in intermediary-based collaborations. These intermediary-based collaborations came to the fore as an important ingredient in supporting SMEs digital innovation in the first study. Practitioner reports also identified that these intermediary-based collaborations, like field labs in the Dutch context (Stolwijk & Seiffert, 2016), do not always live up to their potential (Grond et al., 2021). Therefore I was interested in getting a more nuanced understanding of what practices in intermediary-based collaborations can support or hamper digital innovation in manufacturing SMEs. To analyze the unfolding of these intermediary-based collaborations, which are characterized by their focus on specific emerging digital technologies (Grond et al., 2021), I draw on a lens with a practice orientation and process sensitivity: sociomateriality (Cecez-Kecmanovic et al., 2014; Leonardi, 2011; Leonardi et al., 2019; Orlikowski & Scott, 2008, 2014). As most SMEs entering these intermediary-based collaborations are not or only to a limited extent familiar with these emerging digital technologies, it makes sense to draw on a perspective that pays attention to how these social actors and the technology intertwine over time in practice, as this intertwining is likely to relate to the effectiveness of their innovation efforts (see e.g., Barrett et al., 2012). The sociomateriality perspective puts technology front and center, since its materiality is deeply enmeshed or imbricated with social practices in its creation and use (Leonardi, 2011; Orlikowski & Scott, 2008). Put simply, the practices these technologies afford or constrain, for instance innovating products or processes, are dependent upon not only technological components, but also on the people deploying them in their work. Hence, this perspective goes beyond acknowledging digital technology's impact on organizational practice, but instead argues that technology plays a central and constitutive role in the organizational process

(Bailey et al., 2022; Barrett et al., 2012; Lebovitz et al., 2022; Waardenburg et al., 2022; Yoo et al., 2012). In particular, I focused on sociomaterial practices: the space where social actors and material artifacts interact and imbricate (Cecez-Kecmanovic et al., 2014; Leonardi, 2013). Applying this to a digital twinning field lab, I focused specifically on social actors representing the participating manufacturing firms and the intermediary, and digital twinning technology and its components as material artifacts. This perspective enabled me to develop a more detailed understanding of which practices in these intermediary-based collaborations may be supportive of and/or detrimental to digital innovation in participating manufacturing firms.

Taken together, the three theoretical perspectives I draw on to investigate interrelated sub-phenomena of crossing organizational boundaries for digital innovation in SMEs are distinct but also interconnect: each deals with how organizations utilize resources, albeit from different angles. The RBV provides a static lens on resources, and views them as assets to be controlled by an organization for competitive advantage. The resourcing perspective provides a more dynamic, process-oriented view, focusing on how resources are enacted through social practices. Sociomateriality further specifies this resourcing process by showing how material and social elements are intertwined, co-constituting resources in practice. Hence, while the RBV is more concerned with "what" resources a firm has, the resourcing and sociomateriality perspectives focus on "how" resources are created and enacted in specific contexts, emphasizing the dynamics underlying this process. Furthermore, as the resourcing and sociomateriality perspectives are both grounded in practice theory, they recognize that agency is entangled with the social and material practices actors participate in. In contrast, the RBV places more emphasis on the role of structure, or, in other words, the "what" that enables or constrains agency. These perspectives can thus inform each other - the structure of supportive internal and external resources for digital innovation can provide a starting point for the process of developing valuable resources through practices and human agency. Thereby, these perspectives together can give us a more layered understanding of relevant resources for digital innovation and how these are created in practice.

Research design

The objective of this dissertation was to develop a deeper understanding of a complex phenomenon, manufacturing SMEs' crossing organizational boundaries to pursue digital innovation. Linking to calls for theoretical pluralism to explain complex phenomena (Cloutier & Langley, 2020; Cornelissen et al., 2021; Cornelissen & Kaandorp, 2022; Cornelissen, 2023; Sandberg & Alvesson, 2021; Shaver, 2020; Tsoukas, 2017), I combined configurational and process theoretical grammars in three separate studies.

Configurational theorizing focuses on conceptualizing complex systems of interdependency that can systematically co-vary with certain outcomes (Furnari et al., 2021). Characterized by the assumption of causal complexity, it assumes that phenomena are explained by multiple combinations of antecedent conditions. In theorizing configurational causation, scholars track how multiple causal conditions combine into distinct configurations, or 'causal recipes' (Ragin, 2008) that are constituted by 'integrative mechanisms' (Furnari et al., 2021; Misangyi et al., 2017). In the first study, in line with configurational theorizing, I used a qualitative comparative analysis (QCA) design, a set-theoretic method increasingly used in management and innovation research (Kraus et al., 2018; Kumar et al., 2022). QCA's goal is to determine which configurations, or combinations of conditions, are sufficient or necessary for an outcome of interest to occur (Ragin, 2008; Schneider & Wagemann, 2012). Despite the suitability of QCA for a more systematic comparison of larger-N samples and the possibility to use quantitative data, it remains largely a qualitative research method, using case information to further substantiate findings. Hence, I use QCA in an abductive manner to explore how conclusions drawn from empirical data relate to previously developed theoretical hunches, and in this way can inform theorizing (Misangyi et al., 2017; Ragin, 2000). Relying on configurational theorizing and applying QCA, I explored which configurations of internal resources, external resources, and environmental contexts support or hamper manufacturing SMEs digital innovation initiatives. The main data source was the European Manufacturing Survey 2021 (EMS), of which I used a subset of the data related to the 2021 Dutch survey with questions covering 2018-2021. The response contained 184 cases, of which 174 valid cases were included in the QCA analyses. The findings provided an 'explanatory scheme' (Fiss, 2011; Furnari et al., 2021), which profiles advanced digital technology use - a phenomenon - by attributing resources and contexts - a set of distinguishing aspects - and examining their prominence and centrality in a multidimensional structure. This provided insight into multiple consistent resource and context configurations that supported or hampered digital innovation in manufacturing SMEs. This explanatory scheme helped me to categorize more broadly prominent and central relationships between all these conditions, and highlighted the central role external resources played across the identified consistent paths. Hereby the explanatory scheme formed a basis for developing a more processual understanding of the integrative mechanisms underlying *how* actors in manufacturing SMEs cross organizational boundaries to pursue digital innovation (following e.g., Cornelissen, 2023).

As configurational theorizing is less equipped to deal with processes that extend over time (Cornelissen & Kaandorp, 2022; Schneider & Wagemann, 2012), I turned to more processual approaches in the second and third studies. The objective of the second study was to trace how actors in manufacturing SMEs attribute value to external resources over time and put them to use in the internal organization, conceptualized as external resourcing. I adopted a comparative case study approach following Eisenhardt (1989, 2021), purposefully selecting four manufacturing SMEs. As digital innovation is a broad phenomenon (Nambisan et al., 2017), I selected cases that were relatively heterogeneous in terms of envisioned innovation outcomes, like adding services to a smart product (product innovation) or working towards a digital factory (process innovation), the associated digital technologies, and what was manufactured. Through 28 semi-structured interviews I traced activities in the digital innovation process, particularly actors' activities in identifying and developing external resources. Here I followed a study by Nigam and Dokko (2019) that also primarily relied on interviews to create a processual account of resourcing practices. In tracing SMEs resourcing practices and priorities during data analysis, I noticed that these depended on the type of innovation outcome actors pursued, either product- or manufacturing process oriented. Therefore the four cases were grouped according to innovation outcome for further cross-case comparison. This enabled me to further detail *how* actors engaged in external resourcing, which was identified to be of importance in the first study, and further detailing this process per innovation outcome.

In the third study, I was interested in getting a more in-depth processual understanding of a specific type of crossing organizational boundaries to support digital innovation: intermediary-based collaboration. The potential importance of this was also corroborated by the first study. I relied on process theorizing and adopted a qualitative process approach, following the unfolding of an intermediary-based collaboration in the Dutch context, a field lab focused on digital twinning technology, in real time. Process theorizing focuses on conceptualizing the sequencing of events over time that lead to an outcome, such as digital product or process innovation. It entails mapping out an entire causal process for phenomena that are often too complex and chaotic to be captured by a set of more basic propositions (Cloutier & Langley, 2020; Langley, 1999). In particular, it focuses on the emergence, development, growth, and termination of practices over time (Langley et al., 2013). Since it is challenging to anticipate a priori how social and material entities become intertwined, observing the dynamics of how this unfolds in real-time, through process analysis, helped me identify important relations between the participants in the field lab and the digital twinning technology they experimented with (Bailey et al., 2022). The field lab was initiated by a group of researchers from a Dutch knowledge institute that acted as an intermediary organization. In addition, four manufacturing SMEs were involved in the collaboration, which all had no previous experience with digital twinning technology. This enabled me to observe the emergence of sociomaterial practices in real time. In line with the process approach, I relied on various data sources, including observations, interviews, and documents. I collected data for over a total of 27 months, from March 2021, prior to the field labs kick-off, until September 2023, when public funding ceased. I observed over 200hrs of meetings and activities, and complemented these observational data with 25 semi-structured interviews, 450 email conversations, 248 internal, and 28 public documents. In the interviews I asked actors to reflect on milestones and bottlenecks experienced during the collaboration, also within their home organization, relating to both collaborative dynamics and progress of developing digital twinning applications. In addition, the collected documents contained factual data that helped me trace event histories (Langley et al., 2013).

All the data collected for my dissertation were handled in accordance with institutional guidelines and relevant legal requirements, including data protection regulation such as the General Data Protection Regulation (GDPR). All data were anonymized and pseudonymized to protect informants identities and stored securely in an encrypted virtual drive with restricted access owned by the Radboud University. I obtained verbal informed consent from all participants at the start of data collection and ensured they were fully aware of the purpose of the study and what would happen with the collected data.

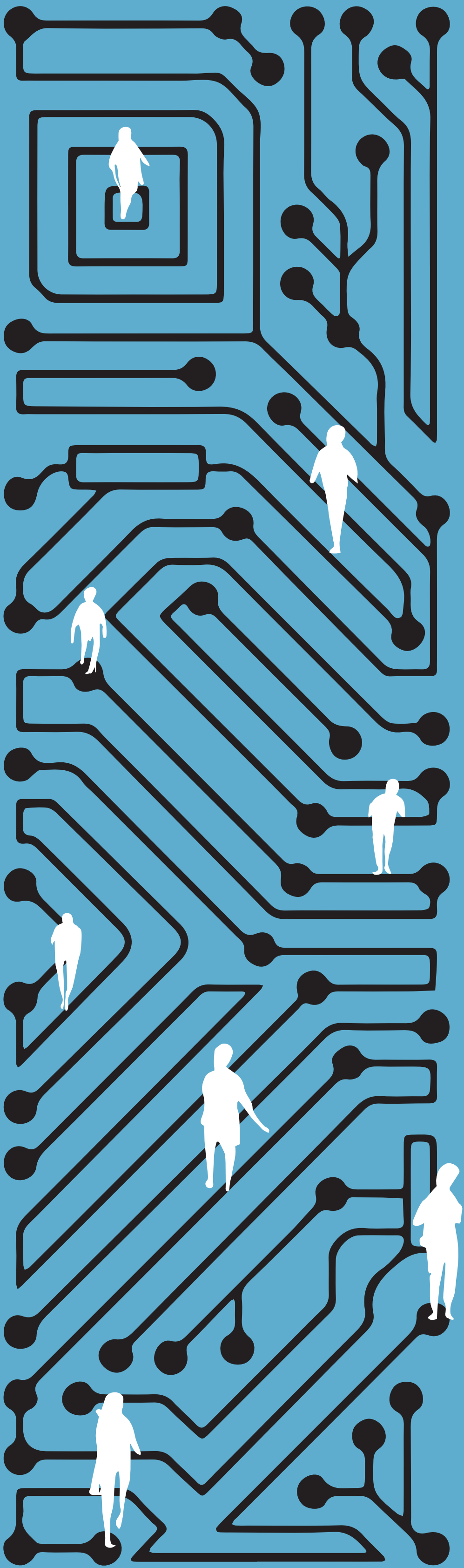
Structure of the dissertation

In the following three chapters of the dissertation, the individual empirical articles are presented. A summarized overview of the included articles can be found in Table 1. Then, to conclude, chapter five delivers on the research objective of this dissertation, discussing and reflecting on the findings of the three empirical chapters. This chapter consolidates the three empirical chapters to elaborate on more general theoretical contributions, practical implications, and boundary conditions and future research suggestions.

I declare that I have conducted the majority of work on the different chapters in this dissertation. I take full responsibility for the content of this dissertation, as well as any potential mistakes. I also acknowledge the valuable and constructive input from my (co)promoters Kristina Lauche, Armand Smits, Robert Kok, and Maarten van Gils, without which this dissertation would not have been possible. I have written Chapters 1 and 5 independently, to which my (co)promoters kindly provided feedback to further finetune and improve these. For the empirical studies in Chapters 2, 3, and 4, I independently conducted the majority of the work, including initial theoretical framing, the research design, and data collection. However, during the initiation of each research project my (co)promoters guided me along the way and provided feedback and acted as valuable sparring partners to sharpen these parts over time. I also conducted the majority of the initial data analysis independently - throughout the projects I alternated between data analysis and frequent collaborative sensemaking sessions with my (co)promoters for further conceptualization, discussing emerging insights to further refine these. I independently drafted the findings and discussions sections which were further improved with the help of my (co) promoters who provided constructive and extensive feedback throughout the empirical studies.

Table 1: Overview of articles in this dissertation

Paper	**Research question**	**Theoretical perspective**	**Research design and data**	**Outlets**
1) SMEs' diverse resource bundles and advanced I4.0 technology (non-)use: A configurational approach	Which resource and context configurations are associated with advanced compared with not advanced I4.0 manufacturing technology use in SMEs?	RBV logic	Qualitative comparative analysis 174 cases	Presented at: - IPDMC Conference 2023 - 11th International QCA workshop 2023
2) External resourcing for digital innovation in manufacturing SMEs	How do actors in manufacturing SMEs engage in exernal resourcing to pursue digital innovation processes	Resourcing	Comparative case study including 4 cases 28 interviews, 900 pages of documents	Currently under the 3rd round of review at Technovation (Minor Revisions) Presented at: - EGOS Conference 2020 - IPDMC Conference 2020 - AOM Conference 2021
3) Unlocking the potential of intermediary-based collaboration to support manufacturing SMEs' digital innovation: The constitutive role of digital technology's hybridmateriality	How are digital technology and social actors intertwined in practice in an intermediary-based collaboration, and how do these practices affect digital innovation?	Sociomateriality	Longitudinal process study 200hrs observations, 25 interviews, 800 pages documents	Presented at: - PROS Symposium 2022 - PROS Symposium 2023 - EGOS Conference 2023



2.

SMEs’ diverse resource bundles and advanced I4.0 technology (non-) use: A configurational approach

Abstract

This study explores resource and context configurations related to SMEs' (not) advanced Industry 4.0 (I4.0) technology use. SMEs are considered to be generally more constrained in their resources, but in some instances can still reach advanced use. Drawing on RBV logic focused on resource bundles and applying a configurational theorizing approach, we explore how diverse combinations of resources and contexts relate to (not) advanced use. Through our fsQCA analysis and primarily drawing on European Manufacturing Survey data, we identified three consistent paths related to advanced I4.0 technology use in SMEs: *fully resourced, selective balancers* and *focused connectors*. Additionally, we identified four consistent paths associated with not advanced use: *low on resources (scarce context), low on resources (rich context), non-absorbers* and *other priorities.* We contribute to literature on resources for I4.0 technology use through providing a more nuanced view of how resource-constrained SMEs can reach advanced use, further unpacking complementarity and substitution effects between internal resources, external resources, and contextual conditions. In doing so, we also highlight the potentially decisive role intermediary-based collaborations can play comparing advanced and not advanced use. Furthermore and more generally, our research advances RBV literature focused on resource bundles by further addressing the role of resource absence for achieving organizational goals.

Keywords

Industry 4.0, RBV, resource bundles, constraints, SMEs, configurational theorizing, fsQCA

Introduction

In this study, we explore resource and context configurations that are associated with SMEs' (not) advanced Industry 4.0 (I4.0) technology use. The use of I4.0 technologies can support firms' long-term competitiveness and enable them to adapt to changing environmental conditions, such as changing customer expectations or shorter product life cycles (Calış Duman & Akdemir, 2021; Horvath & Szabo, 2019). In particular, smart manufacturing, one of the key aspects of I4.0 (Meindl et al., 2021), can improve firms' operational performance, including efficiency and productivity (Büchi et al., 2020; Dalenogare et al., 2018). Yet, although most manufacturing SMEs recognize the importance of I4.0, many struggle with the complexity of its implementation (Frank et al., 2019; Marcon et al., 2022) and the resource intensity of the process (Ghobakhloo & Iranmanesh, 2021; Horvath & Szabo, 2019).

In line with this, previous work has extensively discussed which (individual) resources may be required to support the use of I4.0 technologies. For example, scholars agreed on the pivotal role of digitally skilled employees (as part of human resources) (Bag et al., 2021; Horvath & Szabo, 2019; Müller & Voigt, 2017); showed the importance of connecting I4.0 technologies to existing manufacturing technologies and systems (as part of technical resources) (Ghobakhloo et al., 2022; Marrucci et al., 2023); have highlighted the positive role that external resources can play by collaborating directly with external actors (Agostini & Nosella, 2019; Ricci et al., 2021) or indirectly through intermediaries (Abi Saad et al., 2024; Rossi et al., 2022); and have begun to explore the supportive role that a firm's environment can play (Chen & Tian, 2022).

Taken together, these previous studies show that achieving I4.0 technology use is indeed a complex and resource-intensive endeavor, which can be further supported or constrained by a firm's context. At the same time, SMEs often face resource constraints. For example, scholars suggested that SMEs may lack digitally skilled employees (Horvath & Szabo, 2019; Muller et al., 2018), or may not have technical resources readily available (Mittal et al., 2018). Despite these potential constraints, some SMEs still achieve advanced I4.0 technology use (Frank et al., 2019). Thus, a remaining empirical puzzle is *how* these SMEs are able to do so despite potentially being less-intensively resourced.

To address this empirical puzzle, we draw on resource-based view (RBV) logic (Barney, 1991; Penrose, 1959) and apply configurational theorizing (Furnari et al., 2021; Kumar et al., 2022). In particular, we build on Penrose (1959), who drew attention to the value of resource bundles, or combinations of resources, that, in an appropriate context, can support organizational outcomes (see also Brush & Artz, 1999; Miller & Shamsie, 1996; Sirmon et al., 2008; 2007). Within these bundles, resources may be able to complement (i.e., reinforce) or substitute (i.e., replace) each other (Ennen & Richter, 2010; Pahnke et al., 2023). This RBV logic allows us to explore how, through potentially multiple different resource and context *configurations,* SMEs achieve advanced I4.0 technology use despite the often assumed resource constraints. This also inherently suggests that there can exist multiple and diverse pathways for SMEs to achieve advanced I4.0 technology use. Against this background, our research question is: *Which resource and context configurations are associated with advanced compared with not advanced I4.0 manufacturing technology use in SMEs?*

To identify these resource and context *configurations*, in line with configurational theorizing (Furnari et al., 2021; Kumar et al., 2022; Pahnke et al., 2023), we apply fuzzy set qualitative comparative analysis (fsQCA; Fiss, 2011; Misangyi et al., 2017; Ragin, 2008). This approach is particularly suited to disentangle complex interrelations through the comparative mapping of different combinations of conditions, or *configurations,* and how they are associated with a particular outcome (also known as causal complexity, see e.g., Ragin, 2008). Importantly, to our knowledge there is no readily available RBV framework yet that predicts how different resources and contexts combine in explaining I4.0 technology use. Therefore, we apply fsQCA in an abductive rather than deductive manner (Misangyi et al., 2017; Ragin, 2000), to explore how resource and context configurations are related to (not) advanced I4.0 technology use.

Primarily based on data from the European Manufacturing Survey 2021 (EMS), we systematically compared the I4.0 technology use of 174 SMEs. Based on our fsQCA analysis, we found nine consistent configurations that could be categorized into seven configurational paths. Three paths were associated with advanced use: *fully resourced, selective balancers,* and *focused connectors,* and four with not advanced use: *low on resources (scarce context), low on resources (rich context)*, *non-absorbers,* and *other priorities*.
Our research mainly contributes to the literature on resources for I4.0 technology use.

In our study, the majority of consistent advanced users were not *fully resourced*, but rather less intensively resourced. Our configurational theorizing allowed us to further characterize these SMEs as *selective balancers* or *focused connectors,* and to uncover substitution effects between these two paths. Hence, our research sheds new light on how resource constrained SMEs can still become advanced I4.0 technology users. We also further elaborate on the role of intermediary-based collaborations. Here, we not only expose their relative importance in SMEs' resource bundles for advanced I4.0 technology use, but also identify these as a critical component in comparing advanced and not advanced use. More generally, we also advance the RBV literature focused on resource bundles, by further addressing the largely overlooked aspect of resource absence and its relationship with organizational outcomes that are generally considered to be desirable.

Theoretical background

Advanced and not advanced I4.0 technology use

I4.0 relies on the adoption of digital technologies to collect and analyze data in real-time and provide useful information to the manufacturing system (Lee et al., 2015). Recently, I4.0 has been divided into four interrelated pillars: smart manufacturing, smart working, smart products, and smart supply chain (Frank et al., 2019; Meindl et al., 2021). We focus on smart manufacturing because it is considered to be the core pillar of I4.0 (Frank et al., 2019; Kagermann et al., 2013; Meindl et al., 2021). It describes an adaptive and advanced manufacturing system in which flexible lines automatically adjust production processes for multiple types of products and changing conditions (Dalenogare et al., 2018; Schuh et al., 2017).

In line with these developments, explaining how firms become advanced I4.0 technology users has become a prominent line of research (Lee et al., 2015). In this regard, studies have begun to develop maturity models for I4.0 technology use (Frank et al., 2019; Lee et al., 2015; Lu & Weng, 2018; Schuh et al., 2017). These models typically have an evolutionary outlook, and outline pathways for how technology implementation should occur (Meindl et al., 2021). Furthermore, use patterns are often based on the complexity of the technologies involved, ranging from less complex, such as vertical integration technologies, to more complex, such as flexibilization technologies (Frank et al., 2019). In this way, companies that use more complex I4.0 technologies are generally considered to be the more advanced users. In addition, less complex I4.0 technologies, such as ERP systems, are often building blocks for these more complex technologies.

Despite this, the literature also shows that there is currently a lack of maturity models particularly tailored to SMEs (Mittal et al., 2018). Therefore, in an attempt to explain (not) advanced I4.0 technology use, we decided to rely on a categorization by Frank et al. (2019), which is largely consistent with other maturity models (e.g., Lee et al., 2015; Lu & Weng, 2018; Schuh et al., 2017) and is highly referenced in the I4.0 literature (Meindl et al., 2021). In particular, Frank et al. (2019) categorize I4.0 smart manufacturing technologies into different groups, based on their increasing complexity: vertical integration technologies such as ERP and sensors; energy management and monitoring technologies; technologies for traceability; automation technologies related to industrial robotics; virtualization technologies such as artificial intelligence for production; and additive manufacturing technologies related to flexibilization. We build on these categories to compare advanced and not advanced use across manufacturing SMEs.

Configurations of resources and contexts driving or inhibiting I4.0 technology use

To develop a better understanding of configurations related to (not) advanced I4.0 technology use, we draw on RBV logic. In this context, Penrose (1959) was one of the first to draw attention to resource *bundles,* which she defined as combinations of different types of resources. She further explained how these resource bundles could be positively related to organizational outcomes. RBV logic further suggests that the value of resource bundles is contingent on contextual conditions (Brush & Artz, 1999; Miller & Shamsie, 1996). While certain resource bundles may be productive in one context, for example in a particular industry or region, they may be unproductive in another.

Despite RBV’s emphasis on resource bundles, previous research examining these resource and context configurations has been largely limited to testing simple two-way interactions (e.g., Hitt et al., 2001). Efforts to move beyond such interactions and focus on more extensive resource bundles have been limited (cf. Carmeli & Tishler, 2004). This is arguably at least partly due to the methods used in these previous studies. Regression-based analyses, which are often used, limit the investigation of higher-order (e.g., three-way) interactions (Fiss, 2007), while studying these higher-order interactions may be key to understanding which resource bundles are productive in particular contexts. Here, small-N case studies could delve deeper into understanding productive resource bundles *within* a particular context (e.g., Santos et al., 2023). Yet, these small-N cases studies are often limited in their generalizability and transferability to other contexts (Fiss, 2007). Thus, while undoubtedly valuable for exploring a variety of research questions, the potential of these methods is limited when it comes to systematically comparing on a larger scale the value of *diverse* resource bundles *across* contexts.

To overcome such limitations, we apply configurational theorizing and its related fsQCA methodology (Furnari et al., 2021; Kumar et al., 2022; Misangyi et al., 2017). Herein we join recent studies that have demonstrated the value of applying such an approach in studying multiple resource and context configurations (e.g., Pahnke et al., 2023). Specifically, this application allows us to uncover potential substitutions and complementarities among resources while identifying supporting or constraining contexts. Below, based on prior research, we outline resource- and contextual conditions that could be potentially valuable for advanced I4.0 technology use.

Resource- and contextual conditions related to advanced I4.0 technology use

Following recommendations by Furnari et al. (2021) for the configurational theorizing process, we identify a theoretical anchor on the basis of which we explore relevant conditions related to I4.0 technology use. Departing from RBV logic, we use the notion of a resource as our anchor. In general, resources can be divided into several key types (Barney, 1991). For example, Greene et al. (1997) categorized social, human, organizational, physical, and financial resources, while Hofer and Schendel (1978) distinguished human, organizational, technological, and physical resources. Yet, given the lack of clear consensus on resource categorization, we further identified that scholars generally agree that both internal and external resources are associated with the use of I4.0 technologies (Horvath & Szabo, 2019; Mittal et al., 2018; Muller et al., 2018). Moreover, certain contexts, such as specific regions or industries, may support or constrain resource bundles for I4.0 technology use (Chen & Tian, 2022), which is consistent with RBV logic (e.g., Miller & Shamsie, 1996). Based on this, we include three broad categories in our research: internal resources, external social resources, and contextual conditions. For each category, we identified two relevant conditions, which we discuss individually below. Together these resource and context configurations may jointly relate to SMEs' (not) advanced I4.0 technology use. The conditions we consider are arguably not exhaustive. However, based on our reading of the literature, we argue that their presence or absence may be particularly relevant to I4.0 technology use.

Internal resources. We consider two types of internal resources: human- and technical resources. First, human resources are defined as attributes acquired through experience (Becker, 1964) and reflect employees' education, skills, experience, and knowledge (Hitt et al., 2001). Especially for the use of I4.0 technologies, digitally skilled employees are arguably more necessary than ever (Horvath & Szabo, 2019; Mittal et al., 2018; Müller & Voigt, 2017). However, these may not be readily available in SMEs due to the demands of daily business (Muller et al., 2018) and the current general shortage of skilled workers (Kiel et al., 2017; Müller & Voigt, 2017; Rikala et al., 2024).

Second, in terms of technical resources, previous studies show that I4.0 technologies do not stand on their own. Instead, they should be linked to and built on the existing manufacturing technologies and systems within the company (Bag et al., 2021; Veile et al., 2020). If these can adequately communicate and exchange information with I4.0 technologies, this enables a smoother transition (Ghobakhloo et al., 2022; Marrucci et al., 2023). Thus, appropriate technical resources in the form of existing manufacturing technologies may be relevant for SMEs to further develop the use of I4.0 technologies. However, not all SMEs may have these suitable technical resources readily available, which may act as a constraining factor (Horvath & Szabo, 2019; Mittal et al., 2018).

External social resources. Social resources are defined as connections to or collaborations with people or organizations inside and/or outside the firm (Greene et al., 1997; Srivastava & Gnyawali, 2011). We focus on external collaborations (i.e., external social resources, hereafter external resources), because previous research has identified these as particularly relevant for SMEs in the I4.0 context due to their potential to complement internal resources (Mittal et al., 2018; Muller et al., 2018). Specifically, we distinguish between broad and deep collaborations that are direct or intermediary-based indirect collaborations.

First, we characterize direct collaborations in terms of breadth and depth. Breadth of collaboration refers to the number of partners with which a firm collaborates, while the depth refers to the frequency of these collaborations (Laursen & Salter, 2006). In the context of I4.0, these direct collaborations can help SMEs to identify I4.0 opportunities and provide complementary knowledge (Agostini & Nosella, 2019). For example, Ricci et al. (2021) showed that, in particular broad and deep collaborations positively relate to the extent to which SMEs use I4.0 technologies. Based on this, we argue that broad and deep direct collaborations can potentially support advanced I4.0 technology use in SMEs.

Second, in contrast to direct collaborations, indirect collaborations are arranged through intermediaries. Intermediaries are organizations that support firms' innovation initiatives (Dalziel, 2010). For I4.0, they can support collaborative exchanges between two or more parties (Abi Saad et al., 2024; Rossi et al., 2022), either by providing necessary resources, advice and services (Abi Saad et al., 2024; Caloffi et al., 2023; Gredel et al., 2012) or by facilitating the development of networks and partnerships within and across industries (Caloffi et al., 2023; Gredel et al., 2012). For example, in the Netherlands, the government has supported the development of field labs, in which companies are given the opportunity to share knowledge about and experiment with specific I4.0 technologies, are supported in partnership development, and can benefit from advice and services (Stolwijk & Seiffert, 2016; Stolwijk & Willems, 2019). This support is generally considered to be particularly valuable for SMEs, which often lack the capacity to acquire useful knowledge or skills related to technology use on their own (Caloffi et al., 2023).

Contextual conditions. Research on how I4.0 technology use is contingent on contextual conditions is still scarce, especially with respect to SMEs. Recently, however, a handful of papers have considered how context can be more or less conducive to I4.0 technology use (Marcon et al., 2022), also specifically for SMEs (Chen & Tian, 2022). Generally, a rich context can support advanced I4.0 technology use by SMEs, while a scarce context can be a constraining factor. In this regard, we distinguish two contextual conditions that can produce a rich context: a digitally intensive industry (Calvino et al., 2018; Kim & Kim, 2022) and a leading innovative region (Filippopoulos & Fotopoulos, 2022; Hollanders & Es-Sadki, 2021). As rich contexts are generally considered more conducive to innovation, especially in the context of I4.0 (Chen & Tian, 2022), being in a digitally intensive industry and a leading innovative region may support SMEs' advanced technology use.

Taken together, based on the three sets of conditions – internal resources, external resources, contextual conditions – we can develop hunches (Furnari et al., 2021) about how they may complement or substitute each other. For example, a strong internal resource base may support SMEs' absorptive capacity (Arcidiacono et al., 2022; Cohen & Levinthal, 1990; Müller et al., 2021), which in turn may support technology use (Mahmood & Mubarik, 2020). However, if an SME partially lacks internal resources, these could potentially be substituted or complemented by external resources, which can be further supported by a rich context. For example, external resources may lead to additional relevant knowledge by connecting with outsiders (e.g., Caloffi et al., 2023; Ricci et al., 2021), while a rich context may provide access to knowledge spillovers, which are typically limited by the boundaries between regions (Bottazzi & Peri, 2003; Fritsch & Franke, 2004) or industries (Van der Panne, 2004).

Since, to our knowledge, there is no readily available RBV framework that examines these resource bundles and contexts in combination, our fsQCA analysis aims to empirically and systematically explore how these (sets of) conditions substitute and/or complement each other in the context of (not) advanced I4.0 technology use. Figure 1 presents our preliminary configurational model.

Method

Qualitative comparative analysis as a research approach

For configurational theorizing, we rely on qualitative comparative analysis (QCA), a set- theoretic method increasingly used in management and innovation research (Kraus et al., 2018; Kumar et al., 2022). The main assumption underlying configurational theorizing is causal complexity, which suggests that a phenomenon is explained by multiple combinations of antecedent conditions (Ragin, 2008). Causal complexity has three key elements: conjunction, equifinality, and causal asymmetry. *Conjunction* means that outcomes rarely have a single cause but rather result from the interdependence of multiple conditions.

Equifinality implies that more than one path can lead to a given outcome. *Asymmetry* suggests that a configuration leading to an outcome can be different from a configuration leading to the absence of an outcome (Misangyi et al., 2017; Ragin, 2008).

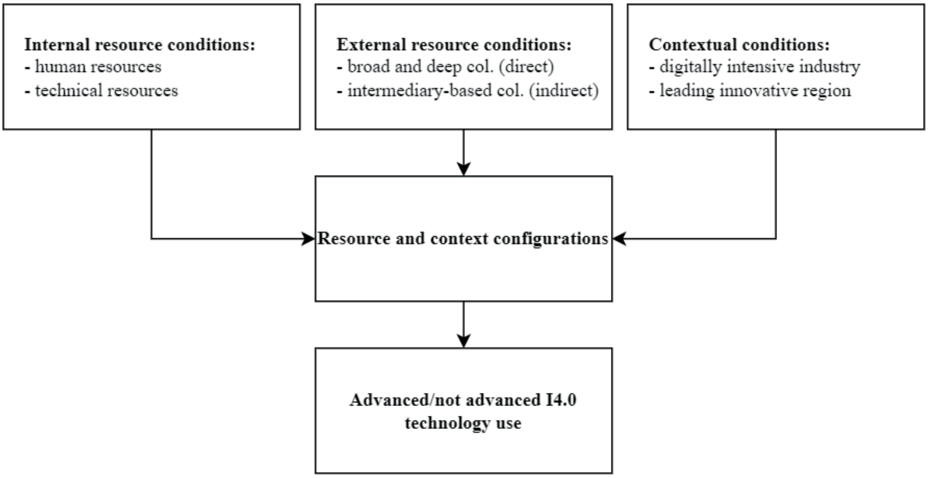


Figure 1: Preliminary configurational model

QCA uses Boolean algebra to compare cases, or groups of cases with common attributes, based on their membership in sets (Ragin, 2008; Schneider & Wagemann, 2012). It typically analyzes how different conditions simultaneously relate to an outcome of interest. The logical combinations of conditions are called *configurations*. The goal of QCA is to determine which of these configurations may be sufficient or necessary for an outcome of interest to occur (Ragin, 2008; Schneider & Wagemann, 2012). To achieve this, cases are assigned set membership scores that vary between 0, which indicates full non-membership, and 1, indicating full membership, to determine their (non) membership in sets. Fuzzy-set QCA (fsQCA) makes it possible to consider the degree to which cases are (non)members of sets (Oana et al., 2021; Ragin, 2008). A 0.5 membership score represents a qualitative crossover point, at which point a case is neither in nor out of a set (Schneider & Wagemann, 2012). The calibration process translates empirical data from each case into set membership scores, which we describe in a separate section for each of the conditions and the outcome.

Despite the suitability of QCA for a more systematic comparison of larger-N samples, it remains largely a qualitative research method. Calibration decisions, especially regarding the crossover point, are preferably based on case knowledge, external benchmarks, and theoretical considerations (Greckhamer et al., 2018; Misangyi et al., 2017). Therefore, we emphasize that in the current study, QCA is used in an *abductive* manner to explore how conclusions drawn from empirical data relate to previously developed theoretical hunches, and in this way can inform theorizing (Misangyi et al., 2017; Ragin, 2000). Here, abduction refers to an "ampliative and conjectural mode of inquiry" that allows researchers to explore "hunches (...) and theoretical elements" that arise with the "recognition of puzzling observations that enable us to discern and construct new plots" (Locke et al., 2008, pp. 907-908). In keeping with this, we decidedly did not design our study to prove or test preconceived configurational hypotheses.

Research setting and data

Our main data source is the European Manufacturing Survey 2021 (EMS). The EMS is conducted by the German Fraunhofer Institute together with research teams from universities in 19 different European countries. EMS data have been used for both academic articles (Kirner et al., 2009; Marcon et al., 2022) and to inform policy and practice (Simons et al., 2017). The EMS addresses technological and organizational innovation in manufacturing firms and includes basic company information, like firm size and industry.

We used a subset of the data related to the Dutch 2021 survey, which was administered to CEOs or operations managers of about 8000 manufacturing firms in various industries with at least ten employees. The questions mainly covered the period 2018-2021. The response contained 184 cases. The cases included in our fsQCA analyses had to meet the following criteria: (1) the firm was an SME, excluding micro-enterprises, and therefore had between 10- 250 employees (European Commission, 2003); and (2) the cases had complete data on all relevant conditions. Based on these criteria, 174 valid cases were included in our analysis. In addition, we conducted 25 interviews with SME managers to gain further insight into the use of I4.0 technologies across manufacturing industries, inform our calibration, and further interpret our findings.

Table 2: Descriptive statistics and calibration of outcome and conditions (N = 174)

Descriptives (raw data)						**Calibration**			
Condition	**Mean**	**SD**	**Min.**	**Max.**	**0 (fully out)**	**0.33 (more out than in)**	**0.67 (more in than out)**	**1 (fully in)**	**Skewness[1] (cal. data)**
Advanced I4.0 technologyuse (outcome)	1.77	1.50	0	4	0, 1	2	3	4	37.93%
Human resources	0.38	0.28	0	1	0	0.33	0.67	1	35.63%
Technical resources	1.44	1.48	0	4	0, 1	2	3	4	35.06%
Broad and deepcollaboration	1.64	1.25	0	3	0	1	2	3	57.47%
Intermediary-based collaboration	0.90	0.72	0	2	0, 1			2	21.26%
Digitally intensive industry	2.49	0.63	1	4	1	2	3	4	51.72%
Leading innovative region	2.22	0.56	1	3	1, 2			3	28.74%

1 Skewness for all the calibrated conditions are within the limits of the 80/20 rule of thumb (Oana et al., 2021)

2

Measures and calibration of conditions

Table 2 provides an overview of the descriptive statistics and calibration.

For our outcome, *advanced I4.0 technology use*, the measure was based on EMS questions covering fourteen I4.0 technologies[2] (Appendix, Table A). For each technology, SMEs indicated if and when they started using it. To ensure that we captured current use, we only considered firms as users if they used I4.0 technology *starting from 2018*. This was a binary measure: firms using (a) technology(s) *starting from 2018* scored 1, no use scored 0. Next, to group our cases according to their most complex technology use, we relied on the Frank et al. (2019) categorization representing increasing technology complexity[3]: 'vertical integration and traceability', 'automation', 'virtualization' and 'flexibilization'. We added a category of 'no use', reflecting SMEs that did not use any I4.0 technologies.

Since the Frank et al. (2019) categorization is not specifically tailored to SMEs and SME-specific models are not currently available (Mittal et al., 2018), we relied on two additional sources of information as basis for our calibration: First, based on our interviews, SME managers indicated that starting to use virtualization technologies is increasingly more complex than using automation technologies: the former refers to real-time communication and data exchange between physical objects and virtual models, while the latter is largely concerned with hardware related to robotics. Second, if the use of virtualization technologies is considered more complex compared to automation technologies, then arguably this would be represented by a decrease in use between these categories in our cases. As can be seen in Figure 2, this was the case. Based on this, we consider both virtualization and flexibilization to be advanced use, and the other two categories to be not advanced use.

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2 The technologies included were those previously indicated to be core to Industry 4.0, in line with Kagermann et al. (2013) and largely in line with Frank et al. (2019)

3 The Frank et al. (2019) framework also included energy management. We were unable to include this category because it was not incorporated in the EMS

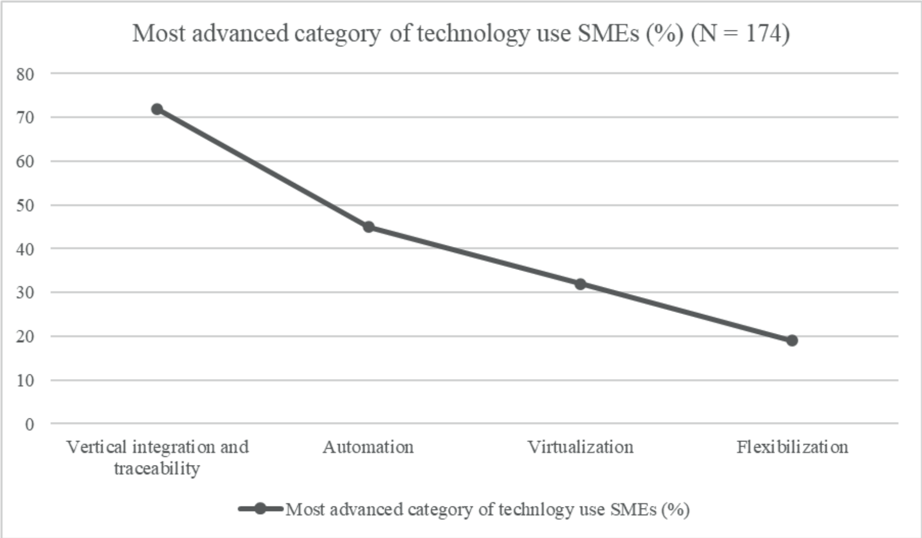

Figure 2: Percentage of most advanced technology use of SMEs per category

Hence, for calibration, we considered SMEs with a maximum of 'no tech' or 'vertical integration and traceability' as 'not advanced users' (fully out = 0); 'automation technologies' as relatively not advanced users (more out than in = 0.33); 'virtualization technologies' as relatively advanced users (more in than out = 0.67), and 'flexibilization technologies' as advanced users (fully in = 1).

We measured and calibrated *internal resource* conditions as follows. First, our measure of *human resources* was based on three EMS questions: (1) percentage of skilled employees[4]; (2) training for digital skills (binary); and (3) no shortage of skilled employees (binary). We calibrated the raw metrics of (1), (2), and (3) individually as crisp sets (fully in = 1, fully out = 0). Specifically, for (1) firms were fully in if they reported that 73% or more of their employees were skilled. The 73% cutoff value was based on four Dutch Labor Force Surveys (Statistics Netherlands, 2018-2021), which showed that, on average, 73% of employees in the manufacturing sector were skilled employees according to our definition (range 72-74%). Based on the individually calibrated measures, we used the compensation method (Pahnke et al., 2023; Ragin, 2000) to create the superset *human resources* by adding the three calibrated scores and dividing them by three, resulting in a four-value categorical fuzzy set.

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4 We considered employees as skilled in case they received at least post-secondary vocational education.

Second, for *technical resources*, our measure again considered the fourteen technologies and the associated categorization (Appendix, Table A). In contrast to the outcome, the EMS questions for this condition asked firms about their technology use *prior to 2018*, which we considered a proxy for the development of relevant technical resources[5] (binary measure). We again recategorized SMEs informed by the Frank et al. (2019) framework (values 1-4). We added a category 'no technical resources' reflecting firms that did not use I4.0 technologies *prior to 2018.* For calibration (four-value fuzzy set), we followed the similar logic as for the outcome condition: firms with advanced technical resources were coded fully in (1); relatively advanced more in than out (0.67); relatively not advanced more out than in (0.33) and not advanced fully out (0).

External resources were measured and calibrated as follows. First, the measure of *broad and deep direct collaboration* (hereafter broad and deep collaboration) was an EMS question that asked firms in which of the five business functions (if any) they collaborated with external actors: service, sales, inputs, production, and R&D, and whether this was once, several times, or continuously. We then, based on Laursen and Salter (2006) and Ricci et al. (2021), recategorized firms that collaborated in at least two functions as broad collaborators and those that collaborated continuously as deep collaborators. These were assigned values from 0 to 3, ranging from no collaboration to broad and deep collaboration. For calibration (four-value fuzzy set) firms were coded fully in (1) for broad and deep collaboration; more in than out (0.67) for broad and not deep *or* deep and not broad collaboration; more out than in (0.33) for not broad and not deep collaboration; and fully out (0) for no collaboration.

Second, for the measure of *intermediary-based indirect collaboration* we relied on an EMS question that asked firms whether they collaborated through intermediaries (hereafter: intermediary-based collaboration). For clarification, the question provided exemplary intermediary organizations in the Dutch I4.0 context: field labs, innovation hubs, regional or national development agencies, or industry-specific development initiatives (Stolwijk & Seiffert, 2016; Stolwijk & Willems, 2019). Firms were further asked to provide more insight into the role of the intermediary: providing financial support, transferring knowledge, assisting with employee recruitment, or

[5] We considered existing manufacturing technologies (before 2018) as a proxy for technical resources since previous research indicated that connecting advanced I4.0 technologies to existing manufacturing technologies and systems ensures a smoother transition (e.g., Veile 2020; Ghobakhloo et al., 2022).

facilitating external collaboration. Based on this question, firms were assigned a value of 0 if they did not collaborate, a value of 1 if they only collaborated directly (without intermediaries) and a value of 2 if they collaborated indirectly through intermediaries. Calibration was crisp: firms that collaborated through intermediaries were fully in (1) those that did not were fully out (0).

Lastly, we measured and calibrated *contextual conditions* as follows. First, the binary measure of *digitally intensive industry* used an EMS question in which firms reported their industry according to two digit NACE codes. We categorized industries according to their digital intensity, based on Calvino et al. (2018) who distinguish high, moderately high, moderately low, and low digital intensity (Appendix, Table B). Next, we calibrated accordingly (four-value fuzzy set): high corresponded to fully in (1); moderately high to more in than out (0.67); moderately low to more out than in (0.33) and low to fully out (0).

Second, the binary measure for *leading innovative region* asked firms about the 12 Dutch NUTS 2 regions in which they were located. Regions were grouped according to the Regional Innovativeness Scoreboard (RIS) for our study's period (Hollanders & Es-Sadki, 2021). The RIS assesses the innovation performance of European NUTS 1 and 2 regions on a set of indicators, systematically comparing 239 regions in 22 EU countries. In the Netherlands, there were three leading, six strong, three moderate, and no emerging innovative regions (Appendix, Table B). For calibration, we constructed a crisp set: firms in leading innovative regions were fully in (1), and in not leading regions fully out (0).

Analytical approach

The primary analyses were conducted using R software, packages SetMethods and QCA (Dusa, 2019; Oana, 2018). We seek to identify which configurations of the specified conditions are sufficient or necessary for (not) advanced I4.0 technology use. A condition is considered *necessary* if it is a subset of a given outcome, while a condition is considered *sufficient* if it can produce the outcome by itself. fsQCA allows for the examination of combinations of conditions, which are called *configurations*, that together are *sufficient* for an outcome to occur. If a *configuration* is sufficient, it indicates that it almost always produces the outcome. (Fiss, 2011; Ragin, 2008).

Two additional terms related to fsQCA require introduction: consistency and coverage (Ragin, 2008). *Consistency* indicates how reliably a combination of causal conditions in each configuration, or the combination of configurations in a solution, is associated with the outcome. High consistency implies that a condition or configuration almost always leads to the outcome, while low consistency implies that it is not reliably linked to the outcome. Additionally, *coverage* is an indicator of empirical relevance, and evaluates the extent to which occurrences of the outcome of interest are explained by a given configuration or a solution as a whole.

Following general recommendations (Greckhamer et al., 2018), we first conducted a necessity analysis to determine if any single condition is necessary for (not) advanced I4.0 technology use. The recommended benchmarks of 0.9 for consistency, 0.6 for coverage, and 0.5 for relevance of necessity (RoN) were applied (Oana et al., 2021). In case a condition exceeds these benchmarks, it can generally be considered necessary for the outcome. There were no conditions that exceeded the required thresholds for necessity related to the presence of the outcome. For the absence of the outcome, the absence of intermediary-based collaboration exceeded the thresholds of 0.9 for consistency, 0.6 for coverage, and 0.5 for RoN (Table 3). However, upon further inspection by plotting the relationship, we identified seven deviant consistency cases in kind (DCCK). In these cases, the absence of intermediary- based collaboration was related to the presence of the outcome, rather than the other way around. In this way, these DCCK attenuated the claim that the absence of intermediary-based collaboration was necessary for the absence of the outcome. Therefore, we decided not to include the absence of intermediary based collaboration as a necessary condition for not advanced I4.0 technology use.

We then continued with the sufficiency analysis. Truth tables were constructed for the presence and absence of the outcome (Appendix, Table C and D) and consolidated following best practices, by checking minimum levels of consistency, PRI thresholds, and DCCK. A consistency cutoff value of 0.78 was used for the presence of the outcome and 0.89 for the absence of the outcome, which are both above the commonly accepted minimum of 0.75 (Fiss, 2011; Ragin, 2008). We also examined the more conservative PRI threshold, which eliminates empirical paradoxes that can arise in subset relations where a configuration is related to both the presence and absence of the outcome. We ensured that each truth table row included in the analysis was above the

0.65 PRI minimum used in recent research (Greckhamer, 2016). The lowest PRI value in our truth table rows for the presence of the outcome was 0.72; and 0.82 for its absence. The truth table rows were logically minimized based on counterfactual analysis, resulting in three solutions: the complex, intermediate, and parsimonious. To adhere to good practices in management research (Greckhamer et al., 2018), we integrated both the intermediate and parsimonious solutions in our results.

Table 3: Necessity analysis for advanced and not advanced I4.0 technology use. *indicates potential necessary condition.

	Advanced I4.0 technology use			**Not advanced I4.0 technology use**		
	Cons. Nec.	**Cov. Nec.**	**RoN**	**Cons. Nec.**	**Cov. Nec.**	**RoN**
Presence of (suitable) human resources	0.549	0.495	0.761	0.403	0.688	0.838
Absence of (suitable) human resources	0.654	0.366	0.495	0.705	0.748	0.711
Presence of (suitable) technical resources	0.545	0.640	0.870	0.231	0.515	0.832
Absence of (suitable) technical resources	0.587	0.287	0.368	0.839	0.778	0.652
Presence of broad and deep collaboration	0.661	0.416	0.585	0.529	0.632	0.692
Absence of broad and deep collaboration	0.416	0.318	0.640	0.511	0.741	0.824
Presence of intermediary basedcollaboration	0.450	0.731	0.932	0.088	0.270	0.835
Absence of intermediary based collaboration	0.550	0.241	0.262	0.913*	0.759*	0.528*
Presence of digitally intensive industry	0.627	0.434	0.640	0.549	0.722	0.784
Absence of digitally intensive industry	0.598	0.412	0.628	0.570	0.743	0.795
Presence of leading innovative region	0.205	0.247	0.767	0.331	0.753	0.910
Absence of leading innovative region	0.795	0.385	0.396	0.670	0.615	0.512

Results

Our fsQCA analyses revealed nine diverse and consistent resource and context configurations, with three pertaining to advanced I4.0 technology use, and six to not-advanced use (Table 4). Standard symbols (Fiss, 2011) were used for reporting: a solid black circle indicates the presence of a condition, and a crossed-out circle its absence. Blank spaces represent 'do not care' conditions, where their presence or absence is immaterial to the outcome. Larger symbols represent core conditions that have a relatively strong connection with the outcome, while smaller symbols represent peripheral conditions that have a weaker connection with the outcome. However, unless there is strong prior theory to suggest otherwise, these should be interpreted as equal parts of the configuration. Therefore this nuance between core and peripheral conditions is only included for transparency (Dwivedi et al., 2018).

The solution for advanced I4.0 technology users has an overall consistency score of 0.84 and a coverage score of 0.37. This means that the configurations in the solution apply to 37 percent of advanced users, and 84 percent of the individual cases in the configurations demonstrate advanced users. For the not advanced users solution these scores were 60% and 92%, respectively. Furthermore, neutral permutations, which are configurations that include the same core conditions and only differ on peripheral conditions (Fiss, 2011), were grouped together (C1a and C1b; C3a and C3b).

Collectively the solutions suggest that there are diverse resource and context configurations that can support firms in reaching advanced I4.0 technology use. Across the solutions, intermediary-based collaboration is present in all configurations for advanced users, and absent for not advanced users. Although previous analyses have shown that this is not a necessary condition, it suggests that intermediary-based collaboration plays an important role in advanced I4.0 technology (non) use. Additionally, we can observe causal asymmetry, meaning that the configurations related to advanced use are not mirror images of those related to not advanced use.

Table 4: Configurational chart for advanced and not-advanced I4.0 technology use

Path	Configurations related to advanced I4.0 technology use			Configurations related to not advanced I4.0 technology use					
	fully resourced	**selective balancers**	**focused connectors**	**low on resources (scarce context)**		**low on resources (rich context)**	**non-absorbers**		**other priorities**
Configuration	C1a	C1b	C2	C3a	C3b	C4	C5	C6	C7
Internal resources									
Human resources	●	●		⊗				⨂	●
Technical resources	•			⨂	⨂	⨂	⨂	⨂	●
External resources									
Intermediarybased collaboration	●	●	●	⨂	⨂	⨂	⨂	⨂	⨂
Broad and deep collaboration	•		•			⊗	•	●	•
Contextual conditions									
Digitally intensive industry	•	•		⨂	⨂	•	⨂		●
Leadinginnovative region		⊗	⨂		⊗	●			⨂
Consistency	1	0.93	0.83	0.92	0.91	0.91	0.93	0.92	0.91
Raw coverage	0.13	0.16	0.34	0.42	0.34	0.09	0.26	0.32	0.06
Unique coverage	0.02	0.01	0.20	0	0.03	0.01	0.01	0.05	0.02
Overallconsistency	0.84			0.92					
Overall coverage	0.37			0.60					

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Table 5: Paths for advanced and not advanced I4.0 technology users

Path label	Conf.	Path	Proposed main driver to the outcome	Additional characteristics
			Advanced I4.0 technology users	
Fully resourced[6]	C1a	The presence of human and technical resources, combined with intermediary-based and broad and deep collaborations and being situated in a digitally intensive industry	In digitally intensive industries, SMEs become advanced users due to full resource access and availability, both internally and externally	C1aSMEs: Had skilled employees, provided training for digital skills, but still indicated skilled-personnel shortages Had prior technical resources related to virtualization or flexibilization Collaborated mostly for R&D, production, and inputs, with customers, suppliers, and knowledge institutes Relied on intermediaries mostly for financial support Were in the *machinery and equipment; electrical equipment;* or *other manufacturing*[7] industries
Selective balancers	C1b	The presence of human resources combined with intermediary-based collaborations and being in a digitally intensive industry and the absence of a leading innovative region	In digitally intensive industries, SMEs become advanced users based on balancing selective internal resources (human resources) with selective external resources (intermediary-based collaborations)	C1bSMEs: Had skilled employees, provided training for digital skills, but still indicated skilled-personnel shortages Relied on intermediaries mostly for financial support Were in the *machinery and equipment* or *repair and installation of machinery and equipment* industries Were not in leading innovative regions
Focused connectors	C2	The presence of intermediary-based and broad and deep collaborations and the absence of a leading innovative region	SMEs becoming advanced users is driven by a focus on external resources: intermediaries support firms in connecting to suitable partners broadly and/or deeply.	C2SMEs: Collaborated mostly for R&D, sales, production and inputs, with customers, suppliers and knowledge institutes Relied on intermediaries mostly for facilitating collaboration Were not in leading innovative regions
			Not advanced I4.0 technology users	

6 In our configurational model, we considered these SMEs to be 'fully resourced' based on the resource conditions we took into account. It is important to note that there may be other types of internal and external resources, such as financial resources, that are not included in our model and may not meet the criteria for being 'fully resourced'.

7 The *other manufacturing* industry includes manufacturing of jewelry; musical instruments; games and toys; medical and dental supplies; and materials not elsewhere classified.

Table 5: Continued

Path label	Conf.	Path	Proposed main driver to the outcome	Additional characteristics
			Advanced I4.0 technology users	
Low on resources (scarce context)	C3a C3b	The absence of technical resources, intermediary-based collaborations, and a digitally intensive industry	SMEs become not-advanced users because they are low on resources and are situated in a scarce context	C3aand C3bSMEs: Mostly had no prior technical resources Mostly did not collaborate Were in the *metal* or *textiles* industries
Low on resources (rich context)	C4	The absence of technical resources, intermediary-based collaborations, broad and deep collaborations, combined with being situated in a digitally intensive industry and a leading innovative region	SMEs become not-advanced users because they are low on resources despite being situated in a rich context	C4SMEs: Mostly had no prior technical resources Mostly did not collaborate Were in the *other manufacturing, machinery and equipment,* or *printing* industries Were in leading innovative regions
Non-absorbers	C5 C6	The absence of technical resources and intermediary-based collaborations combined with the presence of broad and deep collaborations	SMEs become not-advanced users because they are low on internal resources inhibiting them to absorb external resources	C5andC6SMEs: Mostly had no prior technical resources Collaborated directly (without intermediaries) Collaborated mostly for production, inputs, and sales with suppliers, customers, and other firms
Other priorities	C7	The presence of human resources, technical resources, broad and deep collaborations, and a digitally intensive industry in combination with the absence of intermediary-based collaborations and a leading innovative region	Despite internal resources, broad and deep collaborations, and being in a relatively rich context, SMEs become not advanced users: the proposed main driver is that these firms have other priorities	C7SMEs: Mostly had no shortages of skilled employees and provided training for digital skills Had prior technical resources for virtualization or flexibilization Collaborated directly (without intermediaries) Collaborated mostly for sales, production, and inputs with suppliers, other firms, and customers Were in the *furniture production* industry Were not in leading innovative regions

Configurational paths of advanced and not advanced I4.0 technology users

We will now discuss the remaining two steps in the configurational theorizing process: linking and naming (Furnari et al., 2021). This involves specifying the general mechanisms behind the identified consistent configurations and attaching meaningful labels to the different configurations. In so doing, we combine individual configurations into a single, more holistic path when they are logically consistent with one another (Witt et al., 2021). This process was further informed by going back to the EMS data on the underlying cases. Table 5 below summarizes seven identified paths for I4.0 technology use: three for advanced and four for not advanced.

Advanced I4.0 technology users

Fully resourced

The first path is based on C1a and consists of SMEs that combine the presence of internal human and technical resources with intermediary-based and broad and deep external collaboration while being in a digitally intensive industry: machinery and equipment, electrical equipment, or other manufacturing. We refer to this path as *fully resourced* SMEs (Table 5). These SMEs collaborated primarily for R&D, production, and inputs; with customers, suppliers, and knowledge institutes being the most important partners. Intermediaries further provided support through funding. These results suggest that in the *fully resourced* path, a strong resource-base, both internally and externally, was the main driver towards advanced use, further supported by a relatively rich context. Although it is not unexpected that this is a promising approach to achieving advanced use, the reality remains that most SMEs are not fully resourced but rather constrained by limited resources (Horvath & Szabo, 2019). Our findings corroborate this, as C1a had the lowest coverage score of the three advanced use configurations.

Selective balancers

The second path, which we refer to as *selective balancers,* includes C1b. In this path, SMEs combined internal human resources with intermediary-based external collaboration and operated in a digitally intensive industry: machinery and equipment or repair and installation of machinery and equipment. Similar to the *fully resourced* path, these SMEs were also driven by both internal *and* external resources. However, our findings suggest that these internal and external resources were present to a lesser extent in the *selective balancers* path, compared to the *fully resourced* path.

More specifically, in certain industries, *selectively balancing* specific internal resources (human resources) and external resources (intermediary-based collaboration) was sufficient to arrive at advanced 4.0 technology use, even in the absence of a leading innovative region. SMEs in this path depended on intermediaries for support in terms of funding. SMEs could have utilized this funding from intermediaries to enhance the digital skills of their employees, enabling them to work with I4.0 technology, and in turn driving advanced use.

Focused connectors

The third path comprises C3. Similar to the *selective balancers*, also the firms in this path seemed constrained in their overall resources, albeit in a different way. This path involves SMEs achieving advanced use despite not being located in a leading innovative region, through a combination of intermediary-based and broad and deep external collaboration across various areas such as R&D, production, inputs, and sales. The most important collaboration partners were found to be knowledge institutes, suppliers, and customers. SMEs relied heavily on external resources, which we considered to be the main driver, thus we named the path *focused connectors.* The path of *focused connectors* had the highest coverage score, indicating that it had the highest number of SMEs when compared to all three consistent paths for advanced use.

The path of *focused connectors* suggests that certain external resources can complement and reinforce each other for advanced use. Intermediaries provided support through facilitating collaboration, and may have helped SMEs connect with the right partners for further in-depth broad and deep collaboration. Therefore, these external resources together potentially accelerated SMEs' advanced use.

Not advanced I4.0 technology users

Low on resources (scarce context)

The first path, based on C3a and C3b, shared the absence of internal technical resources, intermediary-based external collaborations, and a digitally intensive industry. We refer to this path as *low on resources (scarce context).* This path had the highest coverage score, indicating the highest number of SMEs when compared to all four consistent paths for not advanced I4.0 technology use. We identified as main drivers for this path a limitation of resources combined with a scarce context. It further largely mirrors the *fully resourced* path for advanced use. It is not surprising that these SMEs did not reach advanced use, since they could not depend on a strong internal resource base, take advantage of complementary external resources, or access potential spillover knowledge from a rich context. These constraints together drive not advanced use.

Low on resources (rich context)

Although C4 shares similarities with C3a and C3b in terms of the absence of internal technical resources and intermediary-based external collaboration, it differs in context due to the presence of a digitally intensive industry and a leading innovative region. Therefore, we kept C4 as an individual path which we refer to as *low on resources (rich context).* The main drivers here were having limited resources despite a rich context. Previous research indicates that rich contexts can facilitate knowledge spillovers for innovation purposes (Speldekamp et al., 2020). However, the relative absence of internal and external resources may arguably hinder SMEs from accessing and integrating such spillovers.

Non-absorbers

The third path is based on C5 and C6, which share the absence of internal technical resources and intermediary-based external collaborations, similar to *low on resources (scarce context)* and *low on resources (rich context)*, but also show the presence of broad and deep external collaborations. We refer to this path as *non-absorbers*. Although broad and deep collaborations may have provided complementary knowledge, SMEs were arguably not able to integrate it due to limited technical resources. Therefore, we propose the main driver to not advanced use were the limited internal resources that prevented SMEs from absorbing external resources.

Other priorities

The final path, which comprises C7 and was labeled as *other priorities*, displayed the lowest coverage score. This indicates that only a relatively small number of SMEs in our consistent configurations related to not advanced use are in this path. Despite its relatively low coverage, this path is quite interesting. Firms in this path are relatively similar to *fully resourced* SMEs, except for the absence of intermediary-based collaboration and not being located in a leading innovative region. We propose that the main driver in this path is that these firms likely had *other priorities* than achieving advanced use. Potentially, this state could be explained by the absence of intermediaries, which might have limited these firms' awareness of I4.0 opportunities.

Robustness tests

Following good practice (Greckhamer et al., 2018), we altered the frequency and consistency thresholds from our main analysis to validate the robustness of our results. Specifically, we raised the frequency threshold for inclusion from one to two cases. This did not result in any changes to our original configurations. Additionally, we increased the consistency threshold to 0.9 (Appendix, Table E). For the presence of the outcome we observed two changes. In the *selective balancers* path the broad and deep collaboration condition changed from 'don't care' to 'absent'. This did not change the overarching path we found. In the *focused connectors* path the technical resources condition changed from 'don't care' to 'present'. Yet, since this change did not de-emphasize the focus on external resources, this result is still in line with the original path. Furthermore, for the absence of the outcome C3b disappeared, which made the path *low on resources (scarce context)* specific to the absence of human resources. However, this did not alter the overarching path we identified. In sum, the results of our robustness tests are logically consistent with our main findings.

Discussion

In this study we aimed to answer the research question: Which resource and context configurations are associated with advanced compared with not advanced I4.0 manufacturing technology use in SMEs? Based on configurational theorizing (Furnari et al., 2021; Kumar et al., 2022) and using data from the European Manufacturing Survey as our primary source, we identified three paths associated with advanced I4.0 technology use in SMEs: fully resourced, selective balancers and focused connectors. Additionally, we identified four paths associated with not advanced use: low on resources (scarce context), low on resources (rich context), non-absorbers, and other priorities. In response to recent calls for more insights into how SMEs can achieve advanced I4.0 technology use (Frank et al., 2019; Muller et al., 2018), our findings have implications for the literature on resources for Industry 4.0 technology use and RBV literature more broadly.

Implications for literature on resources for I.40 technology use

Previous studies have demonstrated that achieving advanced I4.0 technology use is a complex and resource-intensive undertaking (Ghobakhloo & Iranmanesh, 2021). Specifically, these studies extensively discussed the importance of internal resources (e.g., Müller & Voigt, 2017), external resources (Ricci et al., 2021; Rossi et al., 2022), and the supportive or constraining role of a firm's context (e.g., Chen & Tian, 2022). At the same time, SMEs often face resource constraints (Horvath & Szabo, 2019; Mittal et al., 2018; Muller et al., 2018), but are in some cases still able to reach advanced use (Frank et al., 2019). Thus far, explanations have focused mostly on the value of individual resources and contexts.

Considering these results in light of the RBV, which emphasizes resource bundles that can vary in value across contexts (Brush & Artz, 1999; Miller & Shamsie, 1996; Pahnke et al., 2023; Penrose, 1959), it is important to note that a focus on the value of individual resources, while valuable in itself, may also obscure potentially important interactions between resource and context configurations. Along this line, our research suggests that focusing on complements and substitutes between resources and how they are embedded in different contexts sheds new light on how SMEs can achieve advanced I4.0 technology use.

Thus, drawing on RBV logic (Penrose, 1959) combined with configurational theorizing (Furnari et al., 2021; Kumar et al., 2022), we focused on the intricate interplay between diverse resources and contexts. We showed how multiple consistent paths are related to (not) advanced I4.0 technology use in SMEs, thereby further unearthing the causal complexity that characterizes this phenomenon. On one hand, and largely in line with what one would generally expect, we show that SMEs with a broad set of productive resources and a supportive context, represented by the *fully resourced* path, consistently achieve advanced I4.0 technology use. However, this is not the largest group of consistent advanced users.

Instead, we also exposed that most of these firms were less intensively resourced. Our configurational theorizing helped us to further characterize these SMEs. Specifically, in light of resource constraints faced by SMEs as discussed in previous works (Horvath & Szabo, 2019; Mittal et al., 2018; Muller et al., 2018), we explain how these firms can achieve advanced use by *selectively balancing* or *focused connecting*. We further expose substitution effects between these two types of users. *Selectively balancing* is characterized by the presence of specific internal and external resources and the absence of others. On the other hand, *focused connecting* builds on external resources only, albeit a broader set of these resources. Together our findings suggest that resource-constrained SMEs can follow diverse yet limited paths towards advanced I4.0 technology use.

Furthermore, the paths related to advanced use are not necessarily mirror images of those related to not advanced use. This suggests that I4.0 technology use is characterized by causal asymmetry: the presence or absence of a condition may produce the same outcome, depending on its combination with other conditions. Previous regression-based analyses (e.g., Mahmood & Mubarik, 2020; Ricci et al., 2021) have not adequately addressed this notion that the availability of resources is not always positively related to SME advanced I4.0 technology use. We expand on this previous research by suggesting that even when resources are (partially) available, SMEs may not be able to achieve advanced use, as evidenced by several of our not advanced use paths.

Further unpacking the consistent not advanced use paths, it was less surprising that some of these SMEs lacked suitable resources and operated in a scarce context. In line with previous research (Mahmood & Mubarik, 2020; Müller et al., 2021), our study also suggests that SMEs with limited internal resources and partial access to external resources struggle to absorb and integrate those resources, thus hindering their ability to achieve advanced use.

Notably, our findings further revealed that some not advanced users operated in a rich context. Previous research suggests that firms can rely on knowledge spillovers to support innovation by being in an innovative region or industry (Bottazzi & Peri, 2003; Fritsch & Franke, 2004; Speldekamp et al., 2020; Van der Panne, 2004). However, our research suggests that for I4.0 technology use, a firm has limited opportunities to benefit from a rich context if it lacks suitable key resources, which likely inhibits SMEs from accessing and integrating these knowledge spillovers.

Lastly, by contrasting consistent advanced and not advanced users, we highlight the significant role of intermediary-based collaborations as external resources. Intermediaries can facilitate collaborative exchanges between two or more parties, either directly by providing resources, guidance, and services, or indirectly by fostering the development of partnerships within and across industries (Abi Saad et al., 2024; Gredel et al., 2012). SMEs can benefit greatly from this support as they may not have the resources to acquire the necessary knowledge or skills related to technology adoption (Caloffi et al., 2023). We add to this research that intermediary-based collaborations are not only important ingredients in SMEs' resource and context configurations, but may even determine the difference between advanced and not advanced use in certain cases. SMEs in the *other priorities* path were comparable in their resources and context to the *fully resourced* firms, except for the absence of intermediary-based collaborations. Yet in contrast to the *fully resourced* firms, the *other priorities firms* were not able to achieve advanced use. While these SMEs had *other priorities,* intermediaries might have been able to help reconnect them to I4.0 opportunities and potentially (re)position them on the path towards advanced use.

Implications for RBV literature

Zooming out, our research also further advances the more general RBV literature, in particular RBV research that has focused on firms' resource bundles. Tracing back to Penrose's (1959) pioneering contribution, and addressed in several more recent works (e.g., Pahnke et al., 2023; Sirmon et al., 2008), this line of thought suggests that resources can create different opportunities and constraints when used in different ways or in combination with other resources. Yet, this research on resource value has primarily focused on testing relatively simple two-way interactions (e.g., Hitt et al., 2001), with limited efforts to explore broader resource bundles and move beyond such interactions (cf. Carmeli & Tishler, 2004). Based on our research, we join emerging voices (Pahnke et al., 2023) suggesting that the use of configurational theorizing and applying fsQCA can be a productive approach to advance resource-centric research, since this enables the unveiling of higher-order interactions between diverse resource bundles and contexts and how these relate to organizational outcomes.

Beyond aligning well with the configurational logic of resource bundles, fsQCA also allows for modeling the contingent effects of resource absence. This approach can be particularly fruitful in studies that focus on SMEs, which are often constrained in their resources (Mittal et al., 2018; Wenke et al., 2021). Previous RBV research has generally suggested that resource weakness is at the heart of negative organizational outcomes, such as decreased performance (Sirmon et al., 2010). We extend this by showing that certain resource constraints do not necessarily hamper positive organizational outcomes, as suggested by our *selective balancers* and *focused connectors* paths. Relatedly, our research further exposes how the criticality of the presence or absence of a particular resource for (not) achieving an outcome can differ across resource types. For example, in our case, *other priorities* SMEs were almost similar to *fully resourced* firms, except for the absence of intermediary-based collaborations, while other resource types had less critical positions in resource bundles.

Practice- and policy implications

For practitioners, and in particular I4.0 enthusiastic SME managers, our findings provide a more nuanced view of how SMEs can achieve advanced I4.0 technology, which can serve as a springboard for competitive advantage. For many SMEs, starting to implement and use advanced I4.0 technologies may seem a daunting task due to demands of day-to-day business and potential resource constraints. Our research shows that, even in the face of resource constraints, SMEs can achieve advanced I4.0 technology use: either by focusing on external resources or by partially balancing internal and external resources. We also draw the attention of SME managers to the importance and potential value of engaging with intermediaries who can further expose I4.0 technologies' opportunities, provide financial support, or facilitate connections with the right types of partners. At the same time, we further highlight the conditions under which it would generally be very difficult to reach a state of advanced use, even if some suitable resources or a rich context were present.

Our research also has implications for policy makers that wish to further support SMEs' I4.0 journeys and increase the competitiveness of their area. Given the importance of intermediary organizations suggested by our research, such as the collection of 'field labs' in the Netherlands (Stolwijk & Seiffert, 2016; Stolwijk & Willems, 2019) or 'digital innovation hubs' in the European context (Stolwijk & Butter, 2015), policy makers are advised to treat these as an important means of supporting SMEs. Not only can policy-makers play a role in maintaining or even increasing the number of these intermediaries, they could also help make them more visible and accessible to SMEs. Another recommendation for policy-makers is to reflect on the importance of the connectedness between resources, as suggested by our research, when renewing policies. For example, two of our advanced user configurations showed the combined presence of both intermediary-based collaboration and the presence of appropriate human resources. In this sense, policies focused on intermediaries could be aligned and go hand in hand with targeted labor market and educational policies.

Limitations and suggestions for future research

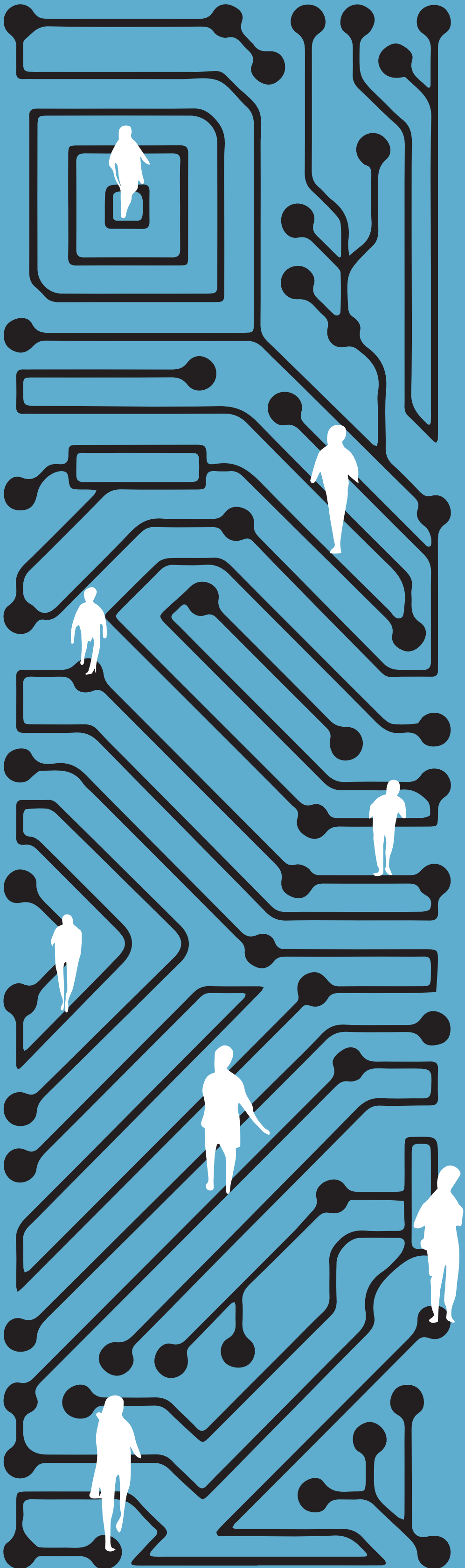
We acknowledge that this study has limitations which can provide opportunities for future study. In light of methodological limitations, while by applying fsQCA we could reveal complex causal dynamics at play, the method is not well equipped to deal with processes that extend over time (Cornelissen & Kaandorp, 2022; Schneider & Wagemann, 2012). Future research could apply a more processual approach (Langley et al., 2013) to unpack questions such as whether certain sequences of acquiring resources would benefit firms most or how changing environments would influence productive resource bundles. Another aspect of fsQCA is that there are limits to the number of antecedent conditions that can be included in a configurational model, because this has to be balanced with sample size (Marx & Dusa, 2011) and the exponentially increasing interpretation complexity of more extensive models (Greckhamer et al., 2018). With our research we made sure we built on prior research to include conditions in the modeling space available. However, we acknowledge that there is more resource variety and it would be valuable for follow-up studies to explore interactions with types of resources that we did not include in our model, like financial resources. Additionally, our measurement of I4.0 technology use was limited to a binary statement. Future research could therefore focus on a further assessment of the extent of advanced I4.0 technology use within SMEs.

Furthermore, our included outcome considered advanced I4.0 technology use. While RBV research has considered intermediate outcomes (Pahnke et al., 2023), its eventual aim is to further explain firms' competitive advantage (Barney, 1991). Although previous literature has argued that I4.0 technology use can be a springboard for competitive advantage (Calış Duman & Akdemir, 2021; Horvath & Szabo, 2019), future studies could more thoroughly interrogate the connection between resource and context configurations and competitive advantage in the I4.0 context.

Lastly, we focused on the full range of manufacturing industries in explaining advanced I4.0 technology use. However, it could be that for certain manufacturing industries there is less urgency to use advanced technologies - a nuance we did not fully include in our analysis. Although previous research indicates that the manufacturing industry as a whole could benefit from advanced use (Büchi et al., 2020; Dalenogare et al., 2018), further research could provide a more nuanced picture of how suitable resource and context configurations may differ across different industries.

Conclusion

Compared to large firms, SMEs often face more extensive resource constraints that can make it more difficult for them to achieve advanced I4.0 technology use. In this study we used RBV logic and configurational theorizing, to expose that, under these conditions, SME could achieve advanced use through *selectively balancing* partial internal and external resources or by *focusing on connecting* to a broader set of external resources. At the same time, we uncover the conditions under which it would be generally very difficult to reach a state of advanced use, even if some suitable resources or a rich context are present. Our hope is that these findings will encourage further research on resources and contexts for I4.0 technology use, and provide valuable insights for both SMEs on their I4.0 journeys and policy makers.



3.

External resourcing for digital innovation in manufacturing SMEs

Abstract

Manufacturing SMEs face specific challenges in pursuing digital innovation, such as limited internal resources and less experience in identifying opportunities and in managing structured innovation processes. Hence, accessing complementary external resources is crucial for these firms to support their digital innovation processes. However, these complementary external resources are often distant and unfamiliar. Previous studies have paid limited attention to the process of how SMEs identify and evaluate these resources and put them to use in their internal organization. Drawing on a resourcing perspective, we trace how actors in manufacturing SMEs engaged in *external resourcing* for digital innovation. We identify three distinct but interconnected resourcing practices: *pursuing, discovering*, and *internalizing*. Zooming out, we also find that specific temporal patterns in resourcing practices and resourcing priorities were rooted in characteristics of innovation processes regarding organizational structure and activities; and customer interactions. We contribute to the digital innovation literature by unpacking how external resourcing can help manufacturing SMEs to address their specific challenges by providing structure for the innovation process and enabling connections between externally developed and existing internal resources.

Keywords
digital innovation, external resourcing, practice perspective,
product innovation, process innovation, manufacturing SMEs

Introduction

In this paper we explore how actors in manufacturing SMEs engage in external resourcing to pursue digital innovation processes. These firms operate in a world increasingly permeated by digital technology (Blichfeldt & Faullant, 2021), in which digital innovation can be considered a new imperative (Hund et al., 2021; Urbinati et al., 2022; Yoo et al., 2012). It involves the creation of market offerings, business processes, or models driven by the uptake of digital technologies like robotics, additive manufacturing, artificial intelligence, augmented- and virtual reality, and digital twinning (Bogers et al., 2022; Nambisan et al., 2017). Digital innovation can positively affect manufacturing firms' performance by enabling operational efficiency and speedier process innovation (Liu et al., 2023), or supporting new product and service creation (Blichfeldt & Faullant, 2021). For example, BMW implemented digital twins of their manufacturing process in thirty factories, which enabled them to create digital images of automobile parts and assemblies and model the related manufacturing process, resulting in improved overall production speed and efficiency (Caulfield, 2021; Garnsey, 2020).

Although digital innovation offers unprecedented opportunities for manufacturing firms, it also poses significant managerial challenges due to high degrees of novelty and complexity (Bogers et al., 2022; Moschko et al., 2023). Firms have to reconcile the 'new' and the 'old' (Oberlander et al., 2021; Vial, 2019) when "actively selecting resources of an offering and configuring them with other resources, or even rethinking their usage and purpose" (Henfridsson et al., 2018, p. 91). At the same time, they also have to navigate the increasingly distributed nature of digital innovation (Nambisan et al., 2017; Yoo et al., 2012) by bringing together internal resources with those that originate externally (Moschko et al., 2023; Sestino et al., 2020; Svahn et al., 2017). These studies have demonstrated that actors need to meticulously balance their resourcing efforts, as overemphasizing internal resources inhibits identifying opportunities across organizational boundaries, while overly focusing on external resources can result in a disconnect with established internal practices. Yet, while external resources are crucial for pursuing digital innovation, the process of *resourcing* them (Feldman, 2004; Feldman & Worline, 2011) is particularly challenging because complementary external resources will often be relatively distant and unfamiliar. This means they often need to be identified and developed in an iterative fashion, including instances of reorientation and trial-and-error (Deken et al., 2018).

Against this background, small- and medium-sized enterprises (SMEs) encounter even more prevalent managerial challenges because they face more difficulties in identifying digital innovation opportunities (Benitez et al., 2020; Horvath & Szabo, 2019) and are less experienced in managing structured innovation processes (Giotopoulos et al., 2017; Pessot et al., 2023; Radas & Bozic, 2012). Also, limited internal resources, for instance due to financial constraints (Chiappini et al., 2022; Mittal et al., 2018), make accessing complementary external resources crucial for them in supporting their digital innovation initiatives (Muller et al., 2018). Some previous studies have demonstrated that manufacturing SMEs can benefit from tapping into external resources, for instance through connecting with customers or knowledge institutes, to recognize opportunities for digital product or manufacturing process innovation (Agostini & Nosella, 2019; Ricci et al., 2021). However, these studies have largely overlooked *how* over time actors in SMEs attribute value to these resources and subsequently put them to use in their internal organization. Developing a more processual account of this *external resourcing* is therefore imperative to investigate the specific challenges manufacturing SMEs face in pursuing digital innovation.

We draw on a perspective that both has a resource and process sensitivity: *resourcing* (Feldman, 2004; Feldman & Worline, 2011). As an application of practice theory, resourcing focuses on the actions people draw upon to identify, develop, and put resources to use (Feldman & Worline, 2011). We focus on *external resourcing*: how actors identify and develop resources across organizational boundaries and transform these for use, to become resources-in-use, inside their organization. By focusing on specific activities of attributing value to resources (e.g., Feldman & Quick, 2009), this perspective allows us to assess if and how micro-level instances of resourcing develop in a certain direction to energize a more extensive digital innovation process. Based on this, our research question is: *How do actors in manufacturing SMEs engage in external resourcing to pursue digital innovation processes?*

Using a comparative case study approach (Eisenhardt, 1989, 2021), we identified three interconnected external resourcing practices: *pursuing, discovering,* and *internalizing*. These practices were distinct in that they varied according to their focus (ill- or well-defined) and locus (within or across organizational boundaries) of resourcing. Zooming out, we identified different temporal patterns and resourcing priorities depending on innovation *outcome:* a pattern of pursuing – discovering – internalizing with a social resource priority for product innovation, compared to a pattern of discovering – internalizing – pursuing with a technical resource priority for process innovation. The characteristics of each digital innovation process we identified, regarding the organizational structure and activities on one hand and customer interactions on the other hand, helped us explain these differences.

We contribute to the literature on digital innovation by unpacking how manufacturing SMEs can navigate challenges they frequently face in their innovation processes. First, our findings suggest that external resourcing is shaped by 'building blocks' created after each resourcing cycle, which can assist actors in focusing and shaping subsequent resourcing activities. This provides a sense of structure for the unfolding process and can enable progress towards innovating products and processes. In this way, we address how through external resourcing manufacturing SMEs can mitigate challenges such as difficulties in identifying digital innovation opportunities (Benitez et al., 2020; Horvath & Szabo, 2019), and having less experience in managing structured and deliberate innovation processes (Giotopoulos et al., 2017; Pessot et al., 2023). Second, our findings demonstrate how SMEs can navigate the challenge of connecting newly developed external resources with the existing internal resource base by alternating their locus of resourcing activities over time. Hereby we contrast previous studies that demonstrated how actors ensured this connection simultaneously through a technical solution (Svahn et al., 2017), and show instead how for SMEs alternating between developing resources externally and internalizing them over time is also a fruitful approach to address this challenge.

Theoretical background

Digital innovation in manufacturing SMEs

We define digital innovation as "the creation of (and consequent changes in) market offerings, business processes, or models that result from the use of digital technology" (Nambisan et al., 2017, p. 224). It brings together previously separate products, entities, and industries, by allowing participation from multiple parties and by accumulating information from multiple sources (Nambisan et al., 2019; Yoo et al., 2012; 2010). A multitude of digital technologies are at the core of digital innovation, but literature consolidates the main technologies for manufacturing firms to be robotics, additive manufacturing, and augmented- and virtual reality (Blichfeldt & Faullant, 2021).

Previous literature has distinguished between digital innovation *as a process* and the resulting *outcomes* of digital innovation. *Outcomes* of digital innovation can include new manufacturing processes, products, services, and business models (Hund et al., 2021; Nambisan et al., 2017). These outcomes do not necessarily need to be digital themselves, as long as they are enabled by the use of digital technologies (Fichman et al., 2014; Nambisan et al., 2017; Oberlander et al., 2021). The digital innovation *process* considers the sequences of actions and events triggered by digital technologies and links innovation capabilities, organizational structures, boundaries, and technology management in firms (Correani et al., 2020). Studying digital innovation *as a process* has recently started to receive increased research attention (Urbinati et al., 2022). This enables scholars to pay specific attention to practices, activities, and mechanisms driving its orchestration (Nambisan et al., 2017; Urbinati et al., 2022), through which manufacturing firms can achieve particular digital innovation *outcomes.*

Orchestrating the digital innovation *process* presents significant challenges for actors in manufacturing firms with respect to their existing internal resource base (Oberlander et al., 2021). This resource base should be transformed with complementary resources when pursuing digital innovation (Moschko et al., 2023; Svahn et al., 2017). These complementary resources are not always available within organizational boundaries: for example, customers can act as external resources in co-creating new digital services or products (Oberlander et al., 2021; Zhang et al., 2020). Hence, manufacturing firms must decide whether they develop complementary resources internally themselves or draw on external resources (Sestino et al., 2020). For example, in their case study of the Volvo connected car initiative, Svahn et al. (2017) elaborate on the challenges managers encountered as they had to develop the skills and relationships of people operating within established internal work processes, while at the same time engaging with external resources to progress with the initiative. This materialized in a tension for managers between focusing on internal and external resources. Similarly, Moschko et al. (2023) showed that managers aiming to digitalize their manufacturing systems experienced the need to collaborate with both internal actors and external sources, but this resulted in additional challenges as they thought in functional silos, were unwilling to share resources, and strived for control. Hence, manufacturing firms may recognize the need to develop complementary resources using external sources to support their digital innovation initiatives, yet their anchoring in existing internal resources and practices can present challenges for successfully orchestrating this process.

Given their resources constraints (Horvath & Szabo, 2019; Muller et al., 2018; Pessot et al., 2023), it might not always be possible for manufacturing SMEs to develop resources for digital innovation internally. Hence, it is not surprising that the "uptake of digital technologies remains particularly low among small firms even for technologies that seem particularly relevant for SMEs" (OECD, 2017, p.36). To engage in digital innovation, SMEs require a combination of multiple, complementary resources (Eller et al., 2020), which they do not always have access to within their organizational boundaries (Mittal et al., 2018; Muller et al., 2018). Tapping into complementary external resources, for instance through customers, suppliers, consultancies, or knowledge institutes, holds potential for their digital innovation *outcomes* in terms of product and manufacturing process innovations (Agostini & Nosella, 2019; Ricci et al., 2021).

These external resources can be technical in nature, as employees in SMEs can have limited technical skills and knowledge to use digital technology (Muller et al., 2018). As digital innovation is embedded in not only technical but also social systems (Lyytinen, 2022; Sandberg et al., 2020; Wang et al., 2020), the literature also increasingly emphasizes the importance of accessing complementary social resources for digital innovation (Eller et al., 2020; Svahn et al., 2017). For example, SMEs transform from being product manufacturers to becoming providers of digital innovation enabled solutions, providing repair and maintenance, consulting, or services like digitization of processes, to their customers (Muller et al., 2018). As this requires transforming the existing internal resource base, potentially creating tensions between the 'old' and the 'new' (Oberlander et al., 2021; Vial, 2019), it is likely that SMEs need complementary social resources to manage such transformations (Pessot et al., 2023).

Taken together, based on our reading of prior literature, the specific challenges manufacturing SMEs face in their digital innovation processes potentially relate to various aspects: their often limited internal resources, the challenges they face in developing a variety of complementary resources outside their organizational boundaries, and the difficulty of integrating these external resources into the existing internal resource base.

External resourcing for digital innovation

We draw on a resourcing perspective, which connects to the 'practice turn' in organization studies (Feldman & Worline, 2016; Schatzki et al., 2001). This perspective is well suited for our study as it emphasizes the integration and use of resources, like social or technical knowledge or skills, in dynamic and context-dependent change and innovation processes (Schneider et al., 2021). By tracing resourcing *activities* and broader *practices,* a resourcing perspective enables developing a processual account of potentially different uses of seemingly similar resources (Feldman & Worline, 2016). Thus, in the context of manufacturing SMEs, by paying attention to specific practices, it allows us to trace how actors identify and develop resources across organizational boundaries, and how they transform them for use by integrating them in the internal organization to pursue digital innovation initiatives. We refer to this process as *external resourcing.*

The resourcing perspective (Feldman, 2004; Howard-Grenville, 2007; Sonenshein, 2014; Wiedner et al., 2017) is linked to earlier work on resource value, for example resource dependence theory (Salancik & Pfeffer, 1978) and the resource-based view (Barney, 1991). The resourcing perspective departs from these earlier perspectives by emphasizing how the value of a resource arises from its meaning in interrelated practices (Feldman & Worline, 2016). Thereby it addresses the criticism of these earlier perspectives as providing static conceptualizations that emphasize innate qualities of resources, without explaining how resources gain their value (Kraaijenbrink et al., 2010). While potential resources indeed have innate qualities (e.g., 'rocks are heavy') that give them the potential to become useful (e.g., 'rocks are building material'), the resourcing perspective emphasizes that action is necessary to access these qualities. Without action, a potential resource is not useful and does not become a resource-in-use (e.g., 'rocks can be used to build bridges and resource connections *or* fortresses and resource defense'). Thus, resourcing refers to the process through which actors turn potential resources, such as knowledge, relationships, or material objects, into resources-in-use to accomplish objectives (Feldman, 2004). Skillful use can turn the same potential resources into resources-in-use for different outcomes (Sonenshein, 2014), which can in turn alter actors' resourcing objectives. Therefore, resources and the objectives they support are mutually adjusted in a recursive relationship (Feldman & Worline, 2011).

In the digital innovation process, complementary external resources may be difficult for actors to identify upfront. Due to the complexity and high degree of novelty and uncertainty associated with the digital innovation process (Moschko et al., 2023), external resources for digital innovation may often be distant and unfamiliar, which can lead to an iterative trial-and-error process in identifying and developing complementary resources with multiple external sources (Deken et al., 2018). For example, Deken et al. (2018) in their study of a car manufacturer aiming to develop new digital services based on vehicle usage data, showed that partnering needs were unknown upfront and only were identified through an extensive resourcing process in interaction with more than thirty potential partners. On top of that, the objectives of the innovation initiative changed course multiple times due to interaction with specific external sources, illustrating the mutually adjusted recursive relationship between resources and objectives, and the role external partners played in this.

Furthermore, for manufacturing firms in particular, there is a need to effectively match and integrate external resources developed across organizational boundaries with existing internal resources (Moschko et al., 2023; Svahn et al., 2017). For example, Elsahn and Siedlok (2021) showed that the success of various resourcing initiatives by manufacturing firms, for which the envisioned innovation outcome was developed with external sources, was dependent on whether actors could make this fit with existing resources in the organization. Tesla developed the idea to start producing respiratory medical equipment during the COVID pandemic driven by societal discourse and government requests but failed to develop safe devices and scale up their production, as they could not link the project to their existing machinery used originally for assembling cars. Integrating external resources and making them fit for use is likely to be even more pressing for SMEs since they tend to lack the financial capacity to invest in new machinery and therefore need to integrate software capabilities with their existing machine base (Muller et al., 2018).

Based on our reading of the literature, external resourcing for manufacturing SMEs not only encompasses identifying and developing complementary resources across organizational boundaries, but also adapting and integrating these external resources with existing internal resources. Previous literature suggests that external resourcing to pursue digital innovation can be associated with trial-and-error and reorientations. A resourcing perspective, through focusing on how actors attribute value to resources, allows us to trace this process and the associated trial-and-error and reorientations. Thereby we can assess if and how micro-level instances of resourcing develop in a certain direction (Feldman & Quick, 2009). In our case, whether instances of resourcing can energize a more extensive digital innovation process in manufacturing SMEs.

Method

We adopted a comparative case study approach following Eisenhardt (1989; 2021). Case studies provide rich data and allow for the investigation of contemporary challenges in organizations (Yin, 2014), such as digital innovation processes. Moreover, building on the concepts of digital innovation and resourcing, a comparative case study serves to replicate, contrast, and extend findings thereby supporting our aim of theory elaboration (Eisenhardt & Graebner, 2007).

The context of our study was the Dutch manufacturing industry, where SMEs' digital innovation is generally considered an important driver to remain competitive (Ministry of Economic Affairs and Climate Policy, 2023; Smart Industry Netherlands, 2022). To ensure we selected cases in which the phenomenon of interest was present to a high degree and could be traced relatively easily (Pettigrew, 1990), we adopted a purposeful sampling strategy. Since digital innovation is a broad phenomenon (Nambisan et al., 2017), the selected cases were relatively heterogeneous in terms of envisioned innovation *outcomes,* the associated digital technologies, and what was manufactured. Yet, to support meaningful comparisons, we aimed at keeping aspects like the number of employees (between 100-225) and the innovation timeline (between 2014-2020) relatively similar. Based on this, we selected four Dutch SMEs focused on pursuing various digital innovation outcomes (Table 6).

Table 6: Case overview

Case	**SaltspreaderCo**	**CyclingCo**	**BakingCo**	**MetalCo**
Employee N	200	225	225	100
Established in	1949	1910	1846	1997
Manufacturer of	Salt spreading vehicles	Bicycles for people with a disability	Industrial baking lines	Sheet metal
Timeline digital innovation process	2014-2019	2016-2020	2015-2020	2014-2020
Digital technologies	Product sensors, Internet of Things, big data analytics	Industrial robotics, 3D-print manufacturing, digital twinning	Product sensors, Cloud, Internet of Things	Industrial robotics, Internet of Things, 3D-modelling, artificial intelligence
Type of digital innovation *outcome*	Product-service: scaling up sale of service contracts ('de- iced roads')	Process: digital factory using digital twinning	Product-service: scaling up sale of service contracts ('customer data platform')	Process: digital factory using artificial intelligence

Data collection

We started data collection through interviewing in January 2020 at SaltspreaderCo and CyclingCo and added two cases around mid-2020, BakingCo and MetalCo. Our primary data source was semi-structured interviews (Patton, 2002). Following a snowball approach, we interviewed actors internal and external to the focal organization, who were considered influential in the digital innovation process. In the interviews we focused on tracing activities in the digital innovation process, particularly actors' activities in identifying and developing external resources. Here we follow a recent study by Nigam and Dokko (2019) that also primarily relied on interviews to create a processual account of resourcing practices. We asked questions on topics like important milestones and barriers related to the digital innovation process and the development of resources, potentially with external partners. In total, we conducted 28 in-depth interviews with 26 informants between January and December 2020, lasting between 45-90 minutes. All interviews were voice recorded for verbatim transcription. The interviews were conducted in Dutch, and the quotes used in this paper have been translated into English.

The information collected through the interviews was complemented with secondary sources aimed at facilitating triangulation (Yin, 2014). We considered internal documentation provided by interviewees as well as publicly available data on company websites, in magazines, and press releases. Among others, we collected internal presentations, company newsletters, magazine articles, and annual reports, totaling over 900 pages. These secondary sources supported the interpretation and contextualization of information provided by the interviewees and helped us to familiarize ourselves with the firms. They also contained factual data like timestamps of activities, which further enabled tracing process histories (Langley et al., 2013). In two cases, data were also collected during company visits (SaltspreaderCo and CyclingCo), including a tour of the production facilities and informal conversations with several informants. Combining our interviews with these secondary data sources supported developing a reliable chronology of each innovation process. A further specification of our data sources can be found in the Appendix.

Data analysis

Our data analysis followed an iterative process, alternating between data, emerging interpretations, and relevant literature (Strauss & Corbin, 1998). Data analysis started alongside our fieldwork (Locke, 2000). The authors less involved in data collection took an outsider perspective, critically reflecting on and challenging the first author's initial hunches and emerging insights. As a team of researchers, we critically discussed emergent findings in biweekly meetings to substantiate our theorizing (Locke et al., 2008).

We analyzed our data in three steps, relying on case-study procedures (Eisenhardt, 1989; 2021), allowing us to trace external resourcing for each case. First, we started by analyzing within-case data, writing a case narrative for each case, and creating a timeline of events (Langley et al., 2013; Poole et al., 2000). We defined events as actions by internal or external actors that influenced the digital innovation process. We paid specific attention to tracing activities that crossed organizational boundaries. Within the case narratives and event list, we tried to capture 'what' happened 'when', and 'which actors' were involved. Most events considered boundary crossing activities, for example, actors attending workshops focused on digital technology, or visiting other manufacturing firms for new perspectives on digitalization. Others were activities within the boundaries of the organization, like following up on external activities by implementing a robot welding machine into manufacturing operations, using technical resources acquired in external workshops, as in the case of CyclingCo.

Second, by zooming in (Nicolini, 2009) on the individual narratives and event lists, we started our coding. Where appropriate, we borrowed existing concepts from the literature, but we made sure to leave room for emerging insights. In this coding round, important aspects that emerged were whether resource needs were well defined upfront or not (partly based on Deken et al., 2018), and whether collaboration took place across or within the boundary of the organization. Based on these dimensions, different resourcing *practices* (in line with Schneider et al., 2021) could be identified. Resourcing *practices* consisted of an *input, resourcing activities,* and an *output.* This input was usually a previously developed resource, which formed a 'building block' for subsequent resourcing activities. These resourcing activities resulted in an output, a resource, that could be more social or technical in nature. Within these resourcing practices, resourcing activities were not always straightforward and included alternating external sources and refocusing resource objectives. For example, in the case of SaltspreaderCo, difficulties in collaborating with a supplier to develop smart driving routes for salt spreading vehicles made actors realize that they would have to change their resourcing strategy and turn to other suppliers to achieve their resourcing objectives.

The two dimensions that we settled on for distinguishing different resourcing practices were (1) the identification of resource needs (focus), which could be either relatively well-defined or ill-defined; and (2) where the resourcing was concentrated (locus). This could be either internally (within the organizational boundary) or externally (across the organizational boundary) (see Table 7).

Table 7: Overview of central concepts

	Focus (resource needs)	**Locus** (of activity)	**Examples**
Discovering	Ill-defined: when actors did not have a clear idea of the resources they would need to develop externally to further digital innovation	Across organizational boundaries	CEO of SaltspreaderCo 'stumbles upon' external consultant that can support with organizational reconfiguration and servitisation. Actors at CyclingCo get a first overview of digitalization opportunities through a masterclass and a futurologist.
Pursuing	Well-defined: when actors built on relatively specific previously developed resources, thereby having a more specific idea of relevant complementary resources	Across organizational boundaries	R&D engineer of BakingCo collaborates with supplier to outsource the technical architecture of a dashboard, for which the first steps were made by the organization itself. Actors at MetalCo start AI project, building on previous experiences with digital infrastructure and 3D modelling for production.
Internalizing	Well-defined: when actors built on relatively specific previously developed knowledge and resources, thereby having a more specific idea of relevant complementary resources	Within organizational boundaries	CEO and operations manager of CyclingCo collaborate with internal employees to adapt bike frames to make them fit for robot welding. Service manager at BakingCo creates awareness for sales of services among employees.

Based on these characterizing dimensions, we eventually could distinguish between three different resourcing practices: (1) *discovering,* characterized by resource needs that were relatively ill-defined and resourcing across organizational boundaries; (2) *pursuing,* characterized by resource needs that were relatively well-defined and resourcing across organizational boundaries; and (3) *internalizing,* characterized by resource needs that were relatively well-defined, and resourcing within organizational boundaries. Furthermore, we found that resources developed in each of the resourcing practices served as 'building blocks' and inputs for subsequent resourcing.

Third, we zoomed out (Nicolini, 2009) and undertook a cross-case comparison. Zooming in on the external resourcing trajectories for each of the cases, we noticed that the focus on different innovation *outcomes,* either more process- or product innovation related, was important in steering actors' resourcing requirements. Therefore, we grouped the four cases according to innovation *outcome:* (1) product innovation if use of digital technology resulted in changes in or new offerings, and (2) process innovation if new elements were introduced in manufacturing operations (following Blichfeldt & Faullant, 2021; Nambisan et al., 2017).

We further noticed that the content of the identified practices of pursuing, discovering, and internalizing was similar across cases, but followed a different temporal pattern related to the specific digital innovation *outcomes*. As we explored possible explanations for this phenomenon, we found that the two temporal patterns and resourcing priorities differed in terms of characteristics of the innovation processes regarding the organizational structure and activities on one hand and customer interactions on the other hand.

Results

We first zoom in on each of the cases and then zoom out to compare similarities and differences between the product and process innovation cases. A more detailed overview of the activities in the resourcing practices can be found in Table 8 and Figures 3a/b. Each resourcing practice consists of an *input, resourcing* activities, and an *output.* Resourcing activities in each practice are numbered and correspond with the numbers of resourcing activities in Table 8 and Figures 3a and 3b.

Table 8: Resourcing trajectories per case with supporting empirical data

PRODUCT INNOVATION		PROCESS INNOVATION	
SaltspreaderCo	**BakingCo**	**CyclingCo**	**MetalCo**
PURSUING (focus: needs well-defined; locus: across organizational boundaries)	**PURSUING (focus: needs well-defined; locus: across organizational boundaries)**	**DISCOVERING (focus: needs ill-defined; locus: across organizational boundaries)**	**DISCOVERING (focus: needs ill-defined; locus: across organizational boundaries)**
Input: customer interested in buying 'de-iced roads' instead of machines: *"That was the project that got everything rolling. The goal there was that the customer just had to push a button to start the de-icing of the roads". (project manager)* 2014	**Input:** Start by extracting data from customers' baking lines *"we started in 2016, just started extracting data from our bakery lines, uploading these data to the cloud, and we're still working on that" (R&D Engineer)* 2016	**Input:** CEO noticed a regional discourse on Industry 4.0 through network, which arouses interest 2015	**Input:** CEO noticed a regional discourse on Industry 4.0 through network, which arouses interest 2014
Resourcing activity P1 Project manager collaborates with external supplier to develop GPS de-icing routes for customer *"A supplier in the Netherlands provided a simulation program, software that lets you calculate routes. They did that for garbage trucks, delivery services, and now for salt spreading vehicles. We asked them to develop routes for us". (project manager)* 2014	**Resourcing activity P1** R&D department starts building the technical infrastructure for the platform themselves, including a simple website and storing product data from customers in the cloud *"The whole infrastructure of the platform, all those functionalities, we were very busy with building those. We had to build a website from scratch, with web pages showing the data, that had to work properly as well". (R&D Engineer)* 2016	**Resourcing activity D1** Management team participates in Industry 4.0 workshop *"Together with a few firms we visited [pioneering firm in digital transformation] to follow a masterclass there. We experienced 3D-printing and used a drone, all that sort of stuff" (external advisor)* 2015	**Resourcing activity D1** Management team visits other manufacturing firms for inspiration on digitalization *"We tried to exchange knowledge with firms in our region via an innovation cluster" (supply chain manager)* 2014
Resourcing activity P2 Project manager has difficulties with external supplier about the GPS route application: *"We tested their routes with the customer and I was not satisfied. It seemed they did not understand me so I stopped the collaboration". (project manager)* 2014	**Resourcing activity P2** R&D department outsources technical infrastructure to supplier: *"In the end, we outsourced the technical infrastructure - gathering data, saving it in the cloud, hosting the website, an external party started doing that for us in 2018. That way we could focus more on configuring the data". (R&D Engineer)* 2018	**Resourcing activity D2** Management team envisions possible end goal for process innovation: a digital factory incorporating digital twinning technology: *"We would like to develop a virtual copy of our factory connected to the entire manufacturing process. Ideally, this virtual copy can be used for establishing new production plants in other locations". (CEO)* 2015	**Resourcing activity D2** CEO attends work groups with other manufacturing firms of metal industry for digitalization *"This industry, the metal industry, meets each other via the platforms of [branch organization]. Usually we get together with 50 to 100 firms of which most CEOs know and trust each other". (CEO)* 2014

Table 8: Continued

Resourcing activity P3 Project manager sets up collaboration with a freelancer (supplier) *"Well, I decided to give it a shot and further develop the routes with a freelancer". (project manager)* 2014	**Resourcing activity P3** R&D department goes back to customers - we have data, what functionalities do you want to see? - did not work... *"We made the data available to our customers and thought - if we show them we have so many data, our customers will start asking questions and start figuring out things they want to do with the data [...] But that was not how it worked - the customer just wanted ready to use functionalities". (R&D Engineer)* 2018	**Resourcing activity D3** Management team invites futurologist *"Well, unknown makes unloved right, so we invited a futurologist to show everyone that the world is changing, and we have to change along with it [regarding digitalization]" (CFO)* 2015	**Resourcing activity D3** CEO and engineers explore digitalization possibilities with knowledge institute and suppliers *"Together with a knowledge institute in the region and some employees we started exploring a digital infrastructure with five suppliers" (CEO)* 2014
Resourcing activity P4 Project manager developing route application with freelancer and tests this with customer *"Together with the freelancer we started developing technical solutions for issues in the spreading routes". (project manager)* 2014	**Resourcing activity P4** R&D department decides to operationalize performance of bakery lines dashboard and tests this with customers *"We stepped in with the R&D team and started building a dashboard that showed our customers their operational performance in simple figures" (R&D Engineer)* 2018	**Resourcing activity D4** Actors visiting and being visited by other manufacturing firms for new perspectives on digitalization of process *"Let other firms visit you, your firm can learn a lot from that. Exchanging knowledge by letting them visit you, you'll get a lot of feedback, but you learn from that, if they look at your production process. From machine experts in particular" (CEO)* 2015	**Output**: technical resource: concrete idea of digital technologies that could be implemented towards digital factory 2014
Output: technical resource: ability to extract data from salt spreading vehicles in pilot project 2014	**Output:** technical resource: ability to extract data from baking lines and present this in dashboard for a few customers 2018	**Output:** technical resource: concrete idea of digital technologies that could be implemented towards digital factory 2015	
DISCOVERING (focus: needs ill-defined; locus: across organizational boundaries)	**DISCOVERING (focus: needs ill-defined; locus: across organizational boundaries)**	**INTERNALIZING (focus: needs well-defined; locus: within organization)**	**INTERNALIZING (focus: needs well-defined; locus: within organization)**
Input: technical resources to extract data from salt spreading vehicles in pilot project with customer as basis, but actors realise that scaling up implies reconfiguring the organizational structure and work processes *"To structure that, you have of course the technical side, but, on the other hand, there's also the reconfiguration happening in the organization"* (CEO) 2014	**Input**: technical resources to extract data from baking lines and present this in dashboard for a few customers as basis, but actors do not know how to scale this up 2018	**Input:** technical resource: concrete idea of digital technologies that could be implemented towards digital factory as basis 2015	**Input:** technical resource: concrete idea of digital technologies that could be implemented towards digital factory as basis 2014

Table 8: Continued

Resourcing activity D1 CEO 'stumbles upon' consultant with experience on servitisation projects: *"I met a consultant, who was very much focused on servitization. He had already done something similar at a manufacturing firm somewhere else. We got to talking and he was surprised that we had developed some services ourselves". (CEO)* 2015	**Resourcing activity D1** Management team in need of someone with a different background than engineers (focused on social skills) to set up reconfiguration of organizational structure and work processes for scaling up sales of services 2018 *"When I got here, there was basically no project, so I was the one who got the ball rolling regarding the transformation". (service manager)*	**Resourcing activity I1** First step towards digital factory (robotics): operational managers getting an understanding of the parts of the 'regular' bike frame that could be robot welded *"We aimed to robot- weld all standard bicycle parts, and we started with the bike frame" (CEO)* 2015	**Resourcing activity I1** First step towards digital factory (robotics): Starting with an internal project to set up digital infrastructure for production 'Sheet21' *"That project, setting up that digital infrastructure, helped with cutting down our lead times. We started informing colleagues about that via WhatsApp and through newsletters" (CEO).* 2015
Resourcing activity D2 CEO collaborating with consultant: *"He helped us to map everything. We act very pragmatically, acting a lot on gut feel. So he helped us structure [the change process]". (CEO) "He [consultant] was basically hired for managing that project, not really the technical side of it, but more implementing that change in the organization" (project manager).* 2015	**Resourcing activity D2** Service manager structures end goal for reconfiguration - selling services as organization's 'business card' *My role is to make sure that the transition towards that end goal runs smoothly. So I'm responsible for the growth, organizational structures, and services that contribute to that" (service manager)* 2018	**Resourcing activity I2** First step towards digital factory (robotics): Management team hires of two specialised welding engineers *"We hired two professionally trained welding engineers, who have a lot of expertise regarding welding. In the end that helps us to create a better product". (operations manager)* 2016	**Resourcing activity I2** First step towards digital factory (robotics): Production employees inspired by supplier suggest implementing robotic pressing brake *"Employees at the pressing department had noticed that one of our suppliers delivered robotic combinations. They wanted to have it, the employees themselves. It enriched their work as well since they started programming the robot themselves" (CEO)* 2015
Output: social resource: change readiness of majority of employees: *"we shared internal newsletters, hosted focus groups. We made it a recurring agenda item for the departmental meetings. Little pinpricks, sharing successes" (CEO).* 2015	**Resourcing activity D3** Management team and service manager struggle with employee team in organization and realizing social knowledge is necessary *"That used to be really challenging - it was a very autistic club. The technicians did not want to know of it, and didn't understand any of it" (CEO)* 2019	**Resourcing activity I3** First step towards digital factory (robotics): Training employees to program or work with robots *"You can see when our people visit those training sessions they make huge leaps forward. They get out of their own world" (CFO)* 2016	**Resourcing activity I3** First step towards digital factory (robotics): Partial changes in the employee team *"We noticed that some of our engineers could not work with the changes, and we transferred these to other departments where they felt more comfortable" (IT manager)* 2016

Table 8: Continued

	Output: social resource: slowly getting ready for change in the organization *"This trajectory, at least to my opinion, does not revolve around products or technical knowledge, now everyone starts to understand this, but the biggest challenge is peoples' mindsets, getting them ready to change" (service manager)* 2019	**Resourcing activity I4** First step towards digital factory (robotics): Management team transferring employees who do not want to work with robotics to repairs department *"Some employees started out as 'cool' bike mechanics could not adapt to their new roles [...] but we're a social organization, the management created a new department for them where they felt at home" (operations manager)* 2016	**Output:** technical resource: robotized operational activity (bending) 2016
		Output: technical resource: robotized operational activity (welding) 2016	
INTERNALIZING(focus: needs well-defined; locus: within organization)	**INTERNALIZING(focus: needs well-defined; locus: within organization)**	**PURSUING(focus: needs well-defined; locus: across organizational boundaries)**	**PURSUING(focus: needs well-defined; locus: across organizational boundaries)**
Input: social resource of change readiness of majority of employees developed with external consultant for managing reconfiguration as basis 2015	**Input:** social resource of change readiness developed with new employee for managing reconfiguration as basis 2019	**Input:** technical resource: robotized operational activity (welding) as basis 2016	**Input:** technical resource: robotized operational activity (bending) as basis 2016
Resourcing activity I1 Actors reconfigure the organizational structure and work processes by establishing a solutions department *"We established a solutions department, and they basically decide what the solution will look like. They are quite strict about that, but that was a necessary development" (CEO).* 2016	**Resourcing activity I1** Service manager develops roadmap with different stages for standardizing services *"Regarding the sales of services we decided that eventually it should make up around 30% of our revenues. That means we will be developing towards level two or level three of servitization in the coming years" (service manager)* 2020	**Resourcing activity P1** Second step towards digital factory (3D-printing): Operations managers doing a 3D print manufacturing project with suppliers *"[In that project] we learned a lot by developing skills for 3D-printing together" (CFO)* 2017	**Resourcing activity P1** Second step towards digital factory (3D-modelling): Engineers involved in 3D modelling project for production with other manufacturing firms *"Together with four manufacturing firms we digged deeper into 3D modelling for production, making use of subsidies provided by our region. That project is still ongoing" (supply chain manager)* 2018

Table 8: Continued

Resourcing activity I2 CEO hires solutions department manager (SDM, new employee) *"I took over part of the portfolio of the hardware delivery manager, so I focus more on the solutions and the digital part. I'm responsible for two consultants, a trainer, a software support employee, and a project manager, and we make sure that we can deliver the solutions to the customer" (SDM)*. 2018	**Resourcing activity I2** Management team realizes new types of employees are needed for sales of services and use of data *"You need people with a different qualification, and data analysts were the people we did not have in our firm. But now we do, and that only gets bigger and bigger" (CEO)* 2020	**Resourcing activity P2** Second step towards digital factory (3D-printing): Operations managers implementing 3D print manufacturing at CyclingCo together with suppliers *"Currently we print quite some plastic parts. For products that we only produce in small amounts, we bought 3D-printers together with our suppliers" (CEO)*. 2019	**Resourcing activity P2** Third step towards digital factory (AI): Operational managers develop capabilities for AI for production in working groups with other manufacturing firms *"In the smart industry working groups, they start focusing on SMEs - a lot of the technologies look beautiful, but are quite difficult to implement for SMEs on their own, like artificial intelligence" (supply chain manager)* 2018
Resourcing activity I3 Solutions development manager standardizes solutions *"We develop different modules that can be combined into a total solution fitting with our customer's needs. The role of our department is to bring down the variety of modules by standardizing them" (SDM)* 2019	**Resourcing activity I3** Service manager expands team for sales of services by hiring new employees *"Over the years, the number of FTEs for the service department increased. I can't innovate when we keep the same number of FTEs, I can't ask my team to start working 150%, so we needed new people" (service manager)* 2020	**Resourcing activity P3** Third step towards digital factory (digital twinning): Chief digital officer and operations managers collaborating with other manufacturing firms in digital twinning project to develop digital twin applications *"Sharing experiences in this digital twin project with other manufacturing firms, both good and bad, is very helpful towards developing our own digital twin applications" (CDO)*. 2020	**Resourcing activity P3** Third step towards digital factory (AI): CEO invests in AI project with other manufacturing firms to develop AI applications *"Together with a few other manufacturing firms we have set up a project where we explored which AI applications could optimize our production process" (CEO)* 2020
Resourcing activity I4 Management team and solutions development manager changing employee team and training employees *"Because of these changes, there are employees that either drop out or that develop themselves; there are employees that can't think in this new way, so people will leave or we will have to hire new employees"(CCO)*. 2019	**Resourcing activity I4** Service manager further standardizes sales of services together with new service department *"Despite COVID, we did quite well - we almost achieved the growth in services we wanted. We see that everyone starts to go in the right direction, and that everyone's mindset is changing" (service manager)* 2020	**Output:** technical resource: manufacturing process with initial digital twinning applications creating further opportunities towards developing a digital factory 2020	**Output:** technical resource: manufacturing process with initial AI applications creating further opportunities towards developing a digital factory 2020
Output: social resource: reconfigured organizational structure and work processes to sell digital services 2019	**Output:** social resource: reconfigured organizational structure and work processes to sell digital services 2020		

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Zooming in: external resourcing for digital innovation processes focused on a *product* outcome

For external resourcing in the digital innovation process focused on a *product* outcome we identified three consecutive resourcing practices: *pursuing, discovering,* and *internalizing.* To illustrate this external resourcing trajectory, we zoom in on the SaltspreaderCo case in more rich detail here than the BakingCo case. The relatively similar resourcing trajectory for BakingCo is described in more detail in the Appendix.

For *pursuing*, the *input* was a customer requesting a service solution based on a vision of de- iced roads at the press of a button, instead of merely buying a salt spreading vehicle. The focal actor was a project manager who explored this request in a pilot project in close collaboration with this customer in 2014.

As first *resourcing activities* related to this pilot project, project members settled on developing technical resources for extracting data from the firm's salt spreading vehicles. Because these were not fully available within the organization, the project manager started his external resourcing by collaborating with a supplier to develop smart driving routes for de- icing roads (P1). Hence, in terms of the *pursuing* practice, there was a relatively clear idea what resources were needed, and the project manager crossed organizational boundaries for developing them. The supplier usually designed smart GPS routes for garbage trucks, which turned out to be easier than developing smart driving routes for salt spreading vehicles: *"For salt spreading vehicles, the routes have to be perfect – it mustn't happen that a vehicle runs out of gas halfway through the route. But they did not understand my concerns, they said they always did it like this" (project manager).* These frustrations led to the termination of this collaboration (P2). The project manager, reorienting the resourcing activities, continued the development of smart driving routes with a freelancer (P3): *"We combined different information sources to create an algorithm that could filter out issues along the spreading route. For example, for our salt spreading vehicles it matters whether a passageway is 4 or 12 meters wide, so we had to be able to filter that information".* Thus, by collaborating with this freelancer the project manager could develop the technical abilities required for the pilot project, which enabled further testing with the customer (P4). Taken together, for this *pursuing* practice, resource needs were relatively well-defined and anticipated upfront, which made that the project manager ended the collaboration with the first supplier, looking for another external actor that was a better fit in developing the required technical resources.

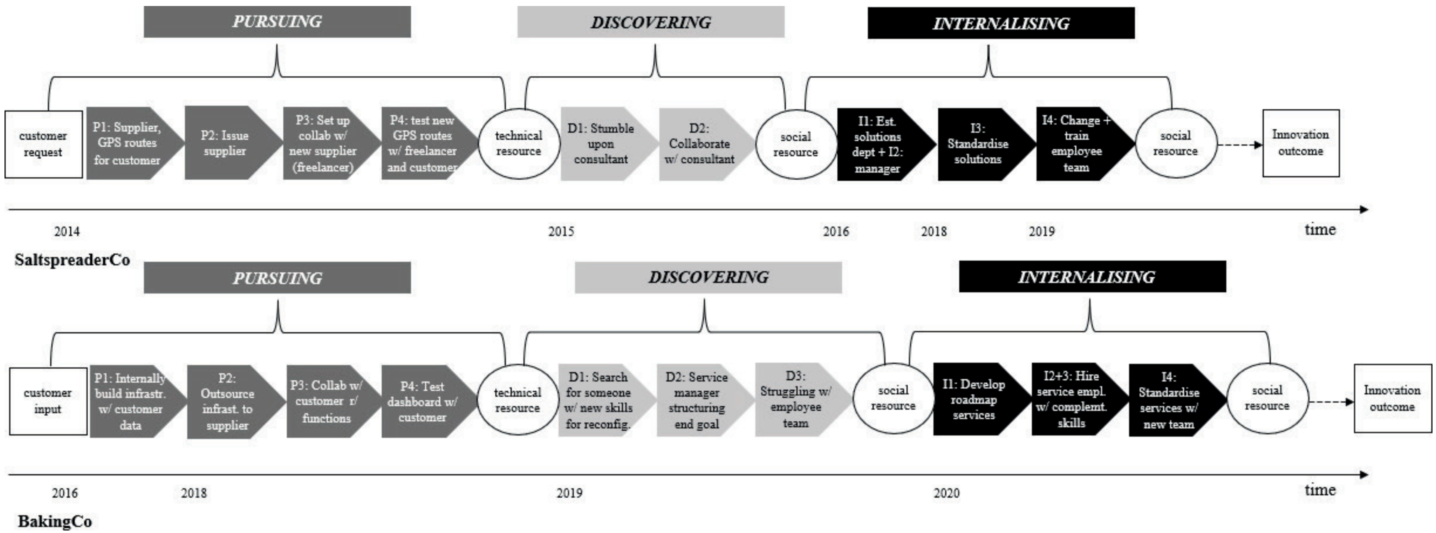

Figure 3a: Timeline product innovation. Circles represent interim inputs/outputs, boxes represent input and final outcome, arrows represent resourcing activities.

3

Hence, these technical resources developed with the freelancer to extract data from their salt spreading vehicles, which could serve as a basis for developing product-service solutions, were the *output* of this practice. Based on this we characterized *pursuing* as resourcing across organizational boundaries aimed at meeting well-defined resource needs.

The *output* of the *pursuing* practice served as *input* for the subsequent *discovering* practice: The successes of extracting product data in the pilot project with the customer sparked the CEO's interest and channeled attention towards the potential of selling services based on product data more broadly. Yet, in attempting to scale up the sales of services, the CEO and other senior managers experienced difficulties in convincing internal employees: *"Of our 200 employees, 90% can only think in nuts and bolts [...] if it's not on paper, it's not there. Well, that's not the case with services based on data extracted from our machines, so that clashed" (project manager).*

Considering *resourcing activities,* these actors started to realize that technical resources alone would not suffice in supporting the transition to selling services. However, it was not really clear to them what they would need to further manage the transition and where to find this. At the same time, the CEO spent a lot of time on developing and maintaining his external network and literally 'stumbled upon' a consultant in 2015. This consultant seemed to have complementary skills, but these could not be specifically pinpointed by the CEO (D1): *"I met a consultant who already supported another manufacturing firm with a servitization trajectory. We got to talking and he was surprised that we had developed some potential services in our pilot project ourselves".* The CEO hired the external consultant, and together started to prioritize the development of social resources by engaging in a dialogue with the employees on the reconfiguration of the organizational structure and work processes by merging the sales and aftersales department (D2): *"There is always tension between the competences and culture of the past [selling 'tough' machines] and selling services, which can hinder this transition [...] We no longer focused solely on content, but started talking with employees about how they could embrace the sales of services. Take a software engineer, he feels comfortable in a completely different environment than the hardware guys. When the new structure [merging sales and aftersales] became clear it gave everyone something they could hold onto" (external consultant).* By collaborating with the external consultant, employees' resistance towards selling services to complement their salt spreading machines gradually decreased. In addition, the management team bit by bit built further experience and skills regarding managing the reconfiguration of the organizational structure and work processes. Taken together, for this discovering practice, resource needs were relatively ill- defined and less anticipated upfront, and their development was largely based on the CEO crossing organizational boundaries. Thus, we characterized *discovering* as resourcing across organizational boundaries aimed at meeting ill-defined resource needs. The resulting *outcome* of the *discovering* practice was a higher change readiness of the majority of employees, which can be referred to as a social resource. This supported the reconfiguration of the organizational structure and work processes, which would have been much harder without the help of the external consultant: *"The employees needed time to 'unfreeze', to warm up to the idea of selling services. During the trajectory, I helped them to get ready for change" (external consultant).*

The social resource developed in the *discovering* practice served as *input* for subsequent *internalizing.* Here existing resources inside the organization were taken as a basis, and together with the previously developed external resources were adapted and made fit for use for the sales of services. Hence, for this *internalizing* practice resource needs were relatively well-defined, and efforts were mainly put into combining resources instead of searching for them. These activities largely took place within organizational boundaries.

After the collaboration with the external consultant ended, the management team's first *resourcing activity* was to effectively merge the sales and aftersales department into a new solutions department (I1): *"We established a solutions department, which is basically in charge of the design of the services and solutions we sell" (CEO).* At its establishment in 2016 the solutions department was managed by the hardware delivery manager, but as the sales of services increased, he could no longer combine his duties. Therefore it was decided to hire a solutions development manager in 2018 (I2): *"I focus solely on the solutions, services, and digital part of the machines" (solutions development manager).* Since an increasing share of SaltspreaderCo's customers was interested in buying solutions, a de-iced road, instead of salt spreading vehicles, requests for solutions became more varied which increased workloads across departments: *"Previously we took on every service request, which then became a pet project in our workshop [...] But that meant starting from scratch every time to develop a solution. So now we are standardizing modules that can be combined into a total solution" (solutions development* *manager).* Thus the solutions development manager started standardizing the solution modules (I3). Despite these developments, part of the employee team changed around 2019, since not everyone could live with the new direction of the firm (I4): *"Most employees enjoy expanding their skills, but some are not able or willing to move along in this new direction. If these employees leave us, we hire new people with the right expertise" (CCO).*

Thus, in the *internalizing* practice, internal actors focused on making the social resources developed with external actors fit with existing internal resources and putting these to further use in the organization, leading to an organization that was better equipped to more frequently sell standardized services. Hence, the resulting *output* of this *internalizing* practice was a social resource: a reconfigured organizational structure and work processes to sell digital services. This *internalizing* practice is characterized by resourcing that takes place within organizational boundaries aimed at meeting well-defined resource needs. Taken together, over the course of the resourcing trajectory, actors' resourcing priorities shifted from technical to social resources, to enable reconfiguring the organizational structure and work processes: *"We used to hire only engineers, even for sales positions, due to their technical expertise [...] but we realized we needed people with a different perspective to help our organization move in new directions" (CEO).*

For BakingCo, the other product innovation case, the external resourcing trajectory unfolded relatively similar: from *pursuing* to develop technical skills to extract data from baking lines for their customers, to *discovering* to develop higher change readiness for the reconfiguration of the organizational structure and work processes required for upscaling the sales of services, to *internalizing*, to integrate previously developed resources and further standardize the sales of services internally. Yet, we identified some nuanced differences in terms of resourcing activities within each practice. For instance, in *pursuing* BakingCo's R&D engineer at times struggled to collaborate with customers in designing functionalities for the dashboard showing operational performance, while for SaltspreaderCo's project manager collaboration with the customer in the pilot project unfolded relatively smoothly.

The outcomes of each of the practices were also similar, with a focus on technical resources in the *pursuing* practice, and on social resources for the *discovering* and *internalizing* practice. Further, the type of external sources for resourcing were comparable, the only difference being that BakingCo's CEO

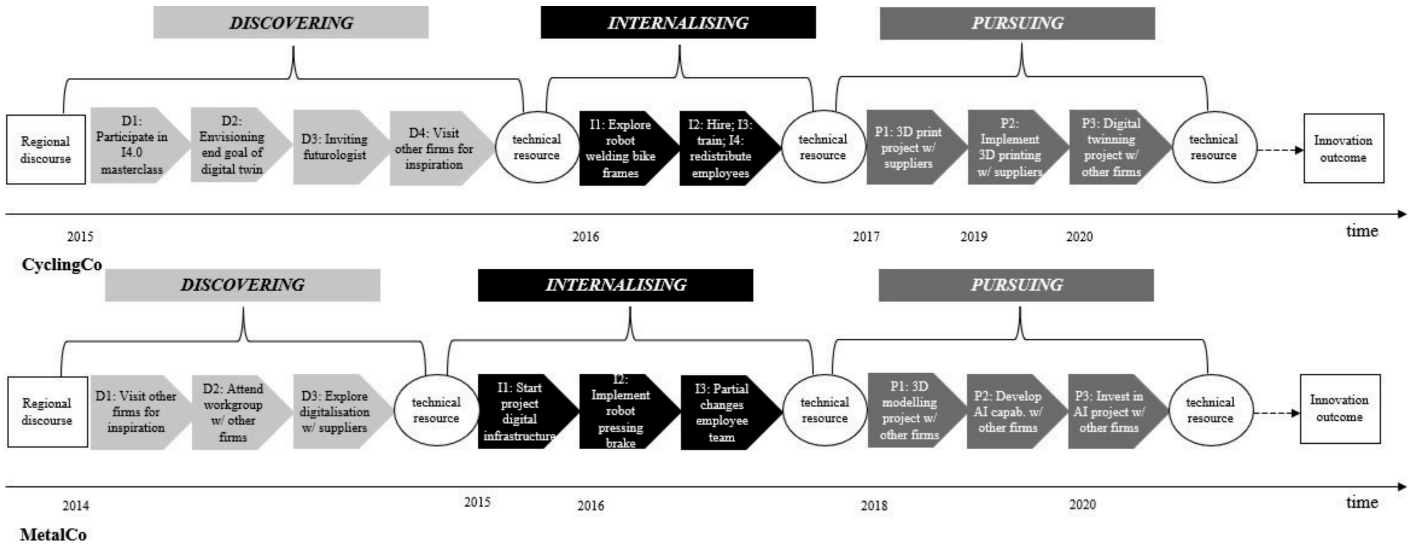

Figure 3b: Timeline process innovation. Circles represent interim inputs/outputs, boxes represent input and final outcome, arrows represent resourcing activities

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hired a service manager in the *discovering* practice, while SaltspreaderCo's CEO chose to collaborate with an external consultant in this practice. However, for both organization's the aim was to bring in a new perspective that might support the development of social resources for reconfiguring the organizational structure and work processes.

Zooming in: external resourcing for digital innovation processes focused on a *process* outcome

For external resourcing in the digital innovation process focused on a *process* outcome we identified the same three resourcing practices but in a different sequence: *discovering, internalizing,* and *pursuing.* To illustrate this external resourcing trajectory, we zoom in on the CyclingCo case in more rich detail than the MetalCo case. The relatively similar resourcing trajectory in the MetalCo case is described in more detail in the Appendix.

In CyclingCo's region, a discourse on digitalization and Industry 4.0 had started to develop around 2015. Through his network, the CEO became aware of this discourse that sparked his interest. This was the *input* for the *discovering* practice.

The *resourcing activities* in the *discovering* practice started with the management team participating in a general workshop in the organization's region focused on the opportunities of Industry 4.0 for manufacturing organizations (D1): *"A sense of urgency was created by participating in that Industry 4.0 workshop. There, we got a taste of all the different aspects of Industry 4.0" (CEO).* Through this workshop, the CEO convinced the rest of the management team regarding the potential of digital technology, and together they started drafting an envisioned outcome for innovating their manufacturing process (D2): *"That digital factory [points to a visualization of CyclingCo's vision] is always on our mind, it is the end goal. We are in the process of slowly working towards it" (operations manager).* To inspire their employees, a futurologist was invited (D3): *"We invited a futurologist who really shook us awake and showed us what the future could look like with digitalization" (CEO).* Furthermore, to craft a more specific image of potential digital technologies that could support them towards their envisioned outcome, actors visited -or were visited by- other manufacturing firms with an interest in digitalization (D4): *"Your own firm can learn a lot by allowing other firms to visit. Exchanging knowledge through these visits can provide valuable feedback, especially if they observe your production process, machine experts* *in particular" (CEO).* The *output* of this *discovering* practice was the relatively concrete idea of digital technologies that could be implemented towards a digital factory. Because this was largely based on technological insights, we consider this a technical resource. For this *discovering* practice at CyclingCo, resourcing needs were ill-defined at first, as actors were intrigued by digital technology but did not know where to start. This pushed actors to first initiate resourcing activities across organizational boundaries and only later discover more concrete opportunities.

The concrete idea of digital technologies that could be implemented towards a digital factory developed under *discovering* served as *input* for the subsequent *internalizing* practice. Here existing resources inside the organization were taken as a basis, and together with the previously developed external resources were adapted and made fit for use for digitalizing operational activities. *Resourcing activities* involved taking a first step towards a digital factory using robotics. Operations managers started experimenting with how the welding of their existing bicycle frames could be robotized (I1): *"As a starting point, we took the existing frame and described the specific hand-welding steps. We explored how far we would get with that, having the same type of frame welded by a robot" (operations manager).* Based on this experimenting, the management team hired two specialized robot welding engineers for programming the robots (I2): *"They have a lot of robot welding expertise. That really helped us to create a better robot-welded frame" (operations manager).* Production employees were then offered technical skills training to learn how to operate the robots to weld the bicycle frames (I3). Several employees felt uncomfortable with this development and experienced difficulties in operating the robots. The management team found a way to redistribute these employees to a newly established repairs department, where they could continue their original work of repairing and assembling bicycles by hand (I4): *"The diehard bike mechanics, the real technicians, expressed that with the robotization their job became too boring. So we established a repairs department, and the bike mechanics went there" (CFO).* These *resourcing activities* resulted in an *output,* a robotized operational activity, welding, which we classified as a technical resource. In the *internalizing* practice, resource needs were well-defined since internal actors built on the relatively concrete idea of integrating robotics in an operational activity. Actors mainly operated internally, to confront new and existing resources and digitalize one step in the manufacturing process: welding of the bike frames.

The robotized operational activity developed under *internalizing* served as *input* for *pursuing. Resourcing activities* consisted of internal actors crossing organizational boundaries again to examine which more advanced digital technologies could further optimize production. The second step in further working towards a digital factory was to start experimenting with 3D-print manufacturing, developing virtually modelled sketches for the 3D-printer which could also serve as a basis for digital twinning (P1). Operations managers collaborated with other manufacturing firms, suppliers, and knowledge institutes in a project to implement 3D-printing for small series, since it was too complicated to explore this internally on their own (P2): *"The CEO told me that he wanted both his suppliers and CyclingCo itself to be able to use 3D printers. He invested in this project since he wanted to be a 3D-printing pioneer in his region" (external advisor).* Through collaborating with external actors in this project, CyclingCo was able to implement 3D-print manufacturing in their production process, in particular for small series: *"Currently we print quite some plastic parts. We mainly use it for manufacturing products in small series, using 3D-printers we bought together with our suppliers" (CEO).* Lastly, as a third step towards a digital factory, complementing the implementation of 3D-print manufacturing in 2020, CyclingCo's operations manager and chief digital officer participated in a project with other manufacturing organizations and a knowledge institute focused on developing digital twin applications for production (P3): *"In the digital twin project, we want to learn from other firms' perspectives regarding digital twin technology, and seek to develop ways to implement it into our manufacturing process" (CDO).* Towards the end of this resourcing practice, CyclingCo was still in the process of implementing digital twinning technology in production. Hence, the *output* of *pursuing* was a manufacturing process with initial digital twinning applications, which created further opportunities towards developing a digital factory. We considered this a technical resource. For this practice of *pursuing*, we considered the resource needs as well-defined since actors built further on technical competencies and knowledge they had built up in-house regarding robotics. Following their end goals of a digital factory using digital twinning, they had developed a more concrete idea which external collaborations and resources were required to achieve this. Thus we characterize *pursuing* as resourcing across organizational boundaries aimed at meeting well-defined resource needs. Taken together, over the course of the resourcing trajectory, actors prioritized developing technical resources to overcome their relative inexperience with digital technology at the start of their initiative. Developing social resources also received attention, for instance through establishing a repairs department for employees struggling to accommodate to robot welding, thus dealing with potential resistance, but seemed less challenging and happened internally.

For MetalCo, the other process innovation case, the external resourcing trajectory unfolded relatively similar from *discovering* to develop a concrete idea of the potential of digital technologies through visiting other firms and network events, to *internalizing* to set up a project for a digital infrastructure starting with a robotic pressing brake, to *pursuing* to engage in next steps for the digital infrastructure focusing on 3D modelling and artificial intelligence with other firms and knowledge institutes. Yet, we found some nuanced differences in terms of resourcing activities within each practice. For instance, for *internalizing,* the implementation of a robotic pressing brake at MetalCo was driven by employees from production who wanted to contribute to the digitalization of the production process. In contrast, at CyclingCo, *internalizing* was more top-down, with the management team deciding to start with robot welding the bike frames. The outputs of each of the practices were also similar, with actors predominantly focusing on developing technical resources across the practices. Further, the type of external sources for resourcing were comparable, with actors relying mostly on regional discourse, other manufacturing firms, and knowledge institutes for inspiration and support.

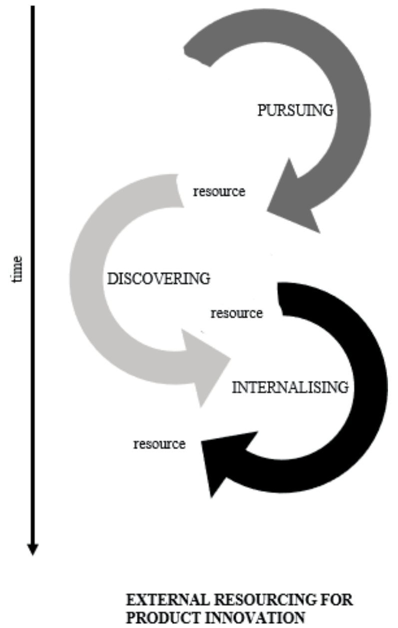
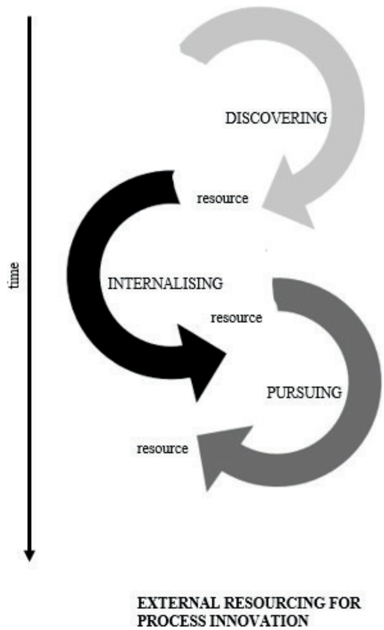
Zooming out: external resourcing for different digital innovation outcomes

Zooming out, we noticed two main differences for the two innovation *outcomes.* First, the same identified practices of *pursuing, discovering,* and *internalizing* aimed at product innovation occurred in a different temporal pattern of *discovering*, *internalizing,* and *pursuing* for process innovation. Second, we also observed that actors who aimed at product innovation prioritized developing social resources in their external resourcing, while actors who aimed at process innovation emphasized technical resources. To develop a deeper explanation for these differences, we further scrutinized the digital innovation processes and identified core characteristics that created affordances and constraints for how actors shaped their external resourcing (see Table 9). These explanations for the differences are described hereafter, at the end two main similarities are explained.

Table 9: Zooming out: cross-case comparison external resourcing for different digital innovation outcomes.

Digital innovation *outcome*	**Product**		**Process**	
Case	**SaltspreaderCo** Smart salt spreading vehicle and services based on its data	**BakingCo** Smart baking line and services based on its data	**CyclingCo** Digital factory using digital twinning technology	**MetalCo** Digital factory using artificial intelligence
Main external sources	Customer Several suppliers External consultant	Customer Supplier Service manager	Regional discourse Several manufacturing organizations Knowledge institute Suppliers	Regional discourse Several manufacturing organizations Knowledge institute Supplier
Characteristics of digital innovation *process*	Interdependent structure of multiple organizational elements was suitable for selling salt spreading vehicles but not for scaling up sales of services. Actors thus reconfigured the organizational structure and work processes by merging sales and aftersales with external consultant, with implications for other departments like production. Interdependence with customers early on in a pilot project helps actors to develop an early validation of selling services based on data of salt spreading vehicles on a small scale.	Interdependent structure of multiple organizational elements was suitable for selling baking lines but not for scaling up sales of services. Actors thus reconfigured the organizational structure and work processes and created a service manager role to organise this holistically with implications for other departments like R&D. Interdependence with customers early on by using customer data and testing functionalities of dashboard helps actors to develop early validation of selling services based on data of baking lines on a small scale.	Envisioning an outcome of a digital factory using happened independently from customers, which made anticipating consequences for customer experience, like product safety, difficult. Independent structure of operational activities organised in steps like welding, coating, and assembling enabled actors to innovate step by step.	Envisioning an outcome of a digital factory happened independently from customers, which made anticipating consequences for customer experience, like product quality and speed, difficult. Independent structure of operational activities organised in steps like cutting, bending, and deburring enabled actors to innovate step by step.

Table 9: Continued

Explains	⇓	⇓
Temporal pattern of external resourcing trajectory	***pursuing***, which yields early validation of the potential of selling services based on product data. This early validation mitigates the potential constraints arising from reorganising the interdependent organizational structure and work processes. ***discovering*** paves the way for putting external resources to use through ***internalising.***	***discovering***. The independent structure of the operational activities enables innovating them independently and ***internalising*** a first step towards the envisioned outcome. Yet this requires further ***pursuing*** to develop external resources for implementing additional steps towards the envisioned outcome.
External resourcing priority	**Social resources** need to be developed to reconfigure interdependent organizational structure and work processes	**Technical resources** need to be developed for continuous incorporation of new technological elements
Visualised overview of temporal patterns		

For the *product* innovation outcome, actors had to deal with an organizational structure and work processes characterized by relatively high levels of interdependence. Both manufacturing firms had to reconfigure multiple organizational elements geared towards manufacturing and sales of products into a structure that would enable the development and sales of a service component at a broader scale. This required reconfiguring the organizational structure and work processes in a holistic fashion by breaking them down and building them up again. For instance, in the case of BakingCo, actors created the role of service manager to reconfigure the organizational structure and work processes as well as to establish a service department: "*What is most* *important is keeping everything together. Selling services is not detached from our data infrastructure, nor is it disconnected from our manufacturing process. It's interconnected in many ways. Maintaining this holistic perspective proved very challenging" (CEO).* This reconfiguration also required a change in mindset across the organization, including the manufacturing department. In addition, actors also experienced high interdependence with customers. In both cases, running pilot projects (SaltspreaderCo) and testing functionalities (BakingCo) in close collaboration with customers early on supported the required reconfiguration of the organizational structure and work processes by showing the potential of selling services on a small scale.

The interdependencies created affordances and constraints for how actors progressed with product innovation and resulted in a specific temporal pattern for and resourcing priority of external resourcing. Interdependence with customers triggered specific requests and led to focused external resourcing through ***pursuing***. This yielded early validations of the potential of selling services based on product data on a small scale and *"really got the ball rolling" (project manager SaltspreaderCo).* These validations and the associated innovation potential laid the groundwork for taking the leap to embrace the innovation and reconfigure the organizational structure and work processes. In BakingCo this was noticeable in an increasing sense of urgency *"Before [experimenting with the dashboard] the sense of urgency in our organization was low. A large part of our employees thought 'what a bunch of morons', they did not understand where this could lead us" (CEO BakingCo).* This materialized in further external resourcing through ***discovering***, in which actors developed the necessary resources for loosening organizational elements and reorienting direction. Here the actors prioritized ***social resources*** because these were not sufficiently available inside. In the words of BakingCo's CEO: *"Our engineers mainly wanted to build machines and they didn't understand all the things [we wanted to develop] around it [...] that's why we brought in the service manager, someone with a different background and a new perspective, to drive progress in this new direction."* Reorienting the direction was supported by the discovering practice and paved the way for further organizational reconfiguration. This was supported by ***internalizing*** by which actors put external resources to further use within the organization.

Thus, in the case of product innovation, the potential constraints that the interdependent structure of multiple organizational elements could bring for progressing in the innovation process, were softened through exploiting customer interdependence early on, which created the affordance through which actors dared to 'take the leap' and reconfigure the organization.

Conversely, overall, process innovation was characterized by relative independence. The envisioned innovation outcome - the manufacturing process - consisted of an independent structure of operational activities, like welding, coating, and assembling in CyclingCo, and laser cutting, bending, and deburring in MetalCo. This independence enabled innovating these operational activities step by step: *"Basically the [operational activities in the] manufacturing process did not change [...] for instance welding the bike frame [...] so the evolution of manufacturing our bicycles in a digitalized way happens in small steps" (operations manager, CyclingCo)*. Furthermore, actors also faced independence with respect to their customers: customers were distant from the manufacturing process, which meant that innovators could not rely on their requests as input for the digital innovation process. As a result, process innovators were unable to anticipate how customers would experience the effects of the envisioned process innovation outcomes on the product before actually trialing them. As the operations manager of CyclingCo reflects, only *"in hindsight [after having implemented robot welding], it delivered a better product"*, showing that actors could only trial consequences for the customer after implementation of a certain technology.

The independent structure of operational activities together with relative independence from customers contributed to a different temporal pattern and resource priority for process innovation compared to product innovation. The triggering regional discourse on digitalization remained relatively abstract to actors, which meant that they had to reach further and engage in external resourcing through ***discovering*** early in the innovation trajectory. This resulted in a specification of what digitalization could mean for the organization and in envisioning an innovation outcome. Then, the relative organizational independence of the operational activities eased the internal innovation process, as it did not require a complete and instant reconfiguration of the manufacturing process as a whole. This supported ***internalizing*** external resources in a first step towards the envisioned outcome. For example, CyclingCo took a first step by *"changing the bike frame to make it suitable for robot welding" (operations manager).* Yet, because this was only a first step in the overall production process, actors had to subsequently turn to ***pursuing*** to secure the required external resources for implementing additional steps: *"We started out really small by digitizing small steps [...] it expanded like a* *piece of patchwork" (CEO, MetalCo)*. Because process innovation required the continuous incorporation of new technological elements, actors prioritized the development of ***technical resources*** in their external resourcing.

So, for process innovation, the core characteristics were the reverse of those identified for product innovation. Customer independence potentially constrained actors in implementing a digital factory, as an envisioned outcome, as actors could not trial implications of such a digital factory for customer experience beforehand. Yet independence of operational activities created the affordance to innovate these activities step by step to trial customer experience after each step.

Our cross-case analysis also identified two similarities in external resourcing for the two types of innovation. First, in both types, *discovering* was followed by *internalizing*, which indicates the importance of connecting newly developed, previously distant external resources with existing internal resources. Connecting with external sources to meet ill- defined resource needs only became fruitful if actors also subsequently sought internal connections for further integration. Here, *internalizing* was required since actors had to connect previously *ill-defined* external resources to the existing internal resource base. These resources are potentially quite distant from those that existed internally. For example, an idea to work towards a digital factory is potentially quite distant from internal actors that are inexperienced in using digital technologies. In their external resourcing actors thus alternated their locus of activities between across and within organizational boundaries, as internalizing external resources was required to put these to use and connect these to the existing resource base in the organization. Second, we found that external resourcing encompassed more than just formal external collaborations. For instance, in the *discovering* practice, external resourcing also included actors being influenced by regional discourse or visiting other manufacturing firms (process outcome) and hiring new employees with a different background (product outcome).

Discussion

While we know that digital innovation in manufacturing SMEs benefits from external resources (Agostini & Nosella, 2019; Ricci et al., 2021), previous studies have paid limited attention to the process by which external resources are identified, developed, and put to use in the organization. Therefore our study aimed to answer the question: *How do actors in manufacturing SMEs engage in external resourcing to pursue digital innovation processes?* We build on Deken et al. (2018), who applied a resourcing perspective to study digital innovation, by specifically zooming in on SMEs and the implementation process beyond the early innovation stages. Our study corroborates their findings that external resourcing is characterized by trial and error, and that resourcing needs and the associated direction of the innovation initiative can be reshaped by both external and internal actors throughout this process, which they call 'prospective resourcing'. Also in our cases, actors did not necessarily know in advance which resources would be most productive for their digital innovation initiative – which only became clearer as resourcing progressed. We complement these findings by identifying three novel external resourcing practices - pursuing, discovering, and internalizing - that are specific to the digital innovation processes of manufacturing SMEs.

These practices provide further detail to the external resourcing process beyond meeting ill- defined resource needs, by also including instances where actors pursue well-defined resource needs across organizational boundaries in more straightforward cases. Furthermore, we unpack how, beyond 'prospective resourcing', actors integrate external resources in the existing internal resource base, to put them to use, through internalizing.

Our findings extend earlier research on digital innovation in manufacturing SMEs in two main ways. As a first contribution, we further unpack the process of digital innovation and how actors shape this process towards different outcomes through their external resourcing. Hereby we connect to previous studies that called for a more processual understanding of digital innovation (e.g., Bogers et al., 2022; Correani et al., 2020). We do so by shedding further light on how the broad orchestration mechanisms of managing boundaries and developing capabilities to leverage digital technologies as proposed by Urbinati et al. (2022) are enacted through *external resourcing* in manufacturing SMEs.

Zooming in, our findings suggest that external resourcing is shaped by 'building blocks' created after each resourcing cycle. These building blocks assist actors in focusing and shaping subsequent resourcing activities. They not only support the development of more clearly defined digital innovation opportunities - which previous studies indicated to be particularly challenging for SMEs (Benitez et al., 2020; Horvath & Szabo, 2019) - but also the gradual progression towards the materialization of these innovation outcomes over time.

Hereby we challenge prior research which identified that SMEs when pursuing digital innovation can be hampered by their less structured and deliberate innovation processes compared to larger firms (Giotopoulos et al., 2017; Pessot et al., 2023; Radas & Bozic, 2012). Although the innovation process was indeed relatively emergent, our findings demonstrate how the building blocks developed through actors' external resourcing efforts provide a sense of structure and enable progress towards innovating products and processes by further shaping and refining the process along the way.

Zooming out, a related finding is that the specific temporal pattern of the external resourcing practices, and therefore large parts of the digital innovation processes, are afforded and constrained by the characteristics in terms of independence and interdependence of what is being innovated. Earlier research had found that having to reconfigure an organizational structure and work processes can constitute a constraint if actors transition from classical product manufacturers to providers of digital innovation enabled solutions (Muller et al., 2018). Our research shows that for product innovation, interdependence with customers can also afford joint experimentation and thereby early validation on a small scale, which supports actors in 'taking the leap' to break down and rebuild the highly interdependent structure of multiple organizational elements. Conversely, for process innovation, we found that envisioning an outcome such as a digital factory happened relatively independently from customers, with actors being triggered by other external sources like regional discourse. This lack of interaction could have constituted a constraint for continuing their innovation initiatives, as they could only trial implications for customer experience after having implemented a digital technology in their operational activities. However, the independent structure of these operational activities afforded actors to push forward: they could innovate their operational activities towards a digital factory step by step, trialing implications for the customer after each step. This connects to earlier studies that have shown implementing basic technologies first can serve as building blocks for implementing more advanced technologies as next steps (Frank et al., 2019; Meindl et al., 2021). We extend these studies by illustrating the external resourcing process through which actors can implement these digital technologies step by step.

Hence, reconciling the 'new' and the 'old' (Oberlander et al., 2021; Vial, 2019) was significantly shaped by working towards a particular outcome. Our findings shed light on how this reconciliation unfolded through specific temporal patterns of external resourcing: from pursuing via discovering to internalizing for product outcomes; and from discovering via internalizing to pursuing for process outcomes. This was by no means an automatic process – it required substantial managerial agency. For instance, actors had to kick-start the initial external resourcing practice, but also had to decide whether and how to proceed based on intermediate resourcing outcomes. This implies that for SMEs that typically do not rely on predetermined innovation processes as they would be too overly structured for them (Giotopoulos et al., 2017), the relatively structured nature of external resourcing affords the development of specific orchestration mechanisms for digital innovation.

Our results also suggest that the characteristics of independence and interdependence shaped specific resourcing priorities. This is a largely overlooked aspect in the literature, which has generally used rather broad terms to underline the social-technical nature of digital innovation (Hund et al., 2021; Lyytinen, 2022), also for manufacturing SMEs (Eller et al., 2020). Our findings indicate that while both types of resources, technical and social, were necessary, actors prioritize them differently: For product outcomes actors prioritized the development of social resources to help them reconfigure multiple interdependent organizational elements, while for process outcomes, they prioritized technical resources to facilitate the continuous incorporation of new technological elements. Our study thus provides a more detailed perspective which type of external resources may be more prevalent in a specific context.

Our second contribution is to further unpack how actors navigate the challenge of connecting newly developed external resources with the existing internal resource base, particularly for manufacturing SMEs. Our processual lens enabled us to provide a more dynamic account of how actors connect external and internal resources to transform their existing resource base, by alternating the locus of their resourcing activities. In doing so, we add to previous research that identified challenges associated with connecting internal to external resources (Moschko et al., 2023; Svahn et al., 2017). In these studies, overemphasizing internal resources hindered the identification of opportunities beyond organizational boundaries, while excessive focus on external resources resulted in disconnecting from established internal practices. Addressing this challenge, Svahn et al. (2017) showed how actors largely relied on a technical solution – Volvo Cloud – to support this connection between external resources and internal practices simultaneously. Our findings instead suggest that for SMEs alternating over time between developing resources externally and internalizing them to connect with the existing resource base can be a fruitful approach to addressing this challenge. Instead of relying on a technical solution, the switch from discovering to internalizing was largely managed by externally inspired choices of senior managers for envisioning process innovations, or through relying on temporally hired outsiders for envisioning product innovations.

Zooming in on the 'external' aspect of the digital innovation process, our analyses suggest that external resourcing can also be afforded by other sources than external collaboration, and that these sources are likely to vary over the course of the innovation process. For example, we found that in the early stages of the process innovation trajectories, external resourcing was based on a more general regional discourse on digitalization and short visits to other manufacturing firms. Another example is hiring new employees with a suitable background, which we found later in the product innovation trajectory. With these findings, we extend previous studies on digital innovation in manufacturing SMEs that have traced the origin of external resources to collaboration partners, like customers, suppliers, and knowledge institutes (Agostini & Nosella, 2019; Benitez et al., 2022), and to the breadth and depth of engagement with these actors (Ricci et al., 2021). Our findings show that actors can also identify and pursue opportunities for digital innovation based on regional discourse, on informal networks, or by bringing in new employees.

Practical implications

Our study offers insights for managers and business practitioners how to overcome the specific challenges for digital innovation in SMEs. Our findings suggest how managers can identify and develop external resources and connect them to existing internal resources. Especially early on, digital innovators may get inspired and acquire complementary knowledge through external activities. The downside of this is that their actions become almost invisible for other employees of the firm, which can lead to the *'not invented here'* syndrome and jeopardise the digital innovation initiative. To avoid this, managers should involve other members of the organization in the digital innovation process to ease the implementation of the external resources.

SMEs typically do not have overly structured innovation processes. Approaching external resourcing as a process of discovering, pursuing, and internalizing can provide managers with a sense of structure without the burden of a very formalized innovation process. Our findings suggest that it makes sense to align these practices with the firm's predominant type of innovation: process- or product-oriented. The type of innovation can also have implications for the type of external resources that may become most relevant for the innovation process. For transitioning from manufacturing products to also selling digital services, our findings suggest managers need to develop social resources either internally or externally. For implementing a digital factory, managers will need to continuously develop technical skills and expertise to implement with emerging digital technologies.

Our findings also indicate that external resourcing encompasses more than formal collaborations. Managers can also gather inspiration by visiting other firms, drawing on regional discourse, or attending events in their network. This may potentially be a more accessible way for managers in SMEs to explore digital innovation opportunities without having to set up formal collaborations immediately.

Limitations and future research

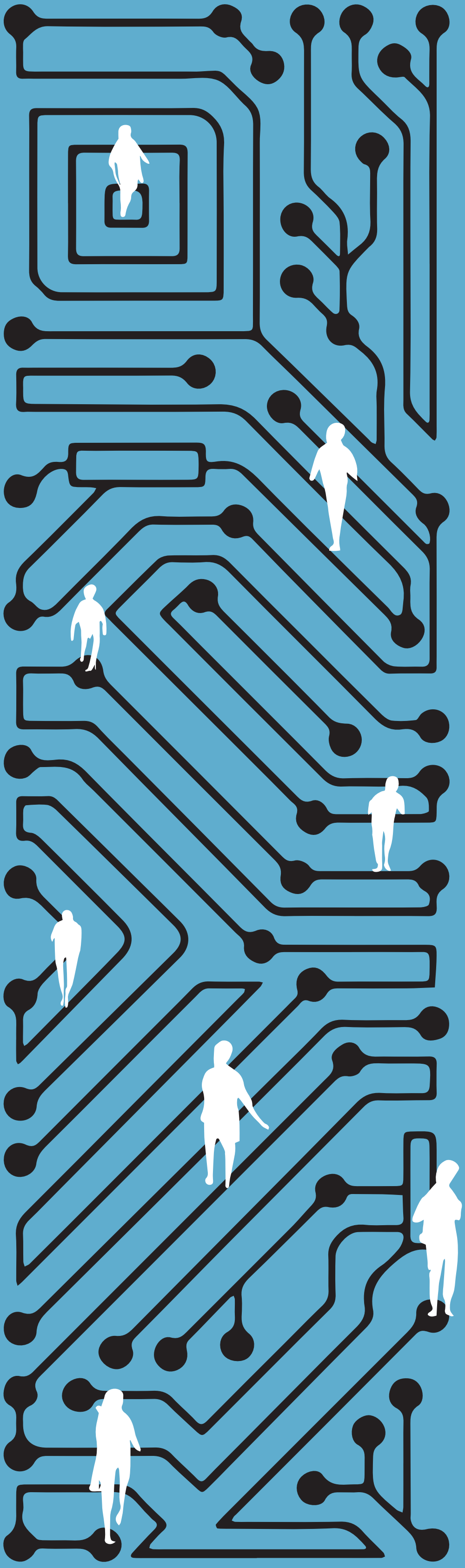
As every study also our research is not without limitations to be addressed in future research. First, we studied four manufacturing SMEs within the Dutch context that were all part of the same geographical region, the eastern part of the Netherlands. While these four SMEs were suitable for studying actors external resourcing in pursuing various digital innovation outcomes, our specific context may result in possible limitations in terms of generalizability of our findings. Future research could address a broader set of companies from different regions and sectors.

Second, although previous studies in the digital innovation context suggest interrelations between product and process innovation (Blichfeldt & Faullant, 2021), for our data it made sense to distinguish between product and process outcomes, because the focus on different product innovation *outcomes* was important for steering actors' resourcing needs and activities. Understanding the underlying characteristics of these outcomes helped us uncover the specific temporal patterns and resourcing priorities. Future research could further investigate the interrelations between product and process innovation and how these drive one another.

Third, we combined interviews with documents and company visits to trace activities as part of the external resourcing practices for digital innovation. Although previous resourcing studies (e.g., Nigam & Dokko, 2019) have shown that these data are suitable for tracing resourcing activities, we acknowledge that future research could enhance these data by adding real-time observations.

Conclusion

In this study, we explored how manufacturing SMEs engage in external resourcing to pursue digital innovation. Drawing on a resourcing perspective, we identified three distinct but interconnected resourcing practices – *pursuing, discovering,* and *internalizing* – that helped actors shape their resourcing needs and the direction of the innovation initiative throughout the process. The sequence and priorities in these practices differed depending on the innovation outcome actors pursued: either product or manufacturing process oriented. With our findings, we contribute to the literature on digital innovation by unpacking how manufacturing SMEs can navigate challenges they frequently face in their innovation processes. We show that the relatively structured nature of external resourcing helped actors to progress towards their innovation outcomes through intermediate resources that served as building blocks, despite having less experience in managing structured innovation processes as indicated by previous studies. In addition, our findings illustrate how SMEs can overcome challenges related to connecting externally developed resources to the existing internal resource base by alternating the locus of resourcing activities over time. We hope our contributions stimulate further research into digital innovation processes in manufacturing SMEs.



4.

Unlocking the potential of intermediary-based collaboration to support manufacturing SMEs' digital innovation: The constitutive role of digital technology's hybrid materiality

Abstract

Due to the complexity of emerging digital technologies, manufacturing firms are increasingly seeking support for their digital innovation initiatives outside of their organizational boundaries. Intermediary organizations in particular have been forwarded as being able to provide valuable support for these manufacturing firms' digital innovation initiatives. However, while previous research has highlighted the positive role of intermediaries in this regard, our understanding of why such collaborations sometimes fall short of expectations remains limited. Drawing on a sociomateriality perspective, this study explores the intertwining of digital technology and social actors within intermediary-based collaborations. Focusing on a Dutch field lab where manufacturing firms and an intermediary organization explored the potential of digital twinning technology for product and process innovation, we observed the emergence of dynamic sociomaterial practices over time. Our analysis reveals three interrelated practices: emphasizing the digital realm, making sense of the hybrid realm, and nurturing the hybrid realm. Our findings suggest that effective digital innovation depends on actors' ability to engage with the hybrid materiality of digital technology. While emphasizing the digital realm can lead to disconnecting from technology's physical materiality, which was detrimental to innovation, practices that embrace hybrid materiality enabled effective responses to material and social challenges and enabled innovation. We contribute to digital innovation literature by highlighting the constitutive role of digital technology's hybrid materiality. In addition, we offer insights for the intermediaries literature, suggesting the need to design collaborative spaces that facilitate proximity to physical artifacts to unlock the full potential of collaborative efforts. Overall, our study offers a more nuanced understanding of these intermediary-based collaborations, shedding light on both supportive and detrimental practices for fostering digital innovation in manufacturing firms.

Keywords

digital innovation, digital twinning, hybrid materiality, sociomateriality, intermediary-based collaboration

Introduction

Manufacturing firms operate in a world that is increasingly permeated by digital technology (Bailey et al., 2022; Hund et al., 2021; Stanko & Rindfleisch, 2023; Yoo et al., 2012). The use of these digital technologies offers unprecedented opportunities related to product, manufacturing process, and business model innovation (Blichfeldt & Faullant, 2021; Bogers et al., 2022; Nambisan et al., 2017). Digital technologies are characterized by the integration of digital capabilities into objects which previously had a purely physical materiality (Yoo et al., 2012). For example, Tesla developed a digital twin for each of its electric cars leaving the factory, to enable data transfer between the car and Tesla's factories. By analyzing real-time vehicle data, the electric car's battery can be optimized according to their usage to enable larger sustainability and resource efficiency (Coors-Blankenship, 2020; van Dyck et al., 2023).

Recent studies show that digital innovation, driven by the uptake of these digital technologies such as robotics, digital twins, artificial intelligence, and additive manufacturing, can positively affect the performance of manufacturing firms (Blichfeldt & Faullant, 2021; Liu et al., 2023). However, it also poses significant challenges, due to, among others, the complexity and distributed nature of these digital technologies that underlie digital innovation (Bailey et al., 2022; Ghobakhloo & Iranmanesh, 2021; Hund et al., 2021). For example, manufacturing firms may not have sufficient knowledge, resources, or competencies in house to engage in digital innovation on their own (Bogers et al., 2022; Urbinati et al., 2022). Thus organizations are increasingly driven to seek support for their digital innovation initiatives outside their organizational boundaries (Moschko et al., 2023; Svahn et al., 2017).

Intermediary organizations, in particular, have been forwarded as being able to provide valuable assistance to firms in their digital innovation initiatives (Abi Saad et al., 2024; Holland et al., 2024; Rossi et al., 2022). For example, these intermediaries can provide resources, advice, and services, and at the same time facilitate the development of partnerships and networks within and across industries (Caloffi et al., 2023; Gredel et al., 2012). Also in practice the potential value of intermediary organizations to support digital innovation has been recognized. For instance, in the Dutch context, national and regional governments endorse the establishment of 'field labs' where manufacturers can experiment with digital technology, exchange best practices, receive advice and services, and obtain further support in partnership development

(Stolwijk & Seiffert, 2016; Stolwijk & Willems, 2019). Field lab evaluations have shown that these settings can indeed increase awareness among participating manufacturing firms about the potential benefits of utilizing digital technologies for product and process innovation (see e.g., Grond et al., 2021). However, they also found that the realization of digital innovations related to smart products or digital factories at the participating firms remains limited due to the heterogeneity of manufacturing firms experimenting in these field labs, for instance since they differ in digitalization levels, and these field labs' focus on specific technologies, such as digital twins, robotics, or artificial intelligence, that do not always fit manufacturing firms' current digitalization needs.

So far, to our knowledge, the literature on intermediaries does not provide an explanation as to why these collaborations, such as these Dutch field labs (Grond et al., 2021), do not always reach their full potential in supporting firms' digital innovation. Instead, these studies mainly demonstrate the positive role that intermediary organizations play, among others, through facilitating partnership development and providing advice and resources (Abi Saad et al., 2024; Holland et al., 2024; Rossi et al., 2022). However, in other contexts, scholars have shown that engaging in collaborations with multiple actors can add a layer of complexity (e.g., Dionne & Carlile, 2024; Hilbolling et al., 2022). As a result, our understanding of how manufacturing firms and intermediaries collaborate for digital technology implementation to achieve product and process innovation remains rather one- sided. One possible explanation for this may be that these studies primarily consider digital technologies as contextual factors, rather than recognizing them as constitutive elements of the collaborative dynamics between participating manufacturing firms and intermediary organizations. Yet, often these intermediary-based collaborations center around specific digital technologies, such as artificial intelligence (Holland et al., 2024) or the Internet of Things (Rossi et al., 2022). Thus, viewing these technologies as core to the collaborative process may provide a more nuanced understanding of the practices that support the digital innovation process of manufacturing firms, as well as those that may be less supportive or even detrimental.

To this end, we draw on a sociomateriality perspective, which argues that technology cannot be reduced to a contextual factor, since its materiality is deeply enmeshed or imbricated with social practices in its creation and use (Cecez-Kecmanovic et al., 2014; Leonardi, 2011; Leonardi et al., 2019; Orlikowski

& Scott, 2008, 2014). Also in relation to emerging digital technologies, such as digital twinning, scholars addressed the need for a more relational view of how these intertwine with social actors in practice (Bailey et al., 2022; 2019). In other words, the practices these technologies enable or constrain, such as innovating products or processes, are dependent upon not only the components of the technology, but also on the people who deploy them in their work. Thus, this implies a shift in thinking from acknowledging digital technology's impact on organizational practice, towards recognizing that it plays a central and constitutive role in the organizing process (Bailey et al., 2022; Barrett et al., 2012; Lebovitz et al., 2022; Waardenburg et al., 2022; Yoo et al., 2012).

Therefore, drawing on this perspective we focus on sociomaterial practices, which refer to a space where social actors, such as participants in an intermediary-based collaboration, and material artifacts, for instance digital twinning technology, interact and imbricate (Cecez- Kecmanovic et al., 2014; Leonardi, 2013). This may enable us to get a more nuanced understanding of which practices in these intermediary-based collaborations may be supportive of and/or detrimental to digital innovation in participating manufacturing firms. Against this background, we ask *how are digital technology and social actors intertwined in practice in an intermediary-based collaboration, and how do these practices affect digital innovation?*

Our empirical setting involved a Dutch field lab, which brought together four manufacturing firms and a knowledge institute, acting as an intermediary organization. Together these actors investigated the potential of digital twinning technology for product and process innovation. The manufacturing firms were heterogeneous in terms of their existing digitalization levels, as well as the type of digital twin they focused on, which was either product or process focused. As these firms lacked prior experience with digital twinning technology, we were able to observe the emergence and evolution of sociomaterial practices over an extended period of time in collaborating with the intermediary. Viewing digital twinning technology as a central component, we developed a process model that illuminates how the hybrid materiality of this technology was at the core of driving collaborative dynamics as well as the progress of developing digital twin applications. The process model visualizes three dynamic sociomaterial practices: *emphasizing the digital realm, making sense of the hybrid realm,* and *nurturing the hybrid realm.* Our findings suggest that only through making sense of and nurturing the hybrid realm, actors could adequately respond to material and social challenges to enable digital innovation of products and processes. In contrast, emphasizing the digital realm hindered effective innovation since actors operated relatively disconnected from the physical materiality of the technology.

Our research mainly contributes to digital innovation literature. We advocate to not only acknowledge the constitutive role digital technology plays in innovating products and processes, but to more specifically account for the key role of the technology's *hybrid materiality* in this process. In particular, our findings suggest that in case actors overemphasize emerging technologies' digital materiality, this may lead to significant material and social challenges which are detrimental to innovation of products and processes. More generally, our study also has implications for the literature on intermediaries. We provide a more nuanced understanding of the supportive role intermediaries can play, by also unpacking practices that can be detrimental to firms' progress towards innovating products and processes. In doing so, we also provide a possible explanation for why intermediary-based collaborations in the Dutch context do not always flourish. Our findings suggest that, to unlock the full potential of these collaborations, intermediaries need to engage with technology's hybrid materiality and refrain from overly emphasizing digital aspects. This may be achieved, for instance, through designing the collaborative space in a way that enables at least temporary proximity to physical artifacts.

Theoretical background

A sociomateriality perspective on digital technologies and innovation

In the manufacturing industry, digital innovation has been recognized as an important driver of competitive advantage (Blichfeldt & Faullant, 2021; Liu et al., 2023). It concerns the creation of new products, manufacturing processes, or business models through the use of digital technology (Hund et al., 2021; Nambisan et al., 2017). Thus, digital technologies are considered to be at the heart of digital innovation, with their implementation unlocking the potential to increasingly digitalize products, processes, and business models (Bailey et al., 2022; Ghobakhloo & Iranmanesh, 2021; Hund et al., 2021). More generally, these technologies incorporate digital capabilities into objects that previously only had physical materiality (Yoo et al., 2012). Physical materiality refers to artifacts that are visible and tangible, difficult to alter, and evoke a sense of place and time, while digital materiality refers to the capabilities of software incorporated into physical artifacts to manipulate digital representations, such as virtual models or simulations (Leonardi, 2010; Yoo, 2013). For instance, McLaren partnered with Deloitte and Dell to place over 300 sensors on their Formula 1 racing cars, collecting a trove of big data to help construct a digital representation of both the car on the race track and the driver inside it (McLaren, 2020). In this case, a car is no longer solely composed of physical materiality, but is constantly in close relation to and influenced by a digital representation, reflecting its digital materiality, also known as a digital twin.

We focus on digital twinning technology as an exemplary representation of both types of materiality. Digital twinning technology involves a real-time synthesis of the physical and digital worlds, consisting of three main components: a physical object, a digital replica, and a connection between the two (Fukawa & Rindfleisch, 2023; Parrott & Warshaw, 2017). Here, twinning refers to the synchronization of the physical with the digital which is enabled by the two entities sharing data reciprocally (van Dyck et al., 2023). For manufacturing firms, digital twinning technology can facilitate effective decision-making, optimize manufacturing systems, and support the development of new products and services (Tao et al., 2018). It is an emerging digital technology that is still in an early stage of development (Fukawa & Rindfleisch, 2023). Digital twinning has received increased interest in practice, with a number of leading firms, such as Tesla, employing it (Coors-Blankenship, 2020). Also in digital innovation literature, scholars have started to explore characteristics of this technology and its potential for innovation in the manufacturing industry (Fukawa & Rindfleisch, 2023; van Dyck et al., 2023). Digital twins are often most easily associated with physical products (Haag & Anderl, 2018; Porter & Heppelmann, 2014), yet according to Fukawa and Rindfleisch (2023) they can also be used to digitally replicate a physical process. Based on this, these authors develop a digital twinning typology, distinguishing between product-focused and process-focused digital twins. A product-focused digital twin involves digitalizing a physical product or service, such as an automobile, and ensuring a real-time connection to this physical product that can optimize its performance. In contrast, a process- focused digital twin encompasses the digitalization of the process of developing and manufacturing a product or service, such as the activity of prototyping or assembling an automobile.

Furthermore, these digital technologies, such as digital twinning, not only consist of their digital and physical materialities, but are also inherently social (Bailey et al., 2022; Hund et al., 2021; Yoo et al., 2012; 2010). In applying a sociomateriality perspective, we argue that these material and social components are intertwined in practice (Cecez-Kecmanovic et al., 2014). This perspective is underpinned by a relational ontology which assumes that "the social and the material are inherently inseparable" (Orlikowski & Scott, 2008, p. 456). Orlikowski and Scott (2008) propose sociomateriality as an alternative to dominant approaches that assume technology, work, and organizations should be conceptualized separately. Instead, sociomateriality forwards the view that there is inherent inseparability between the technical and social.

To provide an example of the inherent separability between the technical and social, we refer to a series of papers by Orlikowski and Scott (Orlikowski & Scott, 2014, 2015; Scott & Orlikowski, 2014). The authors compared two systems for generating hotel reviews and ratings: The British Automobile Association (AA) and Tripadvisor. They aimed to examine the production of knowledge in digital social-media platforms compared to more traditional review methods in the hospitality sector. The AA, representing the traditional approach, relies on professional inspectors to review and rate hotels, who follow relatively stable routines and standards set by the association. In contrast, Tripadvisor reviews and ratings are produced by a blend of people and algorithms, with routines changing and being enacted dynamically over time. Through this comparison, the authors illustrate how specific relationships between the social and material produce diverse meanings and knowledge, influencing reviewers, hospitality services, and market dynamics accordingly. In particular, the Tripadvisor example shows how technology, in this case the social-media platform, is not a neutral tool but actively shapes and is shaped by social practices. Thereby it provides an often used example illustrating how the sociomateriality perspective considers the intertwined relationships between social practices, technologies, and organizational outcomes.

Thus, sociomateriality research is dedicated to studying how technologies, work, and organizations are connected through recursive intertwining. Within the sociomateriality tradition, the relational basis of the original proposal by Orlikowski and Scott has also triggered numerous counterviews and competing proposals (Faulkner & Runde, 2012; Leonardi, 2012; Mutch, 2013). For example, in contrast to Orlikowski and Scott (2008) who view the social and material as inherently inseparable, Leonardi (2012, p. 34, 42) considers the materiality of technology as independent of people, persisting across space and time, while presenting specific affordances and constraints for people using technology. We thus acknowledge that various ways of thinking coexist under the umbrella of sociomateriality. However, beyond recognizing that sociomaterial accounts on organizing adopt different ontological positions, our main takeaway from this perspective is to consider the co- constitution of the social and material and the performative role technologies play in organizing, instead of viewing technologies as neutral tools (in line with Cecez-Kecmanovic et al., 2014).

In this vein, numerous works in the sociomateriality tradition have shown across different contexts how technology's materiality is closely intertwined with social *practices* during its creation and use (Jones, 2014; Lebovitz et al., 2022; Leonardi, 2011; Leonardi et al., 2019; Venters et al., 2014; Waardenburg et al., 2022). Studying the intertwining of technology, work, and organizing *through practice* received increased attention within this tradition (Cecez-Kecmanovic et al., 2014; Leonardi, 2013; Orlikowski, 2007), following the more general *practice turn* in organization studies (Feldman & Worline, 2016; Feldman & Orlikowski, 2011; Nicolini, 2012). Sociomaterial *practices* refer to the space where social actors and material artifacts interact and influence each other, which Leonardi (2011) conceptualizes as imbrication. This approach is based on the idea of performativity, indicating that both the social and the material are created through practices. In this way, material entities, such as technologies, and social actors are performed and continuously brought into being through recursive practices (Orlikowski, 2010).

Although many previous works in this tradition have explored how sociomaterial practices can drive organizing, usually less emphasis is put on distinguishing between the physical and digital materialities that are inherent in digital technologies. In particular in relation to emerging digital technologies, such as digital twinning, this hybrid materiality, i.e., the constitutive relation between digital and physical materiality, seems important. The study by Barrett et al. (2012) is one of few which explicitly recognizes digital and physical elements as two distinct forms of materiality embedded in a robotics innovation. During the implementation process, software changes could rapidly alter the digital aspects of the robot, while mechanical changes to the robot's hardware took multiple months to complete. This demonstrates the importance of considering the dynamic interrelationships between digital and physical materialities and workplace practices, which has the potential to provide a more nuanced view of the digital innovation process.

In sum, we join emerging voices (e.g., Bailey et al., 2022) which advocate for renewed attention towards the central and constitutive role digital technology plays in the organizing process. In line with this, we adopt a sociomateriality lens and pay specific attention to the hybrid materiality of digital twinning technology and its enactment in and interrelation with social practice. Centralizing this hybrid materiality of digital technology may enable us to get a more nuanced understanding of practices that are potentially supportive or detrimental to manufacturing firms' digital innovation initiatives. Since digital innovation is a complex and increasingly distributed process that requires firms to rely on the support of external actors (Bogers et al., 2022; Hund et al., 2021; Moschko et al., 2023; Svahn et al., 2017), we examine these sociomaterial practices in the context of intermediary-based collaborations.

Role of intermediaries in manufacturing firms' digital innovation

Firms are being encouraged to engage in external collaborations to support their digital innovation initiatives (Nambisan et al., 2017; Vial, 2019). In particular, intermediary-based collaborations have received increased attention in both academia and practice due to their potential to support firms' digital technology use to innovate products and processes.

Intermediaries are organizations that support firms in the context of innovation (Dalziel, 2010). In the simplest sense, these organizations facilitate collaborative exchange between two or more parties during various stages of the innovation process (Abi Saad et al., 2024; Lin et al., 2020). The literature on intermediaries acknowledges that there is no single organizational form that can be considered typical for an innovation intermediary. Rather, there are various types of organizations that perform innovation intermediary functions, including public actors, private actors, or a combination of both (Caloffi et al., 2023; Howells, 2006). Intermediaries can support firms' innovation initiatives either directly or indirectly (Gredel et al., 2012). In terms of direct support, intermediaries can assist firms in improving their resources, competencies, and capabilities for innovation (Caloffi et al., 2023; Wright et al., 2008). For example, if firms lack knowledge and competencies for innovation, intermediaries can help them become aware of their needs and provide access to relevant information and training. Relatedly, indirect support involves creating connections between actors in different firms and facilitating and coordinating collaborative processes (Caloffi et al., 2023; Clayton et al., 2018). Intermediaries can potentially bridge differences in knowledge and competencies of collaborating firms (Colovic, 2020), which in turn facilitates knowledge exchange between these firms (Klerkx & Leeuwis, 2008; Leckel et al., 2020).

More recently scholars have begun to examine the potential role of intermediaries in supporting firms' *digital* innovation initiatives, particularly those related to technologies such as artificial intelligence and the Internet of Things (Abi Saad et al., 2024; Holland et al., 2024; Rossi et al., 2022). In general, these studies confirm that intermediaries can play a crucial role in supporting firms' digital innovation by providing direct and indirect support, such as transferring knowledge and providing resources, and building and facilitating a collaborative ecosystem. However, these studies also show that for digital innovation in particular the role of intermediaries is becoming increasingly dynamic. For example, in response to emerging issues and challenges related to digitalization, intermediaries adapt their activities, expertise, and services accordingly (Abi Saad et al., 2024). Instead of merely coordinating or brokering between players that provide or need technological solutions, they have started to create intricate networks of players to solve increasingly complex problems (Rossi et al., 2022).

In line with the growing academic interest, intermediary organizations are also recognized in policy and practice as potentially valuable means to support digital innovation in manufacturing firms. For example, in the Dutch context, an increasing number of publicly or publicly and privately funded 'field labs' provide direct support for manufacturing firms' digital innovation by offering advice, knowledge transfer, and services. These field labs also indirectly contribute to fostering partnership development (Stolwijk & Seiffert, 2016; Stolwijk & Willems, 2019). Field labs typically concentrate on specific digital technologies, such as artificial intelligence, the Internet of Things, robotics, or digital twinning technology. They are comparable to intermediaries that focus on digital innovation in the broader European context, such as digital innovation hubs (Stolwijk & Butter, 2015). Evaluations of these field labs (Grond et al., 2021) have shown that despite potentially increasing manufacturing firms' awareness about digital technologies' potential for innovation, the realization of smart products or digital factories remains limited.

Following recent recommendations to consider digital technology as being central to organizing (Bailey et al., 2022), we argue that applying a sociomaterial approach may enable a better understanding of how technology and social actors together shape the unfolding of intermediary-based collaborations. In tracing these sociomaterial practices we may be able to get a more nuanced view of how these facilitate or impede digital innovation initiatives within the manufacturing firms involved. At the same time, this may help us to develop a deeper understanding of intermediaries' actions that may be less supportive in promoting digital innovation.

Method

Since the way social and material entities become intertwined is challenging to anticipate a priori, observing the dynamics of how this unfolds should help identify important relations (Bailey et al., 2022). To trace how sociomaterial practices evolved throughout an intermediary-based collaboration, we adopted a qualitative process approach. This approach enabled us to identify ways in which these practices supported or hampered digital innovation. Further, a process approach is particularly useful because it focuses on the emergence, development, growth, or termination of practices over time (Langley et al., 2013). Additionally, tracing sociomaterial practices over an extended period has previously been shown to be valuable in studies focused on hybrid materiality in digital innovation (e.g., Barrett et al., 2012).

Research setting

The empirical setting for this study is an intermediary-based collaboration in the Dutch context: a field lab. In the Netherlands, over fifty publicly- or publicly and privately funded field labs have been established, each focusing on a specific digital technology. The aim of these field labs is to enable manufacturing firms to experiment with and develop knowledge around digital technology to promote innovation (Stolwijk & Seiffert, 2016; Stolwijk & Willems, 2019). The field lab included in our research focused on digital twinning technology.

The digital twinning field lab was initiated by an interdisciplinary group of researchers from a Dutch knowledge institute. We refer to this actor group as the intermediary organization. The field lab collaboration involved four manufacturing firms: Medcorp, a supplier and producer of medical X-ray tubes and image processing solutions; Bikecorp, a manufacturer of adapted bicycles for people with disabilities; Truckcorp, a producer of forklift trucks; and Minecorp, a manufacturer of trucks and mobile equipment for the heavy industry, specifically aluminum mining. The intermediary organization required that the manufacturing firms had an interest in developing digital twinning applications either for their products or processes, that the firms were no competitors of each other, and were located in the same region. The intermediary organization also included a relevant technology partner responsible for providing licenses for digital twinning software which the manufacturing firms could use throughout the collaboration.

The intermediary and manufacturing firms obtained funding for the field lab for a period of two years from a regional development agency and an industry-specific (metal industry) branch organization. The field lab aimed to strengthen the innovative and competitive position of the manufacturing industry in a particular Dutch region by focusing on digital twinning technology, according to the field lab grant application. The goal for the manufacturing firms was to develop, experiment with, and jointly learn from digital twinning applications. The intermediary organization was also expected to benefit from this development by gaining shared knowledge on digital twinning applications to further educate researchers and students (field notes, Nov '21).

The field lab served as a revelatory case (Yin, 2014) that allowed us to observe in real- time how digital twinning technology intertwined with social actors over time in this intermediary-based collaboration. Digital twinning technology is characterized by its hybrid materiality, which allowed us to analytically distinguish between the physical and digital materiality embedded in this technology. Thus, selecting this particular case enabled a more transparent observation of the phenomenon of interest (Pettigrew, 1990).

Data collection

In line with our process approach, we relied on various data sources, including observations, interviews, and documents. Data collection began in March 2021, prior to the official launch of the field lab. The intermediary secured public funding for the field lab from September 2021 to 2023. Therefore, our data collection continued until September 2023 when funding ceased. We were able to observe the unfolding of sociomaterial practices in real-time, from the beginning of the field lab until the termination of funding, by having full access to meetings and activities. This enabled us to reconstitute the evolving present (Langley, 2007). An overview of the collected data can be found in Table 10.

Observations. The primary data source were field notes based on the first author's observations of meetings between the intermediary and participating manufacturing firms, between intermediary organization researchers, and other relevant field lab activities.

Observing these meetings and activities provided us with an overview of the most important interactions between the different actors and helped us trace how the collaboration progressed over time. The manufacturing firms involved were geographically dispersed within a region, and meeting locations alternated across these different locations. The first author visited each of the manufacturing firms multiple times. These visits included multiple tours of their production facilities. Attending meetings and activities and visiting firms provided opportunities for informal conversations, building rapport with involved actors, and connecting with actors who were later invited for interviews. Observations of meetings, other activities, and informal conversations were documented in field notes, which were typed up daily (Emerson et al., 2011). The field notes contained rich descriptions and the first author's reflections and emerging interpretations. In total, we observed meetings and other activities for over 200 hours during a 27-month time frame.

Interviews. To complement our observational data, we conducted semi-structured interviews (Patton, 2002) with actors representing the various firms and the intermediary. We followed a snowball approach to ensure that we interviewed all key actors involved in the collaboration. In total, we conducted 25 interviews, each lasting between 30-90 minutes. We interviewed informants for each of the organizations involved in the field lab. All interviewees agreed to voice recording for verbatim transcription. During the interviews, we asked actors to reflect on milestones and bottlenecks they experienced during the collaboration, for instance related to sharing knowledge between the manufacturing firms or to the development of digital twinning applications within their respective firms. In addition, we asked the manufacturing firms to reflect on their motivations for participating in the field lab and the challenges they experienced *within* their organizations during their participation.

Documents. We also collected different types of documents, including 450 email conversations, 248 internal documents that were only shared among the participating actors such as funding applications and results from co-creation projects, and 28 public documents such as press releases, blogs, and articles on websites or in newspapers. The documents contained factual data that helped us trace event histories (Langley et al., 2013), including timestamps of events and opinions from actors both inside and outside of the field lab.

Table 10: Data overview

Data source	Data	Specification
Observations	*Observations:* 200 hrs of meeting and field lab activities observations. *Field notes*: around 200 pages *Multiple company visits and tours* of each of the included manufacturing firms	*Observations of:* Weekly meetings intermediary organization Quarterly meetings between CEOs and intermediary organization Quarterly knowledge sharing sessions between senior managers and intermediary organization (later on monthly) Additional meetings between individual manufacturing firms and intermediary organization Quarterly meetings to present field lab progress to funding organizations Demonstrations of field lab results open for non-participating manufacturing firms in the region
Interviews	*Semi-structured interviews:* 25 with key informants, ranging from 30-90 minutes. *Additional informal interviews* (unrecorded) with, among others, technology partner, intermediary representatives, data engineers for each of the manufacturing firms, and all informants from semi-structured interviews	*Interviewees semi-structured interviews:*Intermediary organization: 1. Project manager 2. Founder digital twinning project 1 3. Founder digital twinning project 2 4. Researcher digital twinning 5. Researcher digital twinning software 6. Support officer relationship management 7. Administrator digital twinning project Medcorp: 1. CEO (2x) 2. Senior manager digitalization (2x) 3. Project manager digital twinning (2x) 4. Production engineer 5. Operations manager 6. Development / R&D engineer Bikecorp: 1. CEO 2. CDO (2x) 3. Operations manager 4. Development / R&D manager Truckcorp: 1. Senior manager digital twinning project (2x) Minecorp: 1. Senior manager digital twinning project (2x)
Documents	*Email conversations:* over 450 conversations (including multiple emails per conversation) *Internal documents*: 248 *Public documents:* 28	*Internal documents*: e.g., powerpoints, progress reports, subsidy application *Public documents:* e.g., press releases, public interviews, news articles

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Data analysis

Our analysis commenced early during data collection and became more focused over time, following an iterative process of sensemaking by alternating between data, emerging interpretations, and relevant literature, which is recommended for theory building (Locke, 2000). The authors less involved in data collection took an outsider perspective, critically reflecting on and challenging the first author's initial hunches. Furthermore, as a team we critically discussed emergent findings to substantiate our theorizing (Locke et al., 2008).

We systematically analyzed our data in multiple steps. An overview of the different steps in our analysis are represented in Table 11. Following best practices for process theorizing (e.g., Langley, 1999), we wrote a rich case narrative and a related timeline of events to capture 'what' happened, 'when' it happened, and 'which actors' were involved. Events were identified by tracing back, through documents, field notes, and interviews, and by following forward, through observations and interviews, starting at the moment we entered the field (Langley, 2007).

Based on the case narrative and event list, we used temporal bracketing (Langley, 1999) to identify different phases that formed our units of analysis. We paid specific attention to how the roles of the intermediary organization and manufacturing firms evolved, to challenges that the intermediary and/or manufacturing firms encountered throughout collaborative activities, and to the progress of developing digital twinning applications. We then refined these initial topics and categorized them into sensitizing concepts, relating to either the social or the material realm. Based on this we identified three temporal brackets: (1) *intermediary organization setting up field lab boundaries,* (2) *struggling to collaborate within field lab boundaries,* and (3) *reconfiguring field lab boundaries towards collaborating bilaterally.* In the first phase, from March 2021 to December 2021, the intermediary organization initiated co-creation projects between the manufacturing firms, students, and intermediary organization researchers and knowledge sharing sessions between the manufacturing firms to discuss experiences, challenges, and best practices arising from the co-creation projects. During the second phase, from January 2022 to January 2023, the manufacturing firms faced challenges in their co-creation projects and encountered difficulties in sharing knowledge and experiences with the intermediary and other firms, which hampered progress towards developing digital twinning applications. The third phase, from February 2023 to September 2023, was marked by a transition to bilateral collaborations between the intermediary and individual manufacturing firms. The number of knowledge-sharing sessions was significantly reduced, and actors mainly collaborated at the space of their home organizations which spurred progress of developing digital twinning applications.

We then engaged in zooming in and out on the identified phases, following recommendations by Nicolini (2009; 2012). This approach has already been shown to be valuable in the sociomateriality tradition (Cecez-Kecmanovic et al., 2014). In zooming in, we focused on the characteristics of the temporal brackets in terms of their prevalent social and material challenges and how these unfolded within each phase. We identified two social and two material challenges: frustration regarding modes of collaboration, mainly related to meeting rhythm and spaces, and knowledge and experience sharing difficulties (social realm); lack of shared understanding of components of digital twinning technology and lack of progress towards developing digital twinning applications (material realm). Within each of the temporal brackets, these social and material challenges varied in terms of how pressing or evident they were perceived to be by the involved actors.

In zooming out, we noticed that social challenges became increasingly pressing and only started to diminish when actors opted to collaborate bilaterally with the intermediary at the space of the home organization. In addition, material challenges became less pressing over time due to developing a better understanding of digital twinning and its related components. These emerging insights further shaped our theoretical understanding of the constitutive role of digital twinning's hybrid materiality in this process, and resulted in the identification of three overarching sociomaterial practices: *emphasizing the digital realm,* in which actors mainly focus on digital aspects of the technology; *making sense of the hybrid realm,* in which actors start temporarily confronting both physical and digital aspects of the technology, and *nurturing the hybrid realm,* in which actors continuously confront physical and digital aspects of the technology. As a final step, we zoomed out further to trace connections between these dynamic practices over time, as local practices do not stand on their own but are rather affected by other practices removed in space and time (Latour, 2007; Nicolini, 2009). This resulted in the development of a process model illustrating the shaping role of digital twinning's hybrid materiality, which is presented in Figure 5.

Table 11: overview of phases and sensitizing concepts in analysis

	Phase 1: Intermediary organization setting up field lab boundaries
Time period	March 2021 - December 2021
Actors involved	Researchers and support staff of intermediary organization; mainly CEOs of Medcorp, Bikecorp, Truckcorp and Minecorp
Dominant coordinating actor	Mainly intermediary organization

	Phase 1
Social realm: collaboration related concepts	
Social challenge: Manufacturing firms' frustration regarding modes of collaboration, mainly related to meeting rhythm and spaces	**Medium:** CEOs and senior managers indicate that they may not always be able to attend quarterly meetings, due to other priorities and geographical distance to field lab
Social challenge: Knowledge and experience sharing difficulties between manufacturing firms	**Medium**: knowledge sharing is limited to sharing software issues experienced by the manufacturing firms. However, in this phase actors do not experience the limited knowledge sharing as an issue yet.
Material realm: technology related concepts	
Material challenge: Lack of shared understanding of components of digital twinning technology among manufacturing firms	**High**: digitalization levels, type of digital twin (product or process) and definition of digital twinning differ per participating firm
Material challenge: Manufacturing firms' lack of progress towards developing digital twinning applications	**High**: no progress is made towards developing digital twinning applications, firms experience issues with licensing of software which inhibits simulation and virtual modeling

	Phase 2: Struggling to collaborate within field lab boundaries	**Phase 3: Reconfiguring field lab boundaries towards collaborating bilaterally**
	January 2022 - January 2023	February 2023 - September 2023
	Researchers and support staff of intermediary organization; mainly senior managers of Medcorp, Bikecorp, Truckcorp and Minecorp	Researchers and support staff of intermediary organization; mainly senior managers of Medcorp, Bikecorp, Truckcorp and Minecorp
	Partial shift from intermediary organization towards senior managers of manufacturing firms	Mainly senior managers of manufacturing firms
	Sensitizing concepts used in analysis	
	Phase 2	Phase 3
	High: senior managers express frustration about quarterly meeting rhythm being not fast-paced enough to deal with urgent issues regarding the development of digital twinning applications. Actors decide to alternate meeting locations monthly.	**Low:** senior managers decide to drastically reduce the amount of joint activities at the field lab, and instead focus on collaborating bilaterally with the intermediary at the space of their individual home organizations, relatively isolated from the field lab space and the other manufacturing firms.
	High: senior managers of Truckcorp and Minecorp express lack of enthusiasm to attend knowledge sharing sessions. Intermediary organization and senior managers of Medcorp and Bikecorp reiterate potential value of sharing issues and experiences. Intermediary and senior managers decide to continue and make the sessions more interactive, linked to a particular issue, and include visits to the production plants of the individual firms.	**Low**: Senior managers' decide to terminate knowledge sharing sessions between firms and instead focus on bilateral collaborations with the intermediary. Intermediary organization can better tailor input to the needs of the individual firms, thus drastically reducing issues in sharing knowledge.
	Medium: intermediary organization identifies differences in definitions of digital twinning between the manufacturing firms. Intermediary initiates joint sensemaking of definition and components of digital twinning technology by relying on visual examples and the ISO-23247 manufacturing standard	**Low**: due to making sense of definition and components of digital twinning in the previous phase, actors realize more proximity to the physical objects being twinned, at the space of the home organization, is required.
	Medium: visiting each of the firm's production plants and discussing digital twinning issues at each of the individual firms provides senior managers with new perspectives on simulation and virtual modeling related to the tangible products and processes at each of the individual firms.	**Low**: collaborating bilaterally with the intermediary at the space of the individual home organizations to ensure close proximity to the objects being twinned results in tangible digital twinning applications at Medcorp, Truckcorp and Bikecorp in particular.

Social and material challenges in the digital twinning field lab

Phase 1: Intermediary organization setting up field lab boundaries

Apart from the researchers representing the intermediary organization, the parties involved had only limited or no prior experience with digital twinning technology. Therefore the intermediary organization suggested potential modes for collaboration within the field lab, particularly regarding the collaboration space and rhythm. These activities were enacted in the proposed way during this first phase of the collaboration.

In terms of collaboration space, the intermediary organization and Medcorp established a physical meeting room dedicated to the field lab at Medcorp's location. This space served a dual function, as it was both intended as a collaborative space isolated from day-to-day-business activities, and as a demonstration space to showcase digital twinning applications that were finished or being refined. Further, the intermediary organization proposed to initiate the development of digital twinning applications through co-creation projects with students. Five separate co-creation projects were conducted in parallel, each focused on a different application for the respective manufacturing firms.

Regarding the rhythm of the collaboration, these co-creation projects typically lasted six months, aligning with the semester scheduling of the involved students. The intermediary organization suggested four consecutive rounds of projects for the duration of the field lab collaboration. To share issues, developments, experiences, and best practices as these co- creation projects unfolded, the intermediary organization proposed to organize knowledge sharing sessions between the senior managers and intermediary once every three months.

Further, the intermediary organization suggested organizing meetings between the CEOs once every quarter to discuss the progress of the collaboration on a strategic level and explore possibilities for continuing the field lab after funding ceased. Additionally, the researchers representing the intermediary organization met weekly to discuss the daily operations and activities of the field lab.

The field lab was launched during the COVID pandemic and the introductory meeting between the CEOs of the manufacturing firms had to be organized virtually:

The meeting begins with the CEO of Medcorp giving a brief introduction to the other CEOs and the intermediary organization: *"The intermediary approached us with the idea of establishing a field lab focused on digital twinning some time ago already. The capabilities of this emerging technology can help us to further digitize and optimize our manufacturing processes and products. While we can choose to do this independently, I believe that by working together, we can accelerate our digitalization efforts by learning from one another.* The CEOs of the other manufacturing firms introduce their respective organizations and their digital twinning goals. Truckcorp's CEO states that they aim to use digital twinning technology to develop virtual models of their trucks in the field for predictive maintenance and improved customer service. These models may also inform their manufacturing process. Minecorp's CEO responds that *"the goals of Truckcorp are similar to our own. We aim to utilize data from our aluminum mining trucks to simulate and optimize performance, ultimately providing better services for our customers.* Bikecorp's CEO explains that they plan to use digital twinning technology primarily for their manufacturing process, creating a virtual copy of their factory linked to the entire manufacturing process. Ideally, this virtual copy of their factory can be utilized for establishing production plants in various locations. Medcorp's CEO ends the introductory round stating that *"our company aims to virtually simulate the prototyping process for our collimators [part of X-ray machine], in order to reduce research and development costs".* To conclude the meeting, the intermediary organization asks the CEOs about their initial impressions of the field lab collaboration. All CEOs respond positively. Truckcorp's CEO is excited about the potential synergies between the manufacturing firms and the opportunity to learn from each other's experiences. Bikecorp's CEO shares this sentiment and wants to start helping and learning from each other. Minecorp's CEO is enthusiastic about embarking on a digital twinning journey with their employees, the intermediary, and students. (field notes, December '21).

The excerpt from the meeting observation indicates that the manufacturing firms were enthusiastic about the collaboration but had different objectives for utilizing digital twinning technology. In particular, Truckcorp and Minecorp were focused on developing simulations of their trucks in the field, which we identified as product-focused digital twins. In contrast, Bikecorp focused on the development of a digital factory, and Medcorp on developing simulations of their prototyping process, thus we identified both these companies as focusing on developing process-focused digital twins.

During these initial meetings, we observed that the actors primarily concentrated on the virtual aspects of digital twinning by gathering data from their processes or products. Using the collected data, they experimented with data simulation and virtual modeling, facilitated by the intermediary organization and involving students. In sharing their experiences, actors mainly focused on the difficulties they encountered in setting up and using, and connecting the various provided software licenses in order to enable the development of simulations and virtual models:

> *"At Medcorp we are still preoccupied with setting up the required software. The collaboration with the technology partner runs smoothly, yet it is more difficult than expected to get the right licenses and make the programs accessible for everyone" (senior manager Medcorp)*

> *"We are exploring the potential of gaming software applications, which may provide us with more optimal virtual models compared to more standard applications" (senior manager Minecorp)*

> *"We experience problems with the software licenses provided by the technology partner. With the license currently provided by the technology partner, we are unable to connect the software to our own digital platforms" (senior manager Truckcorp)*

> *"It is more challenging than previously anticipated to get the software applications for the field lab running" (intermediary organization researcher)*

In almost solely focusing on these digital aspects, we observed that actors spent little time on discussing the interrelated physical components of the technology. By meeting in the collaborative space at the field lab, actors literally created distance between themselves and the products and processes the digital twins were intended to represent. As a result, in this phase, the physical materiality of digital twinning technology received far less attention.

Instead, actors mainly emphasized its digital materiality through their extensive focus on data, software, and virtual modeling. This was reflected by the material challenges actors faced, in terms of not making any progress towards developing digital twinning applications and being stuck at struggling with software issues, and the different digitalization levels, goals for, and definitions of digital twinning existing within the participating manufacturing firms. Social challenges were less prevalent. We observed that CEOs and senior managers did indicate it could be potentially difficult to attend all meetings organized in the field lab, and knowledge sharing was limited to sharing difficulties experienced with software licensing, but actors did not yet experience this as problematic.

Phase 2: Struggling to collaborate within field lab boundaries

During the second phase, social challenges became more pressing, and actors started acting on the experienced material challenges. The senior managers started to express the issues they encountered within the field lab collaboration. For example, in terms of material challenges, they continued to face issues with software licenses provided by the technology partner, which hindered the progress of the co-creation projects and knowledge sharing between firms. Further, in terms of social challenges, the rhythm proposed by the intermediary organization, with three-monthly meetings, did not align well with the rhythm of the manufacturing firms. The firms preferred more short-term responses to deal with urgent issues with the digital twinning applications for which the help of students or the support of the intermediary organization was not always adequate or available. To illustrate, the senior manager of Bikecorp shares his experiences with the first round of co-creation projects:

> *"Perhaps we did not adequately explain the concept of digital twins to students. That may explain why the start of the projects was so challenging. My colleagues, the researchers, and I are mainly responsible for getting the students on the right track, as they cannot be expected to make valuable contributions to developing applications right away. One question that remains is how to transfer the knowledge gained by students in one co-creation project to the next one, without having to start again from scratch. This is especially important given the constant state of flux we are in as an organization, independent of the contributions made by the students. To accelerate the actual development of a virtual model of our machines, it would be useful to explore*

how we can transfer knowledge from one project to the next. This would reduce the amount of time my colleagues and I spend educating students about digital twins, allowing them to contribute immediately to the virtual modeling."

This passage illustrates that the senior managers spent a significant amount of time bringing students up to speed in the co-creation projects, which detracted from virtual modeling and simulation efforts. Although the projects supported the intermediary's goal of familiarizing students with digital twinning technology, the senior managers made little progress in developing applications. Instead, we observed that the senior managers began addressing pressing issues outside of the co-creation projects on their own.

The limited progress within the co-creation projects also hindered knowledge sharing between the manufacturing firms. The senior managers expressed that the focus on different types of digital twins, whether product or process related, further inhibited this knowledge sharing, which was also recognized by the intermediary organization's researchers:

"We focus on different things in the co-creation projects [distinction between product and process digital twin]. This makes it difficult to connect with each other to share your experiences" (senior manager Bikecorp)

"Within the field lab, I think we are most similar to Truckcorp, both in terms of our product and that both our organizations focus on developing a digital twin of it" (senior manager Minecorp)

"The types of digital twins differ substantially – Truckcorp and Minecorp focus on digital twins of their product, while Medcorp and Bikecorp develop process digital twins. These differences beg the question of how we can best share and integrate knowledge between the firms" (IO researcher)

Although the intermediary and manufacturing firms recognized these differences in digital twins for products and processes, we observed that there was still a lack of shared understanding regarding the definition of a digital twinning and its constituent elements:

> *"In theory, a digital twin interacts in real-time with a physical object and a virtual model. However, our definition of a digital twin differs. We collect data to optimize our manufacturing process, so we do not aim for real-time interaction between our machines and virtual models." (senior manager Bikecorp)*

> *"It seems we do not really agree on what defines a digital twin. We often do not go beyond discussing digital shadows, while digital twinning encompasses more than a digital shadow" (senior manager Truckcorp)*

> *"We already have a digital twin of our product, by storing data that we collect from our bikes in the field. That is why we wish to focus on developing a virtual copy of our manufacturing process now" (senior manager Bikecorp)*

The manufacturing firms thus did not agree on the definition of digital twinning. As reflected by the quote from Truckcorp's senior manager above, actors slowly began to realize this themselves. Collecting data from physical objects, such as products, machines or processes, is only the first step towards developing a virtual model of an object that can automatically interact with and optimize the physical object in real-time.

This observed lack of shared understanding of digital twinning technology was one of the material challenges actors faced, which potentially contributed to the limited progress within the co-creation projects and the difficulties experienced in sharing knowledge between firms (social challenge). The intermediary's researchers also started to recognize this:

> *"Currently, the firms are only focusing on developing digital shadows. It seems they do not fully understand what constitutes digital twinning. They are not working towards actually twinning their products or machines." (intermediary organization researcher).*

The intermediary's researchers chose to utilize the ISO-23247 manufacturing standard as the foundation for defining digital twinning and explained this to the senior managers, using a visual example of a car's digital twin (Figure 1) to establish a shared understanding of digital twinning technology. Thus, in this way, actors started to address this material challenge. Our observations showed that the concept of digital twinning was explained by an intermediary organization researcher as a physical object, such as a machine, entire manufacturing process, or product, being linked to a virtual model through sensors that collect data from the physical object. This virtual model can then be used to influence the physical object and adapt its activities and performance. As shown in the visual example, both types of materiality were highlighted by the intermediary organization's researcher: physical materiality, represented by the car, and digital materiality, represented by the virtual model of the car. Additionally, the 'twinning' process was demonstrated through the real-time connection between the virtual model and the car (indicated by arrows), allowing the virtual model to optimize the performance of the physical object.

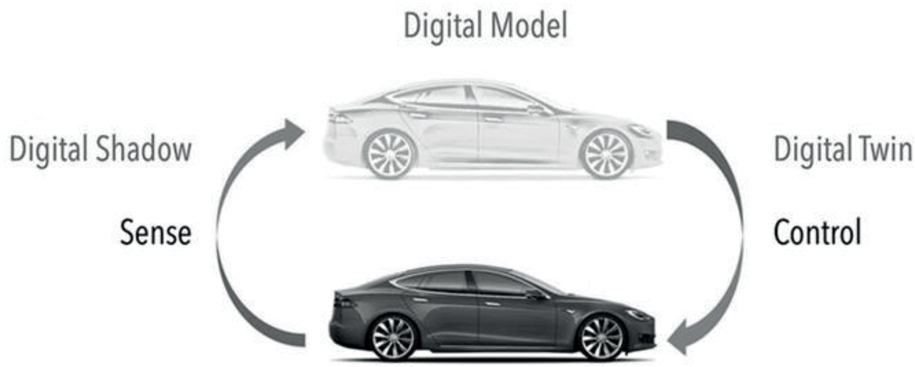


Figure 4: Visual example used by intermediary organization to identify different components, both physical and digital, of digital twinning technology.

This exercise supported the actors in making sense of the influence of digital twinning's hybrid materiality: the virtual model (digital materiality) cannot be developed decoupled from the physical object (physical materiality), which requires proximity to the manufacturing site. Instead of focusing solely on developing virtual models and discussing software, the intermediary organization and senior managers began to consider how to change collaboration practices to ensure closer proximity to the physical objects, in this way starting to address the hybrid materiality of digital twining:

The senior managers of Truckcorp and Minecorp are uncertain about how to proceed with the development of digital twinning applications within the field lab. Truckcorp's manager expresses that he faces difficulties in generating enthusiasm among colleagues, as many prefer to stick to business as usual and do not see the urgency of the digital twinning project. Minecorp's senior manager shares this sentiment: *"We run into similar issues, developing an actual digital twin of our product seems something for the long-term future".* They are interrupted by the senior managers of Medcorp and of Bikecorp, who advocate that sharing experiences, good or bad, is useful for learning from each other. However, Medcorp's senior manager suggests that to enable more interactive sessions, improvements need to be made: *"For instance, the knowledge sharing session could commence with a tour of the hosting company and a brief overview of their current challenges and best practices. This can be followed by an interactive discussion on a predefined topic, centered around a digital twinning issue that all participants have experienced or can relate to".* The intermediary and senior managers decide to align meeting locations with the predefined topic, thus alternating meeting spaces between the manufacturing firms. If one of the companies has already resolved a shared issue, they should host the session. The host firm may then be able to provide concrete examples of proposed solutions. The intermediary and senior managers then shift their focus to discussing challenges related to the co-creation projects with students and intermediary organization researchers. Bikecorp's senior manager notes that *"due to the requirement of submitting problem descriptions for co-creation projects six months in advance, it is difficult to anticipate whether the project will involve pressing issues related to digital twinning application development. Due to our organization's dynamic nature we often have already found a solution for a pressing issue ourselves before the project starts".* The other senior managers confirm that the co-creation projects usually address less pressing issues. The intermediary organization and senior managers agree to decide on the contents of the co- creation projects at the actual start, instead of half a year beforehand, to ensure that these address interesting, timely, and urgent topics to enable further development of digital twinning applications for each of the firms. (field notes, November '22)

As this meeting excerpt shows, actors decided to meet in alternating spaces to connect to the physical objects for which the digital twins were being developed. In addition, the pace of knowledge sharing sessions was increased to better match the short-term orientation of manufacturing firms. In this way, by confronting digital twinning technology's hybrid materiality, collaboration practices gradually changed, and actors started to deal with the pressing material and social challenges. The frequency of collaboration increased from quarterly to monthly meetings to facilitate more rapid knowledge sharing, in this way addressing the social challenges experienced by the manufacturing firms. Additionally, the intermediary organization and senior managers attempted to better connect with the physical materiality of the digital twin by alternating collaboration spaces. We observed that although actors were not always physically present near the product or process for which the individual firms attempted to develop a digital twin, getting a concrete understanding of the production plants and products of each firm served as an inspiration for the senior managers. In addition, sharing best practices and discussing issues each of the firms encountered helped firms in their individual co-creation projects, gaining new perspectives on how to tackle digital twinning related issues.

Phase 3: Reconfiguring field lab boundaries: towards collaborating bilaterally

This phase began with a meeting between the group of senior managers and the intermediary organization at Medcorp. The managers expressed their preference to significantly reduce the number of collaboration activities in the field lab after having visited each of the individual manufacturing firms for experience sharing and inspiration. As a result, the boundaries of the field lab were reconfigured and emphasis shifted to bilateral collaborations between the intermediary organization and individual manufacturing firms. The senior managers began refining their digital twinning applications internally in collaboration with the intermediary at their respective home organizations instead of at the space of the field lab. This was driven by the need for continuous proximity to the physical objects being twinned, which were their processes for Bikecorp and Medcorp, and their products for Truckcorp and Minecorp. Further tailoring collaboration practices to the individual organization’s needs accelerated progress in the development of digital twinning applications. Specifically, Medcorp, Truckcorp, and Bikecorp started progressing towards actually implementing digital twinning applications, sharing their experiences with other firms in the region:

> *"The co-creation projects involving students required more time and effort than anticipated. Additionally, we encountered challenges in generating enthusiasm for the digital twinning project in our organization. Through this experience, we learned about the importance of effective communication across technical, IT, and business employees within the organization. It was very useful to visualize our digital twinning experiments in the production process. This served as an effective communication tool, and connecting with the production employees helped the further development of our applications. Recently, we*

> *completed setting up a physical field lab. This field lab allows both our employees and outsiders to experience what we have accomplished in the co-creation projects so far. Specifically, we have developed a digital twinning application that can guide a patient's stance for taking x-ray images of their hips. Additionally, we created a digital twinning application for our collimator that automatically adjusts its position to simplify taking x-ray images of children, who move more frequently compared to adults" (CEO Medcorp).*

> *"Only after 1.5 years into the project did we begin to make progress in enhancing digital connectivity between Truckcorp, our dealers, and our customers through virtual product modeling. This modeling helps inform the predictive maintenance we offer to our customers. The main challenge we faced was getting everyone on board, as there was generally little enthusiasm for the digital twinning project internally. Our management team has recently become more involved, which has increased internal support. We also learned that digital twining cannot be treated as a side project. If it is treated as such, business as usual will quickly consume people's time for it. Therefore, our employees are now being allocated specific time to work on digital twinning applications. The involvement of students in developing simulations of our trucks, along with internal and external collaboration, helped us gain new ideas and perspectives on digital twinning, which greatly supported our progress". (senior manager Truckcorp).*

> *"Digital twinning should be linked to a specific vision and strategy. Our most important recommendation is to include all employees in this process, although this was not always easy. In our manufacturing process, we developed virtual models of our welding robots. By relying on these virtual models production disruptions can now be resolved almost in real-time, which previously took a production engineer much longer to solve" (senior manager Bikecorp).*

By shifting to bilateral collaborations and the intermediary organization paying closer attention to the specific needs of individual manufacturing firms, continuous proximity to the physical objects being twinned was ensured.

These changes in collaborative practices allowed actors to nurture hybrid materiality, resulting in the first concrete results in terms of successfully implementing digital twinning applications in the individual firms. In this way, both social and material challenges diminished. In terms of social challenges, the difficulties experienced in knowledge sharing between the manufacturing firms disappeared, since actors decided to share knowledge on a smaller scale, bilaterally between the intermediary and the individual manufacturing firms. Relatedly, frustration regarding meeting rhythm and spaces also disappeared since the bilateral collaborations were tailored to the individual organization's needs, rhythm, and space. Material challenges were also no longer evident due to the continuous proximity to the physical objects resulting in tangible digital twinning applications at Medcorp, Bikecorp, and Truckcorp in particular.

Digital twinnings' hybrid materiality and sociomaterial practices: A process model

We now zoom out to discuss how the materiality of digital twinning technology shaped the collaborative process, and became intertwined with social actors as the intermediary-based collaboration unfolded. The underlying dimensions were formed by the social and material challenges actors encountered: frustration regarding modes of collaboration, knowledge and experience sharing difficulties (both social); lack of shared understanding of digital twinning, and lack of progress towards developing digital twinning applications (both material). We then analyzed how actors responded to these challenges, which ranged from not acting upon these challenges if they were perceived as not pressing or evident, to changing modes of collaboration in attempting to deal with either or both of these types of social and material challenges (see also Table 11). As an additional step, we paid specific attention to the role hybrid materiality of digital twinning played within this process, slowly pulling actors from focusing solely on digital artifacts towards also considering the physical objects to be twinned. Based on this we identified three dynamic sociomaterial practices: *emphasizing the digital realm, making sense of the hybrid realm,* and *nurturing the hybrid realm.*

We define *emphasizing the digital realm* as focusing on the digital aspects of digital twinning technology, such as virtual modeling, software, and simulation, in relative isolation from the physical object, such as a product or process, located at the space of the home organizations. Further, *making sense of the hybrid realm,* enabled by developing a shared understanding of the technology, considers starting to pay attention to not only digital aspects of the technology, but also increasingly to the physical objects being twinned by alternating meeting spaces across home organizations to ensure temporary proximity. Lastly, *nurturing the hybrid realm* consists of ensuring continuous proximity to the physical object, a process or product, being twinned at the space of the home organization and in this way being able to pay attention to both the physical and digital aspects of the technology and how these interrelate. To visualize the emergence and changing of the three sociomaterial practices over time, and to highlight the constitutive role of digital twinings' hybrid materiality across these practices, we developed a process model (see Figure 5).

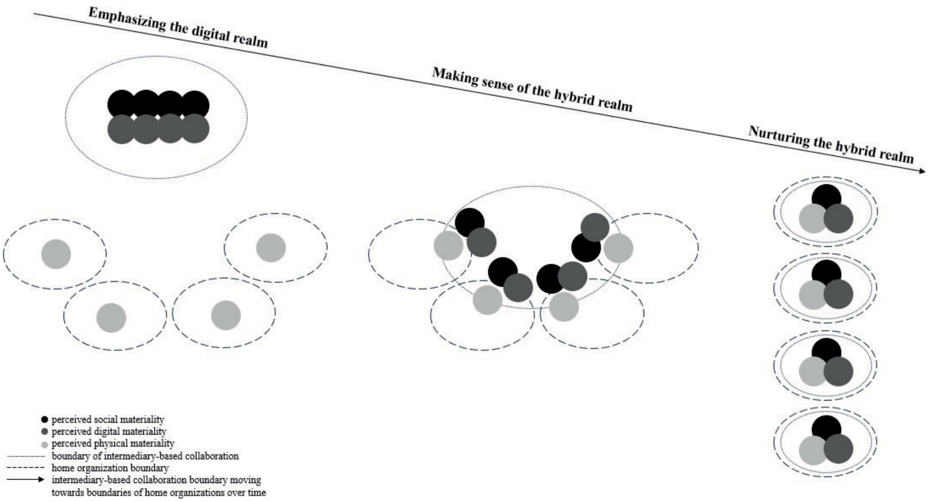


Figure 5: process model representing evolution of interrelated sociomaterial practices over time

In the model, the *emphasizing the digital realm* practice is visualized through actors focusing mainly on social and digital materiality, and the related social challenges and virtual modeling issues, within the space of the intermediary-based collaboration. Relatively isolated from the actors collaborating within the intermediary-based collaboration, is the physical materiality of digital twinning, represented by the physical objects at the space of the home organization. This practice is further characterized by material challenges that were more pressing compared to social challenges. Actors lacked a shared understanding of the components of digital twinning technology, and made no progress towards developing digital twinning applications. In contrast, although knowledge sharing did not go beyond discussing software issues and actors indicated that spending much time within the intermediary-based collaboration to be unfeasible, this did not result in significant difficulties or frustration at this point, which made social challenges less evident.

Driven by social and material challenges which were becoming increasingly evident and pressing to deal with, actors started *making sense of the hybrid realm.* This is visualized by actors' temporarily paying attention to the interrelations between physical, digital and social materiality by alternating meeting spaces, to connect to the physical objects at the individual home organizations being twinned. By alternating these meeting spaces, the boundaries of the intermediary-based collaboration moved closer to, and temporarily interfered with, those of the individual home organizations. In this way, the physical, digital, and social materialities as perceived by actors start to become temporarily intertwined at the boundary of the intermediary-based collaboration and the individual home organization. This practice was further characterized by social challenges becoming more pressing compared to material challenges. Actors' frustration regarding the limited knowledge sharing and unsuitable meeting rhythm that was not helpful for dealing with urgent digital twinning issues increased. In contrast, when actors started *making sense of the hybrid realm,* material challenges became less pressing due to a shared understanding of the digital and physical components of digital twinning starting to emerge on one hand, and senior managers taking the first steps in developing applications inspired by visits to the production plants of the individual firms (i.e., alternating meeting spaces) on the other hand.

Further, driven by the persisting social challenges but diminishing material challenges, since physical and digital materiality are becoming at least temporarily intertwined, actors are enabled to start *nurturing the hybrid realm.* This is visualized through the social, digital, and physical materialities as perceived by the actors being fully enmeshed, supported by the space of the intermediary-based collaboration becoming a part of the individual home organizations in bilateral collaborations. The overlapping of the boundaries of the intermediary-based collaboration and the individual home organizations enabled continuous proximity to the physical objects being twinned. This practice was further characterized by the diminishing of both social and material challenges. Material challenges were no longer evident since actors' understanding of both physical and digital components of digital twinning spurred development of applications by ensuring continuous proximity to physical objects at the space of the home organization. At the same time, social challenges also diminished since knowledge sharing continues on a smaller scale between the intermediary and individual home organizations, instead of between all participants of the collaboration. Relatedly, frustrations of actors regarding unsuitable collaboration rhythms or meeting spaces also no longer existed since these bilateral collaborations were tailored to the rhythm, space, and needs of the individual home organizations.

Zooming out further, we see that across the three sociomaterial practices, shaped by the hybrid materiality of the digital technology, the boundaries of the intermediary-based collaboration gradually move closer to those of the home organizations, to ensure temporary and later continuous proximity to physical objects being twinned. In this way, the collaborative space shifted from within the boundaries of the intermediary-based collaboration, which was relatively isolated from products and processes physical materiality, towards being enclosed in the boundaries of the individual home organizations. In a sense, through *making sense of the hybrid realm* and *nurturing the hybrid realm* actors were being pulled back to their home organizations to not only pay attention to digital and social, but also physical materiality. An isolated collaborative space within the intermediary-based collaboration was thereby no longer useful in supporting effective digital innovation. This further implied that, shaped by the digital technology's hybrid materiality, the roles of the intermediary and participating organizations changed. Instead of facilitating the sharing of knowledge and enabling relationship building between the participating organizations, the intermediary gradually became a knowledge provider for each of the individual participating organizations. This empowered the participating organizations in progressing in their digital innovation initiatives at the space of their home organizations, gradually refraining from sharing knowledge between the firms.

Taken together, our process model illustrates that only through *making sense of* and *nurturing the hybrid realm* persisting social and material challenges that would otherwise hinder effective digital innovation can be reduced. We acknowledge that fundamentally, these social, digital, and physical materialities cannot be separated. Yet, through our zooming in and out, we have been able to uncover that within an intermediary-based collaboration there may be potential pitfalls of overly focusing on technology's digital materiality, which can result in too much distance from the physical materiality of the target products and processes. This can result in both social and material challenges becoming more urgent and pressing, which could only be reduced through *making sense of* and *nurturing the hybrid realm.* This further underscores the constitutive role hybrid materiality plays in shaping these intermediary-based collaborations, and enabling progress towards effective digital innovation.

Discussion

In this study we explored how digital technology and social actors become intertwined in practice in an intermediary-based collaboration, and how these practices affect digital innovation. Drawing on an in-depth longitudinal study at a field lab, we developed a process model that illuminates how the hybrid materiality of digital twinning technology was at the core of driving collaborative dynamics and progress of developing applications. We identified three interrelated sociomaterial practices: emphasizing the digital realm, making sense of the hybrid realm, and nurturing the hybrid realm. Our findings suggest that only through making sense of and nurturing the hybrid realm actors could adequately respond to material and social challenges to enable digital innovation of products and processes, while emphasizing the digital realm, in which actors were relatively disconnected from the physical materiality of the technology, hindered effective innovation. Our findings have implications for digital innovation literature and literature on intermediaries.

Implications for digital innovation literature

With this study, we answer recent calls for renewed attention towards the central and constitutive role digital technologies play in the organizing process (Bailey et al., 2022). We applied a sociomateriality perspective, which enabled us to pay specific attention to the recursive intertwining of material entities, such as digital technologies, and social actors by studying practices over time. Most importantly, our findings suggest the need to acknowledge the *hybrid materiality* of digital technologies in supporting digital innovation initiatives. In case actors over-emphasize emerging technologies' digital components, our findings suggest that this leads to significant material and social challenges which inhibit digital innovation of products and processes.

Concerning this hybrid materiality of digital technology, Yoo et al. (2012) distinguished early on between emerging technologies' inherent physical and digital materiality. The majority of scholars studying digital innovation refer to this seminal work by Yoo and colleagues (2012), but have had limited attention to the potentially constitutive role of this hybrid materiality of digital technology. One of the few exceptions here is the study by Barrett et al. (2012), who examined the implementation of a robotics innovation and how this technology reshaped boundaries, roles and work practices within an organization. They showed that while the digital materiality of the robot could rapidly be altered through updating, changes to the physical materiality by adapting its hardware took multiple months to complete. Together, these changes to the robots' hybrid materiality were interrelated with the changes in roles and collaborative practices of the employees working with it.

Based on our study's findings, we propose that the type of digital technology actors focus on has consequences for how influential its hybrid materiality is in potentially hampering or driving digital innovation. Being one of the few studies paying specific attention to this hybrid materiality, we extend the work by Barrett et al. (2012) in two main ways. First, we argue that the type of digital technology relates to how easily actors can identify the interrelations between physical and digital materiality, which can support nurturing hybrid materiality and in turn drive digital innovation. For example, considering the robotics innovation discussed in the Barrett et al. (2012) article, it was near impossible for actors to ignore the physical materiality of the robot. It was a tangible, physical object, which they could literally bump into and which interfered with the practices in their work space. In comparing robotics to digital twinning technology, potentially the larger number and increased complexity of digital components, reflected by a virtual model, the physical object influencing the virtual model, and the virtual model in turn steering the physical object, may result in actors more easily over-emphasizing digital materiality, and a potential decoupling from the object's physical materiality. However, our findings suggested the importance of tending to both this physical and digital materiality of the object being twinned, since actors paying limited attention to and distancing themselves from the physical object hampered the progress of their digital innovation initiatives. In a similar fashion, there are potentially also emerging digital technologies of which their physical materiality is less influential, compared to their digital materiality, in the process of organizing. For example, while physical servers are a prerequisite for artificial intelligence (AI) to enable sufficient computing power, actors mainly interact with the AI's digital capabilities in the digital space (see e.g., Agrawal et al., 2022; Chui et al., 2022 on ChatGPT). Here, more distance from the physical object enabling the AI's computing power may be less influential on the process of organizing compared to the previously described digital twinning and robotics technologies. Hence, we suggest that the specific digital technologies actors prioritize has implications for the extent to which their hybrid nature can either impede or foster digital innovation.

Second, our findings suggest that the setting in which actors collaborate for digital innovation can potentially influence actors' awareness of and attention to a technology's hybrid materiality, which, in turn, relates to subsequent collaborative dynamics and progress of innovation. For example, in the Barrett et al. (2012) study the robotics innovation was confined to being implemented within one organizational department, a hospital pharmacy. By zooming in on the entanglement of the robots' hybrid materiality and everyday practices of workers, the authors identified how boundary relations among three occupational groups within this organization were reconfigured. In comparison, we zoomed in on an intermediary- based collaboration in which actors were relatively isolated from their home organization, and thereby distanced from the physical object for which a digital twin was developed. Thus although this setting is potentially valuable for sharing experiences and issues related to digital innovation, which has also been demonstrated by previous works (e.g., Rossi et al., 2022), we argue that it also complexifies actors' being able to pay attention to both the physical and digital materiality of the technology, due to potentially being distanced from the physical object at the home organization. This suggests that, in nurturing hybrid materiality, manufacturing firms may need to balance the time spent in close proximity to physical artifacts at the home organization and at a collaborative space outside the organization to tap into relevant knowledge and support innovation for digital products and processes.

Implications for literature on intermediaries

Due to the complexity of emerging digital technologies, manufacturing firms often lack the necessary resources, knowledge, and competencies to engage in digital innovation on their own, and thus actors are increasingly pushed to engage in external collaborations for support (Moschko et al., 2023; Svahn et al., 2017). In this context, intermediary organizations can play a crucial role in supporting firms' innovation initiatives by providing direct and indirect support, such as transferring knowledge and providing resources, and building and facilitating a collaborative ecosystem (e.g., Caloffi et al., 2023). In particular, recent studies have started to explore how intermediaries can support firms' digital innovation initiatives, focused on digital technologies such as artificial intelligence and the Internet of Things (Abi Saad et al., 2024; Holland et al., 2024; Rossi et al., 2022).

Our findings corroborate that in the digital innovation context intermediary organizations play an increasingly dynamic role, adapting their activities in response to participating firms' emerging priorities, needs, and feedback (Abi Saad et al., 2024), by focusing on both transferring knowledge and facilitating a space for collaboration (Rossi et al., 2022). Beyond this corroboration, our findings extend this research by suggesting that this dynamic role is intricately linked to the hybrid materiality of digital technology, thus contrasting the predominant view in previous works of technology as a contextual factor influencing collaborative dynamics. By paying specific attention to how the hybrid materiality of the digital technology shaped the intermediary-based collaboration, we have also been able to unpack practices in which the intermediary role was less supportive of firms' progress towards digital innovation. In this way, we provide a more nuanced picture compared to previous works that mainly emphasize the roles and activities through which intermediaries *support* firms' digital innovation initiatives (e.g., Abi Saad et al., 2024; Rossi et al., 2022), and instead show instances in which the role and activities of intermediaries are potentially detrimental.

In doing so, we also provide a possible explanation for why intermediary-based collaborations in the Dutch context, i.e., field labs, do not always flourish (Grond et al., 2021). For example, in the *emphasizing the digital realm* practice, the intermediary's establishment of an isolated collaborative space, relatively disconnected from the physical materiality of the technology (i.e., objects) located in the home organization, was detrimental to initiating the digital innovation of products and processes. In contrast, in *making sense of* and *nurturing the hybrid realm,* the intermediary supported actors in addressing the social and material challenges they experienced by developing a shared understanding of the technology's physical and digital components, and supported the actors in refraining from overemphasizing digital aspects by ensuring temporary and later continuous proximity to physical artifacts. Thus, we do not deny the supportive role that intermediaries can play in firms' digital innovation initiatives, yet our findings suggest that they may need to more specifically account for the constitutive role of the technology's hybrid materiality. Since our findings reveal that overly emphasizing digital materiality can be detrimental, intermediaries may assist actors to better attend to hybrid materiality by, for example, designing the collaborative space to allow for proximity to physical artifacts.

Practice and policy implications

For practitioners, in particular managers of manufacturing firms, our findings suggest that to facilitate digital innovation of products and processes, actors are advised to equally consider both the physical and digital components of the technology involved. Our research indicates that, for digital twinning technology, if managers overly focus on the digital components, such as software for virtual modeling and simulation, they can lose sight of the physical component, such as a car, for which the twin is being developed. Losing sight of this physical component made it more difficult for actors to later reconnect with the physical object for which the digital twin was created, resulting in a more challenging innovation process.

Furthermore, our findings indicate that managers seeking support in their digital innovation journeys can benefit from collaborating in intermediary-based collaborations, such as field lab settings in the Dutch context. Specifically, we provide insights into the value of actors' proximity to the physical products or machines being twinned when discussing challenges and best practices within such collaborations. In this way, managers can arguably benefit most from knowledge sharing between firms and the intermediary organization to put to use in their home organizations.

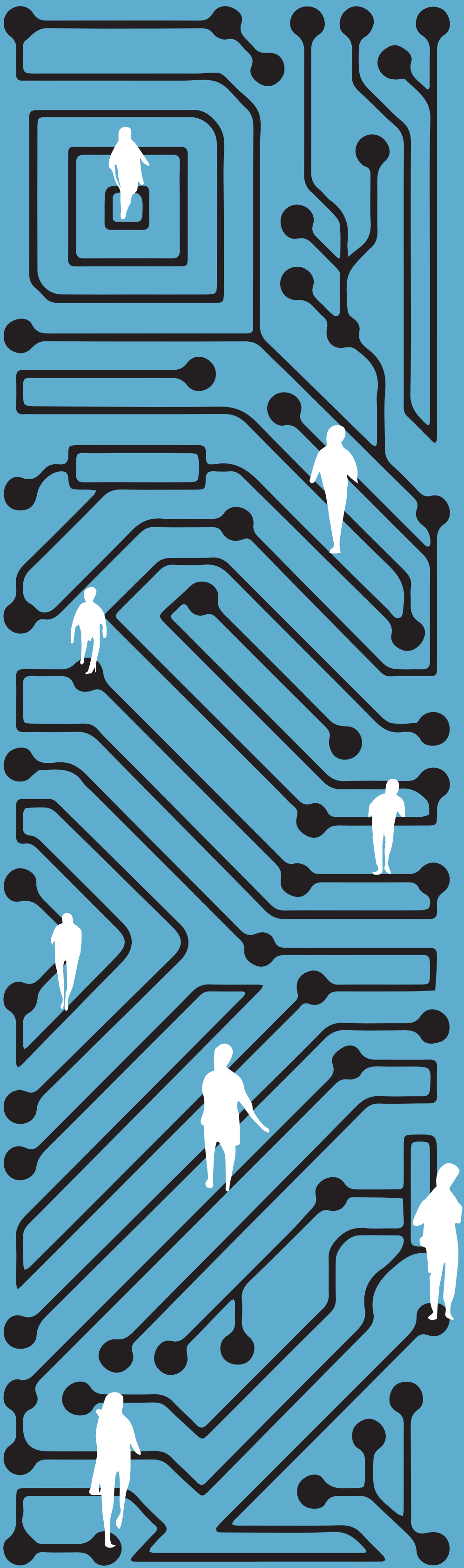
This relates to our recommendations for policy makers. When establishing field lab initiatives that focus on a specific digital technology, it may be important for the intermediary organization to consider that collaborating with manufacturing firms in a field lab setting, which is relatively isolated from the respective home organizations and thus the physical components of digital twins, may potentially hinder innovation and lead to frustration within the collaboration. Therefore, when designing field labs, one option would be to provide a physical object being twinned within the field lab space to allow actors to experience both physical and digital components of digital twinning. Alternatively, they can avoid using an isolated field lab space and instead provide alternating spaces, for example at each of the home organizations, for actors to experience different types of digital twins focused on various machines, manufacturing processes, or products.

Limitations and future research

Our study is not without limitations, which may provide opportunities for future research. Our study focused on the use of digital twinning technology to innovate products and processes in a field lab setting. It is possible that focusing on different digital technologies, where physical materiality may be more or less influential compared to digital twinning technology, could lead to different interactions between hybrid materiality and social actors in practice. As discussed earlier, the physical materiality of robotics innovations may be more evident than that of artificial intelligence. Therefore, future research could more systematically compare the hybrid materiality of various digital technologies and their intertwining with social actors in practice, and how these support or hinder further innovation of products and processes.

Relatedly, as we focused on an intermediary-based collaboration with multiple manufacturing firms, each focusing on different types of digital twins, may have presented more profound collaborative challenges. To address this, future studies could explore the role of hybrid materiality in collaborations within a single organization or in interorganizational collaborations aimed at developing a single digital twin for a specific product or machine. In these contexts it may be easier for actors to nurture hybrid materiality, potentially resulting in less or other social or material challenges.

Lastly, local practices do not stand on their own but rather are affected by other sociomaterial practices removed in space and time (Latour, 2007). Thus, we zoomed in and out (Nicolini, 2009; 2012) to discern how the identified practices evolved over time within the field lab setting, from emphasizing digital materiality, to confronting and later on nurturing hybrid materiality. However, previous experiences with other digital innovation initiatives with different foci of the participating organizations potentially influenced how practices came into being and evolved in the field lab setting. Since this was beyond the scope of our research, we only focused on the time frame of the field lab initiative and not on these previous experiences. Adapting this time frame and including these practices further away in time and space may be a potentially viable avenue for future research to provide a more in-depth explanation of why actors may overly emphasize digital materiality.



5.

Discussion

The objective of this dissertation was *to provide a deeper understanding of how actors in manufacturing SMEs cross organizational boundaries to pursue digital innovation*. I examined this in three separate empirical studies. In each of these empirical studies, I addressed a sub part of the phenomenon, for which I included the most suitable approach and theoretical perspective. The first study, drawing on RBV logic and applying a configurational approach, demonstrated that diverse yet limited resource- and context configurations are related to advanced and less advanced digital technology use in manufacturing SMEs, and that resource-constrained SMEs can reach advanced use through accessing specific combinations of external resources. The second and third study focused on, respectively, tracing back and following actors' practices in pursuing digital innovation in real-time. The second study, drawing on resourcing logic, explored various ways to cross organizational boundaries through external resourcing, while in the third study, drawing on sociomateriality logic, I zoomed in on one specific form, namely by participating in an intermediary-based collaboration. Together, these empirical chapters helped me to understand different pieces of the digital innovation puzzle in SMEs. Together, these explanations contributed to a holistic understanding of crossing organizational boundaries to pursue digital innovation.

In the following section I will first summarize the main findings of the three empirical studies. Then, the three studies are brought together to formulate the theoretical contributions of the dissertation to digital innovation literature. Third, I discuss practice- and policy implications. Finally, the boundary conditions and related directions for future research are discussed.

Summary of main findings

Study 1: SMEs' diverse resource bundles and advanced I4.0 technology (non-)use: A configurational approach

The goal of the first study was to compare a larger number of manufacturing SMEs on digital innovation outcomes, and to identify how some SMEs are able to innovate their digital technology use despite potentially being constrained in their internal resources. The research question in this study was: *Which resource and context configurations are associated with advanced compared with not advanced Industry 4.0 manufacturing technology use in SMEs?*

I drew on RBV logic (Penrose, 1959) and relied on configurational theorizing (Furnari et al., 2021; Ragin, 2008) to explore how diverse combinations of resources and contexts relate to advanced I4.0 technology use (or lack thereof). I focused on productive resource bundles. Applying fsQCA, I identified three paths that were associated with advanced I4.0 technology use in manufacturing SMEs: *fully resourced, selective balancers,* and *focused connectors.* In addition, I also identified four paths associated with not advanced I4.0 technology use: *low on resources (scarce context), low on resources (rich context), non- absorbers,* and *other priorities.* The findings suggest that resource-constrained SMEs can follow diverse yet limited paths towards advanced I4.0 technology use, either by selectively balancing internal and external resources, or by focused connecting to external resources. In addition, across paths associated with advanced use, SMEs consistently accessed external resources, either through intermediary-based and/or broad and deep collaborations with external actors. Further, the findings point towards the significant role of intermediary-based collaborations as external resources for SMEs pursuing advanced digital technology use. The absence of these collaborations were potentially the only ingredient from keeping *other priorities* SMEs from consistently achieving advanced use. These intermediaries might have been able to reconnect them to I4.0 opportunities and potentially (re)position them on the path towards advanced use. Hence, these findings together confirmed and further detailed the key role that crossing organizational boundaries plays to access external resources that can alleviate potential resource constraints for SMEs pursuing digital innovation and technology use.

Study 2: External resourcing for digital innovation in manufacturing SMEs

As there is a limited understanding of *how* actors in SMEs over time attribute value to external resources and put them to use in the internal organization, the goal of the second study was to analyze: *How do actors in manufacturing SMEs engage in external resourcing to pursue digital innovation processes?*

I drew on a resourcing perspective (Feldman, 2004; Feldman & Worline, 2011) and applied a comparative case study approach (Eisenhardt, 1989; 2021). I selected four Dutch manufacturing SMEs and compared the trajectories for those innovating products versus those innovating manufacturing processes. In analyzing these, I identified three interconnected external resourcing practices: *pursuing, discovering,* and *internalizing.* The specific innovation outcomes actors focused on, being product or manufacturing process, was important in steering actors' resourcing requirements. While the content of the identified practices was relatively similar across cases, they followed a different temporal pattern related to these specific digital innovation outcomes. Also, actors focused on product innovation prioritized the development of social resources while actors focused on process innovation prioritized technical resources. In further comparing these digital innovation processes, I identified characteristics, related to organizational structure and activities and customer interactions, that created affordances and constraints for how actors shaped their external resourcing. For product innovation early interdependence with customers created affordances to continue on the innovation journey. In contrast, having to reconfigure the interdependent organizational structure and work processes from manufacturing and selling products towards enabling the sales of services presented a potential constraint. In contrast, innovating the manufacturing process relatively independently from customer input served as a potential constraint, while the independent structure of operational activities created the affordance of innovating these step by step. Taken together, this study provided insights into external resourcing practices at manufacturing SMEs, and further detailed these per innovation outcome.

Study 3: Unlocking the potential of intermediary-based collaboration to support manufacturing SMEs' digital innovation: The constitutive role of digital technology's hybrid materiality

We currently have insufficient insight into why intermediary-based collaborations sometimes fall short of expectations in supporting SMEs digital innovation processes. Therefore, in this study I aimed to develop a better understanding of both potentially supportive and hampering practices. My research question was: *How are digital technology and social actors intertwined in practice in an intermediary-based collaboration, and how do these practices affect digital innovation?*

Drawing on a sociomateriality perspective (Leonardi, 2011; Orlikowski & Scott, 2008) and relying on process theorizing (Langley et al., 2013), I longitudinally followed a Dutch field lab that brought together four manufacturing SMEs and a knowledge institute acting as an intermediary organization. As the involved manufacturing SMEs had limited prior experience with digital twinning technology, actors had to navigate both social and material challenges, which varied in terms of how pressing they were perceived to be. Social challenges, related to collaboration dynamics, became increasingly pressing and only started to diminish when actors decided on collaborating bilaterally with the intermediary at the space of their home organizations. Material challenges, related to the development of digital twin applications, became less pressing over time due to actors jointly developing a better understanding of digital twinning and its related components.

Building on how actors navigated these social and material challenges as the intermediary-based collaboration unfolded, I observed the emergence of three dynamic sociomaterial practices over time: *emphasizing the digital realm, making sense of the hybrid realm*, and *nurturing the hybrid realm*. My findings suggest that effective digital innovation within such intermediary-based collaborations depends on actors' ability to engage with the hybrid materiality of digital technology: the hybrid materiality of digital twinning was at the core of driving collaborative dynamics as well as the progress of developing digital twin applications. Only through making sense of and nurturing the hybrid realm, actors could adequately respond to material social challenges to enable digital innovation of products and processes. Emphasizing the digital realm hindered effective innovation since actors operated relatively disconnected from the physical materiality of the technology.

Theoretical implications

This dissertation provides a study into the value of crossing of organizational boundaries for actors in manufacturing SMEs to pursue digital innovation. Digital innovation has often been conceptualized as a broad, complex, and multifaceted phenomenon with implications across multiple levels (Appio et al., 2021; Bogers et al., 2022; Dąbrowska et al., 2022; Hund et al., 2021; Nambisan et al., 2017). Hence, gaining a more holistic understanding of this phenomenon in the specific context of manufacturing SMEs benefits from a phenomenon- driven approach combining multiple forms of theorizing. Instead of practicing theoretical pluralism by combining grammars into a single mixed-methods study (e.g., Clarke et al., 2019; Cloutier & Langley, 2020; Slager et al., 2023), I opted to combine configurational and processual grammars as part of a program of research on a phenomenon (Cronin et al., 2021; Post et al., 2020; Shaver, 2020). Hereby I responded to recent calls to combine multiple forms of theorizing to help create a more complete and accurate explanation of a phenomenon (Cornelissen, 2023; Sandberg & Alvesson, 2021; Tsoukas, 2017). By moving away from propositional theorizing, which has been criticized to overly simplify complex phenomena in its theorizing (Cornelissen, 2023; Tsoukas, 2017), and combining configurational and process grammars instead to explain a complex phenomenon, I developed initial insights into how theoretical pluralism can be given shape in practice (Cornelissen & Kaandorp, 2022), potentially providing an initial "proof of concept" (Cornelissen, 2023, p. 17). Further, through this phenomenon-driven and explanatory approach I tried to better connect to challenges practitioners are experiencing in the real world (Petriglieri, 2020; Tsoukas, 2017; Weick, 2003; 2007), in an attempt to move away from offering an idealized, mechanical image of organizational phenomena (Barley, 2016). Combining and comparing insights from the three empirical studies enabled me to further unpack the ways in which manufacturing SMEs can navigate the specific challenges they face in pursuing digital innovation. These relate to, among others, facing resource constraints (Chiappini et al., 2022; Mittal et al., 2018), having less experience in identifying digital opportunities (Benitez et al., 2020; Horvath & Szabo, 2019) and managing structured innovation processes (Giotopoulos et al., 2017; Pessot et al., 2023; Radas & Bozic, 2012). I have also been able to show that for SMEs to address these challenges and engage in effective digital innovation processes, it was essential to cross organizational boundaries for accessing complementary resources. Yet crossing organizational boundaries, for instance through external resourcing, also adds an additional layer of complexity, as actors have to ensure a connection between existing internal and newly developed external resources. In addition, the external sources SMEs interact with vary over the course of the digital innovation process, for example shifting from opportunity exploration through regional discourse to more targeted collaborations with suppliers to develop new technical competencies. Lastly, I further detailed how the crossing of organizational boundaries unfolds for product versus process innovation outcomes, and how the entanglement of social actors and the hybrid materiality of digital technology is at the core of driving collaborative dynamics and progress of digital innovation.

Contributions to digital innovation literature

By integrating theoretical perspectives that pay attention to both structure (RBV logic) and agency (resourcing and sociomateriality), further delineating which resources, as a starting point, are supportive of digital innovation and specifying how these are created in practice, I was able to develop a more layered understanding of crossing organizational boundaries for digital innovation in SMEs. This concretely resulted in further advancing digital innovation literature in multiple ways: by conceptualizing digital innovation as a causally complex phenomenon, as a process, and further conceptualizing digital innovation's socio-technical nature.

Conceptualizing digital innovation as a causally complex phenomenon: unpacking multiple potential pathways for manufacturing SMEs

Pursuing diverse digital innovation outcomes has been shown to be a complex and resource- intensive undertaking for manufacturing SMEs in particular (Ghobakhloo & Iranmanesh, 2021), due to the specific challenges they face (Horvath & Szabo, 2019; Mittal et al., 2018). Key resources have been indicated to be both internal, such as human and technical resources (Müller & Voigt, 2017), and external, such as direct and indirect collaborations (Agostini & Nosella, 2019; Ricci et al., 2021; Rossi et al., 2022), to the firm, and their productivity is conducive of a firm's environment (Chen & Tian, 2022). There is currently a limited understanding of how SMEs reach advanced use of digital technologies (Frank et al., 2019), which can be seen as a precursor for related digital innovation outcomes (Blichfeldt & Faullant, 2021; Liu et al., 2023). With this dissertation, I provided a deepened understanding of the multiple paths SMEs can follow towards achieving advanced digital technology use and, relatedly, positive digital innovation outcomes.

In particular, in Chapter 2, relying on configurational theorizing (Furnari et al., 2021; Ragin, 2008) and drawing on RBV logic (Brush & Artz, 1999; Miller & Shamsie, 1996; Pahnke et al., 2023; Penrose, 1959), I detailed which resource bundles are productive in specific contexts for SMEs to achieve advanced digital technology use. Not surprisingly, SMEs with a broad set of productive resources and a supportive context can reach advanced use. Yet this was not the largest group of consistent advanced users: most of these firms were less intensively resourced. In light of resource constraints faced by SMEs as discussed in previous works (Horvath & Szabo, 2019; Mittal et al., 2018), I explain how through selectively balancing specific internal and external resources, or by building on a broader set of external resources through focused connecting, these SMEs still can achieve advanced use.

My findings also showed under which conditions it would become generally difficult for SMEs to reach advanced use. These paths were not necessarily mirror images of those related to advanced use. Hence, digital technology use is characterized by causal asymmetry: the presence or absence of a certain

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resource may produce the same outcome, depending on its combination with other conditions. Previous regression-based analyses (e.g., Mahmood & Mubarik, 2020; Ricci et al., 2021) have not adequately addressed this notion that the availability of resources is not always positively related to advanced digital technology use. Thus I expand this research by suggesting that even when resources are (partially) available, SMEs are not always able to achieve advanced use, as evidenced by several of our not advanced use paths.

Together this shows that there is no one-size fits all approach for SMEs to reach advanced digital technology use, and thus to pursue digital innovation. By focusing on complements and substitutes between resources and how they are embedded in different contexts, I was able to shed new light on under which conditions SMEs can achieve advanced digital technology use, and under which conditions this would become difficult. Thereby, more broadly, I further unearthed the causal complexity that characterizes digital innovation, while highlighting through which paths, even when facing resource constraints, SMEs can reach advanced digital technology use.

This is further substantiated by findings from Chapter 3, which further details how these pathways, in relation to crossing organizational boundaries, differ when SMEs pursue either digital product or process innovation outcomes. My findings suggest that the specific temporal pattern of external resourcing practices, and therefore large parts of the digital innovation processes, are afforded and constrained by the characteristics in terms of independence and interdependence of what is being innovated. In pursuing digital innovation outcomes, SMEs have to reconcile the 'new' and 'old' (Oberlander et al., 2021; Vial, 2019). For product innovation, previous research showed that actors often have to reconfigure an organizational structure and work processes to transition from classical product manufacturers to providers of digital innovation enabled (service) solutions (Muller et al., 2018). This interdependent structure of multiple organizational elements can constitute a constraint for actors in progressing with product innovation. However, my research shows that for product innovation, interdependence with customers can afford an early validation of selling service solutions based on digitalized products on a small scale, by which actors are supported to 'take the leap' to break down and rebuild the interdependent structure of multiple organizational elements. In contrast, for process innovation envisioning an outcome of a digital factory happened rather independently from customers. Here instead, actors were triggered by other external sources such as regional discourse on digitalization. This independence from customers could have constituted a constraint for continuing digital process innovation, only being able to trial implications for customer experience after having implemented a digital factory. However, the relatively independent structure of operational activities in the manufacturing process afforded actors to push forward by enabling them to innovate their operational activities towards a digital factory step by step, trialing customer implications after each step. This corroborates previous studies that have shown implementing basic technologies first can serve as building blocks for implementing more advanced technologies as next steps (Frank et al., 2019; Meindl et al., 2021).

Thus, reconciling the new and old in pursuing digital innovation was significantly shaped by working towards a particular outcome. My findings shed light on how this reconciliation unfolded through specific temporal patterns of external resourcing: from pursuing via discovering to internalizing for product outcomes, and from discovering via internalizing to pursuing for process outcomes. Overall, these findings from Chapter 2 and 3 further unearth the complexity of the digital innovation phenomenon. Throughout the multiple paths SMEs can take in pursuing digital innovation, my findings show that crossing organizational boundaries for complementary resources is a prerequisite. In addition, I further expose through which external resourcing practices SMEs can pursue digital innovation, further detailing the temporal pattern of these processes for digital product and process innovation.

Conceptualizing digital innovation as a process: further detailing underlying practices and mechanisms of manufacturing SMEs

Furthermore, research into digital innovation has started to stress the importance of studying digital innovation *as a process* instead of overly focusing on digital innovation *outcomes* such as digitalized products or manufacturing processes (Urbinati et al., 2022). In particular in Chapters 3 and 4 I further unpacked the process of digital innovation specific to manufacturing SMEs, by tracing back and following forward, and how actors shape this process towards product or manufacturing process outcomes through their crossing of organizational boundaries. Hereby I connect to previous studies that called for a more processual understanding of digital innovation (e.g., Bogers et al., 2022; Correani et al., 2020). I do so by further exposing how the broad orchestration mechanisms of managing boundaries and developing capabilities to leverage digital technologies as proposed by Urbinati et al. (2022) are enacted in manufacturing SMEs through crossing organizational boundaries. More specifically, through unpacking the process of external resourcing in Chapter 3, and through zooming in on a particular type of crossing organizational boundaries, engaging in intermediary-based collaboration, in Chapter 4.

In particular, in Chapter 3 I show how the process of digital innovation, through unpacking the notion of external resourcing, is shaped by building blocks created after each resourcing cycle. These building blocks enable actors to focus and shape subsequent resourcing activities, which support the gradual progression towards materializing specific innovation outcomes over time. This challenges prior research which suggested that SMEs can be hampered by their less structured and deliberate innovation processes compared to larger firms (Giotopoulos et al., 2017; Pessot et al., 2023; Radas & Bozic, 2012). Although my findings corroborate that the innovation process was relatively emergent, I demonstrate how these building blocks provide a sense of structure, enabling actors to progress towards innovation products and processes by further shaping and refining the process along the way. Hence, the relatively structured nature of external resourcing affords the development of specific orchestration mechanisms for digital innovation. However, external resourcing for digital innovation is by no means an automatic process, as it requires substantial managerial agency. Not only do actors have to kick-start external resourcing and thus the digital innovation process, but also have to decide whether and how to proceed based on these building blocks, which serve as intermediate resourcing outcomes.

Moreover, in line with previous studies into resourcing (e.g., Deken et al., 2018), I show that external resourcing, and likely the broader concept of crossing organizational boundaries, is characterized by trial and error, and that resourcing needs and the associated direction of the innovation initiative can be reshaped by both external and internal actors throughout this process. Actors do not necessarily know in advance which resources are most productive in pursuing digital innovation. This was further substantiated by findings from Chapter 4, in which I further unpack a specific type of crossing organizational boundaries in pursuing digital innovation – by engaging in intermediary-based collaboration. Connecting to prior studies mainly highlighting the positive role intermediaries can play in supporting digital innovation (e.g., Abi Saad et al., 2024; Holland et al., 2024; Rossi et al., 2022), I further expose instances in which the role and activities of intermediaries are potentially detrimental to manufacturing SMEs digital innovation initiatives.

More specifically, my findings suggest that these intermediaries may need to more specifically account for the constitutive role of digital technology's hybrid materiality. Overly emphasizing a technology's digital materiality can hamper both collaborative dynamics in the intermediary- based collaboration and in progressing towards digital innovation outcomes at the manufacturing SMEs. To prevent this, intermediaries may assist actors in manufacturing SMEs to better tend to technology's hybrid materiality, for instance by designing collaborative spaces that allow for proximity to physical artifacts being digitalized.

Relatedly, through my processual approach in Chapters 3 and 4, I was able to provide a deepened understanding of how actors can navigate the managerial challenge of connecting newly developed external resources with the existing internal resource base in pursuing digital innovation. Hereby I add to prior research that identified challenges associated with connecting internal to external resources (Moschko et al., 2023; Svahn et al., 2017). These studies demonstrated the delicate balance between actors focusing on internal and external resources, where overly emphasizing internal resources hindered the identification of (digital) opportunities beyond organizational boundaries, and excessive focus on external resources resulted in disconnecting from existing internal practices. Addressing this challenge, Svahn et al. (2017) showed how actors supported this connection between external resources and internal practices simultaneously, by largely relying on a technical solution: Volvo Cloud.

Instead, my findings from Chapter 3 suggest that, in particular for manufacturing SMEs, alternating over time between developing resources externally and internalizing them to connect with existing internal resources can be a fruitful approach to addressing this challenge. This was further substantiated by findings from Chapter 4, which demonstrated how, over time, boundaries of the intermediary-based collaboration were reconfigured and moved closer to the individual firms' home organizations. Eventually this resulted in bilateral collaborations with the intermediary within the boundaries of the home organizations, to ensure continuous proximity to existing artifacts, the products or manufacturing processes for which digital twins were being developed. Overall, this implies that for manufacturing SMEs in particular there may be other approaches to navigating the challenge of connecting external and internal resources than previously identified in literature. Instead of addressing this challenge simultaneously, my findings further unpack how SMEs can ensure this connection over time.

Conceptualizing the socio-technical nature of digital innovation

With this dissertation I also provide a deeper understanding of the socio-technical nature of digital innovation. Previous literature has generally used rather broad terms to underline this socio-technical nature (Hund et al., 2021; Lyytinen, 2022), also for manufacturing SMEs (Eller et al., 2020). By applying a sociomateriality perspective in Chapter 4, I was able to further unpack the recursive intertwining of material entities, like digital technologies, with social actors by studying dynamic practices over time. Hereby I answer recent calls for renewed attention towards the central and constitutive role that digital technologies play in the organizing process (e.g., Bailey et al., 2022). Most importantly, I identified three interrelated sociomaterial practices – emphasizing the digital realm, making sense of the hybrid realm, and nurturing the hybrid realm. These illuminate how the hybrid materiality of a focal technology is at the core of driving collaborative dynamics and the progress of developing applications. My findings suggest that only by making sense of and nurturing the hybrid realm, actors can adequately respond to social and material challenges within an intermediary-based collaboration, thereby supporting both collaborative dynamics and the progress of developing digital applications for products and processes. This suggests the need to better acknowledge how the hybrid materiality of digital technologies intertwines with social actors in supporting manufacturing SMEs digital innovation initiatives.

I propose that both the type of digital technology actors focus on and the collaborative setting they are in can potentially influence actors' awareness of and attention to a technology's hybrid materiality, which, in turn, relates to the progress of digital innovation initiatives. Hereby I extend work by Barrett et al. (2012) who studied the implementation of a robotics innovation, which is one of the few studies paying specific attention to this hybrid materiality. First, I argue that the nature of the digital technology relates to how easily actors can identify interrelations between its physical and digital materiality. This can support nurturing hybrid materiality and in turn stimulate digital innovation. For instance, digital twinning technology comprises many digital components, which can result in overlooking its physical materiality, as my findings show. For robotics, in contrast, actors cannot ignore its physical materiality, as they literally bump into a physical artifact during their work practices (Barrett et al., 2012). For artificial intelligence, physical materiality may be less influential, as actors primarily interact with its digital capabilities in the digital space, rather than with the physical servers required for it (see e.g., Agrawal et al., 2022; Chui et al., 2022 on ChatGPT). In contrast to digital twinning, actors may therefore be more readily aware of and able to nurture the hybrid materiality of robotics and artificial intelligence. Consequently, I propose that the relative ease of identifying and nurturing hybrid materiality, which in turn can foster digital innovation, depends on the specific type of digital technology(s) actors focus on.

Second, the collaborative setting can also further complexify actors' ability to nurture digital technology's hybrid materiality. Zooming in on an intermediary-based collaboration where actors met in a space relatively isolated from the home organization, this also distanced them from the physical object for which a digital twin was developed. Corroborating previous studies that these settings are potentially valuable for sharing experiences and issues related to digital innovation (e.g., Abi Saad et al., 2024; Holland et al., 2024; Rossi et al., 2022), I further detail this and argue that this setting also complexifies actors' ability to pay attention to both the physical and digital materiality of the technology, by being distanced from the physical objects at the home organization. This implies that, in participating in intermediary- based collaborations to access complementary resources, manufacturing SMEs may need to balance the time spent in close proximity to physical artifacts at their home organization with time spent in a collaborative space outside the organization to support innovation towards digital products and processes.

In addition, in Chapter 3 I provided further insights into why actors may prioritize technical or social aspects of digital innovation. My findings suggest that while both technical and social resources are necessary, actors prioritize them differently in pursuing specific innovation outcomes. When pursuing product outcomes actors may prioritize the development of social resources to support them in reconfiguring multiple organizational elements to transition to product-based services, while actors pursuing process outcomes may mainly require technical resources to facilitate the continuous incorporation of new technological elements. In this way, I extend previous studies that used rather broad terms underlining the socio-technical nature of digital innovation (Eller et al., 2020; Hund et al., 2021; Lyytinen, 2022) by providing a more detailed perspective of specific contexts where technical or social aspects of digital innovation may require more attention.

Practical implications

In addition to contributing to theory, this dissertation also forwards practical implications, both practitioner and policy related.

Crossing your organizational boundaries is valuable, but be aware of the additional layer of complexity it may add.

For many SMEs, starting the digital innovation journey may seem a daunting task, due to, among others, the demands of the day-to-day business, potential resource constraints, and not having a lot of experience in identifying opportunities related to developing smarter products or manufacturing processes. Albeit being a highly complex and contested process filled with trial and error, both internally and externally, the crossing of organizational boundaries did help managers to gain novel ideas, perspectives, and support for their digital innovation initiative, hence enabling them to slowly progress towards developing smarter products and processes. To take away some of this potential complexity that can be associated with crossing organizational boundaries, my findings from the third Chapter highlight that SMEs can also gather inspiration for digital innovation by drawing on regional discourse, attending one-off or regular events in their network, and visiting or being visited by other firms. For example, a CEO of one of the manufacturing SMEs I interviewed emphasized that for them visiting other manufacturers and having these visit them was one of their most important sources for new perspective, knowledge or expertise - something they could not do without. For SME managers this may potentially be a more accessible way for exploring digital innovation opportunities within their network, without having to set up formal collaborations immediately.

However, my findings also suggest, despite their additional layer of complexity, the value of engaging in more formal collaborations, for example by participating in field labs. SMEs can consider participating in these field labs when they have moved beyond the phase of exploring opportunities presented by emerging technologies, and want to progress further by experimenting with developing applications for smarter products or processes. This is supported by findings from Chapter 2, which provided initial insights in the potential value of these intermediary-based collaborations like field labs, as all SMEs reaching advanced digital technology use participated in these specific collaborations. In addition, in Chapter 4, SMEs participating in these field labs emphasized that, despite struggling with developing suitable collaboration practices, sharing experiences, not only good but also bad, with digital twinning provided new perspectives which they could put to use in further developing digital twins of their products and processes.

Break up the digital innovation process in smaller steps to enable progress, and align policy with it

SMEs typically do not have overly structured innovation processes and potentially less experience in managing these (Giotopoulos et al., 2017; Radas & Bozic, 2012). However, in Chapter 3, I demonstrated that approaching the crossing of organizational boundaries as a process cut up in smaller steps of discovering, pursuing, and internalizing, can provide managers with a sense of structure without the burden of a very formalized innovation process. Engaging in these smaller steps, exploring digital innovation opportunities first, experimenting with specific applications for smarter products or processes, and internalizing these in the organization subsequently, can provide SME managers with intermediate outcomes on the basis of which they can assess whether they should progress with their digital innovation initiatives. This also links to, already implicitly mentioned above, the type of external sources most valuable in each of these steps of the innovation process: while managers can draw on regional discourse or more one-off events in exploring opportunities, participating in more formal collaborations, for example participating in field labs, may support further experimentation with specific technologies.

In addition, for policy makers, this entails that to further increase the effectiveness of these field lab collaborations in supporting manufacturing SMEs digital innovation initiatives, the design of these field labs should potentially be better aligned with the phase of the digital innovation journey manufacturing SMEs are in. While findings of both Chapters 2 and 4 suggest the value of these field labs as a means to support SMEs digital innovation, policy makers can play a role in developing a more targeted approach in connecting SMEs that are ready to experiment with a specific digital technology for innovation to field labs.

These field labs could then dedicate more time to experimenting with the development of smart products or digital factories together with these SMEs. In turn, this would allow these field labs to focus less on creating awareness for digital innovation opportunities, for which other policy instruments may be better suitable, like organizing information events in regional networks. Potentially this could support further unlocking the value of these specific field labs for manufacturing SMEs, with which policy makers still struggle in practice (Grond et al., 2021).

Prevent the 'not invented here' syndrome - involve the internal organization from the start of the digital innovation initiative

While SME managers may get inspired and acquire complementary knowledge through their external activities, the downside is that their actions may become almost invisible for other employees in the firm. This can lead to the 'not invented here' syndrome and jeopardize the digital innovation initiative. In this light, my findings emphasize the value of connecting these external activities to the internal organization, involving other members of the organization early on to ease the implementation of external resources. For example, as shown in Chapter 3, a strategy of SME managers was to create room for other employees in the organization to attend conferences or participate in training to 'get out of their comfort zone' and develop digital skills. In addition, to deal with potential resistance, SME managers may think of ways to accommodate employees that cannot get used to working with digital technologies. For example, in Chapter 3, SME management of a bike producer reassigned these employees to other departments for them to continue repairing bicycles in 'the traditional way'.

The importance of being able to connect early on to the internal organization was also underlined by insights from Chapter 3. Here, SMEs that were not able to reach advanced digital technology use, were mostly hampered by not having access to the right tools internally to actually profit from resources across organizational boundaries, for example by engaging in broad and deep interorganizational collaborations or having access to knowledge spillovers by being part of a highly innovative region or digitally mature industry. This suggests that involving the internal organization early on may further support the connection between external activities and internalizing complementary resources to support the digital innovation initiative.

Digital technology is only part of the complex puzzle - you need people to make technology work

Lastly, for SME managers, the findings of this dissertation highlighted the importance of paying attention to not only technical aspects, reflected by both the digital and physical components of a technology, but also social aspects, in pursuing digital innovation. Throughout the data collection process, when talking to CEOs, other managers, and production employees, it stood out that when discussing digital technology and innovation, people tended to focus on technical aspects. However, while being an important aspect of digital innovation, it is only part of the complex puzzle, and the success of digital innovation initiatives is largely dependent on the interrelations of these technologies with social actors. In particular, in Chapter 3 findings suggested that throughout the innovation process, both the development of complementary technical and social resources received attention. However, the type of innovation SME managers focus on, either manufacturing process or product, can have implications for the type of resources that become most relevant during the innovation process. For transitioning from manufacturing products to also selling digital services managers needed social resources to manage a reconfiguration of their organizational structure and work processes, which they could not do without support from external parties. To implement a digital factory, in contrast, managers continuously had to focus on developing technical skills and expertise to implement with emerging digital technologies. However, here managers did not lose sight of the importance of social aspects, for instance by reassigning employees to other departments where they felt better at home when they could not get used to working with digital technology to prevent resistance. The importance of paying attention to both these social and technical aspects was further substantiated by findings from the fourth Chapter, as these indicated that overly focusing on either these social or material aspects led to frustrations within the field lab setting and inhibited progress to digital innovation outcomes.

Relatedly, another recommendation for policy makers is thus to reflect on the importance of connectedness between these social and technical aspects when renewing policies. For example, in Chapter 2, the majority of SMEs' reaching advanced digital technology use combined experimenting with technical aspects in intermediary-based collaborations with appropriate human resources. In this sense, policies focused on developing more targeted approaches to the goal of intermediary-based collaborations, as previously discussed, could go hand in hand with targeted educational and labor market policies.

Boundary conditions and future research

In this paragraph, I further reflect on the limitations of this research which also lead to opportunities for future research. First, I relied on qualitative approaches, in the form of case studies and set-theoretic approaches (QCA), which influence the generalizability of my findings. These approaches were in line with the aim of this dissertation to better understand *how* and *why* actors engage in crossing organizational boundaries to pursue digital innovation. However, it is likely that my findings cannot be transferred one on one to the context of larger organizations or other sectors. Despite this limitation, there are opportunities for theoretical generalisation, for instance related to studying digital innovation as a process and that this process unfolds differently according to the type of outcome pursued, which is likely to also be applicable beyond the context of manufacturing SMEs. This opens op opportunities for future research, for example in exploring how crossing organizational boundaries to pursue digital innovation unfolds in larger organizations or in other sectors than the manufacturing industry.

Also limiting the generalizability of the findings is that all the SMEs included in this dissertation were located in the Netherlands, with the SMEs included in Chapter 3 and 4 also being part of the same geographical region. The reason to choose SMEs from the same geographical context was to limit institutional variation and investigate regional aspects. SMEs in the Netherlands perform better on average than other countries in the EU in their basic technology usage, but still require support in accessing and implementing more advanced technologies like artificial intelligence (European Commission, 2023). Potentially, countries in which SMEs are lagging behind or further ahead in terms of digitalization, the crossing of organizational boundaries to pursue digital innovation may unfold differently.

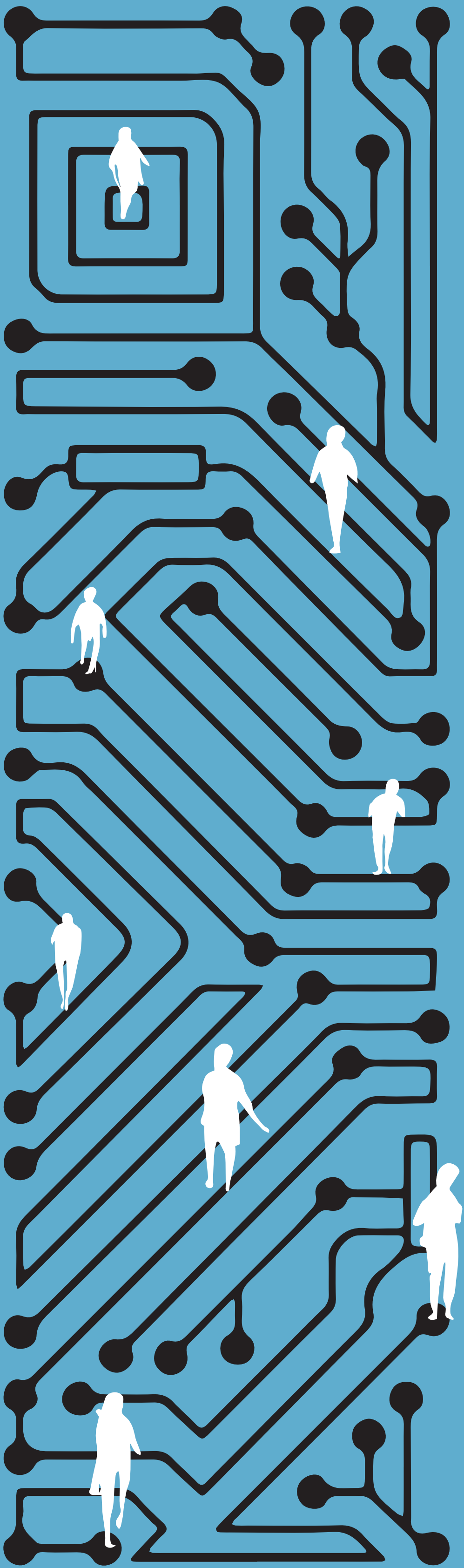
However, this opens up opportunities for future research. For example, further configurational research could explore how the crossing of organizational boundaries relates to advanced digital technology use across countries to unpack further potential nuances in terms of key resource combinations in different contexts. In addition, scholars could also further explore how SMEs access complementary resources in collaborations across country borders which are increasingly being promoted in European Commission policy to spur digital transformation across the EU (European Commission, 2023b).

In addition, I only relied on forms of theorizing that pertain to so-called explanatory theorizing, which share the aim to better explain complex phenomena and were thus in line with the objective of this thesis (Cornelissen et al., 2021; Sandberg & Alvesson, 2021). Thus, other interpretative and critical theorizing grammars (Cornelissen et al., 2021) were left outside of view. To further support causal triangulation, future research could explore the potential of combining approaches to theorizing distinct epistemologies.

A further limitation of this dissertation was that I did not examine potential interrelations between digital product and process innovation. Previous research already pointed towards these interrelations, both for more traditional innovation (Crossan & Apaydin, 2010; Utterback & Abernathy, 1975) and digital innovation (Blichfeldt & Faullant, 2021). Analytically separating between digital product and process innovation enabled me to compare differences and similarities across these processes in Chapter 3, in particular in relation to how actors cross organizational boundaries in pursuing each of these outcomes. Here, my informants did hint at already having digitalized their manufacturing process before starting to engage in digital product innovation. Also in Chapter 4 actors deliberately chose to focus on either developing digital twin applications for their manufacturing process or to smarten their products. However, as this was beyond the scope and aim of my research, I did not further explore these potential interrelations. Future research could further explore how digital product and process innovation interrelate in manufacturing SMEs in particular, for instance by further examining suitable strategies for pursuing both types of innovation in light of the specific managerial challenges these firms face.

In addition, across the three Chapters, due to the proposed socio-technical nature of digital innovation, I mostly emphasized the role of social and technical resources and thus did not consider the role other resources played. However, beyond technical and social resources, previous research also indicated other types of resources, like financial resources (Chiappini et al., 2022; Muller et al., 2018), that can support or constrain SMEs digital innovation. Thus, future research could aim to include additional types of internal and external resources in systematic comparisons to explore how these substitute or complement each other in supporting SMEs digital innovation.

Lastly, there were also methodological limitations related to the individual empirical studies. For example, in Chapter 2 I applied fsQCA, in line with configurational theorizing, which enabled me to reveal complex causal dynamics at play, unpacking multiple different resource and context combinations related to advanced digital technology use. Yet, this method is known for presenting a rather static overview, and is not well equipped to deal with processes extending over time (Cornelissen & Kaandorp, 2022; Schneider & Wagemann, 2012). Further, in Chapter 3 I relied on retrospective interviewing combined with documents and company visits. This approach may be subject to respondent bias, as informants may not be able to remember past activities correctly or may portray these more socially correct or favorable. However, this approach has been proven valuable by previous studies in tracing resourcing activities (Nigam & Dokko, 2019).



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Appendices

Chapter 2

Table A: List of I4.0 technologies included in the EMS questionnaire. Categorization adapted from Frank et al. (2019)

Vertical integration and traceability (not advanced I4.0 technology use)	**Automation (relatively not advanced I4.0 technology use)**	**Virtualization (relatively advanced I4.0 technology use)**	**Flexibilization (advanced I4.0 technology use)**
Software for production planning and scheduling (e.g., ERP system)	Industrial robots for manufacturing processes (e.g., welding, painting, cutting)	Software for product design simulation (e.g., product performance, parts reliability)	3D printing technologies for prototyping (prototypes, demonstration models, 0 series)
Near real-time production control system (e.g., systems of centralized operating and machine data acquisition, MES)	Industrial robots for handling processes (e.g., depositing, assembling, sorting, packing processes)	Software for production process design simulation (e.g., digital twin of a production process)	3D printing technologies for manufacturing of products, components and forms, tools)
Product-lifecycle-management-systems (PLM) or product/process data management	Collaborating robots (not separated by barriers)	Software for advanced computation, simulation and data analysis using high performance/ edge computing	
Mobile/wireless devices for programming and controlling facilities and machinery (e.g., tablets)	Mobile industrial robots (autonomously moving around the shopfloor)		
Digital solutions to provide drawings, work schedules or work instructions directly on the shop floor			
Digital exchange of product/ process data with suppliers/customers (Electronic data interchangeEDI)			

Table B: Overview categorization digitally intensive industries (Calvino et al., 2018) and leading innovative regions (Hollanders & Es-Sadki, 2021)

Digital intensive industries	
Industry type (two digit NACE code)	**Digital intensity classification (Calvino et al., 2018)**
motor vehicles, trailers and semi-trailers (29); other transport equipment (30)	High
wood and wood products (16); paper and paper products (17); printing (18); computer, electronic and optical products (26); electrical equipment (27); machinery and equipment (28); furniture (31); other manufacturing (32); repair and installation of machinery and equipment (33)	Medium-high
textiles (13); wearing apparel (14); leather (15); coke and refined petroleum (19); chemicals and chemical products (20); pharmaceutical products (21); rubber and plastic products (22); other non-metallic mineral products (23); basic metals (24); fabricated metal products (25)	Medium-low
food products (10); beverages (11); tobacco (12)	Low
Leading innovative region	
NUTS 2 region	**RIS classification (Hollanders & Es-Sadki, 2021)**
Noord-Brabant; Noord-Holland; Utrecht	Leading
Flevoland; Gelderland; Groningen; Limburg; Overijssel; Zuid-Holland	Strong
Friesland; Drenthe; Zeeland	Moderate
No Dutch regions included	Emerging

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Table C: Truth table for presence of the outcome (advanced I4.0 technology use) (excluding empty rows)

Row	Human resources	Technical resources	Broad and deepcol.	Intermediary based col.	Digitally intensive industry	Leading innovative region	Advanced use	n	incl	PRI
29	0	1	1	1	0	0	1	5	1	1
31	0	1	1	1	1	0	1	4	1	1
43	1	0	0	1	1	0	1	2	1	1
61	1	1	1	1	0	0	1	2	1	1
63	1	1	1	1	1	0	1	4	1	1
64	1	1	1	1	1	1	1	2	1	1
47	1	0	1	1	1	0	1	2	0.889	0.858
45	1	0	1	1	0	0	1	2	0.832	0.784
13	0	0	1	1	0	0	1	4	0.88	0.737
15	0	0	1	1	1	0	1	3	0.782	0.722
49	1	1	0	0	0	0	0	6	0.701	0.553
14	0	0	1	1	0	1	?	1	0.668	0.573
9	0	0	0	1	0	0	?	1	0.664	0.569
17	0	1	0	0	0	0	0	6	0.621	0.452
56	1	1	1	0	1	1	0	3	0.616	0.378
51	1	1	0	0	1	0	?	1	0.599	0.374
53	1	1	1	0	0	0	0	4	0.591	0.361
16	0	0	1	1	1	1	0	4	0.582	0.5
46	1	0	1	1	0	1	?	1	0.569	0.398
19	0	1	0	0	1	0	0	4	0.555	0.369
23	0	1	1	0	1	0	0	4	0.519	0.296
21	0	1	1	0	0	0	0	2	0.499	0.213
52	1	1	0	0	1	1	0	4	0.498	0.299
24	0	1	1	0	1	1	0	3	0.470	0.183
18	0	1	0	0	0	1	?	1	0.453	0.249
55	1	1	1	0	1	0	0	3	0.453	0.142
22	0	1	1	0	0	1	0	3	0.437	0.183
35	1	0	0	0	1	0	0	6	0.419	0.171
3	0	0	0	0	1	0	0	8	0.414	0.215
33	1	0	0	0	0	0	0	6	0.407	0.158
39	1	0	1	0	1	0	0	7	0.381	0.163
37	1	0	1	0	0	0	0	2	0.351	0.077
6	0	0	1	0	0	1	0	6	0.332	0.084
38	1	0	1	0	0	1	0	2	0.332	0.066
34	1	0	0	0	0	1	?	1	0.317	0.189
8	0	0	1	0	1	1	0	8	0.304	0.075
5	0	0	1	0	0	0	0	9	0.303	0.114
1	0	0	0	0	0	0	0	17	0.298	0.096
36	1	0	0	0	1	1	0	2	0.285	0.117
7	0	0	1	0	1	0	0	10	0.297	0.088
4	0	0	0	0	1	1	0	6	0.212	0.083
2	0	0	0	0	0	1	0	3	0.208	0.095

Table D: Truth table for the absence of the outcome (not advanced I4.0 technology use) (excluding empty rows)

Row	Human resources	Technical resources	Broad and deepcol.	Intermediary based col.	Digitally intensive industry	Leading innovative region	Not advanced use	n	incl	PRI
42	1	0	1	0	0	1	1	2	0.953	0.934
41	1	0	1	0	0	0	1	2	0.946	0.923
12	0	0	1	0	1	1	1	8	0.944	0.925
10	0	0	1	0	0	1	1	6	0.939	0.916
11	0	0	1	0	1	0	1	10	0.930	0.912
4	0	0	0	0	1	1	1	6	0.929	0.917
2	0	0	0	0	0	1	1	3	0.917	0.905
1	0	0	0	0	0	0	1	17	0.913	0.888
9	0	0	1	0	0	0	1	9	0.911	0.886
59	1	1	1	0	1	0	1	3	0.909	0.858
36	1	0	0	0	1	1	1	2	0.905	0.883
33	1	0	0	0	0	0	1	6	0.888[8]	0.842
28	0	1	1	0	1	1	0	3	0.881	0.817
35	1	0	0	0	1	0	0	6	0.880	0.826
43	1	0	1	0	1	0	0	7	0.879	0.836
26	0	1	1	0	0	1	0	3	0.874	0.817
25	0	1	1	0	0	0	0	2	0.864	0.787
34	1	0	0	0	0	1	?	1	0.841	0.811
3	0	0	0	0	1	0	0	8	0.839	0.785
18	0	1	0	0	0	1	?	1	0.819	0.751
27	0	1	1	0	1	0	0	4	0.799	0.704
52	1	1	0	0	1	1	0	4	0.785	0.701
57	1	1	1	0	0	0	0	4	0.770	0.639
60	1	1	1	0	1	1	0	3	0.766	0.622
51	1	1	0	0	1	0	?	1	0.760	0.626
19	0	1	0	0	1	0	0	4	0.740	0.631
46	1	0	1	1	0	1	?	1	0.716	0.602
17	0	1	0	0	0	0	0	6	0.687	0.548
49	1	1	0	0	0	0	0	6	0.631	0.447
16	0	0	1	1	1	1	0	4	0.583	0.5
5	0	0	0	1	0	0	?	1	0.557	0.431
14	0	0	1	1	0	1	?	1	0.554	0.427
13	0	0	1	1	0	0	0	4	0.439	0.263
15	0	0	1	1	1	0	0	3	0.434	0.278
45	1	0	1	1	0	0	0	2	0.389	0.216
47	1	0	1	1	1	0	0	2	0.332	0.142
64	1	1	1	1	1	1	0	2	0.246	0
31	0	1	1	1	1	0	0	4	0.142	0
39	1	0	0	1	1	0	0	2	0.142	0
63	1	1	1	1	1	0	0	4	0.105	0
29	0	1	1	1	0	0	0	5	0.095	0
61	1	1	1	1	0	0	0	2	0.062	0

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8 0.89 was chosen as a consistency cutoff due to the high number of DCCK (2 out of 3 cases) in the successive truth table row 28

Table E: Robustness check - raising consistency threshold to 0.9; * indicates change from main findings

	Configurations related to advanced I4.0 technology use			**Configurations related to not advanced I4.0 technology use**					
Path	**fully resourced**	**selective balancers**	**focused connectors**	**low on resources (scarce context)**		**low on resources (rich context)**	**non- absorbers**		**other priorities**
Configuration	C1a	C1b	C2	C3a	C3b*	C4	C5	C6	C7
Internal resources									
Human resources	● (small)	●		⊗				⊗	●
Technical resources	●		●*	⊗		⊗	⊗	⊗	●
External resources									
Intermediary based collaboration	●	●	●	⊗		⊗	⊗	⊗	⊗
Broad and deep collaboration	● (small)	⊗*	● (small)			⊗ (small)	●	●	● (small)
Contextual conditions									
Digitally intensive industry	● (small)	● (small)		⊗		● (small)	⊗		●
Leading innovative region		⊗ (small)	⊗ (small)			●			⊗
Consistency	1	1	1	0.92		0.91	0.93	0.92	0.91
Raw coverage	0.13	0.04	0.21	0.42		0.09	0.26	0.32	0.06
Unique coverage	0.02	0.02	0.11	0.16		0.03	0.02	0.07	0.02
Overall consistency	1			0.92					
Overall coverage	0.25			0.56					

Chapter 3

Table F: Overview of data sources

Case	Data source		
	Interviews	**Documents**	**Total**
SaltspreaderCo	CEO (2x) Chief Commercial Officer (CCO) Senior project manager Hardware delivery manager HR manager Solutions development manager Consultant (external)	Annual reports (391p) Powerpoint firm strategy (15p) Company newsletters (48p) Newspaper articles (40p) Magazine articles (31p)	9 interviews 525 p. documents 1 day observations (site visit)
CyclingCo	CEO CFO R&D manager Operations manager Chief digital officer (CDO) (2x) Advisor 1 (external) Advisor 2 (external)	Newspaper articles (70p) Magazine articles (16p) Company newsletters 92p) Powerpoint digitalisation (22p)	8 interviews 200 p. documents 1 day observations (site visit)
BakingCo	CEO R&D engineer Service manager Innovation manager Facilitator servitisation workgroup 1 (external) Facilitator servitisation workgroup 2 (external)	Newspaper articles (26p) Company newsletters (14p) Sales material (44p)	6 interviews 84 p. documents
MetalCo	CEO CCO IT manager Supply chain manager Projectmanager(external)	Newspaper articles (10p) Magazine articles (21p) Company newsletters (26p) Powerpoint AI (35p)	5 interviews 92 p. documents

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Overview of resourcing practices and related inputs, activities, and outputs for BakingCo (product innovation)

A more detailed overview of the activities in the resourcing practices including empirical support can be found in Table 3 and Figure 1a. At BakingCo, the *input* for *pursuing*, the first external resourcing practice, was customers providing input, access to the data of their baking lines, which triggered the R&D department to start experimenting with product data in 2016 in close collaboration with a few customers. *Resourcing activities* considered developing technical resources for extracting data from customers' bakery lines. The R&D team, led by an R&D engineer, started by internally developing the technical infrastructure for a pilot dashboard that could show the operational performance of baking lines (P1). However, since they learned they would rather focus on designing functionalities to better meet customer needs, the R&D engineer decided to outsource the development of the technical infrastructure to a supplier (P2). Returning to work with their customers, the R&D team started designing functionalities (P3) which eventually resulted in the first version of a dashboard for operational performance for customers' baking lines (P4). This ability to extract data from their baking lines was the *output* of *pursuing,* characterised as a technical resource.

This technical resource served as *input* for subsequent *discovering.* In attempting to scale up the sales of services based on this resource, the management team realised they did not have the skills in house to manage the required reconfiguration of organisational structure and work processes. The CEO hired a service manager in 2018 that could bring in a fresh perspective to help structure the required reconfiguration in a holistic manner (D1). The first task of this service manager was to envision an end-goal and desired servitisation level for the sales of services (D2). The service manager and management team consequently attempted to start convincing employees of the required changes to work towards this end goal (D3). The resulting *output* of the *discovering* practice was a social resource supporting the organisational transformation that could arguably not have been developed without external resourcing: a higher level of change readiness among employees.

This social resource served as *input* for subsequent *internalising. Resourcing activities* started with the service manager drafting an overview of current services and designing a roadmap for standardisation of contracts in 2020 (I1). To accomplish this, she developed different levels of service contracts, ranging from the dashboard showing operational performance to a service contract for predictive maintenance based on the dashboard. The management team and service manager then realised that they needed employees with social expertise, instead or on top of technical, for the sales of services (I2). With the support of the management team the service manager could then expand her service team in 2020 (I3).

These new employees were further trained for the sales of services in the new digital service organisation (I4). The resulting *output* of this practice was thus an organisational structure and work processes that supported the sales of services.

Overview of resourcing practices and related inputs, activities, and outputs for MetalCo (process innovation)

A more detailed overview of the activities in the resourcing practices including empirical support can be found in Table 3 and Figure 1b. In MetalCo's region, discourse around digitalisation and Industry 4.0 sparked the CEOs interest to start exploring opportunities for digitalising the manufacturing process in 2014, which served as *input* for *discovering.* In terms of *resourcing activities,* the CEO started by visiting other manufacturing firms for inspiration (D1), and with the management team participated in a workshop with other manufacturing firms focused on Industry 4.0 (D2). Using this as inspiration, the IT team started exploring the potential of a digital infrastructure for their manufacturing process together with their suppliers (D3). The *output* of this practice was a concrete idea of digital technologies that could be implemented towards a digital factory, which we considered a technical resource.

This technical resource served as *input* for subsequent *internalising. Resourcing activities* consisted of a first step towards a digital factory involving robotics. Actors set up a project internally in 2015 to focus on developing the related digital infrastructure (I1). For this project, upon the request of a group of production employees inspired by one of their suppliers, a robotic pressing brake was installed in production (I2). Further, the employee team partially changed by bringing in new people and retraining current employees to work with digital technologies (I3). Part of these employees developed skills to not only operate but also program the robots. The resulting *output* of this practice was a robotised operational activity, bending, serving as a technical resource.

This technical resource served as *input* for the final practice, *pursuing*. Following their end-goal of a digital factory using artificial intelligence, actors developed a better idea of the additional steps required towards it based on their experiences with the robotic pressing brake, which ensured more focused external resourcing. *Resourcing activities* started with a second step towards a digital factory, by experimenting with the use of 3D modelling in 2018 together with other manufacturing firms to support the digital infrastructure (P1). In 2020, building on the 3D modelling experience, the CEO and other senior managers took a third step towards the digital factory, through their involvement in a research project focused on artificial intelligence, aligning with their goals to become a frontrunner in the region on this subject (P2). In this project, together with other manufacturing firms and a knowledge institute, they took initial steps in developing AI applications for their manufacturing process (P3). The *output* of *pursuing* was thus a manufacturing process with initial AI applications, which created further opportunities towards developing a digital factory.

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English summary

While crossing organizational boundaries may be valuable for actors in manufacturing SMEs pursuing digital innovation, for example by participating in a field lab focused on digital technology, it can also add another layer of complexity in doing so. For example, actors need to coordinate how they collaborate in such a setting, develop fruitful knowledge or resource sharing practices, while at the same time connecting to what is going on in their internal organization. Thus, in crossing their organizational boundaries, actors representing manufacturing SMEs not only have to navigate technical challenges that are associated with exploring new opportunities offered by emerging digital technologies, but also navigate social challenges that may originate from collaborating in a complex setting like a field lab or dealing with potential resistance to change in the internal organization.

Despite increased attention to digital innovation in manufacturing SMEs in both research and practice, there is still a long road to travel concerning manufacturing SMEs' digital innovation journeys. As SMEs may face resource constraints and are mostly taken up by demands of the day-to-day business, there is often less room for innovation (Horvath & Szabo, 2019; Müller et al., 2018). As a result, it is generally acknowledged that manufacturing SMEs struggle to implement digital technologies and embrace digital innovation. Taken together, this doctoral thesis is written from the desire to get a better understanding of how actors in manufacturing SMEs pursue digital innovation. Following a phenomenon-driven and explanatory approach, I pay specific attention to how crossing organizational boundaries can potentially alleviate internal resource constraints.

Digital innovation involves the creation of or changes in market offerings, business processes, or models driven by the uptake of digital technologies like robotics, additive manufacturing, and augmented- and virtual reality (Blichfeldt & Faullant, 2021; Nambisan et al., 2017; Urbinati et al., 2022). Due to the distributed nature of digital innovation, the need for actors to cross organizational boundaries during the innovation process increases (Ghezzi & Cavallo, 2020), while actors should also address trade-offs between internal and external collaboration (Moschko et al., 2023; Svahn et al., 2017). This requires scholars to broaden their scope beyond single organizations (Benitez et al., 2020) and consider how actors cross organizational boundaries, as manufacturing firms may lack the required resources and competences to engage in digital innovation on their own (Sestino et al., 2020).

Against this background, SMEs hold a special place, and may face specific challenges in pursuing digital innovation. For example, they are often taken up by the demands of day-to-day business (Muller et al., 2018), which makes identifying digital innovation opportunities more difficult (Benitez et al., 2020; Horvath & Szabo, 2019). Furthermore, they are generally more limited in their internal resources, for instance due to financial constraints (Chiappini et al., 2022; Mittal et al., 2018) or a lack of digitally skilled employees (Müller & Voigt, 2017), making it crucial for them to cross organizational boundaries – accessing complementary resources to support their digital innovation initiatives (Muller et al., 2018).

A limited number of previous studies started exploring the value of crossing organizational boundaries for manufacturing SMEs to tap into complementary resources, for instance considering types of useful collaboration partners (e.g., Agostini & Nosella, 2019; Ricci et al., 2021) or proposing that engaging in intermediary-based collaboration is particularly useful (e.g., Caloffi et al., 2023). However, we lack an in-depth understanding of how actors cross organizational boundaries to attract, develop, and internalize required resources to pursue digital innovation. It is imperative to develop a better understanding of how crossing organizational boundaries can support manufacturing SMEs in pursuing digital innovation, since digital innovation initiatives do not always flourish (Ghobakhloo & Iranmanesh, 2021), but open up the potential for manufacturing firms to become more sustainable and competitive (Liu et al., 2023). Therefore, the general research objective for this dissertation is to provide a deeper understanding of how actors in manufacturing SMEs cross organizational boundaries to pursue digital innovation.

Research context and design

The objective of this dissertation was to develop a deeper understanding of a complex phenomenon, manufacturing SMEs' crossing organizational boundaries to pursue digital innovation. Linking to calls for theoretical pluralism to explain complex phenomena (Cloutier & Langley, 2020; Cornelissen et al., 2021; Cornelissen & Kaandorp, 2022; Cornelissen, 2023; Sandberg & Alvesson, 2021; Shaver, 2020; Tsoukas, 2017), I combined configurational and process theoretical grammars in three separate empirical studies.

Configurational theorizing focuses on conceptualizing complex systems of interdependency that can systematically co-vary with certain outcomes

(Furnari et al., 2021). Characterized by the assumption of causal complexity, it assumes that phenomena are explained by multiple combinations of antecedent conditions. In theorizing configurational causation, scholars track how multiple causal conditions combine into distinct configurations, or 'causal recipes' (Ragin, 2008) that are constituted by 'integrative mechanisms' (Furnari et al., 2021; Misangyi et al., 2017). In the first study, in line with configurational theorizing, I used a qualitative comparative analysis (QCA) design. QCA's goal is to determine which configurations, or combinations of conditions, are sufficient or necessary for an outcome of interest to occur (Ragin, 2008; Schneider & Wagemann, 2012). The resulting findings are an exploratory scheme (Fiss, 2011; Furnari et al., 2021) which profiled advanced digital technology use – a phenomenon – by attributing resources and contexts – a set of distinguishing aspects – and examining their prominence and centrality in a multidimensional structure. This provided insight into multiple consistent resource and context configurations that supported or hampered digital innovation in manufacturing SMEs. This explanatory scheme helped me to categorize more broadly prominent and central relationships between all these conditions, and highlighted the central role external resources played across the identified consistent paths. Hereby the explanatory scheme formed a basis for developing a more processual understanding of the integrative mechanisms underlying how actors in manufacturing SMEs cross organizational boundaries to pursue digital innovation (following e.g., Cornelissen, 2023).

As configurational theorizing is less equipped to deal with processes that extend over time (Cornelissen & Kaandorp, 2022; Schneider & Wagemann, 2012), I turned to more processual approaches in the second and third studies. Process theorizing focuses on conceptualizing the sequencing of events over time that lead to an outcome, such as digital product or process innovation. It entails mapping out an entire causal process for phenomena that are often too complex and chaotic to be captured by a set of more basic propositions (Cloutier & Langley, 2020; Langley, 1999). In particular, it focuses on the emergence, development, growth, and termination of practices over time (Langley et al., 2013). In the second study I focused on retrospectively tracing resourcing practices which enabled me to further detail *how* actors engaged in external resourcing, which was identified to be of importance in the first study.

In the third study I longitudinally followed SME actors participating in a field lab focused on digital twinning technology, to identify important relations between the participants in the field lab and the digital twinning technology they experimented with (Bailey et al., 2022). All manufacturing SMEs included had no previous experience with this technology, which enabled me to observe the emergence of sociomaterial practices in real time.

Empirical chapters

Study 1: SMEs' diverse resource bundles and advanced I4.0 technology (non-)use: A configurational approach

The goal of the first study was to compare a larger number of manufacturing SMEs on digital innovation outcomes, and to identify how some SMEs are able to innovate their digital technology use despite potentially being constrained in their internal resources. The research question in this study was: Which resource and context configurations are associated with advanced compared with not advanced Industry 4.0 manufacturing technology use in SMEs? I drew on RBV logic (Penrose, 1959) and relied on configurational theorizing (Furnari et al., 2021; Ragin, 2008) to explore how diverse combinations of resources and contexts relate to advanced I4.0 technology use (or lack thereof). I focused on productive resource bundles. Applying fsQCA, I identified three paths that were associated with advanced I4.0 technology use in manufacturing SMEs: fully resourced, selective balancers, and focused connectors. In addition, I also identified four paths associated with not advanced I4.0 technology use: low on resources (scarce context), low on resources (rich context), non- absorbers, and other priorities. The findings suggest that resource-constrained SMEs can follow diverse yet limited paths towards advanced I4.0 technology use, either by selectively balancing internal and external resources, or by focused connecting to external resources. In addition, across paths associated with advanced use, SMEs consistently accessed external resources, either through intermediary-based and/or broad and deep collaborations with external actors. Hence, the findings together confirmed and further detailed the key role that crossing organizational boundaries plays to access external resources that can alleviate potential resource constraints for SMEs pursuing digital innovation and technology use.

Study 2: External resourcing for digital innovation in manufacturing SMEs

As there is a limited understanding of how actors in SMEs over time attribute value to external resources and put them to use in the internal organization, the goal of the second study was to analyze: How do actors in manufacturing SMEs engage in external resourcing to pursue digital innovation processes? I drew on a resourcing perspective (Feldman, 2004; Feldman & Worline, 2011) and applied a comparative case study approach (Eisenhardt, 1989; 2021). I selected four Dutch manufacturing SMEs and compared the trajectories for those innovating products versus those innovating manufacturing processes. In analyzing these, I identified three interconnected external resourcing practices: pursuing, discovering, and internalizing. The specific innovation outcomes, product or manufacturing process, actors focused on was important in steering actors' resourcing requirements. While the content of the identified practices was relatively similar across cases, they followed a different temporal pattern related to these specific digital innovation outcomes. Also, actors focused on product innovation prioritized the development of social resources while actors focused on process innovation prioritized technical resources. In further comparing these digital innovation processes, I identified characteristics, related to organizational structure and activities and customer interactions, that created affordances and constraints for how actors shaped their external resourcing. For product innovation early interdependence with customers created affordances to continue on the innovation journey while having to reconfigure the interdependent organizational structure and work processes from manufacturing and selling products towards enabling the sales of services presented a potential constraint. In contrast, innovating the manufacturing process relatively independently from customer input served as a potential constraint, while the independent structure of operational activities created the affordance of innovating these step by step. Taken together, this study provided insights into external resourcing practices at manufacturing SMEs, and further detailed these per innovation outcome.

Study 3: Unlocking the potential of intermediary-based collaboration to support manufacturing SMEs' digital innovation: The constitutive role of digital technology's hybrid materiality.

We currently have insufficient insight into why intermediary-based collaborations sometimes fall short of expectations in supporting SMEs digital innovation processes. Therefore, in this study I aimed to develop a better understanding of both potentially supportive and hampering practices. My research question was: How are digital technology and social actors intertwined in practice in an intermediary-based collaboration, and how do these practices affect digital innovation?

Drawing on a sociomateriality perspective (Leonardi, 2011; Orlikowski & Scott, 2008) and relying on process theorizing (Langley et al., 2013), I longitudinally followed a Dutch field lab that brought together four manufacturing SMEs and a knowledge institute acting as an intermediary organization. As the involved manufacturing SMEs had limited prior experience with digital twinning technology, actors had to navigate both social and material challenges, which varied in terms of how pressing they were perceived to be. Social challenges, related to collaboration dynamics, became increasingly pressing and only started to diminish when actors decided on collaborating bilaterally with the intermediary at the space of their home organizations. Material challenges, related to the development of digital twin applications, became less pressing over time due to actors jointly developing a better understanding of digital twinning and its related components.

Building on how actors navigated these social and material challenges as the intermediary-based collaboration unfolded, I observed the emergence of three dynamic sociomaterial practices over time: emphasizing the digital realm, making sense of the hybrid realm, and nurturing the hybrid realm. My findings suggest that effective digital innovation within such intermediary-based collaborations depends on actors' ability to engage with the hybrid materiality of digital technology: the hybrid materiality of digital twinning was at the core of driving collaborative dynamics as well as the progress of developing digital twin applications. Only through making sense of and nurturing the hybrid realm, actors could adequately respond to material social challenges to enable digital innovation of products and processes. Emphasizing the digital realm hindered effective innovation since actors operated relatively disconnected from the physical materiality of the technology.

Theoretical implications

This dissertation provides a study into the value of crossing organizational boundaries for actors in manufacturing SMEs to pursue digital innovation. Digital innovation has often been conceptualized as a broad, complex, and multifaceted phenomenon with implications across multiple levels (Appio et al., 2021; Bogers et al., 2022; Dabrowska et al., 2022; Hund et al., 2021; Nambisan et al., 2017). Hence, gaining a more layered understanding of this phenomenon in the specific context of manufacturing SMEs benefits from a phenomenon-driven approach combining multiple calls of theorizing to help create a more complete and accurate explanation of a phenomenon (Cornelissen, 2023; Sandberg & Alvesson, 2021; Tsoukas, 2017). Through this phenomenon-driven and explanatory approach I tried to better connect to challenges practitioners are experiencing in the real world (Petriglieri, 2020;

Tsoukas, 2017; Weick, 2003; 2007), in an attempt to move away from offering an idealized, mechanical image of organizational phenomena (Barley, 2016). Combining and comparing insights from the three empirical studies enabled me to further unpack the ways in which manufacturing SMEs can navigate the specific challenges they face in pursuing digital innovation. These relate to, among others, facing resource constraints (Chiappini et al., 2022; Mittal et al., 2018), having less experience in identifying digital opportunities (Benitez et al., 2020; Horvath & Szabo, 2019) and managing structured innovation processes (Giotopoulos et al., 2017; Pessot et al., 2023; Radas & Bozic, 2012). I have also been able to show that for SMEs to address these challenges and engage in effective digital innovation processes, it was essential to cross organizational boundaries for accessing complementary resources. Yet crossing organizational boundaries, for instance through external resourcing, also adds an additional layer of complexity, as actors have to ensure a connection between existing internal and newly developed external resources. In addition, the external sources SMEs interact with vary over the course of the digital innovation process, for example shifting from opportunity exploration through regional discourse to more targeted collaborations with suppliers to develop new technical competencies. Lastly, I further detailed how the crossing of organizational boundaries unfolds for product versus process innovation outcomes, and how the entanglement of social actors and the hybrid materiality of digital technology is at the core of driving collaborative dynamics and progress of digital innovation.

With my findings I contribute to further advancing digital innovation literature in three main ways. First, by conceptualizing digital innovation as a causally complex phenomenon. With this dissertation, I provided a deepened understanding of the multiple paths SMEs can follow towards achieving advanced digital technology use and, relatedly, positive digital innovation outcomes. In light of the resource constraints faced by SMEs as discussed in previous works (Horvath & Szabo, 2019; Mittal et al., 2018), I explain how through selectively balancing specific internal and external resources, or by building on a broader set of external resources through focused connecting, these SMEs can still achieve advanced use. Together this shows that there is no one-size-fits-all approach for SMEs to reach advanced digital technology use, and thus to pursue digital innovation. This is further substantiated by findings from Chapter 3, which further details how these pathways, in relation to crossing organizational boundaries, differ when SMEs pursue either digital product or process innovation outcomes. Reconciling the new and old in pursuing digital innovation was significantly shaped by working towards this particular outcome. My findings shed light on how this reconciliation unfolded through specific temporal patterns of external resourcing: from pursuing via discovering to internalizing for product outcomes, and from discovering via internalizing to pursuing for process outcomes.

Second, by conceptualizing digital innovation as a process and further detailing the underlying practices and mechanisms for manufacturing SMEs. Hereby I connect to previous studies that called for a more processual understanding of digital innovation (e.g., Bogers et al., 2022; Correani et al., 2020). I do so by further exposing how the broad orchestration mechanisms of managing boundaries and developing capabilities to leverage digital technologies as proposed by Urbinati et al. (2022) are enacted in manufacturing SMEs through crossing organizational boundaries. More specifically, through unpacking the process of external resourcing in Chapter 3, and through zooming in on a particular type of crossing organizational boundaries, engaging in intermediary-based collaboration, in Chapter 4. In particular, in Chapter 3 I show how the process of digital innovation, through unpacking the notion of external resourcing, is shaped by building blocks that provide a sense of structure, enabling actors to progress towards innovating products and processes by further shaping and refining the process along the way. Hence, the relatively structured nature of external resourcing affords the development of specific orchestration mechanisms for digital innovation. Moreover, I showed how external resourcing is characterized by trial and error and how actors can navigate the managerial challenge of connecting newly developed external resources with the existing internal resource base in pursuing digital innovation. My findings imply that for manufacturing SMEs there may be other approaches to navigating this challenge than previously identified in the literature (e.g., Svahn et al., 2017; Moschko et al., 2023): Instead of addressing this challenge simultaneously, my findings further unpack how SMEs can ensure this connection over time.

Third, by conceptualizing the socio-technical nature of digital innovation. Previous literature generally used rather broad terms to underline this socio-technical nature (Hund et al., 2021; Lyytinen, 2022), also for manufacturing SMEs (Eller et al., 2020). By applying a sociomateriality perspective in Chapter 4, I was able to further unpack the recursive intertwining of material entities, like digital technologies, with social actors by studying dynamic practices over time. Hereby I answer recent calls for renewed attention towards the central and constitutive role that digital technologies play in the organizing process (e.g., Bailey et al., 2022). In addition, in Chapter 3 I showed under which conditions actors emphasize the development of either social or technical resources. Together, this led to the development of a more layered understanding of in which contexts technical or social aspects of the digital innovation process might require more of actors attention.

Practical implications

In addition to contributing to theory, this dissertation also forwards practical implications, both practitioner and policy related:

1. Crossing organizational boundaries is valuable, but be aware of the additional layer of complexity it may add: Albeit being a highly complex and contested process filled with trial and error, both internally and externally, the crossing of organizational boundaries did help managers to gain novel ideas, perspectives, and support for their digital innovation initiative, hence enabling them to slowly progress towards developing smarter products and processes. To take away some of this potential complexity that can be associated with crossing organizational boundaries, my findings from the third Chapter highlight that SMEs can also gather inspiration for digital innovation by drawing on regional discourse, attending one-off or regular events in their network, and visiting or being visited by other firms.
2. Break up the digital innovation process in smaller steps to enable progress, and align policy with it: I demonstrated that approaching the crossing of organizational boundaries as a process cut up in smaller steps of discovering, pursuing, and internalizing, can provide managers with a sense of structure without the burden of a very formalized innovation process. Engaging in these smaller steps, exploring digital innovation opportunities first, experimenting with specific applications for smarter products or processes, and internalizing these in the organization subsequently, can provide SME managers with intermediate outcomes on the basis of which they can assess whether they should progress with their digital innovation initiatives.
3. Prevent the 'not invented here' syndrome – involve the internal organization from the start of the digital innovation initiative: While SME managers may get inspired and acquire complementary knowledge through their external activities, the downside is that their actions may become almost invisible for other employees in the firm. This can lead

to the 'not invented here' syndrome and jeopardize the digital innovation initiative. In this light, my findings emphasize the value of connecting these external activities to the internal organization, involving other members of the organization early on to ease the implementation of external resources

4. Digital technology is only part of the complex puzzle – you need people to make technology work: Throughout the data collection process, when talking to CEOs, other managers, and production employees, it stood out that when discussing digital technology and innovation, people tended to focus on technical aspects. However, while being an important aspect of digital innovation, it is only part of the complex puzzle, and the success of digital innovation initiatives is largely dependent on the interrelations of these technologies with social actors.

Dutch summary

Hoewel het oversteken van de grenzen van de organisatie waardevol kan zijn voor actoren binnen MKB productiebedrijven die digitale innovatie nastreven, bijvoorbeeld door deel te nemen aan een field lab gefocust op een specifieke digitale technologie, brengt het ook vaak extra complexiteit met zich mee. Actoren moeten bijvoorbeeld coördineren hoe ze met elkaar samenwerken in zo'n setting, terwijl ze tegelijkertijd aangesloten moeten blijven bij wat er speelt in de interne organisatie. Daarmee krijgen actoren niet alleen te maken met technische uitdagingen die te maken hebben met digitale technologieën, maar ook met sociale uitdagingen die voort kunnen komen uit het samenwerken in een complexe setting zoals een field lab of het moeten omgaan met weerstand voor verandering in de interne organisatie.

Ondanks meer aandacht voor digitale innovatie in MKB productiebedrijven in zowel de academische als praktische literatuur, is er nog een lange weg te gaan met betrekking tot MKB's digitale innovatie. Veel MKB'ers krijgen te maken met een tekort aan resources en hebben het druk met dagelijkse werkzaamheden, waardoor er weinig ruimte overblijft voor innovatie (Horvath & Szabo, 2019; Müller et al., 2018). Daarmee is er consensus over het feit dat MKBs in het algemeen moeite hebben met het implementeren van digitale technologie en het ontwikkelen van digitale innovatie. Deze dissertatie is geschreven met het doel om beter te kunnen begrijpen hoe actoren in MKB productiebedrijven digitale innovatie nastreven. Gebaseerd op een fenomeen-gedreven benadering onderzoek ik specifiek hoe het oversteken van grenzen van de organisatie kan bijdragen aan het verlichten van mogelijk gebrek aan resources binnen de organisatie.

Digitale innovatie heeft betrekking tot het maken of veranderen van het aanbod, proces, of business model van een bedrijf, gedreven door de implementatie van digitale technologie zoals robotica, additive manufacturing, en augmented- en virtual reality (Blichfeldt & Faullant, 2021; Nambisan et al., 2017; Urbinati et al., 2022). Gezien digitale innovatie op meerdere plekken tegelijkertijd plaatsvindt, wordt de noodzaak groter voor actoren om de grenzen van de organisatie over te steken tijdens het innovatieproces (Ghezzi & Cavallo, 2020), terwijl actoren ook zullen moeten balanceren tussen de voordelen van interne en externe samenwerkingen (Moschko et al., 2023; Svahn et al., 2017). Om hierbij aan te sluiten moeten onderzoekers hun scope verbreden buiten individuele organisaties (Benitez et al., 2020), en bedenken hoe actoren deze grenzen dan oversteken, gezien productiebedrijven vaak de resources en skills missen om zelf met digitale innovatie aan de slag te gaan (Sestino et al., 2020).

Tegen deze achtergrond behouden MKB's een speciale positie, gezien zij specifieke uitdagingen tegenkomen in het digitale innovatieproces. Zo zijn ze vaak druk met dagelijkse werkzaamheden waardoor het lastiger wordt om kansen met betrekking tot digitale innovatie te identificeren (Benitez et al., 2020; Horvath & Szabo, 2019). Verder zijn ze vaak gelimiteerd in hun interne resources, bijvoorbeeld door minder financiële resources (Chiappini et al., 2022; MIttal et al., 2018) of een gebrek aan werknemers met digitale skills (Müller & Voigt, 2017), waardoor het belang om de grenzen over te steken alleen maar groter wordt, om zo aanvullende resources te kunnen vinden (Müller et al., 2018).

Een aantal studies heeft de waarde van het oversteken van grenzen voor MKB productiebedrijven bekeken, door bijvoorbeeld onderzoek te doen naar waardevolle samenwerkingspartners (Agostini & Nosella, 2019; Ricci et al., 2021) of de rol van intermediairs (Caloffi et al., 2023). Echter missen we uitgebreide inzichten in hoe actoren grenzen oversteken om benodigde resources te ontwikkelen en intern in te zetten voor digitale innovatie. Het is cruciaal dat we hierover een beter begrip ontwikkelen, gezien deze initiatieven binnen MKBs niet altijd succesvol zijn (Ghobakhloo & Iranmanesh, 2021), maar wel nodig zijn voor productiebedrijven om competitief te blijven (Liu et al., 2023). Daarmee is het onderzoeksdoel van deze dissertatie om een vollediger beeld te ontwikkelen van hoe MKB productiebedrijven hun grenzen oversteken om digitale innovatie na te streven.

Onderzoekscontext en -ontwerp

Het doel van deze dissertatie was om een beter beeld te krijgen van een complex fenomeen, namelijk hoe actoren binnen MKB productiebedrijven hun bedrijfsgrenzen oversteken om digitale innovatie na te streven. Aansluitend bij de noodzaak voor meer theoretisch pluralisme om complexe fenomenen beter te begrijpen (Cloutier & Langley, 2020; Cornelissen et al., 2021; Cornelissen & Kaandorp, 2022; Cornelissen, 2023; Sandberg & Alvesson, 2021; Shaver 2020; Tsoukas, 2017), heb ik in drie empirische studies configurationele en proces theorieën gecombineerd.

Configurationele theorie focust op het conceptualiseren van complexe afhankelijke systemen die systematisch kunnen co-variëren met bepaalde uitkomsten (Furnari et al., 2021). Kenmerkend is de assumptie van causale complexiteit, die ervan uitgaat dat fenomenen uitgelegd kunnen worden aan de hand van meerdere combinaties van antecedente condities. In het theoretiseren van configurationele causaliteit, bestuderen onderzoekers hoe meerdere causale condities combineren in verschillende configuraties, ook wel causale recepten (Ragin, 2008) genoemd. In het eerste empirische hoofdstuk, in lijn met configurationele theorie, heb ik gebruik gemaakt van een Qualitative Comparative Analysis (QCA) onderzoek ontwerp. Het doel van QCA is om te bepalen welke configuraties, of combinaties van condities, voldoende of noodzakelijk zijn om een uitkomst van belang te laten plaatsvinden (Ragin, 2008; Schneider & Wagemann, 2012). De resulterende bevindingen zijn een verklarend schema (Fiss, 2011; Furnari et al., 2021) dat geavanceerd digitaal technologiegebruik - een fenomeen - profileert door resources en contexten - een reeks onderscheidende aspecten - toe te kennen en hun prominentie en centraliteit in een multidimensionale structuur te onderzoeken. Dit verschafte inzicht in meerdere consistente configuraties van resources en contexten die digitale innovatie in kleine en middelgrote productiebedrijven ondersteunden of belemmerden. Dit verklarende schema hielp om prominente en centrale relaties tussen al deze condities breder te categoriseren en benadrukte de centrale rol die externe hulpbronnen speelden in de geïdentificeerde consistente paden. Hierdoor vormde het verklaringsschema een basis voor het ontwikkelen van een meer procesmatig begrip van de integratieve mechanismen die ten grondslag liggen aan hoe actoren in kleine en middelgrote productiebedrijven organisatiegrenzen overschrijden om digitale innovatie na te streven (bv. Cornelissen, 2023).

Omdat configuratietheorie minder geschikt is om om te gaan met processen die zich uitstrekken in de tijd (Cornelissen & Kaandorp, 2022; Schneider & Wagemann, 2012), heb ik in de tweede en derde studie gekozen voor meer procesmatige benaderingen. Procestheorie richt zich op het conceptualiseren van de opeenvolging van gebeurtenissen in de tijd die leiden tot een resultaat, zoals digitale product- of procesinnovatie. Het houdt in dat een volledig causaal proces in kaart wordt gebracht voor fenomenen die vaak te complex en chaotisch zijn om te kunnen worden gevat in een reeks basis proposities (Cloutier & Langley, 2020; Langley, 1999). Het richt zich met name op de opkomst, ontwikkeling, groei en beëindiging van praktijken in de loop van de tijd (Langley et al., 2013). In de tweede studie richtte ik me op het retrospectief traceren van resourcingpraktijken, waardoor ik verder kon detailleren hoe actoren zich bezighielden met externe resourcing, waarvan in de eerste studie was vastgesteld dat het van belang was.

In de derde studie volgde ik longitudinaal MKB-actoren die deelnamen aan een field lab gericht op digitale twinningtechnologie, om belangrijke relaties te identificeren tussen de deelnemers aan het field lab en de digitale twinningtechnologie waarmee ze experimenteerden (Bailey et al., 2022). Alle deelnemende MKB-bedrijven hadden geen eerdere ervaring met deze technologie, waardoor ik de opkomst van sociomateriële praktijken in realtime kon observeren.

Empirische hoofdstukken

Studie 1: Verschillende resource bundels van MKBs en het (niet-)gebruik van geavanceerde I4.0 technologie: Een configurationele benadering

Het doel van de eerste studie was om een groter aantal MKB's in de productiesector te vergelijken op digitale innovatieresultaten, en om te identificeren hoe sommige MKB's in staat zijn om hun gebruik van digitale technologie te innoveren ondanks het feit dat ze mogelijk beperkt worden door hun interne resources. De onderzoeksvraag in deze studie was: Welke resource- en contextconfiguraties zijn geassocieerd met geavanceerd vergeleken met niet geavanceerd Industrie 4.0 productietechnologiegebruik in MKB's? Ik baseerde me op de logica van RBV (Penrose, 1959) en op configuratietheorie (Furnari et al., 2021; Ragin, 2008) om te onderzoeken hoe diverse combinaties van resources en contexten samenhangen met geavanceerd gebruik van Industrie 4.0 technologie (of het gebrek daaraan). Ik richtte me dus op productieve resource bundels. Door fsQCA toe te passen, identificeerde ik drie paden die geassocieerd werden met geavanceerd I4.0 technologiegebruik in productiebedrijven: volledig uitgerust, selectieve balancers, en gerichte verbinders. Daarnaast identificeerde ik ook vier paden die geassocieerd werden met niet geavanceerd I4.0 technologiegebruik: weinig resources (schaarse context), weinig resources (rijke context), niet-absorbers, en andere prioriteiten. De bevindingen suggereren dat MKB's met beperkte resources verschillende maar beperkte paden kunnen bewandelen naar geavanceerd gebruik van I4.0-technologie, ofwel door een selectief evenwicht te vinden tussen interne en externe resources, ofwel door gericht verbinding te maken met externe resources. Bovendien hadden MKB's in alle paden die geassocieerd werden met geavanceerd gebruik consequent toegang tot externe hulpbronnen, hetzij via op intermediairs gebaseerde en/of brede en diepe samenwerkingsverbanden met externe actoren. De bevindingen bevestigden en detailleerden de sleutelrol die het overschrijden van organisatorische grenzen speelt bij het verkrijgen van toegang tot externe resources die potentiële beperkingen interne resources kunnen verlichten voor MKB's die digitale innovatie en het gebruik van technologie nastreven.

Studie 2: Externe resources voor digitale innovatie in MKB's in de productiesector

Aangezien er een beperkt begrip is van hoe actoren in MKB's in de loop der tijd waarde toekennen aan externe resources en deze inzetten in de interne organisatie, was het doel van de tweede studie om te analyseren: Hoe zetten actoren in het MKB in de maakindustrie externe resourcing in om digitale innovatieprocessen na te streven? Ik baseerde me op een resourcingperspectief (Feldman, 2004; Feldman & Worline, 2011) en paste een vergelijkende case study-benadering toe (Eisenhardt, 1989; 2021). Ik selecteerde vier Nederlandse productiebedrijven en vergeleek de trajecten van bedrijven die producten innoveren met die van bedrijven die productieprocessen innoveren. Bij het analyseren van deze trajecten identificeerde ik drie onderling samenhangende external resourcing practices: nastreven, ontdekken en internaliseren. De specifieke innovatieresultaten, product of productieproces, waar actoren zich op richtten was belangrijk bij het sturen van de eisen die actoren stelden aan resourcing. Terwijl de inhoud van de geïdentificeerde praktijken relatief vergelijkbaar was tussen de cases, volgden ze een verschillend tijdspatroon gerelateerd aan deze specifieke digitale innovatie-uitkomsten. Ook gaven actoren die zich richtten op productinnovatie prioriteit aan de ontwikkeling van sociale resources, terwijl actoren die zich richtten op procesinnovatie prioriteit gaven aan technische resources. Bij het verder vergelijken van deze digitale innovatieprocessen identificeerde ik kenmerken, gerelateerd aan organisatiestructuur en -activiteiten en klantinteracties, die affordances en constraints creëerden voor de manier waarop actoren hun externe resources vormgaven. Voor productinnovatie creëerde een vroege onderlinge afhankelijkheid met klanten mogelijkheden om het innovatietraject voort te zetten, terwijl het herconfigureren van de onderling afhankelijke organisatiestructuur en werkprocessen van de productie en verkoop van producten naar het mogelijk maken van de verkoop van diensten een potentiële beperking vormde. Het vernieuwen van het productieproces, relatief onafhankelijk van de input van de klant, diende daarentegen als een potentiële beperking, terwijl de onafhankelijke structuur van operationele activiteiten de mogelijkheid creëerde om deze stap voor stap te vernieuwen. Alles bij elkaar leverde deze studie inzichten op in de external resourcing praktijken bij productiebedrijven in het MKB, en werden deze verder gedetailleerd per innovatieresultaat.

Studie 3: Het potentieel van intermediaire samenwerking ontsluiten om de digitale innovatie van kleine en middelgrote productiebedrijven te ondersteunen: De constituerende rol van hybride materialiteit van digitale technologie

We hebben op dit moment onvoldoende inzicht in waarom intermediaire samenwerkingsverbanden soms niet aan de verwachtingen voldoen bij het ondersteunen van digitale innovatieprocessen in het MKB. Daarom wilde ik in dit onderzoek een beter begrip ontwikkelen van zowel potentieel ondersteunende als belemmerende praktijken. Mijn onderzoeksvraag was: Hoe zijn digitale technologie en sociale actoren in de praktijk met elkaar verweven in een intermediair-gebaseerde samenwerking, en hoe beïnvloeden deze praktijken digitale innovatie?

Op basis van een sociomaterialiteitsperspectief (Leonardi, 2011; Orlikowski & Scott, 2008) en vertrouwend op procestheorie (Langley et al., 2013), volgde ik longitudinaal een Nederlands fieldlab dat vier kleine en middelgrote productiebedrijven samenbracht met een kennisinstituut dat optrad als intermediaire organisatie. Aangezien de betrokken MKB's beperkte ervaring hadden met digital twinning technologie, moesten de actoren zowel sociale als materiële uitdagingen het hoofd bieden, die varieerden in termen van hoe dringend ze werden ervaren. Sociale uitdagingen, gerelateerd aan de samenwerkingsdynamiek, werden steeds urgenter en namen pas af toen de actoren besloten om bilateraal samen te werken met de intermediair in de ruimte van hun thuisorganisaties. Materiële uitdagingen, gerelateerd aan de ontwikkeling van digitale tweelingtoepassingen, werden na verloop van tijd minder dringend doordat actoren gezamenlijk een beter begrip ontwikkelden van digitale twinning en de gerelateerde componenten.

Voortbouwend op hoe de actoren deze sociale en materiële uitdagingen aangingen naarmate de intermediaire samenwerking zich ontwikkelde, observeerde ik de opkomst van drie dynamische sociaal-materiële praktijken in de loop van de tijd: het benadrukken van het digitale domein, het begrijpen van het hybride domein en het koesteren van het hybride domein. Mijn bevindingen suggereren dat effectieve digitale innovatie binnen dergelijke intermediaire samenwerkingsverbanden afhangt van het vermogen van de actoren om zich bezig te houden met de hybride materialiteit van digitale technologie: de hybride materialiteit van digitale twinning was de kern van zowel de samenwerkingsdynamiek als de voortgang van de ontwikkeling van digital twin toepassingen. Alleen door het hybride domein te begrijpen en te koesteren, konden actoren adequaat reageren op materiële en sociale uitdagingen om digitale innovatie van producten en processen mogelijk te maken. Het benadrukken van het digitale domein belemmerde effectieve innovatie omdat actoren relatief los stonden van de fysieke materialiteit van de technologie.

Theoretische implicaties

Dit proefschrift biedt een studie naar de waarde van het overschrijden van organisatiegrenzen voor actoren in kleine en middelgrote productiebedrijven om digitale innovatie na te streven. Digitale innovatie is vaak geconceptualiseerd als een breed, complex en veelzijdig fenomeen met implicaties op meerdere niveaus (Appio et al., 2021; Bogers et al., 2022; Dabrowska et al., 2022; Hund et al., 2021; Nambisan et al., 2017). Vandaar dat het verkrijgen van een meer gelaagd begrip van dit fenomeen in de specifieke context van productiebedrijven in het MKB baat heeft bij een fenomeengerichte benadering die meerdere theoretische oproepen combineert om te helpen bij het creëren van een completere en nauwkeurigere verklaring van een fenomeen (Cornelissen, 2023; Sandberg & Alvesson, 2021; Tsoukas, 2017). Door deze fenomeen gedreven en verklarende benadering probeerde ik beter aan te sluiten bij uitdagingen die praktijkmensen in de echte wereld ervaren (Petriglieri, 2020; Tsoukas, 2017; Weick, 2003; 2007), in een poging om af te stappen van het bieden van een geïdealiseerd, mechanisch beeld van organisatieverschijnselen (Barley, 2016).

Door de inzichten uit de drie empirische studies te combineren en te vergelijken, kon ik verder ingaan op de manieren waarop kleine en middelgrote productiebedrijven kunnen omgaan met de specifieke uitdagingen waarmee ze worden geconfronteerd bij het nastreven van digitale innovatie. Deze hebben onder andere te maken met beperkte resources (Chiappini et al., 2022; Mittal et al., 2018), minder ervaring hebben met het identificeren van digitale kansen (Benitez et al., 2020; Horvath & Szabo, 2019) en het beheren van gestructureerde innovatieprocessen (Giotopoulos et al., 2017; Pessot et al., 2023; Radas & Bozic, 2012). Ik heb ook kunnen aantonen dat voor MKB's, om deze uitdagingen aan te pakken en effectieve digitale innovatieprocessen te starten, het essentieel was om organisatiegrenzen te overschrijden om toegang te krijgen tot complementaire resources. Het overschrijden van organisatiegrenzen, bijvoorbeeld door middel van externe resources te ontwikkelen, voegt echter ook een extra laag van complexiteit toe, aangezien actoren moeten zorgen voor een verbinding tussen bestaande interne en nieuw ontwikkelde externe resources. Bovendien variëren de externe resources waarmee MKB's in aanraking komen in de loop van het digitale innovatieproces, bijvoorbeeld door een verschuiving van het verkennen van opportuniteiten via regionale discussies naar meer gerichte samenwerkingen met leveranciers om nieuwe technische competenties te ontwikkelen. Tot slot heb ik verder uitgewerkt hoe het overschrijden van organisatorische grenzen zich ontvouwt voor product- versus procesinnovatie, en hoe de verstrengeling van sociale actoren en de hybride materialiteit van digitale technologie de kern vormen van de samenwerkingsdynamiek en de voortgang van digitale innovatie.

Met mijn bevindingen draag ik op drie belangrijke manieren bij aan de verdere ontwikkeling van de digitale innovatieliteratuur. Ten eerste door digitale innovatie te conceptualiseren als een causaal complex fenomeen. Met dit proefschrift heb ik een beter inzicht verkregen in de vele paden die MKB-bedrijven kunnen bewandelen om te komen tot geavanceerd gebruik van digitale technologie en, daarmee samenhangend, tot positieve resultaten op het gebied van digitale innovatie. In het licht van de beperkte resources waarmee MKB-bedrijven worden geconfronteerd, zoals besproken in eerdere werken (Horvath & Szabo, 2019; Mittal et al., 2018), leg ik uit hoe deze MKB-bedrijven door selectief evenwicht te vinden tussen specifieke interne en externe resources, of door voort te bouwen op een bredere set externe resources door gericht te verbinden, toch geavanceerd gebruik kunnen bereiken. Samen laat dit zien dat er geen one-size-fits-all aanpak is voor MKB-bedrijven om geavanceerd gebruik van digitale technologie te bereiken, en dus om digitale innovatie na te streven. Dit wordt verder gestaafd door de bevindingen van hoofdstuk 3, waarin nader wordt toegelicht hoe deze paden, met betrekking tot het overschrijden van organisatorische grenzen, verschillen wanneer MKB's digitale product- of procesinnovatie nastreven. Het verbinden van oud en nieuw bij het nastreven van digitale innovatie werd in belangrijke mate bepaald door het werken aan dit specifieke resultaat. Mijn bevindingen werpen licht op hoe het verbinden van oud en nieuw zich ontvouwde via specifieke temporele patronen van externe resourcing: van nastreven via ontdekken naar internaliseren voor product, en van ontdekken via internaliseren naar nastreven voor proces.

Ten tweede draag ik bij aan de digitale innovatie literatuur door digitale innovatie te conceptualiseren als een proces en de onderliggende praktijken en mechanismen voor kleine en middelgrote productiebedrijven verder te detailleren. Hiermee sluit ik aan bij eerdere studies die opriepen tot een meer procesmatig begrip van digitale innovatie (bijv. Bogers et al., 2022; Correani et al., 2020). Ik doe dit door verder bloot te leggen hoe de brede orkestratiemechanismen van organisatie grenzen en het ontwikkelen van capaciteiten om gebruik te maken van digitale technologieën, zoals voorgesteld door Urbinati et al. (2022), worden toegepast in kleine en middelgrote productiebedrijven door het overschrijden van organisatorische grenzen. Meer specifiek, door het bestuderen van het proces van external resourcing in hoofdstuk 3, en door in te zoomen op een bepaald type van het overschrijden van organisatiegrenzen, het aangaan van samenwerking op basis van intermediairs, in hoofdstuk 4. In het bijzonder laat ik in hoofdstuk 3 zien hoe het proces van digitale innovatie, door het uitpakken van de notie van external resourcing, wordt gevormd door bouwstenen die een gevoel van structuur bieden, waardoor actoren kunnen toewerken naar vernieuwende producten en processen door het proces gaandeweg verder vorm te geven en te verfijnen. De relatief gestructureerde aard van external resourcing maakt het dus mogelijk om specifieke orkestratiemechanismen voor digitale innovatie te ontwikkelen. Bovendien heb ik laten zien hoe external resourcing wordt gekenmerkt door vallen en opstaan en hoe actoren kunnen navigeren door de bestuurlijke uitdaging om nieuw ontwikkelde externe resources te verbinden met de bestaande interne resources bij het nastreven van digitale innovatie. Mijn bevindingen impliceren dat er voor MKB's in de productiesector mogelijk andere benaderingen zijn om deze uitdaging aan te gaan dan eerder in de literatuur is vastgesteld (bijv. Svahn et al., 2017; Moschko et al., 2023): In plaats van deze uitdaging gelijktijdig aan te pakken, pakken mijn bevindingen verder uit hoe MKB's deze verbinding in de loop van de tijd kunnen waarborgen.

Ten derde draag ik bij aan de digitale innovatie literatuur door de socio-technische aard van digitale innovatie te conceptualiseren. Eerdere literatuur gebruikte over het algemeen nogal brede termen om deze socio-technische aard te benadrukken (Hund et al., 2021; Lyytinen, 2022), ook voor het MKB (Eller et al., 2020). Door in hoofdstuk 4 een sociomaterialiteitsperspectief toe te passen, kon ik de recursieve verstrengeling van materiële entiteiten, zoals digitale technologieën, met sociale actoren verder uitpakken door dynamische praktijken in de tijd te bestuderen. Hiermee beantwoord ik recente oproepen tot hernieuwde aandacht voor de centrale en constitutieve rol die digitale technologieën spelen in het organisatieproces (bijv. Bailey et al., 2022). Daarnaast heb ik in hoofdstuk 3 laten zien onder welke condities actoren de nadruk leggen op de ontwikkeling van sociale of technische hulpbronnen. Samen leidde dit tot de ontwikkeling van een meer gelaagd begrip van in welke contexten technische of sociale aspecten van het digitale innovatieproces meer aandacht van actoren vragen.

Praktische implicaties

Naast het leveren van een bijdrage aan de theorie, heeft dit proefschrift ook praktische implicaties, zowel voor de praktijk als voor het beleid:

1. Het overschrijden van organisatiegrenzen is waardevol, maar wees je bewust van de extra laag complexiteit die het kan toevoegen: Hoewel het een zeer complex en betwist proces is vol vallen en opstaan, zowel intern als extern, hielp het overschrijden van organisatiegrenzen managers om nieuwe ideeën, perspectieven en steun te krijgen voor hun digitale innovatie-initiatief, waardoor ze langzaam vooruitgang konden boeken in de richting van de ontwikkeling van slimmere producten en processen. Om iets van deze potentiële complexiteit die gepaard kan gaan met het overschrijden van organisatiegrenzen weg te nemen, benadrukken mijn bevindingen uit het derde hoofdstuk dat MKB's ook inspiratie voor digitale innovatie kunnen opdoen door gebruik te maken van het regionale discours, eenmalige of regelmatige evenementen in hun netwerk bij te wonen en andere bedrijven te bezoeken of door hen bezocht te worden.
2. Deel het digitale innovatieproces op in kleinere stappen om vooruitgang mogelijk te maken en het beleid erop af te stemmen: Ik heb laten zien dat het overschrijden van organisatiegrenzen benaderen als een proces dat is opgedeeld in kleinere stappen van ontdekken, nastreven en internaliseren, managers een gevoel van structuur kan geven zonder de last van een zeer geformaliseerd innovatieproces. Het doorlopen van deze kleinere stappen, waarbij eerst digitale innovatiekansen worden verkend, geëxperimenteerd wordt met specifieke toepassingen voor slimmere producten of processen, en deze vervolgens worden geïnternaliseerd in de organisatie, kan MKB-managers tussentijdse resultaten bieden op basis waarvan ze kunnen beoordelen of ze verder moeten gaan met hun digitale innovatie-initiatieven.
3. Voorkom het 'not invented here' syndroom - betrek de interne organisatie vanaf het begin bij het digitale innovatie-initiatief: Hoewel MKB-managers geïnspireerd kunnen raken en aanvullende kennis kunnen

verwerven door hun externe activiteiten, is het nadeel dat hun acties bijna onzichtbaar kunnen worden voor andere werknemers in het bedrijf. Dit kan leiden tot het 'not invented here'-syndroom en het digitale innovatie-initiatief in gevaar brengen. In dit licht benadrukken mijn bevindingen de waarde van het verbinden van deze externe activiteiten met de interne organisatie, waarbij andere leden van de organisatie in een vroeg stadium worden betrokken om de implementatie van externe middelen te vergemakkelijken.

4. Digitale technologie is slechts een deel van de complexe puzzel - je hebt mensen nodig om technologie te laten werken: Tijdens het verzamelen van de data, toen ik sprak met CEO's, andere managers en productiemedewerkers, viel het op dat mensen zich bij het bespreken van digitale technologie en innovatie vooral richten op technische aspecten. Hoewel dit een belangrijk aspect van digitale innovatie is, is het echter slechts een deel van de complexe puzzel, en het succes van digitale innovatie-initiatieven is grotendeels afhankelijk van de onderlinge relaties van deze technologieën met sociale actoren.

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About the author / Over de auteur

Steffi Menten is geboren op 20 November 1995 in Valkenburg aan de Geul, Nederland. Na haar middelbare school verhuisde ze naar Nijmegen voor een studie Griekse en Latijnse Taal en Cultuur. Aangezien ze het toch niet zo zag zitten om onderzoeker te worden, wisselde ze naar Communicatie- en Informatiewetenschappen. Tijdens deze bachelor verbleef ze voor het Erasmus+ programma onder andere een half jaar in Canterbury, waar ze vakken volgde aan de University of Kent. Tijdens de bachelor werd haar interesse in het gedrag van mensen in organisaties en netwerken gewekt, waartoe ze besloot een premaster en vervolgens master in Bedrijfskunde te volgen, met de specialisatie Innovatie en Ondernemerschap. Tijdens haar master realiseerde ze zich dat ze het doen van onderzoek steeds interessanter begon te vinden.

Een sollicitatie later werd ze gelijk aangenomen voor haar eerste baan als PhD'er bij het departement Organizational Design & Development, en begon haar onderzoek naar digitale technologie, samenwerking, en SMEs. Ze presenteerde ze haar werk op verschillende conferenties, zoals bij de European Group of Organization Studies (EGOS) conferentie, de Process Research in Organization Studies (PROS) symposia, de Academy of Management (AOM) conferentie, en de Innovation and Product Development Management (IPDMC) conferentie. Het tweede artikel uit haar thesis over external resourcing voor MKBs in digitale innovatie ligt daarnaast met minor revisions bij Technovation. Ook publiceerde ze samen met Maarten van Gils een artikel in het Tijdschrift voor Organisatie en Ontwikkeling, gebaseerd op hetzelfde artikel uit de thesis.

Naast haar het werken aan haar onderzoeksproject gaf Steffi les aan de Hogeschool van Arnhem van Nijmegen aan de Talent Academy, met vakken zoals Big Data, Academische Vaardigheden, en Innovatie in haar takenpakket. Ze gaf ook les aan de Radboud Universiteit in de vakken Organizational Change en Social, Sustainable and Technological Innovation, en gaf daarnaast masterscriptie begeleiding. Ze is ook onderdeel geweest van de PhD council, de ondernemersraad die zitting neemt in de Facultaire Gemeenschappelijke Vergadering (FGV) en de wetenschapscommissie.

Momenteel is Steffi werkzaam als postdoctoraal onderzoeker aan de Tilburg Universiteit, verbonden aan het departement Organization Studies waarbij ze onderzoek doet voor de Academische Werkplaats voor Klimaat en Energie.

In haar onderzoek richt ze zich op de rol die digitalisering en samenwerking tussen bedrijven, in zogenaamde energy hubs, kunnen spelen in het versnellen van de energietransitie.