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# An Activity Theory Analysis of Digital Innovation Orchestration in Industry 4.0

## ABSTRACT


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| Purpose: | This paper explores the orchestration of digital innovation in Industry 4.0 organisations. |
| Methodology: | The study applies the activity theory to explorative multiple case studies. Observations of innovation activities in five business cases take place at two large international organisations. |
| Findings: | The results underline five logics of action that drive digital innovation: 1) digital transformation, 2) technology translation, 3) catalyst agents, 4) digital thread, and 5) empowerment. Further, the case study organisations highlight the importance of developing a sustainable culture capable of continuously adopting new technologies, processes, and infrastructure that will allow the management of digital innovations. |
| Originality: | The study empirically shows the motivations and challenges in orchestrating digital innovation in Industry 4.0 organisations. |
| Keywords: | Digital innovation; Industry 4.0; Orchestration; Logics of action; Digital transformation; Technology translation; Catalyst agents; Digital thread; Empowerment. |
| Classification: | Article \| Research paper |


## QUICK VALUE OVERVIEW

Interesting Because - The inadequate comprehension of digital technologies and their potential hinders managerial and strategic deliberations regarding integrating digital innovation within Industry 4.0 organisations. As shown in this study, the orchestration role of digital innovation provides a possible solution since it shapes practices related to arranging resources, capabilities, or knowledge, enabling organizations to steer and coordinate their innovation endeavors.

Theoretical value - Industry 4.0 organisations require coordinating digital innovation across diverse mediums and digital competencies of agents involved in the process. Thus, orchestration must account for such diversity in the distinct roles and requirements of actors, technologies, and objectives of digital innovation. By drawing on the concept of logic of action, this study demonstrates how the orchestration activities fall into one of the five key categories: 1) digital transformation, 2) technology translation, 3) interaction of catalyst agents, 4) formation of a digital thread, and 5) empowerment. Other key findings are related to the primary motivations for pursuing digital innovation, such as reducing time-to-market, and significant challenges of orchestrating digital innovations, such as the complexity of value networks.

Practical value - Managers might benefit from using motivations, the logic of action, and challenges as a shared language to provide a more holistic understanding of digital innovation in their companies. However, organisations must consider the boundaries of logics of action, since these boundaries might trade off agency and autonomy for the reliability of automated processes and smart tools. Hence, managers should incorporate organisations' strategies and objectives into orchestrating digital innovation."

## 1. INTRODUCTION

Industry 4.0 refers to the accelerated automation and information exchange in manufacturing processes (Ortt, Stolwijk, and Punter, 2020). For manufacturing organisations, Industry 4.0 offers digital innovations that are generated by using digital technologies in innovation processes (Nambisan *et al.*, 2017). Digital innovations draw on the possibility of leveraging knowledge from a broader range of information sources in a way that has not previously been possible. These opportunities, however, often entail complex challenges around organisation strategies, human-technology interactions, data infrastructure and management, ethics, and security. The lack of understanding of digital technologies and their capabilities limits managerial and strategic considerations for implementing them in Industry 4.0 organisations (Reischauer, 2018). Hence, this study aims to find answers to the research question of how digital innovation is orchestrated in Industry 4.0. by empirically examining the use of digital technologies at Industry 4.0 organisations.

Orchestration refers to intended and determined actions undertaken by an actor(s) or organisation(s) to initiate and manage innovation (Dhanaraj and Parkhe, 2006). Existing innovation research often focuses on innovation-network orchestration where innovation is a broad umbrella term (Noviaristanti et al., 2024), and little consideration is given to the orchestration of digital innovation (Dhanaraj and Parkhe, 2006; Schepis, Purchase and Butler, 2021). Digital innovations generally show three key characteristics that differentiate them from traditional innovations (Nambisan et al., 2017): 1) they are products or services in a continuous and open process of change, 2) they challenge the centralised agency mechanisms that predominate in non-digital organisations; and, 3) products and services become more complex, blurring the line between the innovation process and the innovation outcome. Hence, these differences qualify them to be studied separately in innovation and technology management (Cetindamar and Phaal, 2023).

Further, innovation research has often isolated social, material, and conditional factors that influence innovation activities, leading to a silo-mentality in the study of innovation and limiting its advancement (Ortt, Stolwijk and Punter, 2020). Digital innovations are developed and shared instantly with numerous stakeholders through platforms and other tools (Perks *et al.*, 2017; de Reuver, Sørensen and Basole, 2018). A better understanding of how digital innovation happens in practice is required (Ortt, Stolwijk and Punter, 2020). This paper addressed this and proposed the following research questions: *How is digital innovation orchestrated in Industry 4.0?*

We draw on activity theory to shed light on digital innovation by explaining the rationale behind the activity (why), the elements and mechanism influencing the activity (how), and the outcome of the activity (what) (Engeström, 2000). Thus, activity theory could facilitate exploring the activities behind the orchestration of digital innovation, providing a comprehensive perspective that considers the activities and the context where they occur.

This study adopted an exploratory and inductive approach, gathering empirical data that offer insights into the orchestration of digital innovation. Recent advances in digital technologies, such as Industry 4.0, have created a sociotechnical environment that helps companies find new ways of organising business (Beier *et al.*, 2020; Ortt, Stolwijk and Punter, 2020). Even though Industry 4.0 organisations are widely studied, the empirical consideration of the links between digital innovation, digital technology, and orchestration practices still needs to be improved (Ghobakhloo *et al.*, 2023). This study addresses this gap by examining the emerging paradigm of digital innovation in Industry 4.0 and the practices and activities organisations carry out while pursuing digital strategies. The paper starts by summarising relevant literature and introducing the methodology adopted. Then, it presents the findings emerging from the data analysis and discusses their impact on the research objectives.

## 2. LITERATURE REVIEW

Since the early 2010s, professionals and academics have sought to understand digital innovation's motivations, dynamics, and outcomes (Autio et al., 2018). Yoo *et al.* (2012) suggest that digital innovation emerges from the rapid increase of digital capabilities embedded in new products and services. Nambisan *et al.* (2017) highlight that digital innovation also creates business processes or models by utilising digital technology. The latter study suggests three characteristics that differentiate it from the traditional innovation paradigm. First, digital innovation uses digital technologies to generate innovative outcomes—for example, new offerings, methods, or models. Second, it leverages digital tools throughout the innovation process—for example, data analytics, CAD models, or 3D printing. Third, it allows the enactment of innovation solely through digital experiences—including e-commerce, social media, or virtual reality. Nambisan *et al.* also propose the concept of digital innovation management as the "practices, processes, and principles that underlie the effective orchestration of digital innovation" (Nambisan *et al.*, 2017, p. 223). Urbinati *et al.* (2022) further underline how the orchestration of digital innovation becomes one of the fundamental mechanisms of digital transformations, calling for studies to shed light on this mechanism.

## 2.1 Orchestration of digital innovation

The idea of orchestration is equally relevant to the effective management of digital innovation because the complex networks of social and material elements require structure and coordination to successfully attain the objectives of innovation activities and strategies (Hinings, Gegenhuber and Greenwood, 2018; Urbinati *et al.*, 2022). Nambisan *et al.* (2017) use the concept of orchestration to describe the role of one or more organisations responsible for coordinating value co-creation and value appropriation activities. Perks *et al.* (2017) consider organisations using digital tools (value platforms) to orchestrate value networks. This approach illustrates the capabilities digital technologies enable or extend to manage complexity and uncertainty; however, it is limited to the organisations' use of digital platforms as the medium to monitor, moderate, and control value activities. Linde *et al.* (2021) adopt an ecosystem perspective to explore how leading organisations become orchestrators and describe interdependencies among ecosystem members. Recent studies examine network orchestration's role in particular innovation contexts (Ritala, De Kort and Gailly, 2023; Noviaristanti *et al.*, 2024). Noviaristanti *et al.* (2024) considered network orchestration as a set of activities and roles a corporate accelerator performs to coordinate innovation and value generation among network partners.

These studies looked at innovation intermediaries and how they orchestrate networks for innovation, focusing on preparations and actions to orchestrate an ecosystem or innovation network. In these studies, orchestration is perceived as a forging mechanism to establish the rules and conditions for coordinating an innovation ecosystem or network. However, such an approach considers orchestration an episodic event to develop an ecosystem. Instead, the orchestration of digital innovation must consider guiding principles or strategies that enable organisations to manage the continuous adoption and adaptation of digital technologies into offerings and business processes. Accordingly, the concept of orchestration discussed in this paper does not refer to the tools or solutions—often associated with digital technologies—organisations use during innovation activities. Instead, it refers to practices or principles for arranging resources, capabilities, or knowledge that allow organisations to drive and coordinate innovation activities.

## 2.2 Industry 4.0

Industry 4.0 refers to various concepts, technologies, and strategies to increase automation and interconnection among manufacturing processes, systems, and organisations (Beier *et al.*, 2020). The widespread adoption of Industry 4.0 is a meaningful shift towards digitalisation and digital transformation, addressing operational and strategic objectives (Lyytinen, Yoo and Boland, 2016; Nambisan *et al.*, 2017). Recently, researchers have introduced the term Industry 5.0 to describe a combination of organisational principles and technologies to design and manage operations and supply chains as resilient, sustainable, and human-centric systems (Ivanov, 2023). Considering that Industry 5.0 adds societal goals to the principles for human-technology interactions established by Industry 4, this study limits its observations to Industry 4.0 to examine how digital technologies enable or hinder coordinating innovation at organisations, aiming to reach traditional goals such as profits and productivity.

This research recognises a difference between traditional and digital innovation, which is enhanced by the design principles of Industry 4.0—interoperability, data transparency, decentralised decision-making, and technical assistance (Hermann, Pentek and Otto, 2016). *Interoperability* refers to creating and adopting standards that enable actors to participate in any manufacturing process through the value chain. Interoperability standards also allow *data transparency*–the open access to the data generated through the various business processes. Interoperability and openness encourage numerous actors to participate in the value chain in *decentralising decision-making*. Finally, *technical assistance* refers to implementing technological systems to manage the complexity of digital supply chains, automating most of the repetitive work and simplifying the interfaces required for the previous design principles. These design principles highlight the differentiation between traditional and digital innovation paradigms (Nambisan *et al*., 2017 and Satwekar *et al*., 2023). In other words, Industry 4.0 organisations face blurring boundaries within and across organisations, diluting each organisation's agency over the innovation processes and changing the focus of innovation from an individualised to a systemic perspective.

Increasing operational efficiency is the most well-known objective of Industry 4.0 (Tortorella, Giglio and van Dun, 2019). This objective combines multiple technological solutions to optimise processes, increase production speeds, and reduce waste. These initiatives are spearheaded by engineering departments and focus on assessing and validating technical solutions. The interest of management literature, however, lies in examining the organisational and strategic aspects that increase efficiency. Industry 4.0 is thus a suitable context for exploring the orchestration of digital innovation.

# 3. RESEARCH METHOD

This study uses an exploratory multiple-case study design (Yin, 2018) by adopting an inductive and exploratory approach to examine digital innovation elements, relationships, and practices (Eisenhardt, 1989). A case study design helps develop insights into theoretically novel phenomena, such as the orchestration of digital innovation in Industry 4.0. (Swanborn, 2010) emphasises the importance of case studies in offering detailed, context-rich insights crucial for understanding complex phenomena, such as Orchestration, in real-life settings. This approach is particularly effective when exploring new or poorly understood areas. For example, a recent study rests on a pharma company as the case study to build a framework for orchestration management at an organisational level (Satwekar *et al.*, 2023). Eisenhardt (1989) highlights that case studies allow for an in-depth exploration of theoretical concepts in real-world contexts. The adopted approach aligns well with the research topic in this paper.

## 3.1 STUDY CASES

Organisations use business cases to describe and justify a project or initiative, as "it evaluates the benefit, cost and risk of alternative options and provides a rationale for the preferred solution" (APM, 2019). However, business cases seek support or approval from stakeholders and adopt a specific perspective, often financial or economic. This study used companies' business cases as a starting point and expanded its scope through interviews, observations, and document analysis. The objective was to complement existing business cases that reflect the sociomaterial perspective of the initiative, particularly the role of digital technologies in innovation and their impact on business models for Industry 4.0.

The business cases stemmed from two large international organisations collaborating with other companies to design and develop digital innovations. The participant organisations were Green Manufacturing (GM) and Hybrid Telecom (HT). Both organisations were selected for the study because they had a wealth of experience implementing Industry 4.0 and represented both traditional manufacturing (GM) and fast-changing service (HT) industries.

GM, headquartered in Denmark, has been involved in designing, manufacturing, installing, and servicing renewable energy systems, while HT, headquartered in the UK, is a telecommunications provider developing ubiquitous connectivity solutions forconnected and autonomous vehicles (CAVs). GM was selected because of its vast manufacturing experience and extensive value network. HT was chosen because of its strategic decision-making autonomy and distributed innovation process. The digital innovation orchestration in HT was more complex than in GM due to the more significant number and diversity of collaborating organisations and the wide range of considerations in their business cases, such as commercial perspective.

### 3.1.1 Study case selection

The criteria used to select case organisations considered three characteristics relevant to this study. First, the business cases should emphasise digital technologies as the key driver of the innovation initiative. Second, the business cases should reflect the expected impact of digital innovation on the organisation's business model. Third, the innovation should be relevant to the context of Industry 4.0.

Five business cases were selected for this study: three from Denmark-based company GM (BC1 eCommerce, BC2 Smart Factory, and BC3 Connected Worker) and two from UK-based company HT (BC4 CAVs-for-Retail and BC5 CAVs-for-Health). In addition to the participant organisation criteria, the business cases selected were characterised in three dimensions to refine the selection process. The dimensions are the development stage, orientation towards collaboration, and innovation type (see Table 1). The first business case, *eCommerce*, stemmed from Green Manufacturing and described the process, considerations, and challenges faced while implementing and later expanding a digital consumer channel. The second business case, *Smart Factory*, was part of Green Manufacturing's Industry 4.0 strategy. The third business case, *Connected Worker*, also stemming from Green Manufacturing, focuses on leveraging digital technology to empower workers, referred to as users here. The fourth and fifth business cases, *CAVs-in-Retail* and *CAVs-in-Health,* respectively, stemmed from HT. These cases were selected because they contrast GM cases in various ways. Both CAVs cases use the same collection of technologies as the foundation of their solution, three emergent technologies—5G mobile communication (5G), satellite communication (Satcom), and Connected and Autonomous Vehicles (CAVs); and one information technology tying everything together—cloud computing.

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## 3.2 Data collection

The data collection took place over nine months (2020) and used semi-structured interviews as its primary data source; however, participant observations and document analysis were also conducted to ensure reliability and validity (see Table 2).

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### 3.2.1 Interviews

Executives, managers, engineers, and other relevant stakeholders related to the innovation process within each business case were interviewed using an "interview protocol" (Easterby-Smith, Thorpe and Jackson, 2012). The interviews were tailored to the distinct informants' profiles and the interview objectives. The semi-structured interviews considered three lines of questioning: the understanding of digital technologies, the characterisation of digital innovation, and the organisation's orchestration of innovation activities.

### 3.2.2 Participant observations

Participant observations were used as a data source, following the triangulation strategy to maintain qualitative rigour (Yin, 2018). Participant observation collected data in situ from innovation activities, considering informational and steering meetings, innovation workshops, and daily business operations. This approach offered the opportunity to capture contextual information about innovation activities, the collaboration process, and the challenges encountered.

### 3.2.3 Document analysis

The documents collected during this study consisted of three categories. First, publicly available documentation included web pages, press releases, and secondary data reports. Second, internal strategic documentation includes business case documentation, technology roadmaps, and stakeholder analysis. Third, outlook reports had market, competitor, business models, and value chain analyses. The documentary analysis helped triangulate the findings emerging during data collection.

## 3.3 Data analysis

The process consisted of iterative thematic analysis (Miles, Huberman and Saldaña, 2014) and sense-making (Eisenhardt, 1989). The interview transcripts, observation proformas, and documents were input into NVivo for analysis. The data was segregated, aggregated, and abstracted (Gioia and Thomas, 1996). The data analysis consisted of activity system synthesis and cross-case analysis.

### 3.3.1 Activity-system synthesis: Adopting activity theory lens

Activity Theory (AT) analyses an entire work or activity system, including teams and organisations, and accounts for the environment, history, culture, role of artefacts, motivations, and complexity of real-life activities (Holt and Morris, 1993). While underrepresented in the social sciences literature, AT has been applied in various research contexts, such as organisational studies (Leonardi, 2013) and project-based organisations (Vakkayil, 2010). By focusing on the relationships between activities, actions, operations, and artefacts, activity theory provides a conceptual framework for understanding the social, organisational, and situational contexts within which human activities are framed.

The unit of analysis in AT is the concept of object-oriented, collective, and culturally mediated human activity, or activity system. We specifically adapted Engeström's (2000) activity system to serve as a framework for synthesising each business case in our research. An activity system approach uses three descriptors to characterise each activity: the rationale behind the activity (*why),* the elements and mechanism influencing the activity (*how),* and the outcome of the activity (*what*). The *why* descriptor details an activity's motivation. The motivation might arise from the company mission or vision, a strategic decision, a response to a competitor, or changes in the market, such as changes in consumer preferences or new regulations.

Engeström emphasises the "*how"* of activity and characterises the *how* into six constructs—subject, object, tools, community, division of labour, and rules. In Industry 4.0, the digital innovation activities were much less delimited than in Engeström's study, which meant the boundaries between community, division of labour, or rules were blurred. Consequently, these three constructs were grouped under a single heading of "*conditions*."

Thus, the activity system approach in our study characterises the *how* descriptor by the activity's *subject*, *objective*, *tools*, and *conditions*. The *how* descriptor then focuses on understanding the activity itself. It starts by considering an activity subject and its objective. The activity *subject* can refer to an individual, a team, a strategic business unit, or an organisation. The activity *objective* is often intangible and can refer to a high-level purpose, for example, entering a new market, expanding the product offering, or introducing new technology. This approach considers two influencing elements—an activity's *tools* and *conditions*. An activity's *tools* refer to technologies, information systems, or any other artefact used to attain the activity *objective*. An activity's *conditions* describe a wide range of circumstantial factors that can affect an activity, for example, the involvement of relevant stakeholders, executive support, or the innovation culture in the organisation.

Finally, the *"what"* component describes the outcome of the activity. As opposed to the frequently abstract nature of the activity *objective*, the activity *outcome* emerges from the transformation of the activity *objective* into a concrete output, resulting, for example, in a clearly defined market entry plan, anew production plant, or a technology roadmap for the next five years. Figure 1 summarises the activity systems approach adopted for this research to characterise the digital innovation activities in each business case.

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The activity system framework was used to synthesise the findings for each business case, leveraging the three activity theory assumptions (Kuutti, 1996): 1) that the examined activity has an underlying structure; 2) that the activity is mediated by the tools and conditions under which it is performed; 3) that all the components of an activity be aligned to a specific purpose. In other words, an activity is a phenomenon structured to a specific objective, mediated by the tools and conditions present during its enactment. Table 3 summarises the characterisation of each business case, serving as a proxy for digital innovation through the activity system's objective, motivations, tools,conditions, and outcome constructs. It is worth noting that this study considered the organisation leading each business as the subject.

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### 3.3.2 Cross-cases analysis

The cross-case analysis consisted of various coding rounds that helped to identify themes and patterns in orchestrating digital innovation activities using the business case activity systems as a proxy. Figure 2 describes the process and the iterative cycle adopted during the analysis.

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The data were first coded according to the perceived objectives of the activities driving digital innovation in each business case, particularly those affected by digital technologies. The resulting first-order codes were mainly thematic: ideas or concepts repeatedly appearing throughout the data analysis. The first-order codes were then grouped around common themes. Axial coding (Corbin and Strauss, 1990) was then used to group how respondents described the effects of digital technology on the business case activities and objectives.

These second-order codes were then contrasted and consolidated into aggregated dimensions, reducing the number of codes by eliminating redundancies. The codes and dimensions were discussed until an inter-coder agreement was reached, seeking to improve the reliability and validity of the process. Based on the coding process, subsequent sensemaking, and reflection on the literature, a final data structure and a broader conceptualisation of motivations, logics of action, and challenges in orchestrating digital innovation were reached (see Figure 3).

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# 4. Findings

Our findings provide insights into the role of digital technologies in orchestrating digital innovation in Industry 4.0. The findings describe the motivations, key activities, and challenges for digital innovation orchestration across the five business cases.

The orchestration of digital innovation plays a relevant role, as digital technologies are rarely created to address a specific industrial problem. Instead, organisations consider the digital technologies or technological solutions available to attain their objectives. Logics of action describe the patterns in coordinating technologies, resources, and knowledge for adequately implementing digital innovation. Figure 4 illustrates our findings regarding the orchestration of digital innovation, and a further description of each component is provided below.

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## 4.1 Motivations

Industry 4.0 has pushed the development of new sources of value by combining existing and emerging digital technologies through increased automation and interconnection of processes. Even though many organisations pursue digital innovation to increase their profitability, they often focus on reducing production costs and time to achieve this objective. Yet, an organisation only develops new offerings once it recognises the value of its data and digital technologies. As summarised in Table 4, this study identified three primary motivations for pursuing digital innovation—1) reducing costs, 2) reducing time-to-market, and 3) developing new offerings.

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### 4.1.1 Reduce cost

A common motivator across the business cases examined is their drive to *reduce costs*. Across the entire organisation, digital innovation is often expected to reduce business costs, from production and maintenance to sales and customer service. Large Industry 4.0 organisations, such as those participating in this study, are traditionally detached from end-users. Thus, their perception of value is related to their ability to manufacture their offerings with the expected quality and as quickly and economically as possible.

> *"From the management perspective, two things that support manufacturing have been 1) optimising processes to reduce costs and 2) reducing time-to-market. It is always about that. We do not have activities driven by the possibility of creating extra revenue or something like that. […] the business cases driven by us [manufacture R&D] are things we can do or should do to make cost reductions, faster time-to-market, or better utilisation of factories." Green Manufacturing (GM): Senior Manager (SM) 01.*

### 4.1.2 Reduce time-to-market

Another motivator, repeatedly mentioned by informants, is the constant push to reduce the production and deployment time of existing and upcoming offerings, called *time-to-market*. This motivator is common across many industries, particularly when substantial investment is required to implement new technologies. However, digital innovation in Industry 4.0 is mainly affected by two considerations.

The first consideration is the increasing pace of technology development. Organisations are expected—by vendors and customers—to adopt new technologies at increasingly faster speeds. Organisations producing offerings with significantly long lifecycles are especially affected by this situation. Thus, they perceivedigital innovation as a path to mitigate the speed of change.

> *"The problem is 'the upcoming headache.' I heard this term directly from engineers. [the problem] is not optimising for the current production; the problem is optimising the change in all these products, production, and processes. It is not just optimising the current production line; before we [finish] optimising it, a new product and new processes and technologies are coming. So, our upcoming headache is optimising all these changes." GM: Product Manager (PM) 02.*

The second consideration is mitigating an increase in employee turnover caused by an ageing population and a loss of interest from young workers. Large Industry 4.0 organisations need a highly knowledgeable and skilled workforce. Thus, organisations see digital innovation as a path towards leveraging the experience of senior workers through remote work and increasing the mentoring and training speed of new workers. These trends seek to reduce the "time-to-competency," describing the time required to train workers to address their responsibilities competitively.

### 4.1.3 Increase offerings

An alternative expectation of digital innovation is to produce different and more appealing offerings for existing and new customers. Most business cases adopted a user-centric approach, with the applications especially tailored to the users' requirements. Organisations pursue digital innovation to identify and address the needs of their users. Digital technologies and the data they generate are a source of value for the organisation that seeks to leverage data and digital technologies to createmore efficient processes, either by simplifying the responsibilities of internal users or providing a better fit for the needs of external users.

> *"The most important thing about a [technology-based] project is capturing requirements and working with the customers. Because the stuff that [management] needs is the [digital] thread, the applications are what [the users] need. And so, if you deliver what they need, even if it is just what we call minimum viable product if you have adoption and buy-in, it does not take long [to succeed]." GM: PM01.*

## 4.2 Logics of action

This study found that Industry 4.0 organisations require coordinating digital innovation across multiple physical and digital domains with various degrees of blended mediums. Similarly, the digital competency of the actors found throughout an Industry 4.0 value network varies drastically. Thus, orchestration must account for such diversity in the distinct roles and requirements of actors, technologies, and objectives of digital innovation. This study considered the concept of logic of action—"the implicit relationship between means and goals that is assumed by organisational actors and guides their actions" (Tumbas, Berente and Brocke, 2018)—to classify the orchestration activities found into five categories—1) digital transformation, 2) technology translation, 3) interaction of catalyst agents, 4) formation of a digital thread, and 5) empowerment. Table 5 summarises each logic, namely the rationale driving digital innovation activities.

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### 4.2.1 Digital transformation

Industry 4.0 organisations have been dealing with the increasing pace of technology development for decades. Thus, the rationale for digital transformation goes beyond adopting a single technology or business model. Instead, the "Upcoming Headache" (see Section 4.1.1) for these organisations focuses on developing a sustainable culture capable of continuously adopting new digital technologies, processes, and the infrastructure to support them. Digital transformation is associated with changes in various domains of social life, including the way people interact with technology. However, this restructuring requires stable elements that allow an organisation to pivot implementation and objectives.

> *"[Digital transformation] is a continuous journey, not a revolution. Over the last decade, as opposed to other industries, manufacturing management has been more involved in consolidating manufacturing operations and their supporting systems. […]The focus has been on incorporating new hardware. That requires different kinds of systems and infrastructure support. [The focus] is changing, but it is not the revolutionpeople think. The digital transformation has been going on since the 80s." GM: SM01.*

### 4.2.2 Technology translation

Technology translation as a rationale describes the activities related to understanding the effects of digital innovation on operational, commercial, and strategic processes.

> *"Let me try to explain it by giving an example. Let us say we are doing roboticsnow in the field, so if I explain what we want to do to my developer, I have to talk about the controller, what platform we can use, or how it will connect to the device. Ineed to give them the information and purpose. I have got to talk to them about UI, UX, etc. I craft a message for that stakeholder."*
>
> *"If I explain it to management, I am talking about the value capture opportunity. So, Iwill say that we will record every value to ensure that we do not open ourselves up toliquefied damages, we will ensure compliance with an ISO 8000 standard, and we canreduce the time it takes to [install a product]."*
>
> *"It is just a matter of ensuring that you understand [the technology application] to communicate with different stakeholders and know what they need to hear." GM: SM01.*

### 4.2.3 Catalyst agents

Catalyst agents refer to actors or groups fostering digital innovation. Organisations adopt different operational settings according to their needs. Catalyst agents were found in various forms, for example, technology champions, inter-departmental teams, or spin-off companies. Catalyst agents are often granted a high degree of autonomy and access to vast resources, yet they must adhere to the organisation's digital strategies. In other cases, they are tasked to develop ad-hoc strategies to pursue specific commercial or technological objectives. By allowing the interaction of catalyst agents, firms could speed up the process of digital innovations.

*“We are here to help [HT parent company] develop the business further. That is the right attitude because this project would not exist without [HT parent company]. Hybrid Telecom aims to help [HT parent company] develop this technology. Then we will run those parts whatever [HT parent company] does not want to take on board because they are not part of their core business. They might say, ‘Yes, this service model is excellent, and we want to put our name against it, but we do not want to run this other part because we do not have a department for it.’” Hybrid Telecom (HT): SM03.*

### 4.2.4 Digital thread

With the increased adoption of digital technologies, organisations in Industry 4.0 have seen a substantial increase in data generated from their operations, interactions, and offerings. This explosion of data has created new challenges for gathering, structuring, and storing data. Some organisations have adopted a digital thread strategy to organise the vast data generated within and across organisations. A digital thread creates a universal data structure, a continuous data record constantly enriched at every process or business stage instead of duplicating or detaching it. This approach links products and services to the data generated throughout their life cycle.

The digital thread represents a new paradigm to orchestrate digital innovation, focused beyond fixed outcomes and developing, instead, the infrastructure that enables a continuouscreation of value.

*“Now we can use one object to create a 3D model, put that in a drawing, create different drawing views, and so on. We can use that to generate downstream information. So, that is what we do now, just a continuation. Walk down that path where we take digital information and deliver it to the next person in the food chain or the value chain in a way where they can read that information. Also, continue working on it because it is not just reading; they must do somethingwith it and work on it. We are creating tools that have a digital way to read the information.” GM: PM12.*

### 4.2.5 Empowerment

Organisations see digital technologies as tools to empower their workforce by providing more information and making them responsible for the outcomes of digital innovation activities instead of process steps. This approach aims to take advantage of local knowledge or expertise and close the loop between distinct parts of a business, for example, manufacturing and sales. Local users can tune the orchestration of digital innovation according to their specific needs, make the necessary adjustments, and adopt relevant strategies to deliver improved innovation outcomes.

*“We took a stepped approach. We did not just arrive with a big bang and say everybody should be on board. Instead, we did it in sort of waves. We startedwith 200 users in each region, and then they were responsible for the rest of the rollout. And, of course, we have been engaging with them regarding supervision. When are they going to do what? What are they planning to do next? But then, they had to make themselves accountable for onboarding the rest of the users, so they needed to develop a deployment strategy.” GM: Senior Engineer (SE) 11.*

## 4.3 Challenges

As summarised in Table 6, this study found four significant challenges for orchestrating digital innovation in Industry 4.0: 1) inertia, 2) change management, 3) complexity, and 4) uncertainty.

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### 4.3.1 Inertia

Inertia refers to the challenges found in organisations when trying to drive change; in this case, change refers to the pursuit and orchestration of digital innovation. Inertiacan be observed in two ways. First, when organisations resist the initiation of change—in other words,to start moving, for example, when there is a lack of interest or support to adopt new technological solutions. Second, when an organisation resists changing how it undertakes operations—in other words, changing paths, for example, realising that technology implementation is not delivering good results and delaying the project termination. In both cases, inertia is often ingrained in organisational culture or behaviours towards understanding emerging technologies.

> *"Yeah, the [sales department] is very far ahead. There is also some catch-up [needed] on its infrastructure. For example, let's go out and set up a new application. The whole infrastructure needed around this new application, from the [master data] to the userinterface, is not supported all the way through. So, we need to create workarounds toget that to work; these things are very much in development." GM: SM16.*

### 4.3.2 Change management

Change management pays particular attention to the resistance emerging from users of digital innovation—the people who contribute to the innovation process or use digital innovation outcomes. Change management represents a constant struggle for organisations that must continuously adopt new technologies, processes, or collaborations since new technologies often introduce multiple organisational changes.

> *"When technology comes into play—for us, it was the development of eCommerce— it introduces the need for change management. Many are change drivers in themselves because we need to standardise and optimise processes. We need to work with master data. We must work with the customer and the value proposition we are creating. It changes a lot." GM: SM11.*

### 4.3.3 Complexity

Complexity challenges originate in many areas of Industry 4.0. The most significant source is the increased interconnectedness between processes, systems, and organisations. Value networks are becoming more complex due to the specialisation required by some processes, for example, managing warehouses and inventories, processing payments, or delivering products and services. These tasks have been standardised and commercialised across industries by niche businesses offering specialised products and services.

> *"New collaborations stress how we support our systems because we are very closeto the shop floor, which means that [new technologies] need to run reliably 24/7. After all, the factories run 24/7. [New collaborations] create another layer of complexity onthe runtime. That is why we need to consider the sustainability of the solutions. That is one of my biggest worries. We think carefully about cutting-edge technology solutions, where we are the first mover because that rarely matches sustainability andstability. Stability is something that we build along the way." GM: SM16.*

### 4.3.4 UNCERTAINTY

Uncertainty challenges are arguably the most problematic, emerging from volatility, vulnerabilities, and the unknown. Industry 4.0 organisations are particularly interested in minimising uncertainty since many operations are scheduled weeks or months in advance. This effect is heightened by the general uncertainty about digital technologies and their requirements.

> *"We can do simulations of our products and processes, and we can do them today, butthey are effectively calculators. They are not a digital twin. The real problem is that we do not know what a digital twin is. What kind of fidelity do you need? And how much value can we capture by having a 100% accurate model for a part? And there is an argument that we do not need that today. But I think that is an argument from ignorance because we have never achieved that level of detail." GM: SM01.*

# 5. DISCUSSION

Extant literature on digital technology development, adoption, and use of digital innovations frequently omits observation of the capabilities offered by digital technologies and how organisations develop their innovation activities to leverage those capabilities toward creating value (Linde *et al*., 2021). In doing so, the literature is either silent on how organisations coordinate their innovation activities or how they understand the challenges of technology adoption as being considered by a limited set of individuals. As our research highlights, the challenge with this omission is that digital technologies can provide different capabilities and value if organisations better understand digital technology usage and strategic considerations for implementing digital innovation in Industry 4.0 organisations. Leonardi (2013) highlights the importance of understanding the context in which technologies are developed and deployed.

Our research provided insight into the interests expressed but unfulfilled in the literature for understanding the orchestration of digital innovation in Industry 4.0 (Yoo *et al.*, 2012; Nambisan *et al.*, 2017). In particular, the findings shed light on the considerations for orchestrating digital innovation by bringing forward activities involved in the orchestration and describing the rationale behind innovation activities through the logics of action perspective. We believe that our work complements existing literature on digital innovation management, such as collaborative innovation (Ivanov, 2023), orchestration (Ritala, De Kort and Gailly, 2023; Noviaristanti *et al.*, 2024), and innovation ecosystems (Linde *et al.*, 2021).

The study expands existing knowledge about digital innovation by extending the understanding of digital innovation orchestration in Industry 4.0 organisations, defining key orchestrating activities, coordination requirements, physical to digital, and critical challenges. Our contributions are summarised through motivations, the logic of action, and challenges regarding the orchestration of digital innovations.

## 5.1 MOTIVATIONS

Why organisations engage in digital innovation is fundamental to understanding how to orchestrate it better. Existing literature addresses this question through a variety of theoretical perspectives such as institutional theory (Hinings, Gegenhuber and Greenwood, 2018), sociomateriality (Autio *et al.*, 2018; de Reuver, Sørensen and Basole, 2018), or business strategy (Perk *et al*., 2017). However, the findings from those studies are limited in at least two ways.

First, studies on digital innovations describe a silo-minded approach, limiting their insights into the paradigms established in their disciplines, thus failing to consider alternative perspectives to develop an overarching understanding. Second, these studies assume that digital technology is static. They describe the adoption of digital technology as a singular event that, although it might be subsequently repeated, does not offer insights into the continuous evolution and adoption of the technologies observed in digital innovation. Our work provided a more generalisable description of the motivations for pursuing digital innovation in Industry 4.0. Informants recognised that most digital technologies supporting the business cases examined had been deployed throughout their organisations for many years. However, what has changed in recent years has been their ability to combine these technologies, taking advantage of their properties (Yoo et al., 2012), and incorporating them into business decision processes (Tortorella, Giglio and van Dun, 2019).

## 5.2 Logics of action

Digital innovation offers multiple benefits to organisations that might serve as motivators for adopting new digital technologies. However, it also might create various risks, primarily due to the novelty of emerging technologies and the digital innovation paradigm (Nambisan *et al.*, 2017).

Industry 4.0 organisations have developed various practices and behaviours to mitigate risks and drive innovation to address the new challenges introduced by digital technologies (Yang and Gu, 2021). Our work organised these practices through logics of action, representing emerging *guiding principles* driving the decision-making process in Industry 4.0 organisations. Logics of action approach generally offers a high-level description of an organisation's objectives and represents a crucial initial step toward institutionalising innovation activities (Annosi *et al*., 2022). Organisations often develop logics of action because of the recurrent actions aligned towards a common goal, such as digital innovation, or to address the confusion created by conflicting indications, such as multiple smaller digital strategies developed from the requirements or processes of individual departments.

Finally, organisations must also consider the boundaries of logics of action, which might trade off agency and autonomy for the reliability offered by automated processes and *smart tools*. Such an approach limits the capability of people operating digital technologies to respond to uncertainty and the overall flexibility of the organisation to address rapidly changing environments. As a result, the logics of action explains the rationale behind digital innovation and offers a perspective to incorporate organisations' strategies and objectives into the orchestration of digital innovation in Industry 4.0.

The study brings empirical evidence to recent work that links innovation activities concerning digital innovation and points to innovation logic as a link between organisations and their actions (Satwekar *et al.*, 2023). This contribution supports the findings of Pahnke, Katila, and Eisenhardt (2015) and Nambisan *et al.* (2017), emphasising the importance of understanding and leveraging the logics of action throughout an organisation. It also aligns with research on the interdependence of technological and behavioural dimensions (Ritala, De Kort, and Gailly, 2023).

## 5.3 Challenges

Some of the initial challenges found in the adoption and orchestration of digital innovation have been discussed in the literature—for example, the difficulty of accurate assessment of digital capabilities and readiness (Ortt, Stolwijk, and Punter, 2020), technical issues during the implementation of digital innovation (Rymaszewska, Helo and Gunasekaran, 2017), or the lack of organisational conditions supporting digital innovation (de Reuver, Sørensen and Basole, 2018). However, instead of identifying overspecialised issues concerning specific digital technologies or companies, our work sought to identify common patterns or overarching themes hindering digital innovation orchestration. These challenges reflect organisations' obstacles while coordinating innovation activities, resulting from a lack of understanding or direction in orchestrating digital innovation. By doing so, our work expands the literature on digital innovation by bringing forward the key challenges that should be considered in managing digital innovation (Urbinati *et al.*, 2022).

# 6. Conclusion

Our research focuses on orchestrating digital innovation in Industry 4.0 using activity theory in an explorative multiple case study. Our findings offer details on motivations, the logic of action, and challenges that can improve our understanding of how Industry 4.0 organisations successfully orchestrate digital innovations.

This study contributes to the existing scientific knowledge on digital innovation management by highlighting the importance of understanding and leveraging the logics of action in Industry 4.0 organisations. In other words, the new concepts introduced in this study, such as motivations, the logic of action, and challenges, are expected to serve as a shared language to provide a more holistic understanding of digital innovation in Industry 4.0 organisations.

The managerial implications of this study include offering some tools that practitioners might use to orchestrate their digital innovation activities. For example, the logics of actions might help practitioners develop successful digital business strategies, minimising complexity, and uncertainty. Similarly, practitioners might find better ways of addressing the challenges hindering the orchestration of digital innovation, particularly the inertia and change management challenges.

This study recognises three fundamental limitations. First, the study only examined the orchestration efforts of two large international companies. Future studies must broaden the scope to consider smaller organisations and non-Industry 4.0 settings. Second, the study considered organisations leading the industry in digital innovation. Further studies are required to understand the orchestration efforts of organisations in earlier stages of digital innovation. Third, the lists of motivations, activities, and challenges are not intended to be exhaustive, and further studies may yield additions to the list.

Further work is needed to explore institutional conditions delineating digital innovation management. As observed through the empirical evidence, external factors such as environmental, economic, and political considerations might also affect the orchestration of digital innovation. Internal factors such as culture, leadership, and executive support might also impact digital innovation activities. Future studies must explore these factors and consider the elements supporting the institutionalisation of digital innovation in Industry 4.0. Future studies might also consider the role of society and human-based approaches for orchestrating digital innovation in Industry 5.0, the next generation of Industry 4.0. Finally, future research would benefit from adopting different theoretical lenses and exploring digital innovation in distinct contexts.

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**Figures**

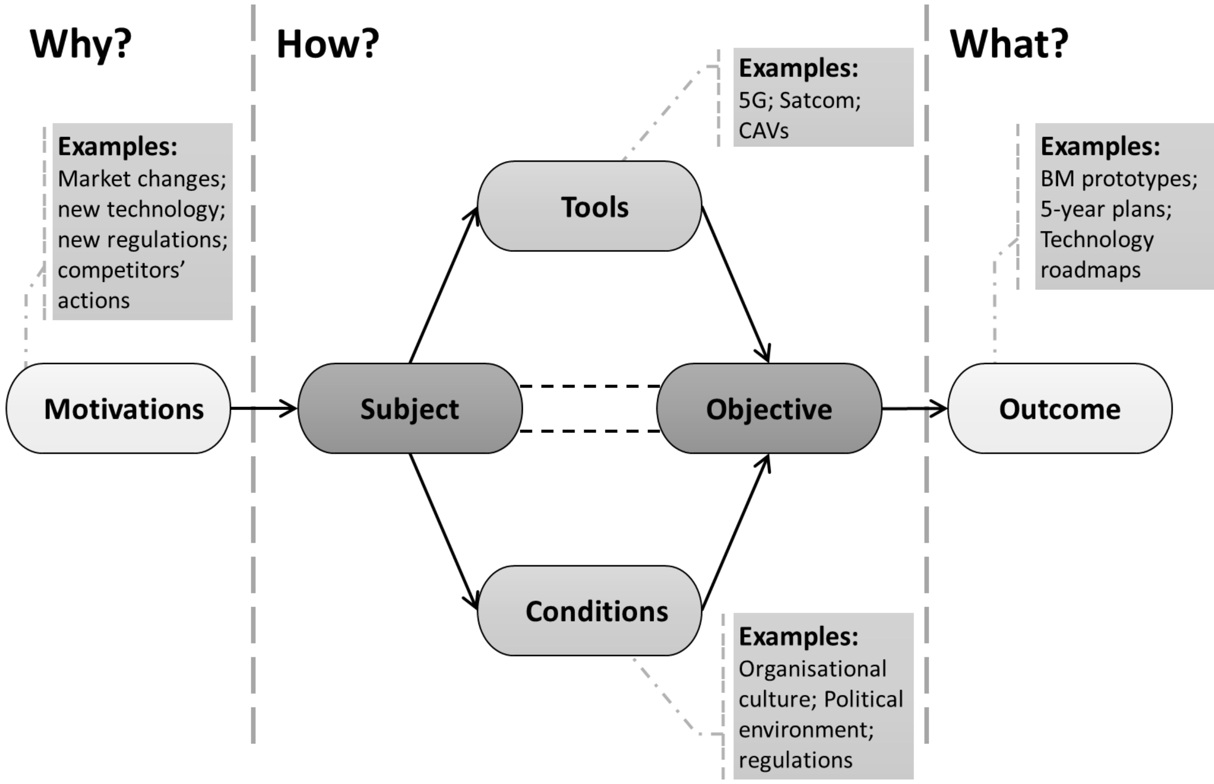


*Figure 1 The Activity System approach adapted from Engeström* (2000)

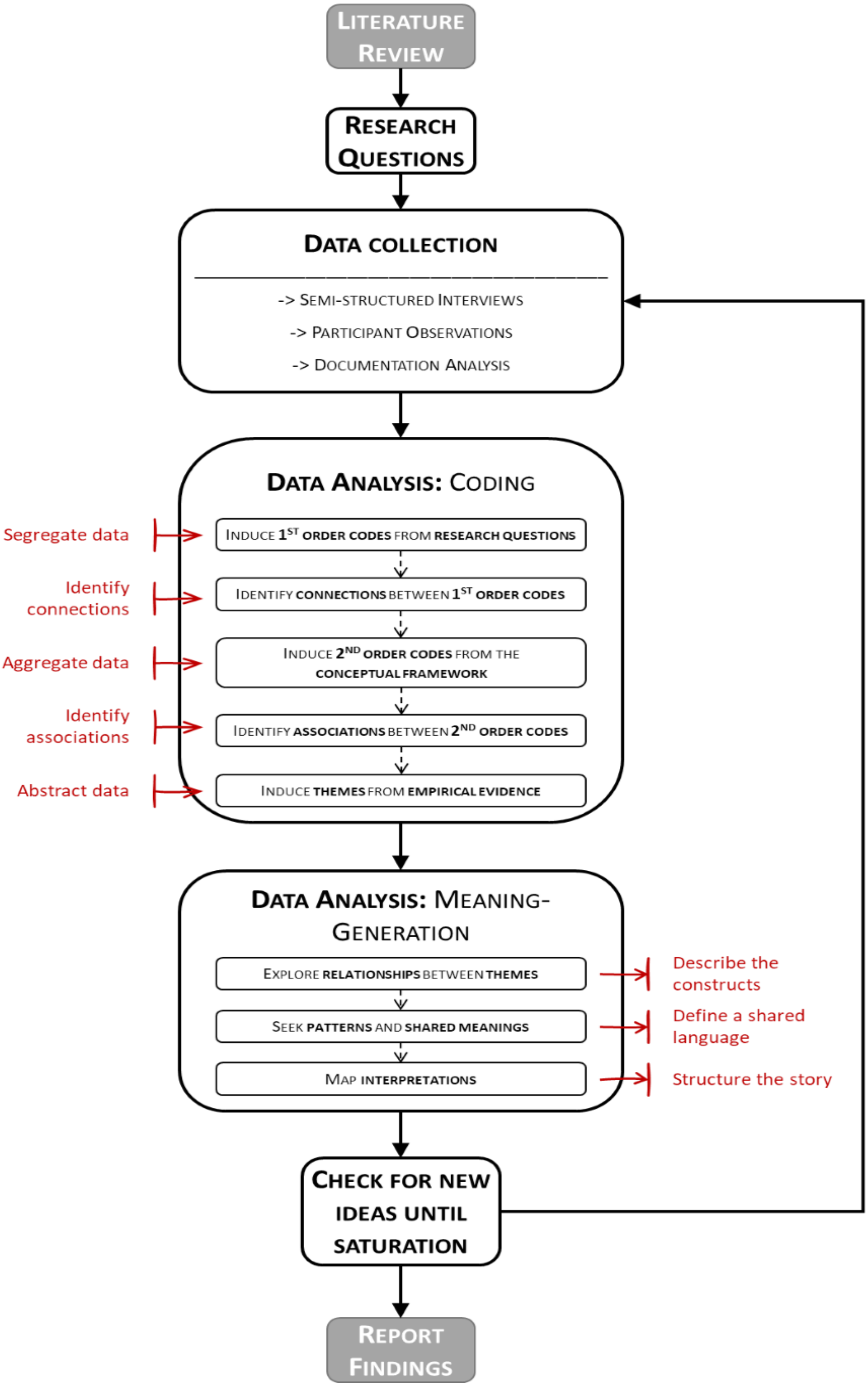


*Figure 2 - Diagram of the data analysis process*

Source: Authors' own

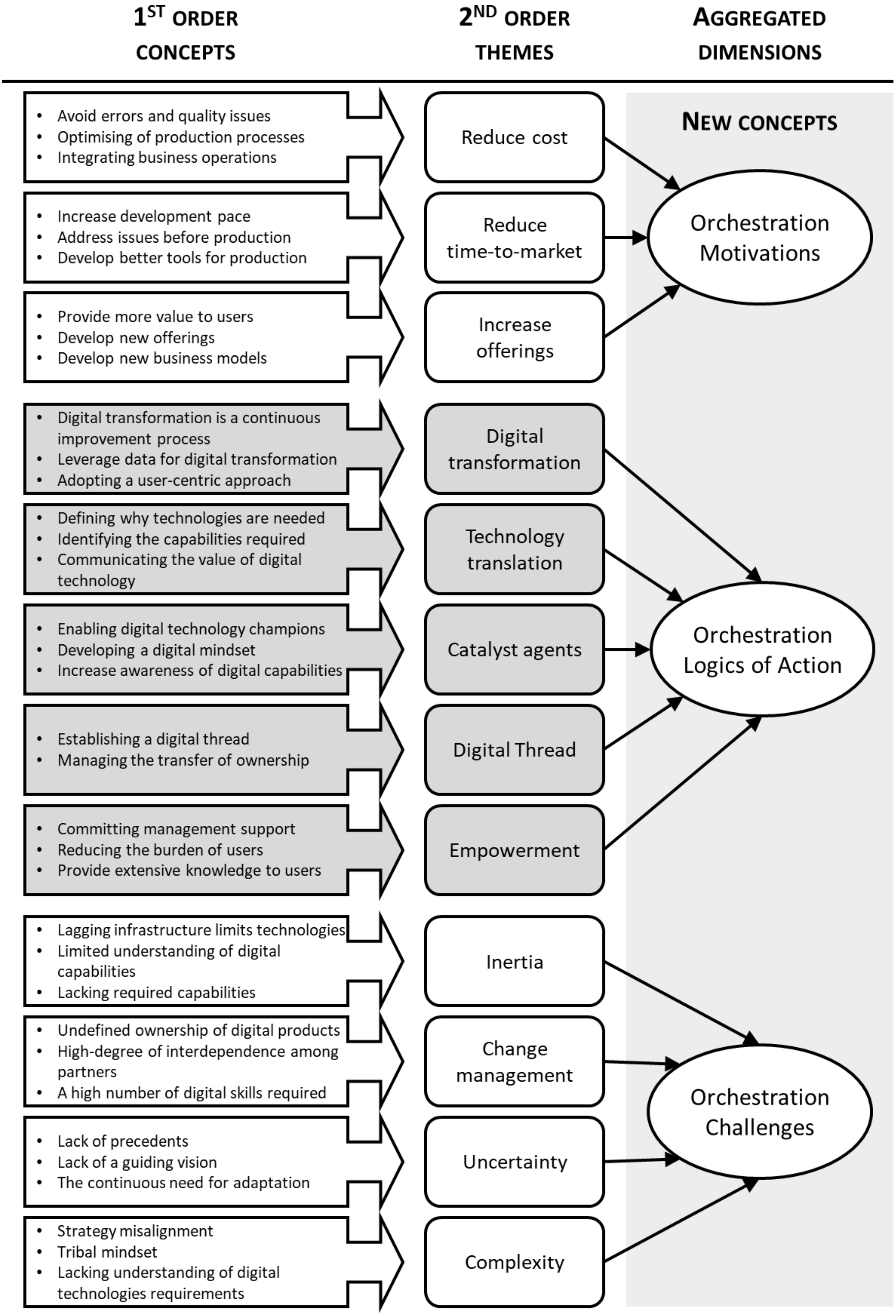


Figure 3 Final data structure – Orchestration of digital innovation in Industry 4.0

Source: Authors' own

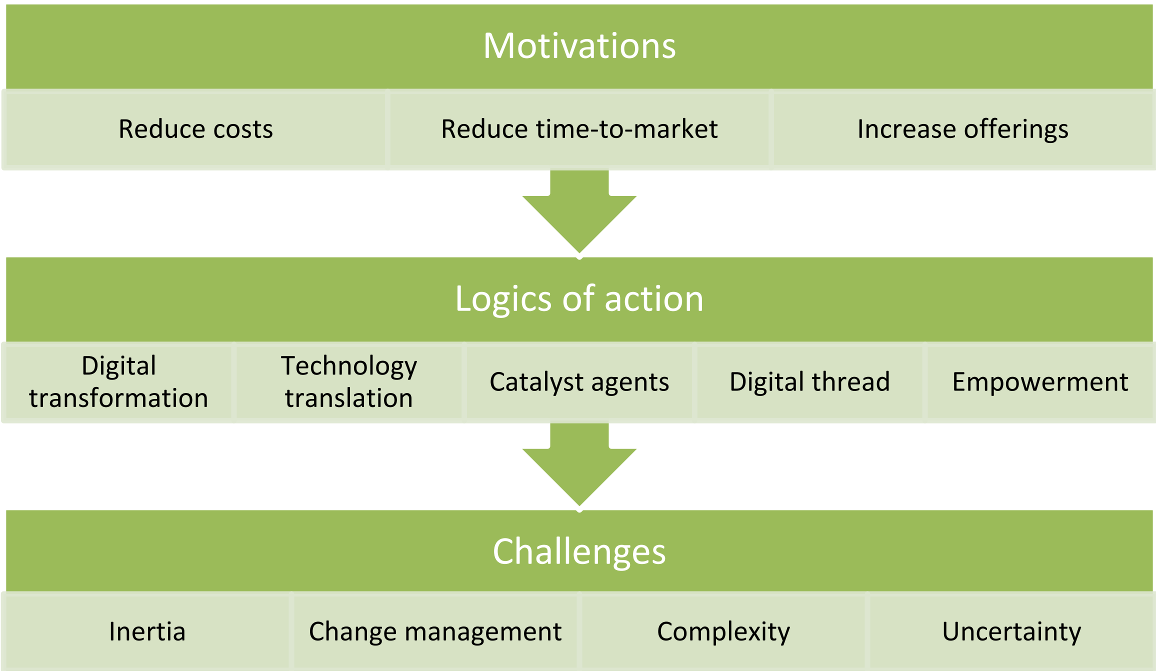


Figure 4 Motivations, logics of action, and challenges for the orchestration of digital innovation

Source: Authors' own

**Tables**

Table 1 Summary of the business cases characterisation

| | **Criteria** | **Objective** | **Stage** | **External Collaboration** | **Relation to Industry 4.0** |
|---|---|---|---|---|---|
| GM | BC1 eCommerce | Improve the sales processes | Expansion | Low | Provide insights into the digital processes in Industry 4.0 |
| | BC2 Smart Factory | Simulate production lines | Execution | Low | Provide insights into leveraging implemented technologies to create new sources of value. |
| | BC3 Connected worker | Provide contextualised | Execution | Low | Provide insights into social and environmental factors and the user- |

| | | | | | |
|---|---|---|---|---|---|
| | | information to workers | | | centric approach of Industry 4.0 |
| HT | BC4 CAVs in Retail | Improve the delivery process in retail | Experiment | High | Provide insights into the use of business models as design and experimentation tools for digital innovation in Industry 4.0 |
| | BC5 CAVs in Health | Develop a solution for telemedicine | Experiment | High | Provide insights into the potential of Industry 4.0 and its technology to create value for external users and customers. |

Source: Authors' own

Table 2 Summary of the data collection

| | **Green Manufacturing (GM)** | **Hybrid Telecom (HT)** |
|---|---|---|
| *Number of workers* | +25,000 worldwide | +125,000 worldwide |
| *Annual revenue 2020* | +15,000 million euros | +45,000 million euros |
| *Data collection period* | December 2019 – March 2020 | November 2019 – June 2020 |
| *No of participants* | Five business units | Six collaborating companies |
| *No of informants* | 25 | 20 |
| *Type of informants* | Executives (EX), senior managers (SM), product managers (PM), and senior engineers (SE) | Executives (EX), senior managers (SM), product managers (PM), and senior engineers (SE) |
| *Number of interviews* | 14 interviews (12 hours) | 13 interviews (10 hours) |

| | | |
|---|---|---|
| *Number of observations* | Three formal observations (5 hours) | 20 observations (30 hours) |
| *Number of documents* | 19 documents<br><br>(approximately 100 pages) | 31 documents<br><br>(about 800 pages) |

Source: Authors' own

Table 3 Activity system for each business case

| ***Business Case*** | **Objective and Motivations** | **Tools (digital technologies)** | **Activity conditions** | **Outcome** |
|---|---|---|---|---|
| *BC1*<br><br>*eCommerce (GM)* | The digitalisation of the sales process:<br><br>• Increase offerings.<br>• Simplify the sales process<br>• Update the required digital infrastructure | • ERP, MES, and PLM software<br>• eShop platform | • Support from executives to expand the activity's scope<br>• Acceptance from other departments<br>• Expansion of the digital-services<br>• architecture | • eCommerce digital channel<br>• Digital thread<br>• Smart tasks lists |
| *BC2 Smart Factory (GM)* | The optimisation of production lines:<br><br>• Reduce time to market<br>• Optimise production<br>• Improve maintenance | • IoT sensors<br>• VR simulation room<br>• CAD models<br>• VR environment development software | • High-level awareness of the technologies involved<br>• Support from<br>• Managers to experiment with the technologies<br>• Gate-based approach<br>• to development | • Factory virtual simulation<br>• Digital twin |
| *BC3*<br><br>*Connected Worker (GM)* | Reduce the time-to-competency:<br><br>• Ensure quality standards<br>• Speed-up training<br>• Empower workers | • AR-enhanced work helmet<br>• Intelligent tools<br>• Digital thread | • User-centric approach<br>• A process based on data enrichment<br>• Focus on social and<br>• environmental challenges | • AR contextual information system |

| ***Business Case*** | **Objective and Motivations** | **Tools (digital technologies)** | **Activity conditions** | **Outcome** |
|---|---|---|---|---|
| *BC4 CAVs-in-Retail (HT)* | Develop an agnostic connectivity platform:<br><br>• Demonstrate technology viability<br>• Identify business opportunities<br>• Address regulatory<br>• Concerns | • Terrestrial (5G) connectivity<br>• Satellite connectivity<br>• CAVs<br>• Cloud computing | • High autonomy granted by the parent company<br>• Partnerships developed with various stakeholders | • CAV platform<br>• Business model prototype |
| *BC5 CAVs-in-Health (HT)* | Implementation of a connectivity platform:<br><br>• Develop protocols to implement the platform<br>• Identify potential<br>• Issues for future implementations | • Terrestrial (5G) connectivity<br>• Satellite connectivity<br>• CAVs<br>• Cloud computing | • High understanding of the technological capabilities<br>• Close collaboration with potential users/customers | • Mobile Telemedicine Unit<br>• Business model prototype |

Notes: Internet of Things (IoT), Virtual/Augmented Reality (VR/AR), Computer-Assisted Design (CAD), Connected and Autonomous Vehicle (CAV), 5G mobile communication (5G)

Source: Authors' own

Table 4 Summary of digital innovation motivations

| ***Motivations*** | **Description** |
|---|---|
| *Reduce cost* | Digital technologies are often expected to reduce the cost of doing business. |
| *Reduce time-to-market* | Digital technologies are constantly pushed to reduce the production and deployment time of existing and upcoming offerings. |
| *Increase offerings* | Digital innovation is expected to produce different and more appealing offerings for existing and new customers, including digital goods and services powered by data and digital technologies. |

Table 5 Summary of orchestration activities for digital innovation defined by logics of action

| ***Logics of action*** | **Description** |
|---|---|
| *Digital transformation* | Digital transformation goes beyond adopting a single technology or business model. Instead, organisations focus on developing a sustainable culture capable of continuously adopting new technologies, processes, and supporting infrastructure. |
| *Technology translation* | Technology translation describes the activities related to understanding the effects of digital technologies on operational, commercial, and strategic processes. |
| *Catalyst agents* | Activities that lead the interaction of catalyst agents, actors, or groups that foster digital innovation. |
| *Digital thread* | A digital thread creates a universal data structure, a continuous data record that is continuously enriched and accessible at every process or business stage. |
| *Empowerment* | Organisations seek to empower workers by providing more information and making them responsible for more significant activities of digital innovation processes. |

Source: Authors' own

Table 6 Summary of digital innovation challenges

| ***Challenges*** | **Description** |
|---|---|
| *Inertia* | Inertia refers to the challenges found in organisations when trying to drive change; in this case, change refers to the pursuit and orchestration of digital innovation. |
| *Change management* | Change management refers to the resistance emerging from users of digital innovation. |
| *Complexity* | Complexity challenges originate from increased interconnectedness between processes, systems, and organisations. |
| *Uncertainty* | Uncertainty challenges emerge from volatility, vulnerabilities, and the unknown introduced by emerging digital technologies. |

Source: Authors' own