Strategic Technological Trajectories in SMEs:

An Analysis of Industry 4.0 Transformation through Managerial Sense-Making, Resource Mobilisation, and Ecosystem Engagement

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the degree of PhD in Economics and Management by

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Introduction

This introduction situates the thesis within its theoretical background and outlines the research carried out in its scope. It begins by highlighting the debates surrounding the concept of Industry 4.0 (I4.0), with attention to its emergence, evolution, and framing as a transformation. It then turns to the concept of small and medium-sized enterprises (SMEs), examining the defining characteristics of these companies and their treatment in I4.0-related literature, which leads to the formulation of the overarching research question. This introduction also reflects on my epistemological positioning as a researcher and how it has evolved over the past four years. Finally, it provides an overview of the thesis structure, presenting the four studies that form its main body.

Behind the Concept of Industry 4.0

Genesis of the Concept

Across decades of industrial development, successive waves of technological changes have repeatedly been framed as marking the advent of a new industrial era. From the rise of electronics to the expansion of computing and digital technologies, each period has been accompanied by claims of a transformative rupture in the organisation of production and work. Yet, these recurring narratives struggle to settle whether such moments signal genuine breaks or reflect a continuous process of technological evolution reinterpreted over time.

It is within this broader dynamic that the concept of I4.0 has emerged, presenting contemporary technological developments – such as interoperability, modularity, virtualisation, and real-time capability – as the foundation of a new industrial revolution (Ghobakhloo, 2018; Lu, 2017). In recent decades, this framing has gained particular traction in a context marked by accelerating pressures from globalisation, mass customisation, and intensifying competition, leaving little room for traditional ways of operating (Hines et al., 2023; Rocha-jácome et al., 2022). In response to this context, the German federal government launched a nationwide innovation strategy with I4.0 (*"Industrie 4.0"* spelled in German) aimed at strengthening the competitiveness of its manufacturing sector (Reischauer, 2018; Schaupp & Diab, 2020). During Hannover Messe 2011, I4.0 was presented as the Fourth Industrial Revolution, designed to align key innovation and technology stakeholders towards the collective advancement of manufacturing companies (Culot et al., 2020; Pfeiffer, 2017). By indicating that the concept illustrates what *"future [will] look like"*, those who coined the concept went beyond its policy scope, offering a society-oriented narrative in which technology appears as the solution to economic, demographic, and ecological challenges (Pfeiffer, 2017, p. 108). Such discourse can be read through the lens of grand narratives of legitimation, where I4.0 is framed either in a speculative mode – aligning technological knowledge with broader social objectives – or in an emancipatory mode – promising liberation from repetitive, low-value tasks (Lyotard & Brugger, 2001).

Since its introduction, the narrative of I4.0 rapidly spread beyond Germany and became a global reference point for industrial transformation (Fogaça et al., 2022; Teixeira & Tavares-Lehmann, 2022). Various countries adapted the concept to their contexts: the United States through "Smart Manufacturing", China through "Made in China 2025", Japan through "Society 5.0", or the United Kingdom through "Fourth Industrial Revolution" (Culot et al., 2020; Lepore & Spigarelli, 2020). Rather than diffusing as a stable and unified model, I4.0 evolved through these context-specific reinterpretations, reflecting the diverse directions through which

technological change unfolds across industrial systems. In this sense, what is labelled as I4.0 corresponds to a set of evolving technological trajectories shaped by national priorities, institutional arrangements, and sectoral dynamics, rather than to a single transformation pathway (Dosi, 1982).

In 2015, European Commission announced its engagement towards I4.0 as a part of its Digital Single Market Strategy, declaring that their challenge was *"to ensure that all industrial sectors make the best use of new technologies and manage their transition towards higher value digitised products and processes, commonly known as 'Industry 4.0'"* (European Commission, 2015). This marked the launch of the creation of Digital Innovation Hubs to establish collaborative platforms for local actors through experimentation, training, and co-developing new solutions (Hervas-Oliver et al., 2020; Teixeira & Tavares-Lehmann, 2022). Between 2011 and 2017, at least 28 initiatives have been launched to support I4.0 implementation by member states of European Union, placing particular focus on SMEs due to their central role in the economies of most member states (Teixeira & Tavares-Lehmann, 2022).

Portrayal of the Concept

Despite its rapid diffusion, the concept of I4.0 still lacks a generally accepted definition, and its meaning shifts depending on the community that mobilises it (Culot et al., 2020; Kowalikova et al., 2020). Such conceptual ambiguity has been shown to facilitate mobilisation of abstract visions, as it allows different actors to project their own priorities and expectations onto a shared but flexible idea (Gioia et al., 2012). The multiplication of country-specific initiatives associated with I4.0 has canalised this ambiguity into conceptual diversity, positioning I4.0 as an adjustable framework across contexts (Meyer, 2019; Oesterreich et al., 2020). For instance, consultancies, proclaimed by some scholars as main fashion-setters, have focused on management solutions for I4.0 implementation, providing companies with roadmaps and readiness assessments for gaining in competitiveness and productivity growth (Madsen, 2019; Oesterreich et al., 2020). As for technology vendors, they mainly contributed to the provision of companies with key I4.0 technological solutions, foregrounding digital integration, cyber-physical systems, and automation as key drivers (Meyer, 2019; Madsen, 2019). At the level of firms, managers often make sense of I4.0 in pragmatic and strategic terms, connecting it either with the most associated I4.0 technologies or a pathway towards cost rationalisation, automation, and re-boosting of productivity (Da Roit and Iannuzzi, 2023; Fogaça et al., 2024; Meyer, 2019). For social partners such as trade unions the focus has been put on the need for reskilling, job protection, and fair transitions, seeking to ensure that I4.0 do not undermine working conditions (Woźniak-Jęchorek et al., 2024).

The volatility of the term is further reflected in the emergence of successor labels such as Industry 5.0 and Industry 6.0. These narratives seek to complement I4.0 by emphasising values that were initially underexplored, such as sustainability, resilience, and the human-centric organisation of work (Fogaça et al., 2025; Kumar et al., 2025). Industry 5.0 advances these priorities by explicitly placing human well-being, social resilience, and environmental sustainability at the centre of industrial transformation, fostering collaboration between humans and machines rather than their substitution (Leng et al., 2022; Sharma et al., 2024). Since 2021, the European Commission has recognised it as a concept *"providing a basis for further development of a collaborative and co-creative vision of the European industry of the future"*, thereby maintaining the legitimacy narrative initiated with I4.0 (European Commission, 2021, p. 14). By contrast, Industry 6.0 remains at a more speculative stage, projecting a future of systemic intelligence, renewable energy integration, and hyper-connected autonomous

production, extending I4.0 into broader ecological and societal horizons (Duggal et al., 2022; Leng et al., 2022; Fernández-Miguel et al., 2024).

Despite the absence of a single definition, the literature consistently portrays I4.0 as a technological paradigm. Whereas some scholars associate I4.0 with a particular technology (Jan et al., 2023; Xin & Wang, 2024), others emphasise the absence of a singular innovation, framing it instead as a collection of interrelated technologies, converging and reinforcing one another (Culot et al., 2020). For the latter, I4.0 centred on interconnection of physical, digital, and human elements through data-driven automation, enabled by technologies such as the Internet of Things, Artificial Intelligence, Augmented Reality, and Big Data (Frank et al., 2019; Gupta et al., 2023; Santos & Sant'Anna, 2024). These technologies are presented as modular enablers, capable of creating smart systems where machines, products, and humans communicate in real time to gain in productivity and product customisation (Zheng et al., 2021; Frank et al., 2019). In doing so, they contribute to decentralisation of processes – a capacity of different components within the same system to work independently – and their virtualisation – virtual replicas of physical processes (Da Silva et al., 2020; Ghobakhloo, 2018).

In parallel to the techno-centric vision of I4.0, scholars have begun to warn that beyond technical feasibility, companies must also manage organisational and human challenges, including cultural change, employee acceptance, and management approaches (Črešnar et al., 2022; Müller et al., 2018). From this perspective, the concept cannot be reduced anymore to the simple implementation of technologies as it launches a whole process of transformation. The one that requires the assessment of internal and external resources, reskilling workforces, rethinking organisational structures, and adapting business models (Carlsson et al., 2022; Hansen et al., 2024; Stentoft et al., 2021).

Industry 4.0 Transformation

To address organisational and managerial issues of I4.0, academic literature follows several dominant objectives. Many studies focus on identifying the enablers and barriers to adoption, including financial, technological, huma, and organisational aspects of firms, as well as policy incentives and open innovation (Müller et al., 2024; Adebanjo et al., 2023; Reis & Camargo Júnior, 2021). Another line of research emphasises the human side of transformation, by identifying the competencies required from managers and operators. Managers are invited to foster innovation acceptance, culture transformation, and organisational learning (Molino et al., 2021; Farina & Fontana, 2021; Shet & Pereira, 2021), while operators should be supported through upskilling of both, hard and soft skills, and task reconfiguration (Cimini et al., 2023; Pinzone et al., 2023; Pedota et al., 2023). In response to these findings, several studies guide companies in implementing I4.0 technologies, offering frameworks to understand their integration pathways in relation to different applications (Frank et al., 2019; Schöggl et al., 2023; Zheng et al., 2021). These studies often detail how technologies can be introduced into manufacturing processes or supply chain, from automation of production lines to predictive maintenance systems and digitally connected supply chains. Another substantial stream of research develops maturity models and assessment tools, designed to measure firms' readiness, benchmark their progress, and identify steps for improvement (Machado et al., 2021; Pozzi et al., 2023; Queiroz et al., 2022). Such models provide prescriptive structured roadmaps, often visualised as staged progressions, that promise to ensure a successful I4.0 transformation if followed. Finally, some contributions examine the role of external actors in supporting firms that want to follow previously mentioned solutions for I4.0. These studies emphasise how regional innovation ecosystems – a geographically embedded constellation of

actors such as governmental institutions, universities or competence centres organised around enabling I4.0 (Adner, 2017; Asheim et al., 2016) – provide firms with resources, training, and experimental environments according to their needs (Antonazzo et al., 2023; Fogaça et al., 2024; Ietto et al., 2022).

Considering the variety of I4.0-related challenges, the concept can be understood as a matter of transformation, varying not only according to companies' technological maturity and business goals but also according to their resources, organisational culture, operators' profiles, management style, and sector-specific ecosystem support (Estensoro et al., 2021; Hansen et al., 2024; Müller, Buliga, et al., 2018). This diversity suggests that I4.0 unfolds as a set of evolving pathways shaped by firms' situated conditions, rather than as a uniform or bounded transformation. These pathways can be understood as technological trajectories, capturing the directions through which technological change develops over time within specific organisational and institutional contexts (Dosi, 1982).

Thus, in this thesis, we approach I4.0 not as a fixed technological recipe, but as a set of strategic technological trajectories unfolding through a multi-level transformation shaped by technologies, organisational practices, ecosystem supports, and perceptions, whose meaning and trajectories vary across firms, their contexts and actors.

SMEs in the Context of Industry 4.0 Transformation

Although initial studies focused on large industrial firms, often assumed to be primary adopters due to their resources and scale, research soon shifted toward SMEs, showing that drivers and barriers differ significantly between small and large organisations (Horváth & Szabo, 2019; Müller et al., 2018). This shift results from several aspects: their overwhelming economic weight in most economies, their role as critical links in industrial value chains, and their vulnerability to exclusion from technological advances if support mechanisms were not adapted to their constraints (Estensoro et al., 2021; Pessot et al., 2020). With their specific characteristics shaping distinct challenges during I4.0 transformation, SMEs have gained scholarly attention as actors whose needs should be considered to adapt I4.0 transformation practices (Ricci et al., 2021; Sony et al., 2024).

Characteristics of SMEs

In this thesis, we partially follow the European Commission's definition of SMEs, which designates firms with fewer than 250 employees (European Commission, 2003). However, as many scholars have underlined, size alone does not capture the particularity of SMEs. Beyond their size, SMEs possess specific structures, cultures, and modes of functioning, which makes them highly distinctive from large companies (Harney & Alkhalaf, 2021; Torrès & Julien, 2005).

While some SMEs are characterised by relatively simple or less formalised organisational arrangements, this should not be considered as their defining feature. Rather than being inherently informal, SMEs tend to display varying degrees of formalisation depending on their sector, growth, and managerial practices. In many cases, decision-making remains concentrated in the hands of the manager or a small dominant coalition, often closely involved in daily operations (Harney & Alkhalaf, 2021; Mintzberg, 1980). Strategic orientations may rely on a combination of experience-based judgement and more formalised planning processes, reflecting this diversity (Moule, 1998). Organisational structures in SMEs are often less layered than in large firms, with minimal divisions of labour and minimal bureaucratisation, which facilitates rapid communication and frequent face-to-face interactions between managers and

operators (Ingham, 1967; Mintzberg, 1980). This proximity enhances operators' visibility of business challenges and fosters a sense of attachment (Harney et al., 2022). SMEs also tend to be resource-constrained, lacking financial means, advanced technological systems, and time for long-term strategic reflection (Cardon & Stevens, 2004; Harney et al., 2022). Training opportunities are limited and often informal, relying on on-the-job learning, trade associations, or short seminars rather than structured programmes (Cardon & Stevens, 2004). These resource constraints, combined with environmental vulnerability, make SMEs highly exposed to customer demands and market turbulence, positioning them more as *"takers"* than *"makers"* of their external context (Harney et al., 2022, p. 3178). At the same time, their small size allows for flexibility, agility, and closer relationships with operators and customers, which can be leveraged as competitive strengths (Harney & Alkhalaf, 2021; Torrès & Julien, 2005).

SMEs Facing Industry 4.0 Transformation

Studies consistently underline that SMEs struggle more than large firms with the requirements of I4.0, due to resource constraints, outdated machinery, and limited absorptive capacity (Pessot et al., 2020; Rauch et al., 2019). They often lack the financial means to invest in costly technologies, the technological infrastructure to ensure interoperability, and the skilled workforce needed to accept and support complex transformations (Horváth & Szabo, 2019; Ricci et al., 2021). SMEs' interactions with external actors – such as universities or technology providers – are also described as hesitant, as such collaborations are often perceived by companies as time-consuming or misaligned with their business needs (Hervas-Oliver et al., 2020; Ricci et al., 2021). In terms of approaching I4.0 transformation, SMEs usually implement I4.0 technologies selectively and pragmatically. Instead of pursuing full-scale vertical and horizontal integration of digital solutions, as often encouraged by prescriptive models, they implement specific technologies that are accessible, affordable, and aligned with their immediate needs (Masood & Sonntag, 2020; Mittal et al., 2020). Shaped by managerial caution towards risk-taking and preferences for short-term strategies, this approach often leads SMEs to introduce sensors, cloud applications, or automation tools incrementally, before or instead pursuing a comprehensive transformation (Havsgård et al., 2024; Martinetti et al., 2024).

At the same time, the literature emphasises the strengths of SMEs, where their small size and proximity between managers and operators foster agile decision-making, flexible adaptation to market changes, and rapid reorientation when necessary (Črešnar et al., 2022; Ghobakhloo et al., 2022). The strong involvement of managers is proven to foster commitment to I4.0 transformation, even under conditions of resource scarcity (Santos et al., 2022; Zoppelletto et al., 2023). Many SMEs prosper in niche markets where customised solutions and close customer interaction are valued, making them natural candidates for developing cutting-edge solutions and applying them in tailored ways (Pessot et al., 2020; Vereycken et al., 2024). Moreover, contrary to the view that SMEs remain hesitant toward collaboration with external actors, several studies show that firms with higher digital maturity or operating in technologically dynamic sectors may actively pursue external resources to support their I4.0 transformation (S. Kumar et al., 2023; Santos et al., 2022). These SMEs, capable of strategically searching for knowledge from customers, suppliers, and consultants, can also adapt such resources within their organisations to overcome internal limitations (Menten et al., 2025; Vereycken et al., 2024). In some contexts, SMEs even take a coordinating role by shaping and expanding their own innovation ecosystems, where collective value creation emerges through reciprocal partnerships and platform-based structures (Benitez et al., 2020).

Despite the growing focus on SMEs, much of the literature treats them as generic units, using them to reflect enablers and barriers or solutions for I4.0 transformation without fully considering *who* changes and decides in these companies (Ghobakhloo & Iranmanesh, 2021; Sony et al., 2024). Scholars often analyse I4.0 in SMEs through frameworks, models, or roadmaps that emphasise technological solutions, readiness factors, and maturity stages, overlooking the real-life examples of strategic decision-making (Addo-Tenkorang et al., 2024; Spaltini et al., 2022). Even when sociotechnical perspectives are mobilised, the focus remains on optimising the interplay between operators and new solutions (Margherita & Braccini, 2021; Sony & Naik, 2020) rather than unpacking how managers experience and come to such solutions. As a result, the critical role of managers as sense-makers and orchestrators of I4.0 transformation is underdeveloped in existing research (Meyer, 2019; Weick, 1995). While studies acknowledge managers as key actors in initiating innovation in SMEs (Lanzolla et al., 2021; Zoppelletto et al., 2023), there is still no comprehensive empirical analysis of how they strategically navigate I4.0 transformation – by shaping its meaning, mobilising internal and external resources, and making strategic choices.

Based on these considerations, this PhD thesis poses the following overarching research question: *How do managers perceive and strategically navigate Industry 4.0 transformation in industrial SMEs?*

Wallonia as a Context to Study SMEs' Industry 4.0 Transformation

While this research question is formulated at a general level, its investigation requires anchoring in a context where I4.0 transformation is enacted through situated organisational and institutional conditions. In this respect, Wallonia – one of the three federal regions of Belgium – provides a particularly relevant setting. This relevance is first reflected in the structure of its economy, where SMEs constitute the dominant organisational form and play a central role in industrial activity. The region hosts more than 80,000 private firms, of which 99.6% qualify as SMEs, positioning them at the core of production systems (AKT, 2024). This industrial backbone, historically rooted in the metalworking and metal processing sectors, the food industry, the glass, ceramics, brick and cement industries and the chemical industry (AKT, 2024; Vincent & Wunderle, 2002), remains a key component of regional economic activity. A significant proportion of these SMEs operate within value chains coordinated by larger multinational groups, which introduces a structural asymmetry between local production activities and the loci of strategic decision-making (Vincent & Wunderle, 2002). This is why this thesis conceptualises SMEs primarily in terms of their organisational size, while still recognising variations in their strategic autonomy.

These dynamics unfold within a complex institutional environment shaped by Belgium's singular form of federalism, which emerged through successive state reforms that transformed a once unitary state into a federal one (Vandermotten, 1998). With distributed power across federal, regional, and community levels, this configuration results in complex governance structures and a diffuse system of coordination (Faniel et al., 2021) In Wallonia, this configuration is operationalised through the Digital Wallonia strategy and reinforced by the Plan de Relance, with the Agence du Numérique coordinating activities and aligning them with regional and European priorities (Gouvernement wallon, 2021; Gouvernement Wallon, 2025). Programmes such as *Industrie et Construction du Futur*, including initiatives like *Made Different* and *StartIA*, structure a network of actors providing SMEs with access to resources, expertise, and support mechanisms.

Taken together, this context forms a resource-rich environment particularly suitable for examining this thesis's research question about how managers perceive and strategically navigate I4.0 transformation in industrial SMEs.

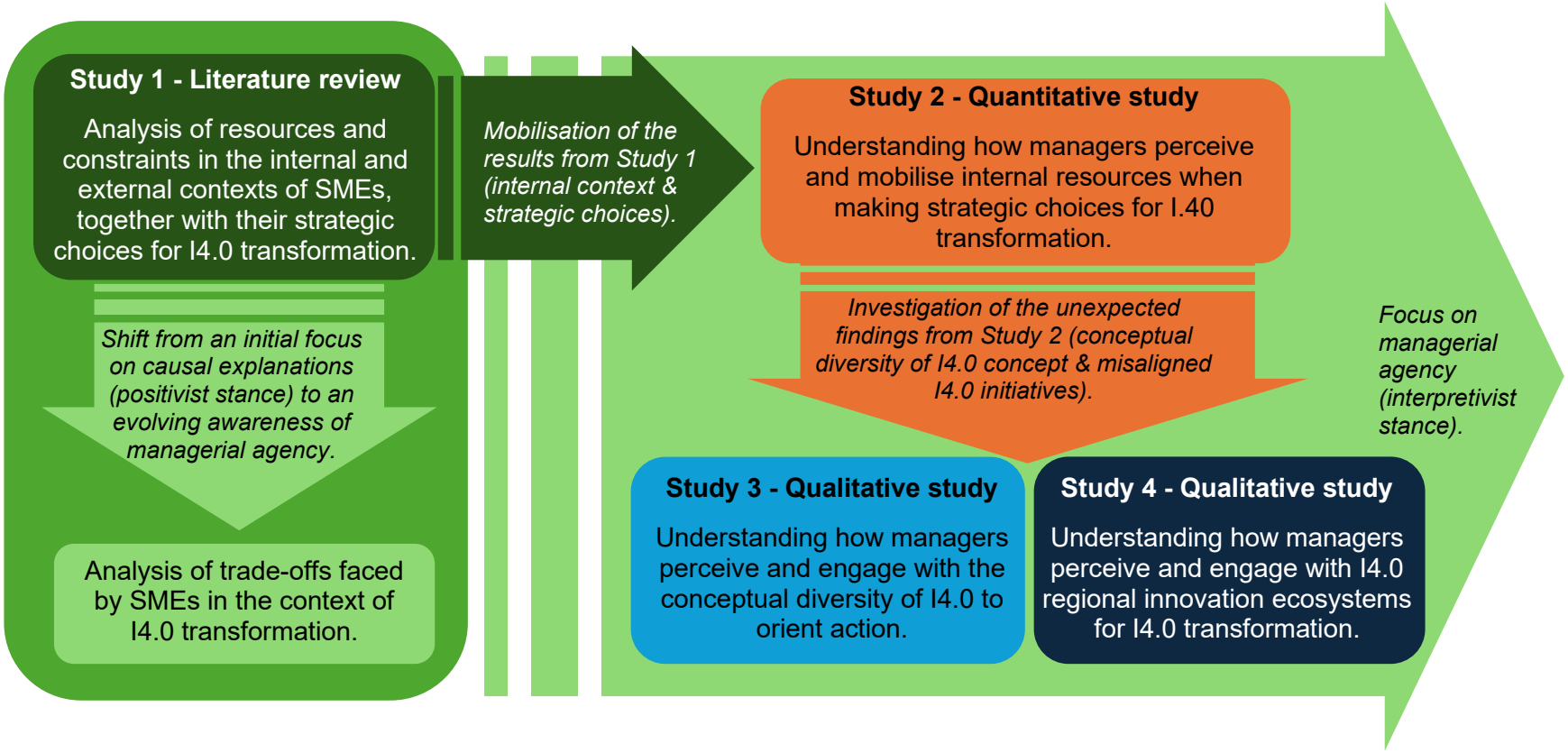
Epistemological Stance of the Thesis

As with any research, the framing of this research question did not appear fully formed at the beginning but was shaped by my epistemological evolution as a researcher. The start of my PhD – launched within a consortium of public authorities, industrial companies, and university members – offered me a carte blanche, on the condition that the focus went beyond the technological dimensions of I4.0 while remaining relevant to the Walloon Region. With this in mind, I turned to the literature on I4.0 that, by the end of 2021, was already abundant.

As a newcomer to research and to the concept of I4.0, I began by exploring its definitions and principles, identifying its main organisational and human challenges, and aligning these insights with the Walloon industrial landscape. My first contact with the research community quickly led me to adopt the positivist stance that prevailed in I4.0 studies (Saunders et al., 2015). In this body of work, I4.0 was presented as if it were a single techno-centric reality (albeit without a consensual definition), structured around technological principles and recurring challenges for firms (Ghobakhloo, 2018; Horváth & Szabo, 2019; Kang et al., 2016; Lu, 2017). Knowledge was largely framed in terms of causal explanations of what – typically conceptualised as enablers and barriers – leads to (un)successful I4.0 adoption, often quantified and generalised (Ghobakhloo et al., 2022; Saunders et al., 2015). Motivated by the fact that SMEs form the majority of the Walloon industrial economy (AKT, 2024) and are consistently portrayed as lagging behind in I4.0 due to resource constraints (Horváth & Szabo, 2019; Pessot et al., 2020), I decided to dedicate my first study to their strategic choices regarding I4.0 and the influence of their resources and constraints on these choices (see Figure 1). For this analysis, I turned to institutional theory to capture the contextual pressures shaping SMEs' strategies (DiMaggio & Powell, 1983; Scott, 2014). However, by framing the causal effects between strategic choices and SMEs' contexts as trade-offs and suggesting that SMEs may respond strategically to such pressures rather than merely conform (Oliver, 1991), this study marked my first step towards an interpretivist stance and my interest in managerial agency (see Figure 1).

The second study emerged as a natural continuation. I sought to test the theoretical insights from the first study empirically through a survey, which meant remaining anchored in a positivist epistemology oriented towards causality and generalisation (Saunders et al., 2015). However, the design of the survey itself already reflected a shift: instead of measing SMEs' resources and choices, I focused on managerial perceptions of these factors. The righteousness of this choice was confirmed during the survey pilot tests. Delivering more developed responses to some questions, managers highlighted misalignments between their SMEs' organisational and social realities and the institutional initiatives designed to support I4.0. Moreover, during data collection, the open question asking them to define I4.0, which I had initially considered as a descriptive addition, generated a strikingly diverse set of responses, highly divergent in both substance and reasoning. Finally, when some managers preferred in-person exchanges to online participation, questions about resources and choices often gave rise to rich discussions about the concrete struggles of SMEs and the ways managers confronted them. Analysing the findings with these insights through the resource-based view and dynamic capabilities theories (Barney, 2021; Teece, 2014) pushed me further towards an agency-driven approach (see

Figure 1. Epistemological evolution of the thesis: from structural perspective towards managerial agency.



I came to understanding that managers act as agents actively sensing, seizing, and reconfiguring resources during I4.0 transformation (Teece, 2014). With this in mind, I started to progressively embracing the interpretivist stance according to which resource mobilisation in the scope of I4.0 transformation is less a measurable entity in isolation and more a multiplicity of factors enacted through managerial practices and interpretations (Saunders et al., 2015; Weick, 1995). As a matter of fact, I came to realise that beyond facing inevitable internal and external pressures, managers act as agents of I4.0 transformation by mobilising, interpreting, and enacting personal, organisational, and ecosystem features (Duberley & Johnson, 2015; Weber & Glynn, 2006).

Building on this realisation, I decided to deepen the unexpected findings of my second study in two times. By focusing on managerial sensemaking (Weick, 1995), the third study analysed it in the context of the conceptual diversity of I4.0, while the fourth examined it in the context of misaligned regional innovation ecosystems (see Figure 1). The semi-directive in-depth interviews conducted for both studies placed managerial discourse at the centre of my research (Johnson, 2002). Here, language was not treated as a mirror of reality but as a tool for meaning construction, actively producing social reality (Fairhurst & Uhl-Bien, 2012; Grant & Hardy, 2004). Managerial perceptions thus became the primary object of inquiry, allowing me to understand behaviours not through causal effects, but rather through the ways managers sustain, articulate, and adapt their understanding of I4.0 within SMEs' transformation context (Duberley & Johnson, 2015; Saunders et al., 2015).

Altogether, each study contributed to my embracement of an interpretivist epistemological stance. Building on the lack of consensus on I4.0 definitions identified in the first study, the conceptual diversity revealed in the second led me to question research that treats I4.0 as a universally accepted and fixed concept (Frank et al., 2019; Gupta et al., 2023). My guiding assumption became that I4.0 is not a neutral but a socially constructed and politically charged concept, which meaning emerges through actors' interpretations (Meyer, 2019; Saunders et al., 2015). From this perspective, what counts as *Industry 4.0*, *resources*, *strategic choices*, or *ecosystem support* is not given a priori but actively produced through managerial sensemaking (Weick, 1995). I came to understand that, beyond facing inevitable internal and external pressures, managers act as agents of I4.0 transformation by mobilising, interpreting, and enacting their personal, organisational, and ecosystem aspects. Consequently, managerial agency, organisational context, and institutional structures are no longer opposing forces but co-constructive: managers' interpretations shape trajectories of I4.0 transformation, while their options are simultaneously shaped by organisational factors – resources, culture, sector, activity – and institutional conditions – existing infrastructure, support, standards, and discourse (Duberley & Johnson, 2015; Müller et al., 2024). By embracing this stance, I thus take a critical position towards mainstream I4.0 research on SMEs, which tends to assume fixed definitions and deterministic models of I4.0, often overlooking the interpretive agency of managers and the plurality of their SMEs' approaches for I4.0 transformation.

Structure of the Thesis

This epistemological evolution is also reflected in the structure of the thesis. The four papers composing it not only document my progressive shift toward an interpretivist stance but also operationalise this stance by examining managerial agency in the context of I4.0 transformation through complementary analytical lenses. Together, they articulate an interpretive understanding of how SMEs' managers perceive and navigate I4.0 transformation

across micro, meso, and macro levels[1]. While the order of the papers does not strictly follow the chronological sequence of my research journey, it was deliberately adjusted to reflect this multi-level perspective: the empirical research initially conducted as Studies 2 and 3 was reordered so that the former now appears as Paper 3 (meso level) and the latter as Paper 2 (micro level). In doing so, each study addresses a specific research gap, formulates a targeted research question, and mobilises an appropriate methodological design, while collectively deepening the understanding of managerial agency within SMEs across different levels of I4.0 transformation (see Table 1).

The first paper establishes the perimeter of analysis by examining existing literature regarding SMEs' strategic choices and regarding contextual enablers and barriers. While previous studies have rarely offered fine-grained analyses of such choices and has not sufficiently explained how enablers and barriers shape them (Horváth & Szabo, 2019; Machado et al., 2021), this study frames the latter elements as institutional pressures that unfold into trade-offs that shape SMEs' strategic responses. It therefore addresses the question: *How do contextual enablers and barriers influence SMEs' strategic choices regarding Industry 4.0 implementation?* A narrative literature review of 39 scientific sources was conducted and analysed through thematic coding, mobilising institutional theory (Oliver, 1991; Scott, 2014). The study was published in the *Springer Book Series Lecture Notes in Information Systems and Organisation* (Zabudkina et al., 2024).

The second paper delves into the micro level of I4.0 transformation, investigating how managers make sense of I4.0 in the first place. Although I4.0 conceptual diversity is often acknowledged in the literature, little is known about how managers themselves construct meaning around the concept and how these interpretations shape their actions across SMEs (Tortorella et al., 2023; Wilkesmann et al., 2018). Thus, the research question is: *How do managers of industrial SMEs engage with the conceptual diversity of I4.0 to orient action?* To answer it, data were collected through an online survey with open questions (96 valid responses) and complemented with 25 semi-directive interviews with CEOs and managers of Walloon SMEs. The data were analysed through a multi-coder typology-building process combined with inductive thematic analysis, mobilising strategic sensemaking perspective (Sharifi & Zhang, 2009; Weick, 1995). The article is currently under review at *Journal of Management Inquiry*.

The third paper turns to the meso level of I4.0 transformation, focusing on how managers mobilise internal resources when making strategic choices. Here, the gap lies in the lack of empirical evidence on how resource configurations actually enter into decision-making, and in the underexplored role of managerial agency in orchestrating resources (Kumar Hajoary, 2024; Somohano-Rodríguez et al., 2022). To address the gap, the study follows the question: *How do resource configurations of SMEs interplay with managers' strategic choices in implementing Industry 4.0?* To answer it, an online survey was distributed to CEOs and managers of Walloon SMEs, yielding 79 valid responses. Multiple correspondence analysis and hierarchical cluster analysis were applied to structure the data, while the resource-based view and dynamic capabilities theories were used to interpret managerial agency in the strategic mobilisation of

[1] In this thesis, the different levels refer to distinct yet interrelated analytical layers of I4.0 transformation: the micro level captures managerial dimension, the meso level the organisational one, and the macro level the institutional perspective.

SMEs' resource configurations (Barney, 1991; Teece, 2014). The article is currently under review (2nd round) at *Technology Analysis & Strategic Management*.

Finally, the fourth paper extends the analysis to the macro level by investigating how SMEs' managers engage with I4.0 institutional ecosystems. The gap addressed here lies in the fact that existing research often describes ecosystems as collaborative networks enabling SMEs in I4.0 transformation, overlooking the interpretive and strategic role of managers in navigating their complexity (Hervas-Oliver et al., 2020; Ietto et al., 2022). This study therefore asks: *How do SMEs' managers engage with I4.0 Regional Innovation Ecosystems in the course of I4.0 transformation?* The study builds on 25 semi-directive interviews with CEOs and managers of Walloon SMEs, analysed through inductive thematic coding around selection, retention, and enactment processes of sensemaking (Weber & Glynn, 2006; Weick, 2004). The article is under review (2nd round) at *Technovation*.

Table 1. Overview of the four studies constituting the thesis.

Papers		Analytical level	Gaps to address	Theoretical lens	Methods & data
1	*Under Pressure: Strategic Choices and Contextual Trade-offs of SMEs Facing Industry 4.0 Implementation*	Meso–macro: analysis of trade-offs between internal and external contextual pressures.	Limited understanding of how enablers and barriers shape SMEs' strategic choice.	Institutional theory (Oliver, 1991; Scott, 2014)	Narrative literature review of 39 articles Thematic coding
2	*Making Sense Before Making Change: How SMEs' Managers Engage with the Conceptual Diversity of Industry 4.0*	Micro: analysis of socially constructed meanings of I4.0 through strategic managerial sensemaking.	Little empirical insight into how managers define and interpret I4.0 and how these meanings guide action.	Sensemaking theory (Sharifi & Zhang, 2009; Weick, 1995)	96 open-ended survey responses and 25 semi-directive interviews with SMEs' managers Multi-coder analysis + thematic coding
3	*Between Resource Configurations and Strategic Choices: A Multifaceted Perspective on Industry 4.0 Implementation in SMEs*	Meso: analysis of managerial perceptions and agency in strategic resource mobilisation.	Lack of empirical evidence on how resource configurations shape managerial strategic decisions for I4.0 transformation.	Resource-based view (Barney, 1991), Dynamic capabilities (Teece, 2014)	Online survey of 79 managers/CEOs in Walloon SMEs MCA and cluster analysis
4	*Go Your Own Way: Managerial Engagement with Regional Innovation Ecosystems for Industry 4.0 Transformation in Belgian SMEs*	Macro: analysis of managerial enactment of I4.0 institutional ecosystems.	Little empirical insight into how managers interpret and strategically engage with I4.0 institutional ecosystems.	Sensemaking theory (Weber & Glynn, 2006; Weick, 2004)	25 semi-directive interviews with SMEs' managers Thematic analysis

Rather than offering four separate answers, these papers collectively illuminate how SMEs' managers perceive and navigate I4.0 transformation from different vantage points. By combining analyses of contextual trade-offs, strategic enactment of I4.0, strategic orchestration of internal resources and ecosystem engagement dynamics, the thesis provides an integrated view of managerial agency within SMEs that would remain invisible from any single perspective. At the same time, they mirror my own epistemological progression from structural explanations of I4.0 transformation towards an interpretive stance, where interpretations, choices, and engagements are seen as enacted by managers and shaped by I4.0 discourses, SMEs' context, and their ecosystem. This design allows the thesis to advance a multi-level understanding of I4.0 transformation in SMEs, showing managers as active agents whose sensemaking activities shape their firms' technological trajectories within broader institutional settings.

The next chapters unfold the four papers forming the core of this thesis, tracing a cumulative exploration of managerial agency across different levels of I4.0 transformation. The concluding chapter bridges these findings through a transversal discussion, drawing out their theoretical and practical contributions, recognising the thesis's limitations, and opening pathways for future research.

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Paper 1. Under Pressure: Strategic Choices and Contextual Trade-Offs of SMEs Facing Industry 4.0 Implementation[2]

Abstract. Besides sharing similar characteristics of staff headcount, turnover, and balance sheet total, each small and medium enterprise (SME) has its unique context that may influence their intention to implement Industry 4.0. The contextual factors encouraging or preventing SMEs from implementing Industry 4.0 receive an increasing attention by the research community. However, there is still a scarcity of studies that go beyond simple inventorying of contextual enablers and barriers and that try to assess their influence on SMEs' strategic choices regarding Industry 4.0 implementation. The authors of this study decided to tackle these gaps by conducting a narrative literature review focused on the following research question: *How contextual enablers and barriers influence SMEs' strategic choices regarding Industry 4.0 implementation?* Analysed through the lens of institutional approach, the results allow the authors to generate a global framework composed of 35 contextual triggers potentially leading SMEs to trade-offs regarding 5 dimensions of strategic choices for Industry 4.0 implementation.

1. Introduction

While traditional industry already has its issues, the emerging paradigm of the fourth industrial revolution, also known as Industry 4.0 or Industry of the Future, couples them with numerous challenges. The concept of Industry 4.0 aims to reunite the industrial players in the scope of a far-reaching network that interconnects data, people, processes, services, and systems inside and among the companies (Bosman et al., 2019; Kohler & Weisz, 2021). In doing so, companies can improve production efficiency and quality, reduce natural resources usage and waste as well as optimize working and safety conditions of their employees (E. Machado et al., 2021; Margherita & Braccini, 2020). As new technologies and capacities to integrate and manipulate them represent basic requirements for Industry 4.0, academic research on the topic is dominated by techno-centric approaches (Margherita & Braccini, 2021; J. Müller et al., 2018; Sony & Naik, 2020). Nevertheless, by focusing only on technology adoption-related problems, industrial firms overlook their transformation on human and managerial levels and risk increasing organisational barriers (Agostini & Filippini, 2019; C. Machado et al., 2021).

Considering its requirements and opportunities, the concept of Industry 4.0 was practically conceived in favour of large enterprises and often neglects the particularities of small and medium-sized enterprises (SMEs) (Horváth & Szabo, 2019; Mittal et al., 2018; J. M. Müller et al., 2018). However, the growing body of academic literature highlights that SMEs often act in the same industrial value chain with large companies, the changing standards of which can influence their positioning towards Industry 4.0 (Estensoro et al., 2021; J. M. Müller et al., 2018). Therefore, both profiles should be considered equally, thanks to distinct approaches, while studying the implementation of Industry 4.0.

Recently, the academic investigation into Industry 4.0 implementation among SMEs has received increasing attention. On one hand, several studies focus on the elaboration of strategic roadmaps and guidelines for SMEs implementing Industry 4.0. These studies reflect on the appropriate ways of implementing Industry 4.0 through the analysis of SMEs'

[2] This chapter reproduces the published article in its original form, with several notes added at the end: Zabudkina, A., Lisein, O., Pichault, F. (2024). Under Pressure: Strategic Choices and Contextual Trade-Offs of SMEs Facing Industry 4.0 Implementation. In: Braccini, A.M., Pallud, J., Pennarola, F. (eds) *Technologies for Digital Transformation*. ItAIS 2022. Lecture Notes in Information Systems and Organisation, vol 64. Springer, Cham. https://doi.org/10.1007/978-3-031-52120-1_7

characteristics (J. M. Müller et al., 2020), their obstacles (Amaral & Peças, 2021), success factors (Ghobakhloo & Iranmanesh, 2021) and outcomes (Verhulst & Brenden, 2021) regarding Industry 4.0. However, little attention has been paid to inventorying the *strategic choices* that SMEs favour in practice regarding Industry 4.0 implementation. On the other hand, numerous studies inventory the most common contextual *enablers* and *barriers* SMEs face while considering Industry 4.0 implementation. Generally, scholars identify and classify various factors that encourage or impede SMEs to implement Industry 4.0: resources constraints, flexible organizational structure, lack of conscious planning, etc. (Ghobakhloo et al., 2022; Horváth & Szabo, 2019; Vrchota et al., 2019). Such classifications are often mobilised to explore the influence of the enablers and barriers on SMEs' intention to implement Industry 4.0 technologies (Estensoro et al., 2021; Stentoft et al., 2021). However, there is a lack of studies exploring the potential influence of these contextual factors on SMEs' *strategic choices* regarding Industry 4.0 implementation.

To address the above-mentioned gaps, this study focuses on the following research question:

How contextual enablers and barriers influence SMEs' strategic choices regarding Industry 4.0 implementation?

The study mobilises the institutional approach according to which the organisations are influenced by pressures arising from external sources (such as government and regulatory agencies) and from within the organization itself (Greenwood & Hinings, 1996; Scott, 2014; Zucker, 1987). Several studies established that companies, including SMEs, can be encouraged to implement Industry 4.0 due to the pressures deriving from the regulatory bodies, accreditation agencies and peer associations (Bag et al., 2021; Fogaça et al., 2022; Gupta et al., 2020). By going one step further, this study aims to explore the influence of pressures emerging from the outer but also inner context on SMEs' *strategic choices* regarding Industry 4.0. To identify the key contextual *enablers* and *barriers* as well as the *strategic choices* of SMEs in the scope of Industry 4.0 implementation, a narrative literature review is conducted (Baumeister & Leary, 1997; Hammersley, 2001). This method is privileged because of its greater possibilities to explore the novel conceptualisation of *enablers* and *barriers* related to Industry 4.0 implementation by SMEs (Baumeister & Leary, 1997; Fan et al., 2022; Hammersley, 2001). It also allows characterising SMEs' *strategic choices* by capturing the orientation of their goals towards desired outcomes of Industry 4.0 implementation. The study results in an analytical framework composed of 35 contextual triggers, potentially leading SMEs to *trade-offs* regarding 5 dimensions of *strategic choices* for Industry 4.0 implementation.

The paper is structured as follows. First, the theoretical background covers the key concepts of the research question. Second, the research methods and data analysis are described. Then, the findings are presented and followed by their discussion. The paper closes with the overview of major contributions and limits of this literature review and suggestions for future research.

2. Theoretical Background

2.1. Industry 4.0

In the scope of progressive globalisation, new technological possibilities and increased competition, the concept of Industry 4.0 marks the beginning of the new industry by amalgamating complex industrial processes with innovative technologies (Kamble et al., 2018;

Margherita & Braccini, 2020; Zheng et al., 2021). By going one step further than digitalisation and computer-integrated processes, Industry 4.0 stands for a far-reaching network of industrial players supported by cyber-physical systems (CPS), based on heterogeneous data and knowledge integration (Schneider, 2018; Zheng et al., 2021). The interpretation of Industry 4.0 often relies on several design principles and technological trends mutually interconnected (Da Silva et al., 2020; Ghobakhloo, 2018). The technological trends refer to the implementation of new technologies. The basic technologies refer to technologies that help to generate data (i.e., sensors, actuators) and transmit it (i.e., Internet of Things) (Klingenberg et al., 2019). The advanced technologies refer to technologies that process data (i.e., big data, cloud computing) and apply it (i.e., smart machines, autonomous robotics) (Klingenberg et al., 2019). The vertical and horizontal integration of these technologies requires designing new processes based on interoperability, virtualisation, decentralisation, and real-time capability (Ghobakhloo, 2018; Zheng et al., 2021). Industry 4.0 is expected to encourage industrial companies to address sustainability issues in terms of economic, social, and environmental impacts (Margherita & Braccini, 2020; J. Müller et al., 2018). Based on the concept of Triple Bottom Line of sustainability, the three dimensions should be faced simultaneously by focusing on the balance among making profit, accounting environmental issues, and contributing into human capital (Margherita & Braccini, 2020; J. Müller et al., 2018). The latter aspect represents an important preoccupation for companies as Industry 4.0 implementation is based on the human-machine interaction (Da Silva et al., 2020; Ghobakhloo, 2018; Sony & Naik, 2020). As a matter of fact, human operators are expected to become *Operators 4.0* as their physical and cognitive capacities can be enhanced thanks to new technologies (Da Silva et al., 2020; Sony & Naik, 2020). Due to the crucial for Industry 4.0 soft skills such as creativity, entrepreneurial thinking, conflict solving and problem-solving, the human role remains fundamental for companies facing such transformation (Cimini et al., 2020; Hernandez-de-Menendez et al., 2020; Pessot et al., 2020).

Since the concept of Industry 4.0 assimilates across countries with different institutional characteristics which can lead to distinct meanings (Fogaça et al., 2022), there is still no generally accepted definition for Industry 4.0 (Schneider, 2018). Thus, this study summarizes the common characteristics of Industry 4.0 as follows: *a horizontally and vertically integrated sociotechnical system that relies on an interconnected spectrum of physical, digital, and human elements, interacting in a network structure, and contributing to the system as a complete entity.* The idea of *complete entity* represents a key element for Industry 4.0, as for its successful implementation companies should be ready to undergo the changes not only on technological level, but, above all, on organisational and human levels (Agostini & Filippini, 2019; Ietto et al., 2022; Margherita & Braccini, 2021).

2.2. SMEs and Their Specific Features

According to the European Commission (European Commission, 2003), to be defined as a SME, an enterprise must employ *"fewer than 250 persons and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million".* Within this category, small enterprises employ fewer than 50 persons and micro enterprises—fewer than 10 persons. Besides the number of employees, the key characteristics of SMEs can be captured via their structure, resources, and culture (Harney et al., 2022). Generally, SMEs experience the resource constraints in terms of financial resources and time availability for strategic decisions (Harney et al., 2022). The studies often present SMEs as ill-equipped to perform important changes on digital or technological level (Ghobakhloo, 2018;

Horváth & Szabo, 2019). Because of their environmental vulnerability, SMEs are often *"under pressure to respond to structural and market-orientation instability"* (Harney et al., 2022, p. 3178). It is often conditioned by their lack of strategic planning to anticipate and respond effectively to changing market environments (Horváth & Szabo, 2019; E. Machado et al., 2021; J. Müller et al., 2018). Whereas continuous improvement is often left out from SMEs' priorities, they remain reactive to supply chain-driven innovations leading to cost reduction or increase in productivity (Hervas-Oliver et al., 2020; J. Müller et al., 2018). In this case, SMEs are used to cooperate with industry-based actors rather than with external ones, such as universities or research centres (Hervas-Oliver et al., 2020; Ricci et al., 2021). The hierarchy system of SMEs often relies on a vertical, short-lined organisation with a centralised decision-making power in the hands of the manager deeply involved in the daily life of the enterprise (Horváth & Szabo, 2019; Moeuf et al., 2020). Thus, the decision about change or innovation is often based on 'gut feeling' of the manager rather than on research and development process, generally undeveloped within SMEs (Mittal et al., 2018). Due to SMEs' informality of working practices, they often benefit from flexible organisational structure and proximity of relations between managers and employees, due to which the latter benefit from straight line of view of business issues and customer experiences (Harney et al., 2022). The functioning of SMEs is mainly geared towards operational activities that lead to highly specialised products (Martinsuo & Luomaranta, 2018; Mittal et al., 2018; Moeuf et al., 2020). It often implies the inclination toward niche markets that allows SMEs to be highly reactive towards customers' needs (Ghobakhloo, 2018; Horváth & Szabo, 2019; Martinsuo & Luomaranta, 2018). By tending to maintain their expertise and keep customers satisfied, SMEs focus on fulfilling the existing orders rather than on improving their generally low degree of process standardisation (Martinsuo & Luomaranta, 2018; Mittal et al., 2018; J. Müller et al., 2018).

2.3. SMEs in the Context of Industry 4.0

The state of Industry 4.0 implementation among industrial SMEs is generally characterised by their struggling to understand this concept and, therefore, the fact of being lagged behind large companies (Pessot et al., 2020; Rauch et al., 2020). Considering the series of factors studied and suggested for Industry 4.0, the concept is globally conceived in favour of large enterprises and often outlooks the particularities of SMEs (Mittal et al., 2018; Moeuf et al., 2020; J. Müller et al., 2018). For instance, to embrace Industry 4.0 as a continuous process based on changes, adaptations, and improvements (C. Machado et al., 2021), a strategic long-term vision developed on multiple levels appears to be key for industrial companies (J. M. Müller, 2019; Schneider, 2018; Somohano-Rodríguez et al., 2022; Veile et al., 2019). However, focused on day-to-day operations and short-term strategies, SMEs often lack a continuous improvement strategy in the scope of Industry 4.0 implementation (Horváth & Szabo, 2019; J. M. Müller et al., 2018; Stentoft et al., 2021). One of the most cited requirements of Industry 4.0—simultaneous integration of Industry 4.0 technologies on vertical and horizontal level—is particularly challenging for SMEs (Agostini & Nosella, 2020; J. M. Müller et al., 2018; Pessot et al., 2020). Besides the difficulty of imposing such transformation to their value-chain, SMEs should deal with their low digitalisation level exposed to the variety and complexity of technological requirements of Industry 4.0 (E. Machado et al., 2021; Rauch et al., 2020; Ricci et al., 2021; Wong et al., 2020). Together with lack of financial and organisational resources, these challenges tend to push SMEs to report Industry 4.0 implementation or limit it to the adoption of basic technologies (Hobscheidt et al., 2021; Horváth & Szabo, 2019; Masood & Sonntag, 2020; Santos et al., 2022).

To address the above-mentioned challenges, the research community conducted several studies. For instance, some studies demonstrate the importance to analyse and mobilise the existing driving forces within SMEs (Horváth & Szabo, 2019; E. Machado et al., 2021; J. Müller et al., 2018). One of the most cited elements driving SMEs to implement Industry 4.0 lays in their flexible organisational structure, which allows responding to changes triggered by Industry 4.0 (J. Müller et al., 2018). SMEs can achieve significant Industry 4.0 outcomes by combining the CEO's dedication to innovation, and employees' participation in innovative activities (Somohano-Rodríguez et al., 2022). Moreover, proactive SMEs are aware of the importance of the committed workforce that goes from shop-floor employees to managers (Santos et al., 2022). Other studies focus on elaborating strategic roadmaps (Ghobakhloo et al., 2022) and frameworks assessing SMEs' Industry 4.0 maturity (Amaral & Peças, 2021). The strategic roadmaps provide the guidelines targeting various areas of transformation that SMEs can apply for a successful transition towards Industry 4.0 (Ghobakhloo & Iranmanesh, 2021). The maturity models establish several stages that define the state of SMEs' readiness or evolution towards Industry 4.0 implementation regarding their resources, skills, and environment (Estensoro et al., 2021; Mittal et al., 2018). The authors stress the importance of nurturing a willingness to change, reinforced by sufficient readiness across employees, technologies, management, external support, and value chain, as critical in enabling Industry 4.0 implementation in SMEs (Ghobakhloo, 2018). The researchers also highlight the importance to align the requirements of SMEs with the requirements of Industry 4.0 that should be articulated into a strategy for a *"progressive, potentially multistep process"* of implementation (Estensoro et al., 2021, p. 2). As SMEs often tend to implement Industry 4.0 without considering required conditions and establishing appropriate foundation and purpose, the strategic roadmaps allow avoiding additional organisational barriers or creating a strategic misalignment (C. Machado et al., 2021).

From institutional perspective, Industry 4.0 can be considered as a trigger for creating of *"new sets of logics and arrangements that would compete with those already existing"* (Oti-Sarpong et al., 2022, p. 4). Therefore, a more in-depth analysis of the contextual opportunities and constraints the SMEs face during Industry 4.0 implementation can help to better understand the *trade-offs* they can be led to make regarding their *strategic choices*.

3. Methodology

Based on a narrative literature review (Baumeister & Leary, 1997; Hammersley, 2001), the study explores the influence of SMEs' contextual *enablers* and *barriers* on their *strategic choices* regarding Industry 4.0 implementation. This method is privileged[1] because of its greater possibilities to explore the studies that combine the elements of both concepts—the strategic choices and their link to the context of SMEs—by focusing on patterns and connections among findings (Baumeister & Leary, 1997). To preserve the transparency and reflexivity of the entire process of narrative literature review (Fan et al., 2022), a two-step research protocol has been established (see Figure 1), as detailed in the following sections.

3.1. Data Identification and Selection

The aim of the first step was to identify and select relevant scientific literature on three main concepts—SMEs' context composed of *enablers* and *barriers* and SMEs' *strategic choices* to implement Industry 4.0. As narrative literature review traditionally begins with *"a small number of articles and books, which are then used to identify key authors and other articles that are*

related to the particular topic" (Jones & Gatrell, 2014, p. 257), the snowballing procedure was conducted in three steps (Fan et al., 2022; Wohlin, 2014).

First, the search for the start set of sources was conducted. It was based on several identification principles (see Figure 1). To facilitate the identification of relevant sources, the key notions were conceptualised (see Table 1). To conduct the search, Scopus database was privileged for its broad coverage of disciplines and publishers (Wohlin, 2014). One of the main characteristics of narrative literature review—the inclusive and flexible organisation of various sources and types of evidence (Fan et al., 2022; Madden et al., 2018)—was used as another identification principle. To enhance this heterogeneity, the study cross-fertilised different kinds of literature and topics regarding SMEs implementing Industry 4.0. Out of 127 document results, only 10 sources were included in the start set due to the in-depth analysis via selection principles (see Figure 1). Second, the iteration of new selection of sources was conducted following backward and forward snowballing (Wohlin, 2014).

Figure 1. Research protocol.

<table>
<tr><td>Resource Identification Principles</td><td colspan="2">• Conceptualisation of key notions.
• Search in Scopus data base via key words: "industry 4.0" OR "industry of the future" OR "fourth industrial revolution" AND "implementation" OR "adoption" AND "SMEs" OR "small medium enterprises" AND "enablers" OR "barriers" OR "challenges" OR "strategy"
• Consideration of all methodological approaches.
• Cross-fertilisation of different kinds of literature: finance, management, production.</td></tr>
<tr><td colspan="3">Number of unique documents identified: N = 127</td></tr>
<tr><td>Resource Selection Principles</td><td colspan="2">Exclusion 1: The notions in the identified documents do not correspond to the conceptualised key notions of enablers, barriers, and context.
Exclusion 2: The elements referring to strategic decision-making of SMEs in the identified documents are absent or not sufficient to identify the strategic choices of SMEs.
Exclusion 3: The use of data, words, and text is absent or not sufficient to establish the influence of SMEs' context shaped by enablers and barriers on their strategic choices.</td></tr>
<tr><td>Screening of Resources</td><td colspan="2">1. Documents removed due to exclusion criterion #1: n= 64
2. Documents removed due to exclusion criterion #2: n = 31
3. Documents removed due to exclusion criterion #3: n = 22
The pool of eligible documents for start set: N= 10</td></tr>
<tr><td>Snowballing technic</td><td>Backward snowballing
Consultation of the references of 10 eligible documents using the resource identification and selection principles.
N = 13</td><td>Forward snowballing
Citation analysis of 10 eligible documents in Scopus database using the resource identification and selection principles.
N = 11</td></tr>
<tr><td>Scopus Alerts</td><td colspan="2">Weekly alerts set in Scopus data base via keywords from Resources Identification Principles (January and April 2022).
N = 5</td></tr>
<tr><td colspan="3">Final pool of eligible resources: N= 39</td></tr>
</table>

<table>
<tr><td rowspan="2">Data coding and analysis</td><td>Coding of contextual enablers and barriers
Cycle 1
• Search for trends of Industry 4.0 via keywords: “enablers”, “drivers”, and “barriers”, “challenges”
• In-depth analysis of the findings of each study to develop the identified trends.
• Use of attributive codes ‘B’ and ‘E’.
Cycle 2
• Categorisation of identified trends by thematic groups.
• 6 thematic categories for inner context.
2 thematic categories for outer context of SMEs.
Cycle 3
• Sub-categorisation of trends in each thematic group.
• 26 triggers leading to contextual pressure in inner context.
• 9 triggers leading to contextual pressure in outer context.</td><td>Coding of strategic choices
Cycle 1
• Search for trends related to conceptualised notion of strategic choices via keywords: “strategy”, “aim”, “purpose”, “result”, “benefit”, “outcome”, “change”, “choose”, “improve”.
• In-depth analysis of the findings of each study to develop the identified trends.
• Use of the attributive code ‘SC’.
Cycle 2
• Categorisation of identified trends by groups.
• 5 thematic groups corresponding to strategies with two strategic choices.</td></tr>
<tr><td colspan="2">Data analysis: Institutional approach (Scott, 2014; Zucker, 1987)</td></tr>
</table>

The backward snowballing allowed to add 13 new scientific sources. The forward snowballing allowed to add 11 new scientific sources (see Figure 1). Finally, weekly alerts were set up on Scopus (see Figure 1). This third step was added to complement the snowballing and identify additional recent papers (Wohlin, 2014). This procedure allowed to add five new scientific sources. Overall, 39 studies were mobilised for the literature review (see Appendix).

Table 1. Conceptualised key notions of the study.

Key notions	Conceptualisation	Authors
Strategic Choices	Orientation of SMEs’ goals and actions towards desired outcomes regarding Industry 4.0 implementation	(Child, 1997; Oliver, 1991)
SMEs’ Context	Inner factors and outer factors shaping the environment of SMEs	(Pettigrew, 1987; Zucker, 1987)
Enablers	Factors that function as vehicles to mobilise SMEs’ efforts to implement Industry 4.0	(Ozorhon et al., 2014)
Barriers	Factors that might reduce SMEs’ ability and hinder their decision to implement Industry 4.0	(Coad et al., 2016)

3.2. Data Coding and Analysis

The coding process of the data was conducted in two times: first, for the notions related to SMEs’ contextual *enablers* and *barriers* and then for the elements related to SMEs’ *strategic choices* (see Figure 1). During each round, the data from analysed studies was systematically extracted and evaluated in several cycles (Saldaña, 2013).

First, the coding was conducted for the notions related to the contextual *enablers* and *barriers* affecting SMEs' implementation of Industry 4.0 (see Figure 1). In the scope of the first-cycle coding, each source was monitored for the factors or trends identified as encouraging or preventing Industry 4.0 implementation within SMEs. The second-cycle coding focused on establishing SMEs' context via categorisation of identified barriers and enablers by thematic groups. To do so, the existing classifications of enablers and barriers were mobilised (Ghobakhloo et al., 2022; Horváth & Szabo, 2019; Martinsuo & Luomaranta, 2018; Orzes et al., 2020; Pessot et al., 2020). The validity and coherence of chosen categories was revised in several rounds of discussion together with the authors of this study. Overall, eight thematic categories—six for inner context and two for outer context—were formed. Since each of these categories counted multiple trends with sufficiently distinctive features, the third-step coding focused on isolating and gathering these trends into subcategories. For each distinctive feature identified in a respective category of *enablers* and *barriers*, the encouraging and obstructing trends were regrouped according to the common characteristics. Through multiple rounds of discussion, the authors achieved a consensus upon 26 triggers leading to contextual pressures in SMEs' inner context and 9 triggers leading to contextual pressures in SMEs' outer context.

Second, the coding was conducted for the notions related to SMEs' *strategic choices* regarding Industry 4.0 (see Figure 1). The inductive approach (Linneberg & Korsgaard, 2019) was focused on SMEs' orientation of goals and actions towards desired outcomes of Industry 4.0 implementation. In the scope of the first-cycle coding, each source was monitored for the factors or trends that reflect SMEs' *strategic choices*. Guided by the key words, the authors conducted an in-depth analysis of the findings of each study to capture the trends that can be referred to as *strategic choices*. The second-cycle coding focused on the categorisation of identified strategic choices by thematic group. The logic behind this process was based on putting together trends related to SMEs' goals and actions regarding Industry 4.0 that have a common strategic dimension. Through multiple rounds of discussion, the authors achieved a consensus upon five thematic groups, each one corresponding to a dimension with two potential *strategic choices* for SMEs facing Industry 4.0 implementation.

Parallelly to this coding process, the authors analysed the data by referring to the institutional approach (Scott, 2014; Zucker, 1987). Institutional theory helped the authors in understanding the external and internal pressures[2] that encourage or impede SMEs in their strategic decision-making regarding Industry 4.0 implementation (DiMaggio & Powell, 1983; Greenwood & Hinings, 1996). The authors also analysed the contextual *enablers* and *barriers* that can lead to *trade-offs* when SMEs make their strategic choices. These *trade-offs* refer to the situations formed by opposite factors—*enablers* and *barriers*—when SMEs choose their priorities regarding Industry 4.0 (Cennamo & Santalo, 2013), as presented in the next section.

4. Results

This section presents the results of the narrative literature review in the following order. First, the pressures triggered by the *enablers* and *barriers* in the inner context of SMEs facing Industry 4.0 are illustrated with several examples. Then, some examples are given to depict the pressures that SMEs might experience from the *enablers* and *barriers* in their outer context. The section concludes with the illustration of several dimensions within which SMEs have two *strategic choices* regarding Industry 4.0 implementation.

Table 2. Pressures in the inner context of SMEs facing Industry 4.0 implementation.

Triggers		Enablers			Barriers	
Organisational Structure	1	Decentralised control with little hierarchical levels	(Cimini et al., 2020; Horváth & Szabo, 2019; J. Müller et al., 2018; Shukla & Shankar, 2022)	→ ←	Organisational complexity with centralized power	(Benitez et al., 2020; Estensoro et al., 2021; Moeuf et al., 2020; Pessot et al., 2020)
	2	Higher chances for larger size SMEs	(Brozzi et al., 2020; Ghobakhloo et al., 2022; Masood & Sonntag, 2020; Somohano-Rodríguez et al., 2022)	→ ←	Small family businesses	(Agostini & Nosella, 2020; Bosman et al., 2019; Cugno et al., 2021; Horváth & Szabo, 2019; Pessot et al., 2020)
	3	Structure compatible for digitalisation	(Ghobakhloo & Ching, 2019; Nwaiwu et al., 2020)	→ ←	Hardly digitisable operational systems	(Martinsuo & Luomaranta, 2018; Mittal et al., 2018; J. M. Müller et al., 2018)
Technological Resources	4	Regular use of company data in decision-making	(Horváth & Szabo, 2019; E. Machado et al., 2021; Moeuf et al., 2020; Rauch et al., 2020)	→ ←	Lack of awareness of the potential impact of data analytics	(C. Machado et al., 2021; Mittal et al., 2020; Moeuf et al., 2018, 2020; J. M. Müller et al., 2018)
	5	Perceived value and ease of use of new technologies	(Ghobakhloo & Ching, 2019; J. M. Müller et al., 2018; Prause, 2019)	→ ←	Lack of knowledge of new technologies and their potentialities	(Brozzi et al., 2020; Ingaldi & Ulewicz, 2020; Martinsuo & Luomaranta, 2018; Orzes et al., 2020; Pessot et al., 2020; Stentoft et al., 2021)
	6	Digital maturity	(Khin & Hung Kee, 2022; Nwaiwu et al., 2020; Shukla & Shankar, 2022)	→ ←	Immature IT infrastructure	(Bosman et al., 2019; Cugno et al., 2021; Ingaldi & Ulewicz, 2020; Martinsuo & Luomaranta, 2018; J. M. Müller et al., 2018; Orzes et al., 2020; Prause, 2019)
	7	Mastering of cybersecurity	(Prause, 2019)	→ ←	Cybersecurity issues	(E. Machado et al., 2021; Moeuf et al., 2018; Pessot et al., 2020; Rauch et al., 2020)
	8	Smart modular workstation	(Bosman et al., 2019)	→ ←	Space constraints	(Orzes et al., 2020; Rauch et al., 2020)
Financial Resources	9	Capacity to anticipate the financial advantages of innovation	(Mittal et al., 2020; Prause, 2019, 2019)	→ ←	Lack of experience in budgeting the adoption of innovation	(Cimini et al., 2020; Horváth & Szabo, 2019; Martinsuo & Luomaranta, 2018; Masood & Sonntag, 2020; Orzes et al., 2020; Rauch et al., 2020)

	10	Financial resource availability	(Estensoro et al., 2021; Ghobakhloo & Iranmanesh, 2021; Khin & Hung Kee, 2022)	→ ←	Limited financial resources and low investments in research and development	(Cimini et al., 2020; Horváth & Szabo, 2019; Ingaldi & Ulewicz, 2020; C. Machado et al., 2021; Masood & Sonntag, 2020; Moeuf et al., 2018; Orzes et al., 2020; Prause, 2019; Rauch et al., 2020)
Human Resources	11	Information and digital technology expertise	(Agostini & Filippini, 2019; Cimini et al., 2020; Ghobakhloo & Ching, 2019; Ghobakhloo & Iranmanesh, 2021; Somohano-Rodríguez et al., 2022)	→ ←	Lack of technical and support expertise	(Ghobakhloo et al., 2022; Ingaldi & Ulewicz, 2020; E. Machado et al., 2021; Moeuf et al., 2018, 2020)
	12	Valorisation of soft skills	(Agostini & Nosella, 2020; Cimini et al., 2020; Shukla & Shankar, 2022)	→ ←	Lack of appropriate soft skills	(Horváth & Szabo, 2019; Ingaldi & Ulewicz, 2020; Moeuf et al., 2020; Orzes et al., 2020; Pessot et al., 2020; Prause, 2019; Rauch et al., 2020)
	13	Employee involvement and empowerment practices	(Estensoro et al., 2021; Ghobakhloo et al., 2022; Horváth & Szabo, 2019; E. Machado et al., 2021; Vereycken et al., 2021)	→ ←	Lack of consideration of workers' autonomy and motivation	(Ietto et al., 2022)
	14	Regular employee training	(Cimini et al., 2020; Ietto et al., 2022; Khin & Hung Kee, 2022; Moeuf et al., 2020)	→ ←	Lack of regular employee training	(Estensoro et al., 2021; Horváth & Szabo, 2019; Ietto et al., 2022; Ingaldi & Ulewicz, 2020; Martinsuo & Luomaranta, 2018; Masood & Sonntag, 2020; Rauch et al., 2020)
Managerial and Organisational Culture	15	Open-minded for change and adaptation leaders	(Agostini & Nosella, 2020; Horváth & Szabo, 2019; Masood & Sonntag, 2020)	→ ←	Leaders with a 'conservative' profile to change	(Horváth & Szabo, 2019; E. Machado et al., 2021; Moeuf et al., 2020)
	16	Management competency for digital transformation	(Ghobakhloo & Iranmanesh, 2021; Moeuf et al., 2020)	→ ←	Lack of digital vision by the top management	(Horváth & Szabo, 2019; J. M. Müller et al., 2018; Pessot et al., 2020; Prause, 2019)
	17	Managers' will to risk	(Estensoro et al., 2021; Vrchota et al., 2019)	→ ←	Lack of risk management tools	(Rauch et al., 2020; Stentoft et al., 2021)

	18	Multidisciplinary knowledge and a good understanding of the operational professions	(Moeuf et al., 2020)	→ ←	Lack of appropriate skills, competencies, and experience	(Ghobakhloo et al., 2022; Horváth & Szabo, 2019)
	19	Change management competency	(Ghobakhloo & Iranmanesh, 2021; Shukla & Shankar, 2022)	→ ←	Lack of experience in change management	(Moeuf et al., 2020; Rauch et al., 2020)
	20	Culture based on experimentation and improvement	(J. Müller et al., 2018; Rauch et al., 2020; Vrchota et al., 2019)	→ ←	Lack of robust culture of adaptation and openness	(Cugno et al., 2021; C. Machado et al., 2021; Martinsuo & Luomaranta, 2018; Mittal et al., 2018)
	21	Culture based on cooperation and sharing	(Agostini & Nosella, 2020; Cimini et al., 2020; Estensoro et al., 2021; Rauch et al., 2020; Vrchota et al., 2019)	→ ←	Lack of cooperation and resistance	(Ingaldi & Ulewicz, 2020; Orzes et al., 2020; Pessot et al., 2020; Rauch et al., 2020; Stentoft et al., 2021)
	22	Effective knowledge-based communication	(E. Machado et al., 2021; Moeuf et al., 2020)	→ ←	Lack of communication and transparency	(Estensoro et al., 2021; Orzes et al., 2020; Pessot et al., 2020; Rauch et al., 2020)
Business strategy	23	Continuous improvement strategy on global scale	(Cimini et al., 2020; Moeuf et al., 2020; Somohano-Rodríguez et al., 2022)	→ ←	Focus on short-term operational strategies	(Horváth & Szabo, 2019; Moeuf et al., 2020; J. Müller et al., 2018; Orzes et al., 2020; Stentoft et al., 2021)
	24	Open innovation for new opportunities	(Agostini & Filippini, 2019; Cugno et al., 2021; Naruetharadhol et al., 2022; Ricci et al., 2021)	→ ←	Lack of access to shared knowledge	(Cugno et al., 2021; Mittal et al., 2018; Somohano-Rodríguez et al., 2022)
	25	Long-term collaboration with other SMEs	(Agostini & Filippini, 2019; Agostini & Nosella, 2020; Ghobakhloo et al., 2022; Ricci et al., 2021; Somohano-Rodríguez et al., 2022)	→ ←	Lack of trust and cooperation with other SMEs	(Benitez et al., 2020; Mittal et al., 2018; Rauch et al., 2020)
	26	Customer-orientated strategy	(Horváth & Szabo, 2019; Khin & Hung Kee, 2022; Martinsuo & Luomaranta, 2018; Rauch et al., 2020)	→ ←	Uncertainty about actual and potential customer needs	(Benitez et al., 2020; Khin & Hung Kee, 2022; Martinsuo & Luomaranta, 2018)

4.1. Pressures in the Inner Context of SMEs

The inner context refers to a complex system of SMEs' structure, resources, culture, and strategy that can be captured between the factors encouraging and impeding Industry 4.0 implementation (see Table 2). According to the current state of the inner context that can tend to be either an *enabler* or a *barrier*, these factors can put SMEs under pressure to adapt their organisation in the scope of Industry 4.0 implementation (Greenwood & Hinings, 1996).

On the level of the organisational structure, SMEs can consider the *enablers* and *barriers* related to the organisational complexity of SMEs (*trigger 1*). The suggestion to decentralise the organisational functions and to reduce the number of hierarchical levels (Cimini et al., 2020; J. Müller et al., 2018; Shukla & Shankar, 2022) can encourage the SMEs with a rigid and bureaucratic organisational structure to adjust it (Benitez et al., 2020; Estensoro et al., 2021). However, the distributed control and simplified internal processes suggested as a favourable precondition for Industry 4.0 implementation (J. Müller et al., 2018; Shukla & Shankar, 2022) can be difficult to introduce into complex organisational structure with centralised decision-making and non-cooperative leadership (Estensoro et al., 2021; Moeuf et al., 2020; Pessot et al., 2020). On the level of human resources, SMEs can face the *enablers* and *barriers* related to their capacity to empower the employees (*trigger 13*). The involvement of employees in decision-making processes (Estensoro et al., 2021; E. Machado et al., 2021; Vereycken et al., 2021) and the commitment to their concerns (Ghobakhloo et al., 2022) are among enabling factors for SMEs facing Industry 4.0 implementation. Nevertheless, such practices can be challenging within certain SMEs, where the employees' well-being and involvement in everyday life of the company are not among their priorities (Ietto et al., 2022). As for managerial and organisational culture, the *trigger 20* can be illustrated by the *enablers* and *barriers* regarding SMEs' capacity to innovate. An organisational culture nurtured by continual internal innovations (E. Machado et al., 2021; Vrchota et al., 2019) can develop a greater ability to respond to changing environment, thus, driving towards Industry 4.0 implementation (J. Müller et al., 2018). However, the mindset of *"if it ain't broke, don't fix it"* within some SMEs can prevent them from investing in Industry 4.0, sticking to old practices (Martinsuo & Luomaranta, 2018, p. 12). Finally, on the level of business strategy, the SMEs' might face *enablers* and *barriers* regarding their capacity to collaborate with other SMEs (*trigger 25*). In fact, the ability to share and exchange tacit knowledge and innovation strategy with other SMEs can encourage Industry 4.0 implementation (Ghobakhloo et al., 2022; Ricci et al., 2021; Somohano-Rodríguez et al., 2022). However, this attitude can represent a real challenge within certain SMEs who privilege an individualistic functioning (Benitez et al., 2020) or lack trust to cooperate with their peers (Mittal et al., 2018; Rauch et al., 2020).

4.2. Pressures in the Outer Context of SMEs

According to the results of the literature review, the outer context of SMEs facing Industry 4.0 can be captured between the *enablers* and *barriers* related to their market conditions and key stakeholders (see Table 3). The presence of these driving and hindering triggers is generally out of the control of SMEs and can put them under pressure to implement or not Industry 4.0 (Prause, 2019).

For instance, SMEs might face the *enablers* and *barriers* related to their labour market (*trigger 29*). The difficulty of finding employees with required expertise can impede (Ingaldi & Ulewicz, 2020) or encourage SMEs to accelerate the automatization of certain processes

Table 3. Pressures in the outer context of SMEs facing Industry 4.0 implementation.

Triggers		Enablers			Barriers	
Market Conditions	27	Market uncertainty driving the innovation	(Benitez et al., 2020; Prause, 2019)	→ ←	Market uncertainty hindering the innovation	(Cugno et al., 2021; E. Machado et al., 2021; Moeuf et al., 2020; Prause, 2019; Stentoft et al., 2021)
	28	Supportive legislation	(Benitez et al., 2020; Stentoft et al., 2021)	→ ←	Restrictive legislation	(E. Machado et al., 2021; Orzes et al., 2020)
	29	Boosting effect of labour shortage	(Horváth & Szabo, 2019, 2019; J. M. Müller et al., 2018)	→ ←	Retarding effect of labour shortage	(Ingaldi & Ulewicz, 2020; Prause, 2019)
Stakeholders	30	Governmental supporting programs	(Benitez et al., 2020; Khin & Hung Kee, 2022; E. Machado et al., 2021; Shukla & Shankar, 2022)	→ ←	Lack of awareness campaigns about existing programs	(Cugno et al., 2021; Ghobakhloo & Iranmanesh, 2021; Somohano-Rodríguez et al., 2022)
	31	Financial support from the government	(Cugno et al., 2021; Ghobakhloo & Iranmanesh, 2021; Khin & Hung Kee, 2022)	→ ←	Problematic tendering systems	(Horváth & Szabo, 2019; Orzes et al., 2020)
	32	Pressure from customers and professional network	(Bosman et al., 2019; Estensoro et al., 2021; Ghobakhloo & Ching, 2019; Khin & Hung Kee, 2022; Martinsuo & Luomaranta, 2018; J. M. Müller et al., 2018; Stentoft et al., 2021)	→ ←	Resistance from customers and professional network	(Agostini & Nosella, 2020; Horváth & Szabo, 2019; Martinsuo & Luomaranta, 2018; Orzes et al., 2020)
	33	Competitive pressure	(Estensoro et al., 2021; Ghobakhloo et al., 2022; Ghobakhloo & Ching, 2019; Horváth & Szabo, 2019; J. M. Müller et al., 2018; Stentoft et al., 2021; Vrchota et al., 2019)	→ ←	Low level/awareness of concurrency	(Ingaldi & Ulewicz, 2020; Khin & Hung Kee, 2022; Martinsuo & Luomaranta, 2018; Orzes et al., 2020)
	34	Industry 4.0 solutions tailored to SMEs' needs	(Ghobakhloo et al., 2022; Moeuf et al., 2020; J. M. Müller et al., 2018; Stentoft et al., 2021)	→ ←	Difficulty to reach technical providers	(Estensoro et al., 2021; Ietto et al., 2022; Ingaldi & Ulewicz, 2020; Orzes et al., 2020)
	35	Sharing of success stories of bigger firms	(Khin & Hung Kee, 2022; Mittal et al., 2018)	→ ←	Lack of inspiring examples of Industry 4.0 implementation	(Martinsuo & Luomaranta, 2018)

(Horváth & Szabo, 2019; J. M. Müller et al., 2018). The government and its programs supporting SMEs in digitalisation and innovation can also present some *enablers* and *barriers* (*trigger 30*). The countries where the government develop constantly such programs can encourage SMEs to implement Industry 4.0 (Khin & Hung Kee, 2022; E. Machado et al., 2021; Shukla & Shankar, 2022). However, the supporting programs can be difficult to benefit from if they are not sufficiently promoted among SMEs (Cugno et al., 2021; Ghobakhloo & Iranmanesh, 2021) or their instructions are not clear (Somohano-Rodríguez et al., 2022). The position of SMEs' professional networks towards innovation can be experienced as an *enabler* or a *barrier* regarding Industry 4.0 implementation (*trigger 32*). The pressure to implement new technologies that comes from customers (Ghobakhloo & Ching, 2019; Khin & Hung Kee, 2022; Stentoft et al., 2021) and firms from the same value chain (Bosman et al., 2019; Estensoro et al., 2021) often encourages SMEs to implement Industry 4.0. The opposite effect can be triggered by SMEs' subcontractors or customers who are not used to seizing the potential of new technologies (Agostini & Nosella, 2020; Martinsuo & Luomaranta, 2018) and refuse to collaborate (Horváth & Szabo, 2019; Orzes et al., 2020). The *trigger 34* is illustrated by the *enablers* and *barriers* regarding the availability of Industry 4.0 solutions adapted to SMEs' needs. Advanced in Industry 4.0 SMEs or technical providers who create the technological solutions adapted to the profile of SMEs can encourage them to implement new technologies (Ghobakhloo et al., 2022; Moeuf et al., 2020; J. M. Müller et al., 2018). However, because of a low-technology industrial sector in which they might operate (Estensoro et al., 2021; Ingaldi & Ulewicz, 2020), SMEs can be disconnected from industries providing such solutions (Ietto et al., 2022) and, therefore, struggle to benefit from such firm-specific solutions.

4.3. Strategic Choices of SMEs

Our review of the literature shows that *strategic choices* made by SMEs regarding Industry 4.0 implementation can take different forms, depending on the orientations they intend to favour (see Table 4). The characterization of *strategic choices* is achieved through five dimensions, each of which encompasses two extreme options between which several alternatives remain possible.

The profitability that SMEs aim by implementing Industry 4.0 (*dimension 36*) can be distinguished in terms of short-term and long-term ROI. SMEs can be attracted by the trend of extending the payback and pursue a long-term generation of benefits and performance improvements (Pessot et al., 2020; Somohano-Rodríguez et al., 2022). However, SMEs can go for more straightforward and low-risk ROI, driven by the concerns about the lack of guarantee of payback and the financial value of the project (Benitez et al., 2020; Bosman et al., 2019; Martinsuo & Luomaranta, 2018). The purpose followed by SMEs while implementing Industry 4.0 (*dimension 37*) is conceptualised in terms of main desired improvements. By focusing on costs reduction and operational efficiency, they easily implement new solutions that allow to improve productivity, lead times and corporate flexibility (Mittal et al., 2020; Moeuf et al., 2018; Pessot et al., 2020). By balancing economic benefits, environmental actions and social capital development, they can mobilise the Triple Bottom Line perspective and expand their goals towards improving energy and resource consumption and working conditions (J. Müller et al., 2018; Pessot et al., 2020). The area of transformation that SMEs focus on by implementing Industry 4.0 is illustrated through two *strategic choices* in the *dimension 38*. SMEs can focus on the improvement of their technological solutions to achieve higher product

Table 4. Strategic choices of SMEs facing Industry 4.0 implementation.

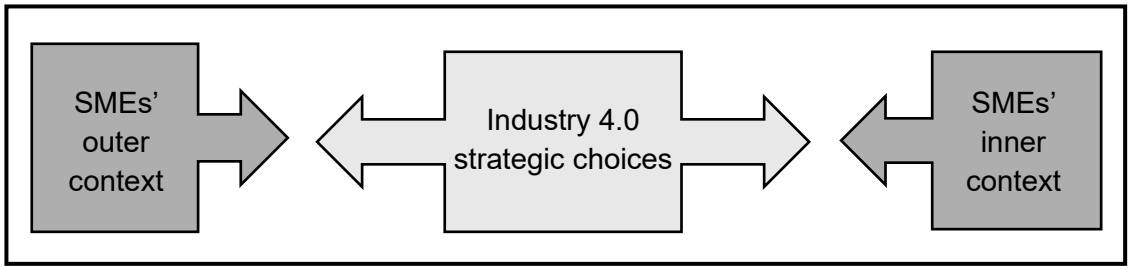
Dimensions		Strategic choice 1			Strategic choice 2	
Profitability	36	Reactive and short-term ROI	(Benitez et al., 2020; Bosman et al., 2019; Ghobakhloo & Ching, 2019; Ingaldi & Ulewicz, 2020; Martinsuo & Luomaranta, 2018; Masood & Sonntag, 2020; Mittal et al., 2020; Moeuf et al., 2018, 2020; J. Müller et al., 2018; J. M. Müller et al., 2018; Nwaiwu et al., 2020; Orzes et al., 2020; Pessot et al., 2020; Prause, 2019; Ricci et al., 2021; Stentoft et al., 2021; Vrchota et al., 2019)	→ ←	Proactive and medium or long-term ROI	(Cimini et al., 2020; Pessot et al., 2020; Somohano-Rodríguez et al., 2022; Verhulst & Brenden, 2021)
Purpose	37	Financial and operational excellence	(Agostini & Nosella, 2020; Benitez et al., 2020; Bosman et al., 2019; Estensoro et al., 2021; Ghobakhloo & Ching, 2019; Ingaldi & Ulewicz, 2020; C. Machado et al., 2021; Masood & Sonntag, 2020; Moeuf et al., 2018, 2020; Pessot et al., 2020; Prause, 2019; Somohano-Rodríguez et al., 2022; Stentoft et al., 2021)	→ ←	Triple Bottom Line	(Agostini & Filippini, 2019; Cimini et al., 2020; Cugno et al., 2021; Horváth & Szabo, 2019; Ietto et al., 2022; Mittal et al., 2020; J. Müller et al., 2018; J. M. Müller et al., 2018; Rauch et al., 2020; Ricci et al., 2021; Verhulst & Brenden, 2021)
Focus	38	Technological capital	(Cimini et al., 2020; Cugno et al., 2021; Estensoro et al., 2021; Ghobakhloo et al., 2022; Ghobakhloo & Ching, 2019; Horváth & Szabo, 2019; Ietto et al., 2022; C. Machado et al., 2021; Mittal et al., 2020; Moeuf et al., 2018; J. M. Müller et al., 2018; Stentoft et al., 2021)	→ ←	Human capital	(Agostini & Filippini, 2019; Agostini & Nosella, 2020; Cimini et al., 2020; Estensoro et al., 2021; Horváth & Szabo, 2019; J. M. Müller et al., 2018; Pessot et al., 2020; Rauch et al., 2020; Vereycken et al., 2021)
Technology	39	Basic technologies	(Agostini & Nosella, 2020; Benitez et al., 2020; Bosman et al., 2019; Estensoro et al., 2021; Ghobakhloo & Ching, 2019; Ingaldi & Ulewicz, 2020; C. Machado et al., 2021; Masood & Sonntag, 2020; Moeuf et al., 2018, 2020; Pessot et al., 2020; Prause, 2019; Somohano-Rodríguez et al., 2022; Stentoft et al., 2021)	→ ←	Advanced technologies	(Agostini & Nosella, 2020; Benitez et al., 2020; Bosman et al., 2019; Cimini et al., 2020; Cugno et al., 2021; Ghobakhloo et al., 2022; Ghobakhloo & Ching, 2019; Horváth & Szabo, 2019; C. Machado et al., 2021; Martinsuo & Luomaranta, 2018; Masood & Sonntag, 2020; Moeuf et al., 2018; Pech & Vrchota, 2020; Pessot et al., 2020; Ricci et al., 2021; Somohano-Rodríguez et al., 2022; Stentoft et al., 2021; Vereycken et al., 2021)
Solution	40	Standard	(Ghobakhloo & Ching, 2019; Masood & Sonntag, 2020; Ricci et al., 2021)	→ ←	Customised	(Benitez et al., 2020; Ricci et al., 2021; Vereycken et al., 2021)

quality and improved time-to-market of products (Ghobakhloo et al., 2022; C. Machado et al., 2021). By privileging the organisational acceptance, new job profiles and designs, new competencies, and clear objectives, SMEs can orient the change towards the empowerment of their human resources (Cimini et al., 2020; Estensoro et al., 2021; Mittal et al., 2020). On the level of solutions allowing to implement Industry 4.0, the *dimension 40* refers to standard or customised solutions. By focusing on the outcomes that a specific technology can offer, SMEs tend to implement off-the-shelf solutions that generally developed by suppliers in response to the needs of large companies (Ghobakhloo & Ching, 2019; Ricci et al., 2021). By prioritising customised solutions, they focus on the development of a new smart business model that goes beyond simple implementation of new technologies (Benitez et al., 2020).

5. Discussion

This study joins the ongoing research discussion about Industry 4.0 implementation within SMEs by elaborating an analytical framework of how SMEs' context can affect their *strategic choices* (see Figure 2). Even if SMEs generally struggle to implement Industry 4.0 through a conscious planning and methodological approach (Horváth & Szabo, 2019; Orzes et al., 2020), they make specific *strategic choices* by orienting their actions and goals towards desired outcomes and established norms of Industry 4.0. Such choices can be influenced by the *enablers* and *barriers* identified in SMEs' inner and outer context. From institutional perspective (Oliver, 1991; Scott, 2014; Zucker, 1987), the *enablers* and the *barriers* that mobilise and hamper SMEs' efforts to implement Industry 4.0 can be interpreted as institutional pressures arising from SMEs' inner and outer context. Such pressures can lead SMEs to contextual *trade-offs* regarding their *strategic choices*.

Figure 2. Analytical framework of SMEs facing Industry 4.0 implementation.



On one hand, this study analyses the pressures triggered by the *enablers* and *barrier*s of SMEs' outer context to illustrate their influence on SMEs' *strategic choices* regarding Industry 4.0. Such pressures can arise from SMEs' organisation field (DiMaggio & Powell, 1983; Mignerat & Rivard, 2009). Industry, professional associations, and inter-organisational networks can be the source of normative pressure pushing SMEs to adhere to norms and to embrace methods considered to be reasonable (Mizruchi & Fein, 1999). Government agencies, parent firms, dominant suppliers and customers can be the source of coercive pressure shaping the behaviour of SMEs through regulations or frameworks to apply (Heugens & Lander, 2009). Best practices, competitors, and peers can be the source of mimetic pressure, stimulating SMEs to adopt similar procedures and attitudes (Barreto & Baden-Fuller, 2006). Following this logic, the present study puts together the *enablers* and *barriers* deriving from the same source of external pressure and emphasises their mutually exclusive nature that can lead SMEs to different *trade-offs*. These *trade-offs* can push SMEs to prioritise an *enabler* or a *barrier* when making their *strategic choices* regarding Industry 4.0 implementation.

Whereas both, enabling and impeding external pressures, can lead to one of *strategic choices*, the papers analysed in the scope of our literature review usually tend to highlight the *enablers* for such matter. For instance, the source of mimetic pressure leading to the *strategic choice* oriented towards long-term ROI could be the sharing of the success stories of Industry 4.0 implementation (Khin & Hung Kee, 2022; Mittal et al., 2018). Generally hesitating about the benefits of long run strategies and their possibilities in terms of covering the initial costs (Benitez et al., 2020; Ghobakhloo & Ching, 2019), SMEs can acquire and replicate the competencies and methodologies that are readily accessible in their field (Caldera et al., 2019). Another potential source of mimetic pressure—successful competitors—can lead to the implementation of advanced technologies (Ghobakhloo & Ching, 2019; J. M. Müller et al., 2018). The fact that SMEs' technologically more advanced competitors are positively perceived by peers within the same industry (Gupta et al., 2020) can convince SMEs to overcome their prejudice about technologies with uncertain results (J. M. Müller et al., 2018). The normative pressure represented by customers' requirements to use specific Industry 4.0 technologies can push SMEs to implement standard solutions as a potential *strategic choice* (Ghobakhloo & Ching, 2019; Stentoft et al., 2021). In case SMEs are the suppliers of large companies who constantly innovate in terms of automation and connectivity, the latter *"call the shots"* by establishing the standards for technological solutions that might be implemented by the first (J. M. Müller et al., 2018, p. 11). Regulatory standards or customers' requirements might exert the coercive pressure pushing SMEs to embrace the *strategic choice* oriented to Triple Bottom Line (Khin & Hung Kee, 2022; Stentoft et al., 2021). Just like SMEs adopting new technologies to reduce carbon footprint across their supply chain (Gupta et al., 2020), the compliance with legal requirements regarding the traceability and security of products can become the starting point to implement Industry 4.0 (Stentoft et al., 2021).

On the other hand, our study analyses the pressures triggered by the *enablers* and *barriers* of SMEs' inner context to illustrate their influence on SMEs' *strategic choices*. The internal source of pressure might derive from the internal dynamics and complexity of SMEs' organisation (Zucker, 1987). Considering that every organization represents a *"mosaic of groups structured by functional tasks and employment status"*, the potential source of pressure can be the divergence of groups' interests regarding SMEs' objectives, organisational structure, and performance evaluation (Greenwood & Hinings, 1996, p. 1033). The way the groups are committed to the current model of organisational functioning—loyal, indifferent, competitive, opposed—can also be the origin of internal pressures (Greenwood & Hinings, 1996). Building upon this reasoning, our study explores the *enablers* and *barriers* related to the similar source of internal pressure and highlights their conflicting nature. Such conflicting nature may lead SMEs to contextual *trade-offs* when making their strategic choices regarding Industry 4.0. Although both supportive and obstructive internal pressures can influence SMEs' strategic decision-making, the reviewed literature usually tends to focus on the *barriers* in this regard. For instance, SMEs may opt for the *strategic choice* with short-term ROI because of their resource constraints (Nwaiwu et al., 2020) and short-term strategic vision (Somohano-Rodríguez et al., 2022). Indeed, avoiding long-term investments can be explained by SMEs' *"business model innovation aspirations"* that are *"often not conscious and not handled as an opportunity but rather as a compulsion"* (Horváth & Szabo, 2019, p. 128). From institutional perspective, such an attitude refers to the status quo value commitment according to which SMEs' actors adhere to the established and commonly used institutional template (Greenwood & Hinings, 1996). The same value commitment can prevent SMEs from embracing the *strategic choice* focused on human capital. As the implementation of Industry 4.0 technologies

may require new competencies, new processes and new testing methods, SMEs can consider such learning curve *"too expensive and time consuming"* (Martinsuo & Luomaranta, 2018, p. 12). This attitude can be explained by SMEs' lack of technical and support expertise of workers (Ghobakhloo et al., 2022; E. Machado et al., 2021), lack of regular employee training (Estensoro et al., 2021; Rauch et al., 2020) and the lack of a robust culture of adaptation and openness (Cugno et al., 2021; Mittal et al., 2018). Generally, SMEs tend to begin with the implementation of basic technologies considered as easily programmable for their environment (Cimini et al., 2020; Ghobakhloo & Ching, 2019; Horváth & Szabo, 2019). Frequently mentioned reluctance of SMEs towards data analysis and lack of perception of its use (Ghobakhloo & Ching, 2019; Prause, 2019; Wong et al., 2020) often slows down the integration of more advanced technologies. However, according to the study conducted by Cimini et al. (2020), once SMEs acquire the necessary basic technologies, they can step further toward more advanced solutions.

Finally, with respect to institutional theory, this study suggests an interesting assumption regarding the contextual *trade-offs* that SMEs may realise by making certain *strategic choices*. From institutional perspective, SMEs, confronted with institutional pressures, seek to respond strategically to gain legitimacy and ensure their survival (Oliver, 1991; Suchman, 1995). Through the tactics of acquiescence strategy, they might decide to conform to the pressures for self-serving reasons (Oliver, 1991). The tactics of compromise strategy allow propelling SMEs' own interests (Oliver, 1991). The strategy of avoidance refers to the tactics of bypassing the necessity of conforming to pressures (Oliver, 1991). The tactics of defiance strategy can lead SMEs to the rejection of the institutional norms (Oliver, 1991). The tactics of manipulation strategy can be applied to co-opt, influence, or control an institutional pressure (Oliver, 1991). Following this logic, the contextual *trade-offs* can become intentional when SMEs must decide which *strategic choice* to make regarding Industry 4.0 implementation. Some *strategic choices*, such as long-term ROI, Triple Bottom Line, or human-oriented change, may refer to acquiescence strategies, whereby SMEs conform to the requirements of Industry 4.0 for reasons that serve their own interests (Oliver, 1991). In this case, SMEs might lean more towards the *enablers* of their context since such transformations help them to embrace Industry 4.0 as promoted by the institutions behind these enablers (Caldera et al., 2019; Gupta et al., 2020; Shibin et al., 2020). The *strategic choices* related to Industry 4.0 technologies where SMEs start by implementing basic technologies to continue with the advanced ones (Cimini et al., 2020) might be explained by compromise strategies where SMEs might pursue their own interests through tactics of balancing (Oliver, 1991). Here, SMEs might be placed between the *enablers* and *barriers* of their context as they seek to strike a balance between the conflicting external pressures or conflicting internal pressures. The *strategic choices* with short-term ROI or technological orientation of change might be partly explained by SMEs' attempt to bypass the need to conform to pressures—the avoidance strategy (Oliver, 1991). For instance, SMEs can implement new technology requiring few processual changes and hire experts to handle this technology to avoid changing the organisational culture, upskilling the workers, or causing workers' resistance (Mittal et al., 2020).

6. Conclusion

The aim of this theoretical study was to identify and analyse the influence of contextual *enablers* and *barriers* on SMEs' *strategic choices* regarding Industry 4.0 implementation. Through narrative literature review (Baumeister & Leary, 1997; Hammersley, 2001), the study

mobilised previous studies focused on SMEs implementing Industry 4.0 and addressed their findings from a novel and original perspective.2728

The obtained framework goes beyond such common characteristics as size, sector of activity, limited financial resources or flexible organisational structure used by existing studies to describe SMEs facing Industry 4.0 implementation (Horváth & Szabo, 2019; J. Müller et al., 2018). The framework captures the uniqueness of SMEs' strategic decision-making by highlighting 35 contextual triggers leading SMEs to potential *trade-offs* regarding 5 dimensions of *strategic choices* in the scope of Industry 4.0 implementation[3]. The authors plan to test empirically the analytical framework with managers and other key actors of SMEs facing Industry 4.0 implementation. The outcomes of this future study are expected to help to adjust several aspects of the framework according to the evolving reality of SMEs. These outcomes are expected also to achieve a better understanding and empirical-based explanation of SMEs' *trade-offs* between contextual elements and *strategic choices* regarding Industry 4.0 implementation.

This study suggests several managerial implications. First, the framework obtained in the scope of this study can be further transformed into a methodological tool for SMEs planning to implement Industry 4.0. The analysis of their specific inner and external contexts may help SMEs to tailor their *strategic choices* for Industry 4.0 implementation according to their needs and specificities. Second, the framework can be transformed into an analytical tool for SMEs already involved in the process of Industry 4.0 implementation. The panoramic analysis of contextual factors likely to influence *strategic choices* may help SMEs to take a step back and assess their current situation related to Industry 4.0 implementation.

This study has several limitations that can be addressed by future research. The identified *strategic choices* do not cover all examples of the orientation of SMEs' goals towards desired outcomes of Industry 4.0. Therefore, the future research is invited to enrich by a more fine-grained categorisation the proposition of SMEs' *strategic choices* regarding Industry 4.0 implementation covered by this study[4]. Since the concept of Industry 4.0 is adopted by countries with distinct institutional characteristics, it gives rise to divergent interpretations (Fogaça et al., 2022). Moreover, the requirements and particularities of Industry 4.0 implementation vary across industrial sectors (Ghobakhloo et al., 2022). Therefore, future research may refine the proposed framework by considering the institutional particularities of specific regions or activity sectors, allowing a more tailored tool to assess the influence of SMEs' context on their *strategic choices* regarding Industry 4.0[5].

Notes

(1) The choice of a narrative literature review is also grounded in the exploratory stage of this research, as the study was conducted during the first year of the doctoral project. At that stage, the research question and analytical angle were still in formation, which made a systematic literature review less appropriate, as such approaches require a clearly defined and narrowly specified question established a priori (Harris et al., 2014). In contrast, narrative reviews allowed addressing broader and more abstract questions about Industry 4.0 challenges for SMEs, progressively refining the inquiry towards contextual factors and strategic choices for Industry 4.0 implementation, by following different lines of enquiry (Baumeister & Leary, 1997; Fan et al., 2022).

(2) The concept of pressure refers here to *"the contextual dynamics that precipitate the need for organizational adaptation"* (Greenwood & Hinings, 1996, p. 1023).

(3) The connection between strategic choices and their underlying triggers can be further clarified by explicitly identifying the role of contextual pressures as activating mechanisms of decision-making. Building on the

institutional perspective adopted in this study, enablers and barriers can be interpreted as triggers that shape SMEs' strategic responses through the pressures they generate. External triggers – such as competitive dynamics, customer requirements, or regulatory frameworks (Benitez et al., 2020; Ghobakhloo & Ching, 2019; Khin & Hung Kee, 2022) – orient strategic choices towards advanced technologies adoption, standard solutions, long-term ROI, or Triple Bottom Line change (Müller et al., 2018; Stentoft et al., 2021). Internal triggers – stemming from resource constraints, organisational culture, or workforce characteristics (Cugno et al., 2021; Horváth & Szabo, 2019) – orient choices towards short-term ROI, technology-oriented change, or basic technologies (Cimini et al., 2020; Martinsuo & Luomaranta, 2018). These triggers interact and generate contextual trade-offs, through which managers prioritise certain pressures when defining their strategic responses to these pressures (Oliver, 1991). In this sense, strategic choices emerge as situated responses to combinations of internal and external triggers, mediated by managerial interpretation.

(4) While the proposed framework of strategic choices captures key orientations of managerial action, it only partially reflects the breadth of strategic domains involved in technological transformation. In this regard, the conceptualisation of strategic choices in SMEs under Industry 4.0 could constitute a research avenue in its own right. Drawing on strategic management literature, future studies could expand this categorisation by integrating additional dimensions such as the scope of transformation (incremental or radical change) (Teece, 2007) or the level of production system integration (machine, line, plant, or supply chain level) (Frank et al., 2019), or the strategic domain in which decisions are primarily situated, including business positioning, technological infrastructure, or organisational arrangements (Henderson & Venkatraman, 1990).

(5) The nature and influence of triggers shaping SMEs' strategic choices may differ when considering larger firms. While SMEs are particularly sensitive to resource constraints, proximity to operational challenges, and immediate external pressures (Harney & Alkhalaf, 2021), larger companies typically operate with more formalised structures, greater resource slack, and established strategic planning processes (Mintzberg, 1982). As a result, triggers in large firms may be more strongly shaped by internal strategic agendas, corporate governance mechanisms, and long-term investment logics, while SMEs' triggers tend to emerge from more immediate interactions between internal constraints and external demands. In this sense, although similar categories of triggers (institutional, organisational, market-based) may be observed across firm sizes, their relative weight, articulation, and temporal orientation are likely to vary. Future research could therefore explore how firm size influences the configuration and prioritisation of triggers shaping strategic choices in the context of Industry 4.0.

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Appendix

Articles included in the literature review.

Reference	Country	Method	Publication
(Agostini & Filippini, 2019)	Italy	Questionnaire and in-depth interviews	European Journal of Innovation Management
(Agostini & Nosella, 2020)	Italy	Survey and in-depth interviews	Management Decision
(Benitez et al., 2020)	Brazil	Case study	International Journal of Production Economics
(Bosman et al., 2019)	USA	Survey	Journal of Manufacturing Technology Management
(Brozzi et al., 2020)	Italy	Survey	Procedia CIRP
(Cimini et al., 2020)	Italy	Case studies	Journal of Manufacturing Technology Management
(Cugno et al., 2021)	Italy	Semi-structured in-depth interviews, multiple case studies	Technological Forecasting and Social Change
(Estensoro et al., 2021)	Spain	Interviews and survey	European Management Journal
(Ghobakhloo & Ching, 2019)	Iran Malaysia	Questionnaire	Journal of Industrial Information Integration
(Ghobakhloo & Iranmanesh, 2021)	Italy, Netherlands, France, Spain, Sweden, Germany, Denmark	Literature review and in-depth interviews	Journal of Manufacturing Technology Management
(Ghobakhloo et al., 2022)	-	Systematic literature review	Journal of Manufacturing Technology Management
(Horváth & Szabo, 2019)	Hungary	In-depth interviews	Technological Forecasting and Social Change
(Ietto et al., 2022)	Italy	Multiple case study	IEEE Transactions on Engineering Management
(Ingaldi & Ulewicz, 2020)	Poland	Quantitative and semi-directive interviews	Sustainability [Switzerland]
(Khin & Hung Kee, 2022)	Malaysia	Survey	International Journal of Computer Integrated Manufacturing
(E. Machado et al., 2021)	Brazil	Interviews	Sustainability [Switzerland]
(C. Machado et al., 2021)	Sweden	Case studies	Journal of Manufacturing Technology Management
(Martinsuo & Luomaranta, 2018)	Finland	Interviews and focus groups	Journal of Manufacturing Technology Management

(Masood & Sonntag, 2020)	UK	Survey	Computers in Industry
(Mittal et al., 2020)	India	Case studies	International Journal of Production Research
(Mittal et al., 2018)	-	In-depth literature review	Journal of Manufacturing Systems
(Moeuf et al., 2020)	France	Interviews	International Journal of Production Research
(Moeuf et al., 2018)	-	Literature review	International Journal of Production Research
(J. M. Müller et al., 2018)	Germany	Case studies	Technological Forecasting and Social Change
(J. Müller et al., 2018)	Germany	Survey	Sustainability
(Naruetharadhol et al., 2022)	Thailand	Survey	International Journal of Technology
(Nwaiwu et al., 2020)	Czech Republic	Survey	Business: Theory and Practice
(Orzes et al., 2020)	Italy, Austria, USA, Thailand	Workshops	Palgrave Macmillan
(Pech & Vrchota, 2020)	Czech Republic	Questionnaire	Applied Sciences
(Pessot et al., 2020)	Austria, France, Germany, Italy, Slovenia	Survey	Journal of Manufacturing Technology Management
(Prause, 2019)	Japan	Survey	Sustainability
(Rauch et al., 2020)	Italy, Austria, USA, Thailand	Workshops	Palgrave Macmillan
(Ricci et al., 2021)	Italia	Survey	International Journal of Production Economics
(Shukla & Shankar, 2022)	India	Case studies	Computers and Industrial Engineering
(Somohano-Rodríguez et al., 2022)	Spain	Questionnaire	Journal of Small Business Management
(Stentoft et al., 2021)	Denmark	Survey and semi-structured interviews	Production Planning and Control
(Vereycken et al., 2021)	EU28	Quantitative analysis of EU survey	Journal of Manufacturing Technology Management
(Verhulst & Brenden, 2021)	Norway	Pilot cases	IFIP Advances in Information and Communication Technology book series
(Vrchota et al., 2019)	Czech Republic	Survey and case studies	Social Sciences

Paper 2. Making Sense Before Making Change: How SMEs' Managers Engage with the Conceptual Diversity of Industry 4.0[3]

Abstract. More than a decade after its emergence, Industry 4.0 (I4.0) remains marked by persistent conceptual diversity, arising from heterogeneous interpretations mobilised by different actors for different purposes. While this diversity has been widely documented, less is known about how managers engage with it in practice, particularly in SMEs, where managers play a decisive role in shaping change. Drawing on a qualitative study of industrial SMEs in Belgium, this paper examines how managers engage with the conceptual diversity of I4.0. The findings show that instead of converging towards a shared understanding of I4.0, managers articulate its meaning in relation to their individual trajectories and organisational contexts. These interpretations take the form of recurring configurations structured around three interrelated dimensions that orient strategic actions. Read through an interpretive lens, the study shows how the conceptual diversity of I4.0 is worked with rather than resolved to enable action within SMEs.

1. Introduction

Over the past decade, Industry 4.0 (I4.0) has become a reference point for industrial transformation, mobilised across policy agendas, organisational strategies, and managerial discourses (Fogaça et al., 2024; Kowalikova et al., 2020). Rather than stabilising around a shared definition, the concept has remained open – which can be sometimes judged as deliberate choice (Gioia et al., 2012) allowing diverse actors to project their own priorities, expectations, and concerns onto it (Meyer, 2019; Pfeiffer, 2017). What initially emerged as a *fourth industrial revolution* has since evolved into a heterogeneous landscape of interpretations, narratives, and promises that coexist under the same label (Oesterreich et al., 2020; Reischauer, 2018). As a result, I4.0 can be perceived less as a clearly bounded data-driven concept orbiting around key technologies such as Internet of Things or Artificial Intelligence (Frank et al., 2019; Gupta et al., 2020) than as an adjustable interpretive space through which change can be imagined, justified, and enacted (Weick, 1995).

This conceptual diversity has been widely documented in the literature. Scholars show how governments, consultancies, technology providers, social partners, and firms contribute to shaping multiple understandings of I4.0, rooted in distinct institutional, sectoral, and strategic logics (Meyer, 2019; Oesterreich et al., 2020; Woźniak-Jęchorek et al., 2024). While this work convincingly establishes the existence of such a phenomenon, it largely treats it as a property of discourse or policy. Much less is known about how this diversity is captured and worked with inside organisations, particularly by those who must translate abstract and shifting expectations into concrete strategic choices. This question becomes especially salient at the level of managers. Faced with an ambiguous and plural concept such as I4.0, managers' most crucial task starts not with choosing what solutions to adopt, but with deciding what I4.0 should mean for their organisation (Weick, 1995). Instead of paralysing action, such an ambiguity can induce variation in interpretations and enable managers to elaborate meaningful orientations for change (Gioia et al., 2012; Maitlis & Christianson, 2014). Yet, despite the growing interest in managerial perceptions of I4.0, existing studies rarely examine how managers actively engage with conceptual diversity, nor how they use it to initiate and stabilise transformation.

[3] This chapter reproduces an article currently under revision (Awaiting Reviewer Scores) at the *Journal of Management Inquiry.*

The need to address this gap is particularly accurate in small and medium-sized enterprises (SMEs), where decision-making power is highly concentrated in the hands of managers (Harney & Alkhalaf, 2021), while resources, time, and innovation support structures are often limited (Estensoro et al., 2021; Horváth & Szabo, 2019). Prior research shows that although SMEs' managers initiate the process of I4.0 transformation, they struggle with elaborating a clear understanding of it (Hansen et al., 2024; Yunus, 2021) and face uncertainty due to organisational trust issues (Lumineau et al., 2023). To date, the phenomenon of conceptual diversity has been demonstrated to lead to heterogeneous understandings among SMEs' managers (Tortorella et al., 2021; Wilkesmann et al., 2018). Yet how these managers work with conceptual diversity – rather than simply struggle with it – remains largely underexplored.

Against this backdrop, our study asks: *How do managers of industrial SMEs engage with the conceptual diversity of I4.0 to orient action?* We address this question through a qualitative study of managers from industrial SMEs in Belgium, where a strong political agenda promoting "Factories of the Future" coexists with an economic fabric dominated by small businesses operating in industrial sectors (SPW & Agence du Numérique, 2021). By examining how SMEs' managers interpret, bracket, and stabilise the meaning of I4.0, this study advances understanding of managerial sense-making under conditions of persistent conceptual diversity. Specifically, it shows how managers frame heterogeneous interpretations into context-specific configurations that orient strategic choices of SMEs.

The paper is structured as follows. First, the literature review discusses the key concepts of the study related to conceptual diversity of I4.0, managerial sense-making and I4.0 perceptions. Second, the methodology presents a two-level approach for data collection and analysis. Next, the findings are presented, followed by a discussion. The paper concludes with an overview of the major implications and limitations of the study, along with suggestions for future research.

2. Theoretical Background

2.1. I4.0: from Conceptual Ambiguity to Conceptual Diversity

Since its introduction at the Hannover Messe in 2011, I4.0 has been characterised by a deliberately imprecise formulation. Early strategy documents presented I4.0 as a far-reaching vision of a *fourth industrial revolution*, associating technological development with economic competitiveness, social progress, and improved work conditions, while remaining strikingly vague about how these goals could be achieved in practice (Pfeiffer, 2017; Reischauer, 2018). As a matter of fact, the actors who coined the concept avoided specifying concrete technical applications or implementation pathways, favouring an expansive and visionary narrative over operational clarity (Pfeiffer, 2017). However, such conceptual ambiguity can be interpreted as functional, serving a strategic purpose by enabling broad alignment, rather than as an unintended lack of precision. Research on strategic and political communication suggests that abstract and evocative visions allow diverse audiences to recognise their own priorities and expectations in a shared message, thereby increasing adhesion and mobilisation without requiring agreement on precise meanings (Gioia et al., 2012; Huckfeldt et al., 1998). When confronted with ambiguous messages, actors tend to rely on their past experiences and frames of reference to interpret them, effectively *"hearing what they want to hear",* which facilitates engagement across heterogeneous contexts (Gioia et al., 2012, p. 367).

This interpretive openness enabled I4.0 to circulate rapidly beyond its German origins, progressively expanding the initial ambiguity into pronounced conceptual diversity. Rather than converging towards a shared definition, countries embedded I4.0 within distinct industrial, economic, and societal priorities, producing a plurality of policy frameworks and labels (Culot et al., 2020a; Lepore & Spigarelli, 2020). In European Union alone, at least 28 initiatives have been launched by member states to support the European policy agenda around I4.0: *Industria Conectada 4.0* in Spain, *Alliance pour l'Industrie du Futur* in France, or *Smart Industry* in Netherlands (Teixeira & Tavares-Lehmann, 2022). Within this diversity of national discourses, different actors contributed into further shaping of I4.0: consultancies have tended to emphasise managerial tools, roadmaps, and readiness assessments, technology providers have foregrounded digital integration and automation solutions, while social partners have focused on skills, employment, and the conditions of a fair transition (Meyer, 2019; Oesterreich et al., 2020; Woźniak-Jęchorek et al., 2024). Taken together, this stream of research shows that I4.0 functions less as a stabilised concept than as an adjustable interpretive space, shaped by competing narratives and policy frameworks. This conceptual diversity directly conditions how managers perceive the concept of I4.0, resulting in spectrum of interpretations.

2.2. Managerial Perceptions of I4.0

Managers' navigation in the context of I4.0 conceptual diversity is often captured in two ways: a lack of understanding or the presence of multiple interpretations (Hansen et al., 2024; Yunus, 2021). The first is particularly common among SMEs' managers, who often fall behind in terms of technological knowledge and adoption due to financial, human, and digital resource limitations of their firms (Estensoro et al., 2021; Stentoft et al., 2021). Moreover, some tend to agree with unfounded beliefs about I4.0, reflecting oversimplified causal expectations or misconceptions about its implementation, more than others (Tortorella et al., 2021). This lack of understanding often fuels managers' hesitation or reluctance towards I4.0 (Ietto et al., 2022), which promotes technologies as central mediators of collaboration, positions data as a key reference for decision-making, and frames technology providers as core stakeholders in firms' everyday operations (Lumineau et al., 2023). Combined with uncertainty regarding I4.0 key principles, benefits, and challenges, it thus affects managers' capacity to establish a clear strategy for their companies' innovation (Hansen et al., 2024).

In the second case, existing studies demonstrate that managers, who are familiar with the concept and engaged at some point in its integration, perceive I4.0 in different ways. Some managers express optimism – expecting reduced workloads and job enrichment – while others fear job losses or perceive I4.0 as an overhyped label (Wilkesmann et al., 2018). In both cases, their individual affinity with new technologies and companies' level of I4.0 maturity tend to affect these perceptions. Although expressed in different terms, managers tend mostly to associate I4.0 with specific technologies such as internet of things (IoT) or big data analytics and automation or machine-to-machine communication (Schaupp & Diab, 2020; Yunus, 2021), aiming for gains in efficiency and productivity, compliance with stakeholders, working process transformation, and adaptability to the market (Da Roit & Iannuzzi, 2023; Fogaça et al., 2024; Meyer, 2019).

While these studies offer an overview of managerial perceptions, most mention them incidentally and rarely analyse them in depth (Da Roit & Iannuzzi, 2023; Yunus, 2021). With the exception of the typology by Wilkesmann et al. (2018), based on managers from the chemical-pharmaceutical industry without specifying the size of companies, no study to date has systematically explored how managers from SMEs perceive I4.0. This gap is critical, given

that SMEs' managers are directly involved in identifying innovation opportunities and shaping strategic responses (Viitala et al., 2022; Zoppelletto et al., 2023). Thus, shifting the analytical lens from prescriptive roadmaps towards managerial sense-making provides a necessary perspective for understanding how I4.0 is enacted within organisations.

2.3. Managerial Sense-Making: from Conceptual Diversity to Strategic Changes

Managers play a central role in organisational change by engaging in sense-making processes that transform ambiguity into orientations for action. When change initiatives are launched in the context of ambiguous visions such as I4.0, this ambiguity rarely paralyses organisations – rather, it induces variation in interpretations, knowledge revisions, and actions, from which some understandings are progressively reinforced and institutionalised (Gioia et al., 2012). In this perspective, sense-making captures how managers build meaning when facing uncertainty, filtered through their experiences, identities, and organizational contexts (Weick, 1995). In SMEs, managerial sense-making has been shown to be strongly relational, as by engaging with employees, clients, and ecosystem actors, managers shape the firm's capacity to innovate (Penttilä et al., 2020; Sharifi & Zhang, 2009). Alongside these relational dynamics, managerial interpretations are filtered through prior experiences and culturally embedded frames (Ivanova & Torkkeli, 2013; Sharifi & Zhang, 2009). For instance, managers' interpretations of stakeholder management or business relationship have been shown to vary across countries, depending on institutional environments, cultural traditions, or language specifics (Ivanova & Torkkeli, 2013; Schlierer et al., 2012). More broadly, managers rely on sense-making to interpret environmental cues such as emerging technologies, shifting market demands, and evolving ecosystem arrangements, which condition whether strategic options are perceived as desirable or feasible (Penttilä et al., 2020). Beyond purely cognitive work, the sense-making combines action-based knowledge derived from managers' prior initiatives with communicative practices and data-related artefacts to test, justify, and adjust their understandings of change (Sarrami et al., 2020; Sharifi & Zhang, 2009).

Consequently, when managers can influence how others understand the future, sense-making becomes a vehicle through which strategic change is initiated and sustained (Maitlis & Christianson, 2014). It allows managers to articulate narratives that link past decisions to future ones and justify emerging courses of action to themselves and others (Sharifi & Zhang, 2009). For instance, managers' underlying beliefs were found to act as decisive performance drivers: when managerial thinking was strategically oriented towards people management, investments in skills and capabilities were sustained, whereas vague interpretations led to hesitant, short-term, or uneven commitments to human capital development (Viitala et al., 2022). Change thus begins less as an action and more as a process of interpretation and envisioned situations – *"a process that revolves around the vision used to frame changes in desired ways of being, seeing, and doing"* (Gioia et al., 2012, p. 365). Managerial sense-making becomes critical process through which ambiguous change imperatives can be translated into organisational change. Applied to I4.0, this perspective sheds light on how managers might operate at the intersection of institutional pressures to innovate and internal constraints of SMEs, making sense of an initially ambiguous vision that has evolved into a landscape of heterogeneous expectations.

3. Methodology

To analyse how SMEs' managers engage with the conceptual diversity of I4.0 to orient action, the study mobilised a sequential design, where the first phase conducted by means of online

questionnaire informed the second phase conducted through semi-directive interviews (Plano Clark, 2010).

3.1. Data Collection

While the research design was intentionally structured, the focal phenomenon examined in this study surfaced inductively, prompted by an unexpected pattern in the data within a broader research project on how SMEs' managers navigate I4.0 transformation. During an online questionnaire designed for this project, an open-ended question was included asking respondents: "How would you define an 'Industry 4.0' transformation project in a few words or phrases?". This question was initially conceived as a descriptive element, aimed at documenting baseline representations. However, as responses accumulated, it became apparent that managers' definitions were strikingly diverse, not only in their substantive content but also in the reasoning and assumptions underlying them. Rather than converging towards a shared understanding, these definitions revealed markedly different ways of framing I4.0, which prompted a reorientation of the analytical focus towards managerial sensemaking.

This questionnaire constituted the first phase of our study. Given the exploratory nature of this phase, the questionnaire was introduced to identify patterns of meaning and variation in managerial interpretations, rather than to produce statistically generalisable results. Accordingly, analytical robustness at this stage was ensured through carefully defined sampling criteria and systematic data cleaning. The online questionnaire was sent to 600 managers of Walloon industrial SMEs, selected from the publicly available database *Entreprises en Wallonie*. Participants were selected based on their position of decision-makers within the firm (CEO or manager), company size (fewer than 250 employees), and industrial activity, with service sectors excluded. The questionnaire was administered via a general email containing a description of the study and an invitation to participate and supported by targeted diffusion through professional and institutional networks in Wallonia, which facilitated access to SMEs' managers – a population that is typically difficult to reach through unsolicited contact approaches. A total of 174 responses were received. This corresponds to a response rate of approximately 29%, which is consistent with prior research showing that surveys targeting top managers and SME owner-managers typically yield lower participation rates, with averages around 30–35% (Anseel et al., 2010; Pielsticker & Hiebl, 2020). Missing or inaccurate values reduced the final sample to 95 valid responses. This data cleaning procedure followed strict inclusion criteria to ensure analytical consistency: only responses explicitly referring to I4.0-related transformation were retained, while those describing respondents' core business activities were excluded. The resulting sample included SMEs of various sizes and ownership structures: 15 firms employed fewer than 10 employees, while 64 belonged to the 11–249 employee category. Most firms were family-owned, followed by international, public, and employee-owned organisations. The sample primarily represented manufacturing industries. All respondents were involved in I4.0-related decision-making, including 79 directors and 16 managers.

Given the exploratory and open-ended nature of the questionnaire responses, it remained difficult to grasp the underlying reasoning and the implications of these definitions for organisational practice of SMEs. To delve into this phenomenon and examine how these perceptions were articulated within specific contexts, a second phase of data collection was conducted through semi-directive interviews. To structure the data collection, we developed an interview guide consisting predominantly of open-ended questions organised around key themes (Djamba & Neuman, 2002). These included participants' roles and backgrounds, their

understanding of I4.0, and the current state of its implementation within their organisations. Questions related to I4.0 understanding aimed to deepen and clarify the definitions identified in the questionnaire phase, while the remaining questions provided contextual material to examine how these interpretations were shaped and translated into managerial actions (Weick, 1995). This structure ensured consistency across interviews while allowing respondents to elaborate on their interpretations and experiences. The interviews lasted between 45 and 80 minutes, were conducted in French, audio-recorded, and transcribed verbatim. For citation in this paper, all excerpts were translated into English by the authors, with care taken to preserve the original meaning. Most interviewees had previously consented to be contacted after the questionnaire. Additional participants were recruited from other SMEs through professional networks to increase variation across sectors and company profiles, while ensuring consistency with the initial sample through identical selection criteria, including company size, sector, and participants' decision-making roles. Data collection continued until thematic saturation was reached, and the evolving interview guide allowed for iterative refinement of questions. In total, 25 interviews were conducted in 22 SMEs active in manufacturing and waste management, with firm sizes ranging from 8 to 135 employees and including both family- and group-owned firms.

In line with ethical standards, all participants were fully informed about the aims of the study, the voluntary nature of their participation, and the confidentiality of their responses. Informed consent was obtained prior to data collection, and data were handled in compliance with institutional and legal requirements.

3.2. Data Analysis

Following data collection, we conducted a two-level analysis in which the two types of data were analysed sequentially but not merged, as they served distinct analytical purposes within the research design. The questionnaire data, based on short textual definitions, were used to inductively construct a typology capturing recurring interpretive dimensions of I4.0. In this sense, the resulting categories were treated as an analytical framework that structures how managers make sense of I4.0. By contrast, the interview data provided situated and processual accounts of managerial interpretations, allowing to examine how these dimensions are enacted in practice (Weick, 1995). Maintaining this distinction ensured analytical clarity between the construction of interpretive categories and their mobilisation in context.

3.2.1. First-Level Analysis of I4.0 Definitions (Questionnaire Phase)

We started with a multi-coder data analysis (Church et al., 2019; Olson et al., 2016) to discern patterns based on similarities in definitions of I4.0 shared by SMEs' managers. This method was deemed most suitable as it aimed to enhance the coding process by adding an extra layer of rigour and scrutiny, while also incorporating diverse viewpoints of researchers (Church et al., 2019). As the aim was to capture shared interpretive patterns rather than to test statistical relationships, intercoder reliability was addressed through iterative comparison, collective discussion, and consensus-building among coders. This approach, commonly used in qualitative multi-coder designs (Hemmler et al., 2022; O'Connor & Joffe, 2020), prioritises interpretive rigour and transparency over statistical agreement metrics.

First, the preliminary codebook was developed through two iterative rounds involving the co-authors who read and inductively analysed the responses. The unit of analysis was each individual textual definition of I4.0 provided by respondents. Given the brevity of responses, coding focused on identifying the dominant interpretive orientation expressed within each

definition rather than exhaustively coding all possible themes. This process resulted in six initial categories, each defined by a short description to guide coding.

Next, six researchers specialised in management studies independently coded the textual definitions of I4.0 using the codebook. They identified keywords and grouped responses into six categories of definitions provided by the codebook. After this independent phase, a collective session was organised to compare the results of individual coding. This meeting revealed that many responses combined elements from multiple logics within a single definition. In such cases, coders assigned each definition to the category reflecting its primary interpretive orientation, based on the central emphasis of the statement and its overall framing. This approach is consistent with holistic coding practices (Saldaña, 2016) and qualitative data condensation principles (Miles & Huberman, 1994), which prioritise the most salient meaning in short textual units to ensure analytical comparability. Discrepancies between coders were systematically discussed and resolved through collective deliberation until full agreement was reached for each definition. Through this iterative process, the six initial categories were progressively regrouped into three higher-order dimensions – means, purpose, and challenge (Gioia et al., 2012). This aggregation was guided by the underlying logic structuring the definitions: categories were grouped according to whether they primarily referred to how I4.0 is adopted, why it is pursued, or the issues and constraints associated with it. During the validation of these results by the authors of the study, the category related to challenges was retained as a distinct analytical dimension and further refined into three specific sub-themes to better capture the diversity of perceived constraints. Throughout the process, coding decisions, category definitions, and examples were documented and iteratively refined, ensuring traceability between raw data, intermediate coding, and the final typology. This iterative process ensured both rigour in categorisation and conceptual clarity in the resulted typology of interpretative dimensions of I4.0.

3.2.2. Second-Level Analysis of Managerial Discourse (Interview Phase)

To contextualise and further elaborate the interpretive dimensions by examining how they were enacted in managerial discourse, the second level of analysis drew on 25 in-depth interviews (Fairhurst & Cooren, 2018; Grant & Hardy, 2004). An initial reading showed that managers' perceptions rarely focused on a single dimension and instead formed situated configurations of meaning, combining means, purpose, and challenge with varying degrees of emphasis depending on the context. Given the diversity of these configurations, four information-rich cases were selected through a purposeful sampling approach, in line with the principle of case-based exemplarity (Yin, 2003), which supports the generation of transferable insights without aiming for statistical generalisation. This approach allowed for maximising variation across perception configurations and contextual conditions, while ensuring sufficient narrative depth for in-depth reconstruction. Specifically, the selected cases (i) exemplify distinct configurations of I4.0 perceptions identified in the typology, (ii) represent variation in sectoral, organisational, and I4.0 maturity-related contexts, (iii) reflect contrasted managerial backgrounds, and (iv) provide sufficiently detailed narratives to support in-depth analysis.

To analyse these cases further, we adopted a thematic coding approach (Gioia et al., 2013), structured around the sense-making process underlying the configurations of managerial I4.0 perceptions (Weick, 1995). The analysis focused on three interrelated analytical axes: how managers understand I4.0, how this understanding is shaped by their individual and organisational context, and how it is enacted in practice.

To capture understanding, we examined how managers interpreted the concept of I4.0 across their narratives, extending beyond formal definitions to include how they described its implementation within their organisations. First-order concepts captured relevant discourse statements and were grouped into second-order themes based on the typology of eight sub-dimensions, comprising the six initial categories and three additional ones refining the challenge dimension. These were then aggregated into three interpretive dimensions – means, purpose, and challenge – previously identified in the first-level analysis of I4.0 definitions. While the dimensions of means and purpose remained stable, the definition of challenge dimension was refined during analysis to capture factors related to the requirements of I4.0, as well as internal and external conditions likely to affect its implementation.

To capture context, we analysed how managers positioned themselves and their organisations, and how they situated the transformation within their firms. First-order concepts reflecting these contextual elements were grouped into second-order themes based on recurring patterns and aggregated into three dimensions: managerial profiles, SMEs' internal conditions, and SMEs' external environment.

To capture enactment, the analysis focused on the actions undertaken by managers in relation to I4.0 transformation. First-order concepts captured concrete practices, which were grouped into second-order themes and aggregated into two dimensions: technology-oriented and human-oriented transformation actions.

4. Results

The results reveal that managers do not perceive I4.0 in a uniform or stabilised way. Instead, their accounts shift between different registers – sometimes concrete and technical, sometimes strategic or aspirational, and at other times openly critical. Rather than converging towards a shared meaning, these accounts reflect the complexity of how managers engage with the conceptual diversity of I4.0.

The results are presented in two steps. We first examine how these different ways of framing I4.0 emerge across managers' definitions. We then explore how these framings are combined and reworked in practice through in-depth case analyses.

4.1. Diversity of Managerial Perceptions behind the Conceptual Diversity of I4.0

When asked to define I4.0 in a few words during the questionnaire phase, managers emphasised different aspects of the concept, depending on what mattered most in their situation. Some focused on concrete tools and technologies, others on the outcomes they sought to achieve, while some questioned its relevance or feasibility altogether. These variations point to distinct ways of framing I4.0 – whether as a set of means, a purpose to pursue, or a challenge to address.

4.1.1. When I4.0 is Framed as Means to Innovate

In most cases, managers perceived the concept of I4.0 as a means, associating it with modes of application or design principles considered essential for its implementation. When reflecting on this matter, they generally described the concept in terms of technological solutions and data-driven tools.

4.1.1.1. Technology

For many managers, the concept was most frequently framed through technologies. Twenty-six managers described I4.0 by naming artificial intelligence (AI), IoT, automation, and

digitalisation as the core of the concept itself, rather than as complementary to it. AI was cited most often. It was portrayed as influencing multiple operational domains rather than a bounded use case. As one manager summarised the key role of the technology: *"we use AI in the company where it is useful and possible".* Another highlighted its industrial reach by describing the *"use of artificial intelligence in the various phases of production, from design to distribution".*

Automation and digitalisation were equally mentioned as essential principles of I4.0 integration. Although these principles constitute only a cornerstone for leveraging such advanced technologies as AI or robotics, SMEs' managers put them forward as essentials of I4.0. One participant, for instance, emphasised the *"digitalisation of internal processes, from ordering to service (remote and preventive)"*, while another underlined the importance of *"integrating the digital dimension into the company's manufacturing and management processes".*

These accounts framed I4.0 less as a destination than as a material vocabulary of modernisation, grounded in industrial problem-solving.

4.1.1.2. Data

For another group of respondents, the concept of I4.0 was mainly about data. Sixteen managers framed I4.0 through data management and the interconnection enabled by I4.0 technologies. They described data flows as the connective backbone linking machines, departments, and functions, often emphasising strategic interdependence rather than measurable outcomes. As one manager explained, *"data and information management using IT and new technologies"* was at the core of their understanding. Another emphasised its operational value by highlighting the *"speed and simplification of the processing of information exchanges in interaction with production tools".*

When addressing the interconnectivity enabled by I4.0, managers often stressed its strategic benefits. They described I4.0 as the interconnection of machinery, tools, and departments through the communication of data flows. One participant illustrated this by referring to the *"interconnecting of data flows between management and planning tools, production tools and HR as a whole".* Another elaborated on its broader impact by pointing to *"all the connectivity methods within a company, which enable the supervision of processes and commercial activity, as well as the tools dedicated to the management and development of the company".*

Here, I4.0 was imagined as a nervous system of the firm, activated through data channels rather than abstract transformation ideas.

4.1.2. When I4.0 Becomes a Purpose to Innovate

Many managers perceived I4.0 as a purpose, associating it with a goal or a set of improvements that I4.0 allows companies to achieve. In this case, they described the concept of I4.0 in terms of transformation, performance, and human-related improvements.

4.1.2.1. Transformation

Alongside the widespread association of I4.0 with technology, twenty-one SMEs' managers described it as a broader transformation, expressing intentions to fundamentally improve and evolve their companies. In most cases, the emphasis was placed on outcomes such as modernisation, digital transformation, or process optimisation, with I4.0 portrayed as an opportunity to reach these results. One manager, for instance, referred to the *"modernisation of an entire structure/company"*, while another highlighted *"an opportunity to radically change*

processes and working methods, incorporating the latest technologies in terms of digitisation, lean manufacturing".

Some participants viewed I4.0 as a transformation project requiring a systematic, organisation-wide approach. As one manager put it, it could be seen as *"a company's structural project based on the strategic vision with the aim of modernising its activities to streamline flows and become more competitive".* Another reinforced this systemic dimension by describing *"all the processes of transformation of companies thanks to the contribution of new technologies linked to digitalisation in order to make them more flexible and agile".*

Others expressed the idea of I4.0 as a starting point for moving towards a new state or direction. One participant called it *"an essential springboard for the development of our organisation"*, while another described it as a *"mandatory change in the extension of the existing state of affairs".*

I4.0 thus appeared as a symbolic lever for resetting the firm's trajectory, anchored in managerial anticipation of important transformations.

4.1.2.2. Performance

By associating I4.0 concept with performance, fifteen managers emphasised its strategic value in shaping the internal and external functioning of their SMEs. Many underlined the capacity of I4.0 to automate or enhance processes, linking it directly to the potential for greater organisational capabilities. Two main approaches emerged from their accounts.

Some described the advantages of I4.0 in broad terms, portraying it as a driver of productivity, efficiency, growth, and competitiveness. One manager envisioned *"an automated and semi-automated industry with a view to greater production, productivity and speed in the execution of work to be carried out".* Another emphasised strategic outcomes, describing how *"integrating AI and IoT into business processes"* could *"boost competitiveness and growth".*

Others tended to present more detailed and concrete expectations about desirable outcomes. While some stressed the potential for improving production processes, product quality, customer relations, or energy management, others gave practical examples of how they imagined I4.0 being applied in their companies. One participant explained that *"matching physical and digital models in real time"* would *"transform production by getting closer to the customer's specific needs as quickly as possible, while increasing productivity through innovation".* Another highlighted sustainability concerns, aiming to *"improve waste sorting and make it more intelligent using new technologies to obtain more homogenous waste".*

Here, performance went beyond the aspired efficiency alone, since resilience, quality elevation, and strategic strengthening were equally at the centre of attention of these managers.

4.1.2.3. Human

For eight SMEs' managers, the goal of I4.0 was to place people at the centre of transformation by improving working conditions. Some participants spoke in broad terms, focusing on the capacity to better connect humans and machines. One manager, for instance, stressed the importance of *"improving human–machine interaction".* Others highlighted the potential to enhance the working environment by replacing low-value tasks or facilitating the flow of information. As one participant explained, I4.0 could *"give people back their added value by*

automating and digitising low value-added tasks". Another pointed to more practical benefits, such as *"reduced administrative workload, [and] bottom-up information feedback".*

With these definitions, managers emphasised the human side of I4.0, underlining improvements in both the quality and efficiency of work execution for operators.

4.1.3. When I4.0 Challenges SMEs

Finally, some managers perceived the concept of I4.0 primarily as a challenge, associating it with factors that undermine its nature or its fit with organisational realities. In this category, nine respondents adopted a critical stance, pointing to conceptual, normative, and resource-related difficulties that SMEs face.

Several managers stressed conceptual challenges, underlining the gap between the portrayal of I4.0 as a revolution and the reality they experienced on the ground. One explained: *"I don't really have any ideas... it seems like theory to me... because it's not the first time I've heard the term industrial revolution without having seen anything happen. We're talking about evolution..."* Another was more severe, calling it *"a concept born in the minds of people who have never set foot in the industry... which has been evolving with all the new technologies... for centuries".* Others simply judged it as *"generally inconceivable in our very specific profession".*

A second layer of challenge referred to normative issues linked to the prescriptive character of I4.0. Some participants expressed a sense of obligation to transform, as one put it: *"It goes beyond a project of transformation, we should sometimes talk about an 'obligation' to transform..."*

Finally, managers raised concerns about resource-related challenges, particularly the fear that SMEs lack human and time resources to meet the expectations associated with I4.0. One participant summarized this difficulty by stating, *"As an SME, it's a fear of not having the resources in terms of time and people to stay with the frontrunners and successfully make the transition to Industry 4.0."*

These definitions reflected both a lack of alignment between the conceptualisation and the practical application of I4.0, and a mismatch between its requirements and the pre-existing conditions of SMEs.

4.1.4. Typology to Capture Conceptual Diversity of I4.0

Taken together, all the forementioned definitions of I4.0 show that managers rarely interpreted I4.0 through a shared terminology. Instead, they captured it through distinct interpretative orientations, reflecting the diversity of positions and priorities among managers: some emphasise *what* I4.0 can offer their SMEs in terms of solutions, others focus on *why* it should be implemented or *how* it challenges their organisational and industrial realities. The obtained typology (see Table 1) thus demonstrates the main dimensions through which SMEs' managers tend to deal with the conceptual diversity of I4.0.

Table 1. Typology of interpretative dimensions for the conceptual diversity of I4.0.

Dimension	Sub-dimension	Definition
Means	Technology	The notions of integrating key I4.0 technologies and/or basic principles such as automation and digitalization.

	Data	The notions of data management and interconnection of various elements through I4.0 processes.
Purpose	Transformation	The notions of transforming and improving companies globally.
	Performance	The notions of enhancing efficiency, productivity, durability, competitiveness, and customer relations.
	Human	The notions of transforming working conditions for human operators.
Challenge	Conceptual	The notions of ambiguity, external construction, or misfit of I4.0, creating confusion about its meaning or applicability.
	Normative	The notions of I4.0 as a prescriptive or obligatory model, generating pressure to conform regardless of context or readiness.
	Resource-related	The notions of insufficient human or time resources to comply with or sustain the requirements of I4.0.

4.2. Multidimensional Configurations of I4.0 Managerial Perceptions

Looking more closely at managers' accounts reveals that these different ways of framing I4.0 do not appear in isolation. In practice, they are intertwined, reinterpreted, and adjusted depending on organisational constraints, personal trajectories, and ongoing transformation efforts. The following cases[4] illustrate how managers combine these different logics and translate them into concrete courses of action.

4.2.1. Case A

Company A is a family-owned SME employing 45 people in the high-precision mechanics sector, with strong national and cross-border commercial relations. Awarded the title of Factory of the Future[5], its ongoing evolution is tied to a culture instilled by the company's founder, known for *"bringing his love of technology to the company"* and still actively involved in its life.

Manager A is one of two co-CEOs with responsibilities focused on operations. After finishing primary school, he followed a work-study program as a metalworker and rapidly started to work, explaining that he *"learned most things on his own".* Having begun his career in the company as a milling machine operator, he moved gradually into supervisory roles before joining the executive team.

His interpretation of I4.0 centres on making data *"clean and usable,"* emphasising its role in drawing *"quick and, above all, reliable conclusions".* The notion of centralised, structured data appears as the cornerstone of his understanding of I4.0. Regarding the term itself, he questions its relevance: *"Where does Industry 4.0 begin and end? It can touch everything",* reflecting on its trendiness: *"It's just fashionable—soon it'll be AI instead. That's where the funding and attention go now."* This fashion volatility coupled with frequent changes within the company makes impossible using *"big names",* so the term of I4.0 is avoided in internal communication in favour of *"continuous improvement,"* which Manager A finds more accessible and less abstract. *"If I talk to a 4.0 machine operator, they'll look at me and say, 'Yeah, that's*

[4] This thesis version of the paper includes additional empirical material in the Appendix for the case studies, extending beyond the journal-submitted version constrained by page limits.

[5] As part of a regional digital strategy, this award can be obtained by manufacturing companies that achieve a minimum score on the seven key transformations defined by Made Different, a national methodological framework focused on interconnection, digitalization, human-centricity, networking, sustainability, and flexibility.

the screen in the machine'" he states, explaining that for him screens represent *"the result of I4.0",* while *"the real 4.0 is everything that happens behind the scenes on the server in terms of data collection".*

For him, the company's ultimate goal is *"to grow in terms of machine hours and turnover"* and to avoid doing so in terms of their team, since they struggle to *"find people to operate the machines".* While the partial automation of the planning reduced administrative work, allowing teams to focus on more specialised tasks, the introduction of machine sensors into quality assurance allowed a more systematic identification of inefficiencies, requiring more people for the task. External pressures and opportunities also shape transformation trajectories. Manager A admits that despite being already advanced in digitalisation, they could do a lot more: *"we still have 36,000 ideas, but we need the time to implement them all".* While his fellow co-CEO prevails a return on investment behind these ideas, Manager A confesses: *"I don't look at it so much, because for me it's more about the pleasure of doing it".*

4.2.2. Case B

Company B is a plastics manufacturer employing 130 people and integrated into an international industrial group. The company is already well advanced in its I4.0 transformation, with interconnected machinery and automated data flows.

Manager B is the digitalisation manager and acts as a liaison between local operations and the group's IT and innovation divisions. With a background in aeronautical engineering, she later combined it with a degree in technology and innovation management, which unlocked a new passion: *"how you take a great idea and turn it into a product and a business that works".* She began in project management, where she spent over a decade, progressing from product delivery and methodology implementation to managing client projects. Before joining Company B, she moved into the logistics sector, where she expanded her skills by *"managing a team of operators on the factory floor"* and discovering *"the IT side of projects",* which she found *"fascinating".*

When sharing her thoughts about I4.0, Manager B expresses scepticism about the term itself: *"I don't really like these big concepts, because then they are used for everything".* She recalls a colleague who rebranded a manual data collection initiative as I4.0, adding ironically*: "They were talking about writing it down on paper, before doing it digitally".* Her own understanding of the concept centres on the combination of data and human levers: *"For me, it's really about successfully combining the power of data with human intelligence so that we can use the data we generate to better analyse our processes". However,* she explicitly distances herself from the idea that automation should replace human workers. *"If it's just to remove people, I'd rather keep my operators because I want my company to retain a human face",* she adds.

Currently, Manager B is leading two large-scale digital transformation projects. The first involves deploying a Manufacturing Execution System (MES) to *"improve production monitoring and combine quality data with process data".* She describes this shift as a move away from manual data entry – where operators *"had to write by hand"* and declare events themselves – towards a system where they focus on *"monitoring their line, analysing process progression, identifying deviations".* The second project concerns the migration to the group's System Analysis Program Development (SAP), intended to replace company's ERP and to "integrate our data with the rest, but also to do business between our factories." However, Manager B notes that their *"business is very different from the rest"* of the group and warns that over-customisation may increase IT maintenance costs, while standardised template can

fail to address local operational needs. Since it is still a transition period, she opted to automate several units to avoid hiring additional local staff, citing the constraint of *"very high imposed costs".*

4.2.3. Case C

Company C is a small, family-owned enterprise employing 20 people in the waste recovery and recycling sector. At the time of the interview, it has been undergoing its I4.0 transformation for almost two years, with several changes still pending implementation: *"We haven't finished yet and it's taken longer than expected".* The company's founder and CEO, Manager C, comes from a background in marketing and administration. Before launching Company C, he previously worked in sales and management.

His understanding of I4.0 is pragmatic and operators-oriented: *"It's everything to do with automation and making work easier for people within a company".* He explains that his interest in digitalisation began with the need to improve process control, particularly to reduce the risk of errors in shipments: *"I sometimes get returns on goods that I send to other continents… the complaints come in two or three months later, which costs me money".* Parallelly, Manager C realised that a bigger change was needed: *"We weren't very automated; it was very manual, and in terms of IT, we still rely heavily on paper",* he admits, adding that this shift was largely led by his son – the company's *"driving force" who "pushes from below and pulls you along".*

The company began its transition by applying for a subsidised diagnostic, which *"didn't cost me anything – well, it cost me time, and we had to play the game properly",* recalls Manager C. Since the transformation is *"complex and costs money",* this regional incentive helped him to get started. The initial goal was to become more efficient: *"There are things that a worker isn't able to see, and thanks to technology, the number of errors can be reduced".* He insists that it was for operational security: *"I wasn't going to get rid of people; it's really to ensure process control, not control in the sense of monitoring people's working hours".* Benefiting from his son's knowledge of the regional ecosystem supporting I4.0 transition, Manager C engaged with external experts in a collaborative project to co-design and implement a sensor-based quality control system. While satisfied with the experience, he warns of the competition risks small companies face when investing in innovation: *"When you develop a project, you have to give everything… whereas for companies with the means, it's easy to copy and paste".*

The transition towards digital tracking of materials from reception to shipping have been challenging, since *"it took a lot of energy to 'convince' the workers and even the employees".* Manager C confesses: *"I have a very friendly staff, but they are really basic",* explaining their difficulties in adjusting to new technologies. To address this, he involved everyone*: "It's an SME, so it's very small",* he explains. This allowed him to understand employees' concerns and simplify the process so that they *"were all talking about the same thing, and then all that was left to do was enter the figures".* He proceeded then with introduction of informal meetings to clarify the project's purpose: *"We explained that this was 4.0, but in a very user-friendly way".*

4.2.4. Case D

Company D is a family-owned SME employing 85 employees in the manufacture of clinical diagnostic products sector. Over recent years, it has made steady progress in digitising its internal processes, moving towards I4.0 transformation: *"We're moving from 2.0 to 3.0, but we are not yet at 4.0".* Manager D holds a degree in biochemistry, complemented by further education in communication and management. Before taking on the CEO role, she worked in

scientific support and technical sales, where she developed a cross-functional understanding of production and client-oriented responsibilities.

When asked about her understanding of I4.0, she responds: *"It's the role of IT in processes, artificial intelligence, and big data".* She sees significant potential in using AI to improve internal operations, notably through systems that could *"measure everything and allow us to monitor it online, telling us when there is an excess".* This, she believes, would help address rising customer expectations, as variability and uncertainty in production are *"much more difficult to accept because they want everything to work perfectly every time they receive it".*

The company already uses an ERP system and has recently installed temperature sensors for monitoring purposes. However, Manager D is clear about existing limitations: *"Some of our equipment is 30 years old",* she notes, adding that *"the analysis is still done by a human".* She draws a distinction between passive data collection and real process improvement: *"What's interesting is analysing the data and seeing the effect; just looking at the data is pointless".* Accordingly, she positions her approach as favouring automation over comprehensive process management, explaining that they are *"moving forward little by little"* and seeking to *"think about what makes sense for each process".*

Beyond technical goals, Manager D also sees I4.0 as a partial response to workforce retention challenges in the manufacturing sector. *"We are using I4.0 to think about how we can better look after our people to make them want to stay",* she explains. She contrasts the older generation, who would stay with the company for 40 years, with younger workers who, after six months, *"ask if there is anything else to do because they are bored".* Between *"enormous"* salary costs and *"fierce competition for talent in a cutting-edge sector",* she acknowledges the difficulty of optimising labour costs: *"Paying someone with a master's degree to take temperature readings in a fridge is a bit expensive".* She thus expresses hope that automating *"repetitive and meaningless tasks"* will shift the work towards requiring *"more critical thinking".*

Operating in a highly regulated and scientifically demanding environment presents additional constraints: *"Whatever we implement will have to be validated for ages",* she points out. This reality places her SME in a difficult position, as implementing complex systems means *"a lot of investments to make to comply, without any financial return"* – yet without validation, *"we can no longer sell".* To navigate this constraint, Manager D opts for systems already validated by larger firms, aiming to *"get the quickest return on investment".*

4.2.5. Cross-Case Synthesis of Managerial Perceptions and Transformation Actions Regarding I4.0

The multidimensional nature of I4.0 perceptions is expressed differently across four configurations, each anchored in specific circumstances shaped by the managers' background, the company's context and environment, and ultimately leads to distinct courses of action (Table 2).

The cross-case comparison highlights how managerial perceptions are rooted in contextual factors. First, managers' educational and professional trajectories largely define the purpose they assign to I4.0. The operational and technologically sensible background of Manager A encouraged him to view of I4.0 not only through speed improvement and production efficiency but also as a way to make it accessible for operators. With a mix of engineer and management-oriented studies, Manager B perceived I4.0 as a structured pathway to improve process analysis and production monitoring, to do business with other factories of the group, and to

empower operators through higher-value tasks. In contrast, the marketing-oriented founder in Company C interpreted I4.0 as a tool to reinforce customer reliability and business image, while the scientifically trained CEO in Company D framed it as an avenue for product quality and human development. Across these profiles, the manager's personal trajectory determines whether I4.0 is seen primarily as a technical infrastructure, a business enhancement, or a human-development opportunity. Second, company structures and external environments shape the perceptions of challenges related to I4.0. In Company A, a high degree of automation and a tight job market prompted awareness of recruitment limitations. In Company B, belonging to a multinational group with high labour costs reinforced cost-efficiency as a dominant concern. The small scale and limited maturity of Company C, combined with access to regional funding programs, oriented the manager's attention to financial dependency and the pragmatic use of external expertise. In Company D, sectoral regulation and talent shortages pushed the CEO to prioritise validated, low-risk technologies. Across cases, company characteristics and environmental pressures determined whether I4.0 transformation is pursued through recruitment adaptation, cost-efficiency optimisation, reliance on external support, or the adoption of validated and low-risk technologies.

The cross analysis also reveals a strong connection between managers' perceptions of I4.0 and their actions towards it. First, across all cases, managers linked I4.0 to human-related purposes: even when they focused on technology or performance, they systematically highlighted improvements for employees. By channelling this aspiration through technological solutions, data accessibility and workstation adaptation became priorities in Company A, process simplification and employees' involvement in transformation – in Company C, and task revalorisation in Company D. Second, resource constraints also strongly shaped managerial decision-making. Decisions were guided by what each SME could realistically sustain – the conceptual fuzziness around the term of I4.0 was resolved by introducing a more comprehensive term by Manager A, high labour costs were mediated through partial automation of processes by Manager B, the costs of I4.0 transformation were addressed through applications to subsidised programs by Manager C, or regulatory pressures were met by adopting solutions already validated by larger companies by Manager D. Finally, managers articulated differently their perceptions into the actions, depending on digital maturity of their companies. In technologically mature firms (A and B), I4.0 was mobilised primarily to enhance performance, leading to technical integration and process optimisation. Manager A advanced internal data-driven improvements, while Manager B led MES and SAP integration to reinforce interconnection across factories. In contrast, the managers of companies C and D emphasised I4.0's purposes and challenges. Manager C pursued stepwise modernisation through public support, expert collaboration, and employee involvement. Manager D linked automation to product quality and retention, adopting incremental and validated solutions suited to her sector's constraints.

Taken together, this cross-case comparison brings the three interpretative dimensions into perspective. While personal background primarily shapes the *why* of transformation, and organisational and environmental conditions define *how* its challenges are perceived and negotiated, the role of means evolves across cases. Rather than remaining isolated technological or data-driven solutions, means become progressively embedded in ongoing organisational transformations, reflecting a shift from what I4.0 can offer SMEs to *what* SMEs do with what I4.0 offers. Through this articulation, heterogeneous perceptions are stabilised into distinct and context-dependent transformation trajectories.

Table 2. Comparative Matrix Summarising Cross-Case Patterns Between Managerial Profiles, Contextual Factors, and I4.0 Actions.

Analytical dimension		**Case A**	**Case B**	**Case C**	**Case D**
Managers' profiles		Operational Self-made Pleasure-driven innovation	Engineering Innovation management Project management IT passion	Marketing Sales Founder	Biochemistry Communication and management Scientific support Technical sales
SMEs' internal conditions		Highly digitised, co-management, founder's technological legacy	Group integration, operators accustomed to automation	Small, low digital maturity, low automation	Partial digitalisation, aging equipment, limited resources
SMEs' Environment		Tight job market in precision mechanics	High labour costs in group context	Regional incentives to support I4.0 implementation	Strict regulation, long validation, talent competition
I4.0 perceptions	*Means*	Data: Data collection and management	Technology: Tasks' automation & digitalisation Data: decision-making, quality & process data, interconnection	Technology: sensor-based systems	Technology: IT, AI, big data Data: data analysis
	Purpose	Performance: Speed, machinery, production Human: I4.0 accessibility to operators	Transformation: business with other factories Performance: process analysis & production monitoring Human: empowered operators, preserving human face & higher-value tasks	Performance: customer-oriented process control Human: work facilitation	Performance: customers' satisfaction, errors' detection Human: higher-value tasks
	Challenge	Conceptual: Fashion-driven concept Resource: problematic hiring	Conceptual: semantic inflation & label misuse Normative: customisation VS standardisation Resource: IT & recruitment costs	Resource: costs, complexity of change, human resistance, large companies as competitors	Resource: costs, fit with existing machinery, complex systems adoption, employee retention, hiring new talents
Key transformation actions		Techno and human oriented.	Techno-oriented.	Techno and human oriented.	Techno and human oriented

5. Discussion

The results of this study show that managers' engagement with the conceptual diversity of I4.0 goes beyond the mere existence of various interpretations. Rather than resolving it or converging towards dominant meanings, SMEs' managers actively work with I4.0's interpretive openness by bracketing the concept and anchoring it in their backgrounds and organisational contexts, and by stabilising selected interpretations through action. By proposing a three-dimensional typology of managerial perceptions and grounding it in four in-depth cases, our findings challenge static and techno-centric representations of I4.0 and contribute to the literature on managerial sense-making under conditions of persistent conceptual diversity.

5.1. Bracketing I4.0 and Anchoring Meaning in Context

Prior studies have demonstrated the absence of a unified definition of I4.0 and the proliferation of heterogeneous interpretations across sectors, actors, and national contexts (Fogaça et al., 2024; Kowalikova et al., 2020). From managerial perspective, this diversity is often interpreted as leading either to confusion or to simplified, technology-driven understandings of I4.0 (Hansen et al., 2024), where the concept is reduced to a set of tools or expected performance outcomes (Yunus, 2021). While these studies document variation in interpretations, they rarely examine *how* managers structure such diversity in practice. Our findings extend this literature by showing that managers engage in bracketing I4.0 through three recurring interpretive dimensions. Rather than constituting fixed categories or attitudes, these dimensions function as interpretive anchors that delimit what is considered desirable (*purpose*), feasible (*means*), but also problematic (*challenge*). Regarding the latter, all the four managers referred to recruitment-related challenges in terms of hiring new talents (Cases A and D), high recruitment costs (Case B), or the risk of not retaining employees (Case D). These challenges align with prior studies reporting SMEs' difficulties in attracting skilled staff in the context of I4.0 transformation (Ietto et al., 2022; Stentoft et al., 2021). Similarly, all participants reported financial and resource-related challenges: managers raised concerns about implementation costs (Cases B and C), complexity of integration (Cases C and D), or standardization constraints (Case B). Such patterns reinforce previous observations that SMEs often lack the capacity to implement complex digital systems (Estensoro et al., 2021; Hansen et al., 2024). Yet we suggest a nuanced interpretation of these recurring patterns by showing that cost and labour market constraints expand their hindering effects towards enabling ones, by reorienting interpretations toward more selective, incremental, and context-specific visions of I4.0. Across all four cases, the purpose dimension incorporated strong human-oriented concerns. While previous studies highlight techno-centric managerial approach towards I4.0 in SMEs (Da Roit & Iannuzzi, 2023), our findings suggest a more nuanced perspective. In fact, managers focused on preserving current staff (Case C), enhancing task value (Case D), or making I4.0 accessible to operators (Case A). This highlights the structural specificities of SMEs, where organizational proximity and flatter hierarchies enhance mutual visibility and relational awareness between managers and staff (Harney et al., 2022). Bracketing process thus demonstrates that, from SMEs' managers point of view, I4.0 appears less as a stable object than as an interpretive space that managers actively organise to prepare a transformation canvas for their SMEs (Meyer, 2019; Wilkesmann et al., 2018).

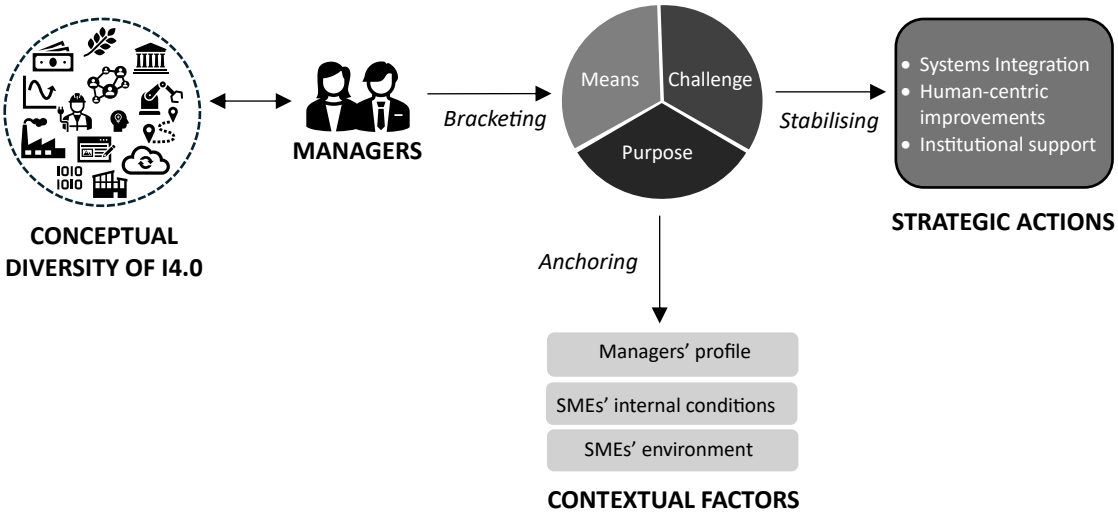
Crucially, this bracketing is anchored in managerial and organisational context, represented by SMEs' internal conditions and environment. Across cases, managers' educational backgrounds, professional trajectories, and functional roles shaped which dimensions were prioritised and how they were combined. These findings resonate with prior work showing that

managerial interpretations are filtered through experience-based and culturally embedded frames (Ivanova & Torkkeli, 2013; Sharifi & Zhang, 2009). They also go further by demonstrating how managers' profile-based interpretations are continuously calibrated according to firm-specific conditions such as digital maturity, workforce characteristics, and existing infrastructures. In this sense, our results challenge explanations that attribute differences in I4.0 engagement primarily to managers' affinity with technologies or firms' digital maturity (Tortorella et al., 2021; Wilkesmann et al., 2018), and instead highlight the diversity of factors that can shape I4.0 interpretations on individual and organisational levels.

5.2. Stabilising Meaning Through Action

Once the conceptual diversity of I4.0 is bracketed through three interpretative dimensions and anchored in managerial and organisational contexts, our study shows that it can be stabilised through action (see Figure 1). Consistent with sense-making theory, meaning does not remain at the level of interpretation but is enacted through strategic choices that give temporary coherence to otherwise ambiguous concepts (Gioia et al., 2012; Weick, 1995). In SMEs, instead of taking the form of full-scale transformation or convergence towards best practices, this stabilisation unfolds through selective and incremental strategic choices that temporarily fix meaning (Gioia et al., 2012). In all four cases, perceptions related to purpose and challenge provided the primary orientation for action, shaping what managers perceived as legitimate and feasible courses of action (Sharifi and Zhang, 2009; Weick, 1995). Managers relied on sense-making to interpret environmental cues – technological developments, market pressures, and ecosystem dynamics – and to translate them into strategic choices (Penttilä et al., 2020): Manager C's challenge-oriented view of I4.0 as costly and complex led him to apply for a subsidised diagnostic and seek external expertise, while Manager D's choice to opt for systems validated by large companies was enacted by perceived challenges related to the highly regulated sector specifics. Importantly, stabilisation also occurred through linguistic choices (Ivanova & Torkkeli, 2013). By deliberately avoiding the I4.0 label and substituting locally meaningful narratives such as "continuous improvement", Manager A reduced resistance and aligned change initiatives with existing identities, fixing one plausible interpretation long enough for coordinated action to proceed.

Figure 1. Managerial Engagement Process With the Conceptual Diversity of I4.0.



While purpose and challenge set the direction, the means-oriented perceptions tend to inform managers with the technical approach for action, confirming previously observed trend of technological affinity influencing I4.0 transformation (Wilkesmann et al., 2018). Choices related to data structuring, system integration, and shop-floor access materialised the interpretations of I4.0-related technologies and solutions, highlighting how envisioned means for organisational transformation became tools in action.

Finally, our findings extend research on storytelling and sensemaking by showing how narratives contribute to the stabilisation of meaning in SMEs. While earlier managerialist views (Peters & Waterman, 1982) positioned storytelling as a sense-giving device to secure compliance, this approach has been criticized for ignoring the fragile and polyphonic nature of organisational narratives (Collins, 2013). In line with this latter perspective, we show that managerial narratives function as coordination mechanisms, linking technical means, organisational purposes, and acknowledged challenges into coherent stories of transformation to be completed, questioned, and co-constructed by operators (Boje, 2001; Denis et al., 2007). This perspective aligns with storytelling as a process of sense-making (Boje, 1991; Brown et al., 2005), where stories emerge as local, situated interpretations of change rather than top-down tools of persuasion. In the SMEs' context, marked with structural proximity among teams (Harney et al., 2022; Horváth & Szabo, 2019), such narratives enable collective engagement, enabling I4.0 to be approached not only as a technical project, but as a story leading towards multidimensional transformation.

5.3. Theoretical Contributions

This study contributes to ongoing debates on innovation management by advancing a sensemaking-based understanding of how managers engage with persistent conceptual ambiguity. Rather than treating conceptual diversity as a discursive artefact (Culot et al., 2020b; Kowalikova et al., 2020), our findings show that managers actively mobilise meaning in ways that shape strategic action. In this respect, the proposed typology of means, purpose, and challenge goes beyond a classificatory device and stands as an analytical articulation of how managers bracket the interpretive space of I4.0. By doing so, this study advances research on strategic decision-making in SMEs, where intuitive actions that are difficult to trace often substitutes for formal strategizing (Harney & Alkhalaf, 2021), particularly in early stages of transformation. By articulating I4.0 in terms of means, purpose, and challenge, the typology shows how managers reduce its conceptual diversity by privileging specific strategic directions.

Our findings invite a reconsideration of the role of I4.0' conceptual diversity within firms by shifting attention from diffusion dynamics to managerial appropriation. Management fashion research portrays I4.0 as a powerful umbrella label, shaped by bandwagon pressures and symbolic alignment that may encourage firms to pursue its promises with limited contextual grounding (Madsen, 2019; Oesterreich et al., 2020). By contrast, our results suggest that, instead of copy-pasting I4.0 directives, managers actively anchor the concept in their own profiles and in the internal and external conditions of their SMEs. This contribution reframes I4.0 a malleable concept appropriated through situated managerial and contextual cues (Penttilä et al., 2020), calling for interpretive frameworks to take precedence over prescriptive roadmaps when analysing I4.0 transformation in SMEs.

Moreover, this study strengthens the role of sense-making in theorising how managerial perceptions translate into strategic action. Our findings extend the role of conceptual diversity as merely mirroring the ambiguity of I4.0 at policy or discourse levels, to its functions as a

strategic driver at the organisational level (Gioia et al., 2012). By bracketing and anchoring – which enhances their trust in upcoming changes (Lumineau et al., 2023) – managers translate I4.0 interpretations into specific actions regarding technology implementation, organisational changes, or support initiation. This stresses the importance of considering managerial sense-making as an active component of strategy-making and calls for more explicit theorisation of how interpretive processes become stabilised through action in transformation contexts.

5.4. Practical Implications

For managers, the typology offers a reflective support tool to better articulate their vision of I4.0 transformation. By identifying where they stand across the three interpretive dimensions, they can clarify their priorities and underlying assumptions, helping them align strategic actions with contextual realities. The case illustrations further imply that transformation narratives should be adapted to each SME's situation, enabling managers to critically assess their strategic choices in light of existing constraints and ambitions. In this sense, the typology can support managerial storytelling as a process of collective sense-making rather than top-down sense-giving (Boje, 2001; Denis et al., 2007). Thus, means-oriented perceptions can help to express *what* I4.0 transformation provides technically to each service of a company. Purpose-oriented perceptions foster collective thinking about *why* it should be pursued, while challenge-oriented perceptions encourage reflection on *how* I4.0 transformation may be hindered. Rather than providing a prescriptive narrative, managers can use the typology to co-construct transformation stories that are rooted in their firm's specific context and help align teams to foster internal commitment to change.

Beyond serving as a reflective support tool, the findings suggest that managers may benefit from approaching the conceptual diversity of I4.0 as a working resource rather than a problem to be resolved. Instead of seeking early convergence on a single definition or roadmap, maintaining interpretive openness can allow managers to explore alternative pathways and avoid irreversible commitments until priorities become clearer within their specific context of transformation.

In addition, the study highlights the constructive role of perceived challenges in orienting strategic engagement with I4.0. Rather than being understood solely as barriers to overcome, constraints related to skills, costs, regulation, or integration complexity can serve as structuring elements that help managers prioritise, sequence, and narrow transformation efforts. In this sense, challenges contribute to shaping selective and context-specific approaches for change, particularly suited to the conditions under which SMEs operate.

5.5. Limitations and Future Research

While this study offers novel insights into the conceptual diversity and sense-making of I4.0 among SMEs' managers, several limitations open pathways for further research. First, the qualitative nature of the research limits the generalisability of findings. The selected SMEs operate within the Belgian industrial context, the cultural, economic, and linguistic patterns of which may influence the managerial interpretations and strategic orientations observed (Ivanova & Torkkeli, 2013; Penttilä et al., 2020). Future studies could extend this work to SMEs in different national or sectoral contexts to explore whether similar typologies emerge or whether new dimensions of perception become important. In particular, sectoral contexts may shape how I4.0 is interpreted, as industries differ in terms of technological intensity, regulatory constraints, production systems, and skill requirements. This influence was particularly visible in Company D operating in manufacture of clinical diagnostic products sector, where strict

regulatory requirements and validation processes significantly constrained the scope and pace of I4.0 adoption, shaping the manager's emphasis on feasibility and risk. Investigating specific sectors would therefore allow future research to examine how contextual conditions structure managerial sense-making and to refine or extend the proposed typology accordingly.

Second, the typology was derived through a two-level qualitative method, which – despite its ability to reveal complexity and hybridity of I4.0 perceptions – depends on the interpretive lens of both researchers and participants. While rigour was ensured through multi-coder validation and cross-case comparison, future research could complement this approach with quantitative or mixed methods designs to test and validate the typology on a broader scale.

Finally, while this study focused on internal sense-making within SMEs, further research could adopt a multi-story approach by including external ecosystem actors such as consultants, technology providers, and policymakers, as suggested by narrative studies on organisational change (Boje, 1991; Buchanan & Dawson, 2007). Future studies could investigate how these external narratives interact with internal sense-making to provide a more comprehensive picture of how I4.0 perceptions are constructed, negotiated, and enacted across organisational boundaries.

6. Conclusion

This study advances understanding of how SMEs' managers engage with the conceptual diversity of I4.0 by showing that meaning is actively constructed and stabilised through managerial sense-making. Rather than a fixed or uniformly interpreted concept, I4.0 emerges as an interpretive space structured around three interrelated dimensions. This proposed typology captures the hybrid and context-dependent nature of managerial perceptions, while the four case narratives illustrate how managers shape these dimensions into situated configurations that guide SMEs' strategic choices. Beyond documenting variation in interpretations, this study shows that conceptual diversity constitutes a resource that managers actively organise to enable action. By bracketing, anchoring, and stabilising meaning, managers transform an initially ambiguous concept into contextually relevant orientations for change. In this sense, conceptual diversity becomes a generative condition of strategy-making rather than a barrier to it.

By moving beyond linear and techno-centric accounts of I4.0 adoption, this study foregrounds managerial agency in navigating conceptual diversity and translating abstract visions into organisationally viable courses of action. More broadly, these findings invite a reconsideration of how digital transformation is studied, suggesting that future research should pay greater attention to the interpretive processes through which managers construct, negotiate, and enact meaning in contexts characterised by persistent ambiguity. Rather than seeking convergence towards stabilised definitions or best practices, understanding transformation may therefore require engaging with the plurality of meanings through which it is made actionable in practice.

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Appendix

Case A

Company A is a family-owned SME employing 45 people in the high-precision mechanics sector, with strong national and cross-border commercial relations. Awarded the title of Factory of the Future[3], its ongoing evolution is tied to a culture instilled by the company's founder, known for *"bringing his love of technology to the company"* and still actively involved in its life.

Manager A is one of two co-CEOs with responsibilities focused on operations. After finishing primary school, he followed a work-study program as a metalworker and rapidly started to work, explaining that he *"learned most things on his own".* Having begun his career in the company as a milling machine operator, he moved gradually into supervisory roles before joining the executive team.

His interpretation of I4.0 centres on making data *"clean and usable,"* emphasising its role in drawing *"quick and, above all, reliable conclusions".* The notion of centralised, structured data appears as the cornerstone of his understanding of I4.0. The notion of centralised, structured data appears as the cornerstone of his understanding of I4.0. This orientation towards data is deeply embedded in the company's transformation process, which unfolds through the progressive integration and centralisation of information systems: *"In fact, our objective is to have all the information in the right place, at the right time. To be able to connect everything, to have data… clean enough to extract conclusions that are very fast and, above all, reliable".* Rather than adopting ready-made technological solutions, transformation develops incrementally from existing practices. For instance, manual planning tools were progressively integrated into the ERP system: *"We used to work very well with Excel files, but it was manual… Now, this Excel file is integrated, it has become a window in the ERP system… that's how we proceeded, task by task, to see what people were doing and integrate it to simplify things as much as possible".* This process relies on a close and evolving collaboration with an external ERP developer, grounded in operational knowledge: *"Once I took over the ERP management… that's when we started to look at what people actually do and how we could digitalise it to make their work easier".*

Regarding the term itself, he questions its relevance: *"Where does Industry 4.0 begin and end? It can touch everything",* reflecting on its trendiness: *"It's just fashionable—soon it'll be AI instead. That's where the funding and attention go now."* This fashion volatility coupled with frequent changes within the company makes impossible using *"big names",* so the term of I4.0 is avoided in internal communication in favour of *"continuous improvement,"* which Manager A finds more accessible and less abstract. *"If I talk to a 4.0 machine operator, they'll look at me*

and say, 'Yeah, that's the screen in the machine'" he states, explaining that for him screens represent *"the result of I4.0",* while *"the real 4.0 is everything that happens behind the scenes on the server in terms of data collection".* This framing also reflects the iterative and uncertain nature of transformation projects for small companies like Company A: *"We are a small structure… things move very fast, sometimes even too fast. If a project doesn't succeed at first, it becomes difficult to relaunch it with the same name… that's why we avoid big labels".*

For him, the company's ultimate goal is *"to grow in terms of machine hours and turnover"* and to avoid doing so in terms of their team, since they struggle to *"find people to operate the machines".* Transformation further unfolds through continuous adjustments of work organisation and roles. Digitalisation reduces some tasks while opening new areas of intervention: *"Before, we couldn't measure it. Now, we sometimes even have too much information… seeing reality is not always pleasant".* Similarly, automation reshapes job content rather than replacing labour: *"Now we have been able to split the task in two… the technical person became production manager… and the planning part became more administrative".* Since these changes require continuous attention to workforce integration and acceptance, Manager A actively manages resistance by ensuring transparency and usability of data: *"The only thing that can become problematic is if it becomes too complicated for people… so we try to explain and show the benefits <…> Before, it felt imposed… now operators can correct their own data. We keep traceability, but they have autonomy".*

While the partial automation of the planning reduced administrative work, allowing teams to focus on more specialised tasks, the introduction of machine sensors into quality assurance allowed a more systematic identification of inefficiencies, requiring more people for the task. External pressures and opportunities also shape transformation trajectories. Certifications, clients, and audits act as triggers for structuring internal processes: *"We participated in a Factory of the Future assessment… and we saw that things were being done, but not structured. So we decided to formalise it properly".* At the same time, the company selectively engages with ecosystem support, combining subsidies, partnerships, and internal development: *"For us, the challenge is that digitalising the workshop requires large investments… it doesn't directly impact turnover, but performance in the medium term".* Transformation remains open-ended and opportunity-driven, combining structured initiatives with exploratory projects such as AI integration: *"We recently launched a proof of concept to integrate artificial intelligence into planning… because we are reaching the limits of what a human can do".*

Manager A admits that despite being already advanced in digitalisation, they could do a lot more: *"we still have 36,000 ideas, but we need the time to implement them all".* While his fellow co-CEO prevails a return on investment behind these ideas, Manager A confesses: *"I don't look at it so much, because for me it's more about the pleasure of doing it".*

Case B

Company B is a plastics manufacturer employing 130 people and integrated into an international industrial group. The company is already well advanced in its I4.0 transformation, with interconnected machinery and automated data flows.

Manager B is the digitalisation manager and acts as a liaison between local operations and the group's IT and innovation divisions. With a background in aeronautical engineering, she later combined it with a degree in technology and innovation management, which unlocked a new passion: *"how you take a great idea and turn it into a product and a business that works".*

She began in project management, where she spent over a decade, progressing from product delivery and methodology implementation to managing client projects. Before joining Company B, she moved into the logistics sector, where she expanded her skills by *"managing a team of operators on the factory floor"* and discovering *"the IT side of projects",* which she found *"fascinating".*

When sharing her thoughts about I4.0, Manager B expresses scepticism about the term itself: *"I don't really like these big concepts, because then they are used for everything".* She recalls a colleague who rebranded a manual data collection initiative as I4.0, adding ironically*: "They were talking about writing it down on paper, before doing it digitally".* Her own understanding of the concept centres on the combination of data and human levers: *"For me, it's really about successfully combining the power of data with human intelligence so that we can use the data we generate to better analyse our processes".* This articulation between data and human interpretation is central in her approach: *"Data has no value if it remains purely statistical… it must be enriched by the operator's knowledge". However,* she explicitly distances herself from the idea that automation should replace human workers. *"If it's just to remove people, I'd rather keep my operators because I want my company to retain a human face",* she adds. This position is also linked to her concerns about the social consequences of digitalisation within the workforce: *"We are losing an entire part of the population… people who have manual intelligence are being asked to develop analytical intelligence, and that will never fully work"*. She further highlights concrete barriers encountered in daily operations: *"We have operators who speak very little French… they can run the machines perfectly, but using digital systems becomes much more complicated".*

Currently, Manager B is leading two large-scale digital transformation projects. The first involves deploying a Manufacturing Execution System (MES) to *"improve production monitoring and combine quality data with process data".* She describes this shift as a move away from manual data entry – where operators *"had to write by hand"* and declare events themselves – towards a system where they focus on *"monitoring their line, analysing process progression, identifying deviations".* This evolution builds on an already advanced digital base and aims to further automate data flows*: "Our machines are already highly connected, and we collect a large amount of data… we are now trying to automate all consumption and production"*. This transformation is implemented progressively through successive adjustments of existing practices rather than through a complete system revision: *"We don't replace everything overnight… we try to build step by step on what already exists".* In this process, identifying what should or should not be digitalised remains a key managerial task: *"Not everything needs to be digitalised… sometimes paper is still more efficient".* At the operational level, the transformation directly affects daily work: *"Today, this work resembles that of a cashier… tomorrow, this task may disappear".* Rather than eliminating work, these changes redistribute tasks and redefine roles: *"We are not removing jobs, we are transforming them… people will have to understand more, analyse more".* This shift requires continuous support and adaptation: *"You can't just introduce a tool and expect it to work… you have to accompany people".* The objective is to reduce low-value tasks and refocus operators on process monitoring: *"We are trying to minimise data entry… so that they can focus on monitoring their production line".*

The second project concerns the migration to the group's System Analysis Program Development (SAP), intended to replace company's ERP and to "integrate our data with the rest, but also to do business between our factories." However, Manager B notes that their

"business is very different from the rest" of the group and warns that over-customisation may increase IT maintenance costs, while standardised template can fail to address local operational needs. This creates a persistent tension in the transformation process*: "We operate in a business that is very different… we cannot fit into the standards",* since it needs to be balanced between standardisation and adaptation: *"If we customise, the IT maintenance cost becomes enormous… but the standard system does not always match our reality".* This tension also reflects differences in priorities between local and group levels: *"The group is looking for standardisation and efficiency, while we are dealing with operational complexity on the ground".* As a result, adaptation becomes a negotiated process rather than a predefined implementation: *"We constantly have to negotiate what we adapt and what we keep standard".*

Since it is still a transition period, she opted to automate several units to avoid hiring additional local staff, citing the constraint of *"very high imposed costs".* More broadly, the transformation unfolds through structured project work and collective coordination: *"We created a project team with one person for each role… each of them had to reinterpret their job within this new system"*. This requires a shift in mindset across the organisation: *"People need to stop thinking in terms of the old system… and understand what the new system enables".* Resistance is expected as part of the process: *"There will be complaints at first… but after a few months, you won't hear them anymore".* Over time, acceptance emerges through use rather than initial adherence*: "At the beginning, people don't see the point… but once they use it, they realise the benefits"*. This confirms that transformation relies as much on learning processes as on technological deployment: *"It's really a learning process for everyone"*.

Case C

Company C is a small, family-owned enterprise employing 20 people in the waste recovery and recycling sector. At the time of the interview, it has been undergoing its I4.0 transformation for almost two years, with several changes still pending implementation: *"We haven't finished yet and it's taken longer than expected… I would say we are at 80–90%, but it took much longer than planned".* The company's founder and CEO, Manager C, comes from a background in marketing and administration. Before launching Company C, he previously worked in sales and management.

His understanding of I4.0 is pragmatic and operators-oriented: *"It's everything to do with automation and making work easier for people within a company".* He explains that his interest in digitalisation began with the need to improve process control, particularly to reduce the risk of errors in shipments: *"I sometimes get returns on goods that I send to other continents… the complaints come in two or three months later, which costs me money".* Parallelly, Manager C realised that a bigger change was needed: *"We weren't very automated; it was very manual, and in terms of IT, we still rely heavily on paper",* he admits, adding that this shift was largely led by his son – the company's *"driving force" who "pushes from below and pulls you along".*

The company began its transition by applying for a subsidised diagnostic, which *"didn't cost me anything – well, it cost me time, and we had to play the game properly",* recalls Manager C. Since the transformation is *"complex and costs money",* this regional incentive helped him to get started. However, engaging with the support ecosystem also revealed significant complexity: *"It's complicated to find your way through the maze of all the support available… for SMEs, it's really discouraging"*, adding that access often requires specific knowledge and resources: *"Big companies have people dedicated full-time to obtaining subsidies… for us, it's much harder".* The initial goal was to become more efficient: *"There are things that a worker*

isn't able to see, and thanks to technology, the number of errors can be reduced". He insists that it was for operational security: *"I wasn't going to get rid of people; it's really to ensure process control, not control in the sense of monitoring people's working hours".* Benefiting from his son's knowledge of the regional ecosystem supporting I4.0 transition, Manager C engaged with external experts in a collaborative project to co-design and implement a sensor-based quality control system. This choice was partly driven by the lack of suitable solutions on the market: *"We spent hours looking for existing programs… but there was nothing that really matched what we do".* Given the company's specific activities, Manager C decided to co-create customised development. This collaboration followed a structured and progressive process: *"We started by defining internally what we needed, then we invited several providers to see what was possible… then we selected one and built specifications together"*. The project required involving multiple internal actors to align expectations: *"We involved everyone… administrative staff, production manager, technical manager, engineer… to make sure we all agreed on the data and tools".* While satisfied with the experience, he warns of the competition risks small companies face when investing in innovation: *"When you develop a project, you have to give everything… whereas for companies with the means, it's easy to copy and paste".*

The transition towards digital tracking of materials from reception to shipping have been challenging, since *"it took a lot of energy to 'convince' the workers and even the employees".* This transformation deeply modifies daily routines and requires new practices at each stage of production: *"Now everything has to be scanned: when it arrives, during production, and when it leaves… there is a whole process behind it".* This introduces new operational constraints and learning efforts: *"Drivers now have to take a scanner, print labels, scan everything, and enter information… even the screen is sometimes too small, they need glasses".* These changes require discipline and consistency: *"I had to tell them: this is not something temporary, it's here to stay".* Manager C confesses: *"I have a very friendly staff, but they are really basic",* explaining their difficulties in adjusting to new technologies: *"They know how to use a phone, but IT is not part of their daily routine".* This gap between technological requirements and workforce capabilities remains a central challenge: *"When you ask them to enter data or scan, even after explaining several times, it remains complicated".* He notes that perceived benefits differ across roles: *"For the company, it's a clear benefit… but for the operator, they don't really see the advantage".* This creates resistance and requires constant follow-up: *"You have to monitor people so that they do it properly… sometimes they cheat out of convenience".*

To address this, he involved everyone*: "It's an SME, so it's very small",* paying attention to make the change accessible: *"We tried to simplify as much as possible so that people speak the same language and only have numbers to enter"*. This allowed him to understand employees' concerns and simplify the process so that they *"were all talking about the same thing, and then all that was left to do was enter the figures".* He proceeded then with introduction of informal meetings to clarify the project's purpose: *"We organised meetings every six weeks, with a drink, to explain the project and discuss problems…We explained that this was 4.0, but in a very user-friendly way".* These moments also served to progressively align interpretations of the transformation: *"We had to explain what 4.0 means in simple terms… so that everyone understands what we are doing".* Over time, this helped stabilise new practices: *"At the beginning, there are complaints… but after a few months, people get used to it".* This long-term process reflects the iterative nature of transformation in SMEs: *"It took two to two and a half years… it doesn't happen overnight".*

Case D

Company D is a family-owned SME employing 85 employees in the manufacture of clinical diagnostic products sector. Over recent years, it has made steady progress in digitising its internal processes, moving towards I4.0 transformation: *"We're moving from 2.0 to 3.0, but we are not yet at 4.0".* This transition reflects a progressive and still incomplete trajectory, shaped by successive adjustments: *"we are not yet clear ourselves on a trajectory… we have implemented changes that were necessary, but we are still reflecting on what should come next".* Manager D holds a degree in biochemistry, complemented by further education in communication and management. Before taking on the CEO role, she worked in scientific support and technical sales, where she developed a cross-functional understanding of production and client-oriented responsibilities.

When asked about her understanding of I4.0, she responds: *"It's the role of IT in processes, artificial intelligence, and big data".* She sees significant potential in using AI to improve internal operations, notably through systems that could *"measure everything and allow us to monitor it online, telling us when there is an excess".* This, she believes, would help address rising customer expectations, as variability and uncertainty in production are *"much more difficult to accept because they want everything to work perfectly every time they receive it".* At the same time, this potential is evaluated in relation to investment priorities and constraints: *"we have a lot of investments to make in general, so we have to decide where we will get the fastest return on investment".*

The company already uses an ERP system and has recently installed temperature sensors for monitoring purposes. However, Manager D is clear about existing limitations: *"Some of our equipment is 30 years old",* she notes, adding that *"the analysis is still done by a human".* She draws a distinction between passive data collection and real process improvement: *"What's interesting is analysing the data and seeing the effect; just looking at the data is pointless".* This situation reflects a gap between data availability and its effective use, as she explains: *"we generate a lot of data, but we don't necessarily know how to use it… looking at data alone has no value".* She also nuances the expected benefits of these technologies: *"we know there is potential, but it is still quite unclear what we will concretely gain from it".* These ambitions are also constrained by the need to adapt or replace existing equipment: *"to analyse our processes properly, we would probably need to change part of our equipment or add measurement systems… which represents a significant investment"*. She emphasises the material limits shaping these decisions: *"we cannot change everything… some machines are still working, so we adapt around them".* Accordingly, she positions her approach as favouring automation over comprehensive process management, explaining that they are *"moving forward little by little"* and seeking to *"think about what makes sense for each process".*

Beyond technical goals, Manager D also sees I4.0 as a partial response to workforce retention challenges in the manufacturing sector. *"We are using I4.0 to think about how we can better look after our people to make them want to stay",* she explains, connecting this to the nature of tasks performed in production: *"there are tasks that are very repetitive, and that is not very motivating in the long term"*. She contrasts the older generation, who would stay with the company for 40 years, with younger workers who, after six months, *"ask if there is anything else to do because they are bored", parallelly highlighting that "finding qualified personnel is extremely difficult… especially in such a specialised sector".* Between *"enormous"* salary costs and *"fierce competition for talent in a cutting-edge sector",* she acknowledges the difficulty of optimising labour costs: *"Paying someone with a master's degree to take temperature readings*

in a fridge is a bit expensive". She thus expresses hope that automating *"repetitive and meaningless tasks"* will shift the work towards requiring *"more critical thinking".*

Operating in a highly regulated and scientifically demanding environment presents additional constraints: *"Whatever we implement will have to be validated for ages",* she points out. She further insists on the implications of these requirements: *"whatever we implement will have to be validated for a very long time… without this validation, we can no longer sell".* This reality places her SME in a difficult position, as implementing complex systems means *"a lot of investments to make to comply, without any financial return"* – yet without validation, *"we can no longer sell".* To navigate this constraint, Manager D opts for systems already validated by larger firms, aiming to *"get the quickest return on investment".* At the organisational level, transformation also involves resistance to change, as she notes: *"when we say we are going to change something, many people react by saying it works well as it is, so why change it?"* This resistance is partly rooted in past experiences of change. As she recalls, the implementation of a previous ERP system *"was a real ordeal"*, and *"some of the more senior employees are still not convinced"*. This history shapes current reactions, reinforcing scepticism towards new transformation initiatives. It is further reinforced by uncertainty regarding the consequences of automation. She observes that *"many think that once they are replaced by a machine, they will no longer be needed"*, highlighting concerns about job security and the meaning of work. In response, Manager D seeks to mitigate these tensions by encouraging dialogue and participation, emphasising that employees *"can come forward with ideas and will be listened to"*.

Paper 3. Between Resource Configurations and Strategic Choices: A Multifaceted Perspective on Industry 4.0 Implementation in SMEs[6]

Abstract. Many industrial SMEs struggle to strategically leverage Industry 4.0 technologies due to widely acknowledged limitations in time, budget, or skills. While prior research suggests pathways to overcome such challenges, little empirical evidence exists on how managers mobilise internal resources in real decision-making. Our study addresses this gap by investigating the interplay between SMEs' resource configurations and the strategic decisions managers make in the context of Industry 4.0. Based on a survey of Belgian SMEs' managers, we introduce four strategic scenarios, challenging the assumption that resource constraints automatically hinder this transformation. Instead, we show that managers can strategically compensate for those constraints by aligning targeted goals, expected ROI, technological solutions, and change management priorities with their available capacities. By moving beyond deterministic roadmaps, this study proposes an empirically grounded typology that highlights managerial agency in shaping Industry 4.0 strategies within SMEs.

1. Introduction

The way small and medium-sized enterprises (SMEs) handle the implementation of Industry 4.0 (I4.0) has been in the loop of scholars for almost a decade now. Compared to large companies, SMEs face greater challenges due to constrained resources, lower levels of automation, and a lack of standardised operational processes when introducing key I4.0 technologies such as the Internet of Things, Artificial Intelligence, and Augmented Reality (Horváth & Szabo, 2019; Müller et al., 2021). By developing innovation strategies that address these barriers and foster cultural and technological change, SMEs' managers can achieve multiple improvements through I4.0 implementation (Müller et al., 2024; Somohano-Rodríguez et al., 2022). However, existing studies generally overlook the analysis of this strategic decision-making process.

On the one hand, managers must define their priorities and desired improvements by formulating strategic choices (Kumar Hajoary, 2024). To support them in this process, previous studies have developed roadmaps for I4.0 implementation (Addo-Tenkorang et al., 2024; Pozzi et al., 2023) and frameworks identifying critical success factors (Hansen et al., 2024; Sony et al., 2024). While offering practical guidelines for strategy development, these studies largely overlook the analysis and conceptualisation of real-world strategic choices made by SMEs' managers. Based on a review of recent SME-focused I4.0 studies, strategic choices are treated as descriptive accounts of SMEs' practices rather than as explicit analytical categories. Only a few scholars have addressed this gap: Müller et al. (2018) and Chen (2024) identified diverse strategic responses among SMEs but did not conceptualise them, while Vereycken et al. (2024) examined such choices exclusively through the lens of technological configurations.

On the other hand, managers must identify resources within their companies that can act as both enablers and barriers to I4.0 implementation (Kumar et al., 2023; Müller et al., 2024). Extensive research highlights that such aspects as financial capacities, digital maturity, management commitment and employees' digital expertise can either foster or hinder the successful implementation of I4.0 technologies in SMEs (Hansen et al., 2024; Santos et al., 2022). However, little attention has been paid to how managers integrate these factors into

[6] This chapter reproduces an article currently under revision (Out for Review (2nd round)) at the journal Technology Analysis & Strategic Management.

their strategic decision-making, since companies' distinctiveness lies in how managers assemble and recombine resources based on their firm-specific configurations (Eisenhardt & Martin, 2007). While some studies emphasise the importance of aligning SMEs' strategies with their enabling internal resources (Kumar Hajoary, 2024; Somohano-Rodríguez et al., 2022), the academic literature lacks empirical studies that examine the potential interplay between these resources and managers' strategic choices.

Bridging the abovementioned gaps, this study investigates the following research question:

How do resource configurations of SMEs interplay with managers' strategic choices in implementing Industry 4.0?

The paper is structured as follows. First, the literature review discusses the key concepts and theoretical framework of the study. Second, the research methods and data analysis are outlined. Next, the findings are presented, followed by a discussion. The paper concludes with an overview of the major contributions and limitations of the study, along with suggestions for future research.

2. Literature Review

2.1. Strategic Choices for I4.0 Implementation

In this study, strategic choices refer to the orientations through which SMEs' managers structure their decision-making regarding I4.0 (Child, 1997). Previous studies approached these choices by focusing on the types of technological solutions SMEs adopt (Vereycken et al., 2024), the pursued goals when selecting these tools (Müller et al., 2018), the nature of changes aimed to enact (Cimini et al., 2020), and the expected return on investment (ROI) of these changes (Chen, 2024). These strategic dimensions are mobilised here build on a prior conceptual typology (Zabudkina et al., 2024), which is adapted to the empirical scope of the present analysis.

When choosing technological *solutions*, SMEs may opt for *standard* off-the-shelf packages with predefined functions that require minimal support (Vereycken et al., 2024). Alternatively, SMEs may choose *customised* solutions, working directly with developers to design costly, but tailored systems through iterative testing and gradual refinement (Amatta & Shaker Ali Agha, 2024; Havsgård et al., 2024).

When setting *goals* for acquiring I4.0 technologies, SMEs often focus on *financial* outcomes, aiming to reduce costs, cut production times, and differentiate their products (Vereycken et al., 2024; Zabudkina et al., 2024). As a result, they frequently overlook *social* goals, such as improving workplace ergonomics and employee well-being, as well as *environmental* goals aimed at reducing resource consumption and waste generation (Santos & Sant'Anna, 2024).

Regarding *change* management, SMEs tend to prioritise a *technological* approach, optimising time management and streamlining lean production through robotisation and data automation (Da Roit & Iannuzzi, 2023; Ietto et al., 2024). In doing so, managers often overlook *organisational* changes, which include upskilling, reskilling, and new job profiles design (Da Roit & Iannuzzi, 2023).

When assessing the financial viability of I4.0 implementation, SMEs' managers often prioritise *short-term ROI* to secure investment approval and achieve a rapid payback (Chen, 2024; Sony et al., 2024). However, when aiming for a business model transformation, SMEs opt for a *mid*

or *long-term ROI,* a strategy fostering the simultaneous management of technological and organisational improvements (Pozzi et al., 2023; Pucci et al., 2024).

Thanks to this conceptual typology, the study provides an original analytical basis for examining and comparing SMEs' strategic decision logics across heterogeneous resource configurations.

2.2. Resource Configurations for I4.0 Implementation

Beyond clear strategic priorities, SMEs' resource configuration, formed by internal resources and constraints, play a crucial role in I4.0 implementation (Estensoro et al., 2021; Müller et al., 2024). Previous studies indicate that certain resources can act as enablers for this transformation, while resource constraints often emerge as barriers (Sony et al., 2024). These dynamics can be observed across several levels within SMEs.

The *financial* level generally refers to SMEs' *available funds* and *experience in budgeting* for innovation (Horváth & Szabo, 2019). SMEs frequently face financial constraints and have limited experience in budgeting for digital transformation (Addo-Tenkorang et al., 2024; Cimini et al., 2020).

The *digital* level refers to SMEs' *knowledge of new technologies*, their *capacity to automate internal processes and data collection*, and their *ability to leverage cybersecurity* practices (Galizia et al., 2023; Ietto et al., 2024). SMEs often show limited awareness of new technologies, cybersecurity, and data management, along with only a vague understanding of their potential value and benefits (Arroyabe et al., 2024; Hansen et al., 2024).

The *organisational* level refers to SMEs' *size*, *ownership* structure, *work organisation* practices, *adaptability* towards change, and *communication* clarity (Črešnar et al., 2022; Zoppelletto et al., 2023). While their size and ownership type influence digital and innovation maturity (Bosman et al., 2019; Brozzi et al., 2020), SMEs benefit from market responsiveness and informal workflows but struggle with the absence of structured innovation and communication management practices (Bhatti et al., 2024; Santos et al., 2022)

The *managerial* level refers to *hierarchy centralisation* in SMEs and managers' capacity for *risk-taking*, *employee involvement in organisational and future-related decision-making*, and *change management experience* (Harney et al., 2022). SMEs often operate with centralised hierarchies, where manager-driven decisions play a key role in fostering or hindering innovation (Sony et al., 2024; Zoppelletto et al., 2023). Although managers' hesitation to experiment with new technologies often slows progress, involving operators in decision-making enhances acceptance and engagement (Da Roit & Iannuzzi, 2023; Stentoft et al., 2021).

The *human* level refers to the *formalisation of training practices* in SMEs, as well as teams' *soft* and *digital skills*, and *collaboration* intensity (Horváth & Szabo, 2019; Zabudkina et al., 2024). SMEs generally benefit from cross-departmental cooperation among operators that contributes to more efficient digital transformation (Harney et al., 2022; Zoppelletto et al., 2023). However, most SMEs generally neglect structured continuous training, resulting in a lack of up-to-date digital and interpersonal skills (Hansen et al., 2024; Tamvada et al., 2022).

Altogether, these levels reflect the multidimensional nature of SMEs' resource configurations, which include resources that can both drive and constrain I4.0 implementation. Building on this typology, the study enables the analysis of how different resource configurations interplay with

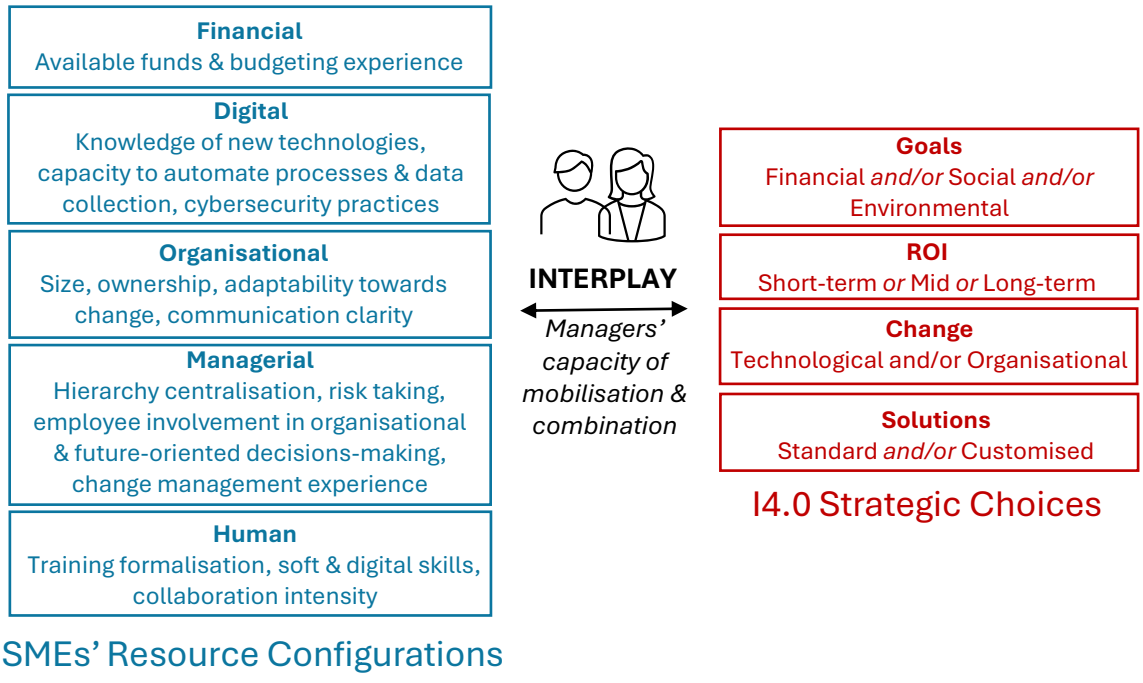
managers' strategic choices. To better evaluate this potential interplay, the study mobilises the lens of Resource-Based View (RBV) (Barney, 1991) and Dynamic Capabilities (DC) theory (Teece et al., 1997) in the next sub-section.

2.3. Resource-Based View and Dynamic Capabilities in SMEs

According to RBV, a firm's unique set of resources – those that are valuable, rare, inimitable, and non-substitutable – is key to gaining competitive advantage (Barney, 1991; Mahoney & Pandian, 1992). However, SMEs must also deal with numerous resource constraints (Hewitt-Dundas, 2006). In response to this issue, several studies stress that driving forces of companies towards innovation can emerge from both resources and constraints (Dolmans et al., 2014; Keupp & Gassmann, 2013). The capacity to mobilise these driving forces is central for DC perspective, according to which managers adapt, integrate, and reconfigure resources and constraints over time to remain competitive (Teece et al., 1997). This perspective also advances the dynamics and uncertainty of the rapidly changing environments in which managers operate as orchestrators in their strategic decision-making (Teece, 2007). However, since dynamic capabilities can be replicated across firms, it is the diversity of resource configurations that leads to unique competitive advantage (Eisenhardt & Martin, 2007). Thus, combining RBV and DC perspectives provides a comprehensive view of managing transformation, where resource configurations and strategic choices can potentially complement and shape each other.

Building on this logic of complementarity, the study positions resource configurations as the empirical expression of SMEs' unique sets of resources and constraints, in line with the RBV perspective. From a DC perspective, serving as a finer-grained analytical lens, strategic choices are conceptualised as the outcomes of how managers mobilise and combine these resources in decision-making. The study thus proposes an analytical framework in which the interplay between resource configurations and strategic choices places managerial agency at the centre of I4.0 implementation (see Figure 1).

Figure 1. Analytical framework of the interplay between SMEs' resource configurations and managers' strategic choices for I4.0 implementation.



3. Methodology

3.1. Data Collection

To identify how SMEs' resource configurations interplay with the strategic choices prioritised by managers for I4.0 implementation, an online questionnaire was designed for data collection.

3.1.1. Survey design and validation

The survey was structured into three sections. The first section collected information on respondents' roles and the level of I4.0 engagement in their SMEs. The second section captured strategic choices using categorical attributes derived from the literature review (see Figure 1), asking respondents to indicate which strategic priorities they primarily pursue in their I4.0 transformation (e.g., technological solutions, goals, change orientation, ROI horizon). The third section assessed resource configurations using attributes identified in the literature review (see Figure 1), asking respondents to evaluate the current state of internal resources and constraints (e.g., hierarchy, digital knowledge, skills) on a five-point ordinal scale ranging from very low to very high.

The questionnaire was piloted to meet content, cognitive, and usability standards (Groves et al., 2011). Content validity was assessed in collaboration with I4.0 and data analysis experts to ensure alignment between survey items and the analytical constructs derived from the literature. Seven cognitive interviews were conducted during the pilot phase to examine how respondents understood the questions, interpreted response categories, and selected answers. Usability aspects, including navigation and interaction with the survey interface, were also assessed. Observations from the pilot phase were systematically coded and used to iteratively refine question wording, response formats, and overall survey design, ensuring conceptual clarity and practical feasibility for respondents.

3.1.2. Survey Distribution and Sample Description

The final questionnaire was sent to 600 managers of industrial SMEs selected from a publicly available database, entitled *Entreprises en Wallonie*. Selection criteria were set regarding company size (under 250 employees), industry sector (excluding all service sectors) and geographical position (Wallonia, the Southern region of Belgium). This geographical context was considered relevant for the study due to the role of SMEs as a substantial part of the region's economy and their growing interest in the use of I4.0 technologies.

A total of 174 responses were received at the end of the survey. Missing or inaccurate values reduced the final sample to 79 valid responses. It included 11 firms had fewer than 10 employees, while 68 belonged to the 10–49 and 50–249 categories. Most were family-owned (57), followed by international (16), public (5), and employee-owned (1) firms. The sample mainly represented manufacturing industries: fabricated metal products (15), electrical equipment (6), rubber and plastic products (6), machinery (7), and food products (7), alongside waste management (5) and construction (4). All respondents were decision-makers: 61 directors and 18 managers.

3.2. Data Analysis

To examine the relationship between strategic choices and resource configuration within SMEs, we proceeded in two steps (see Figure 2), using the R package FactoMineR (Lê et al., 2008).

In the first step, a Multiple Correspondence Analysis (MCA) was applied to the strategic choice attributes, treated as active variables. MCA enabled dimensional reduction of the categorical data and the identification of latent dimensions summarising SMEs' strategic choices.

Figure 2. Overview of the two-step data analysis procedure.

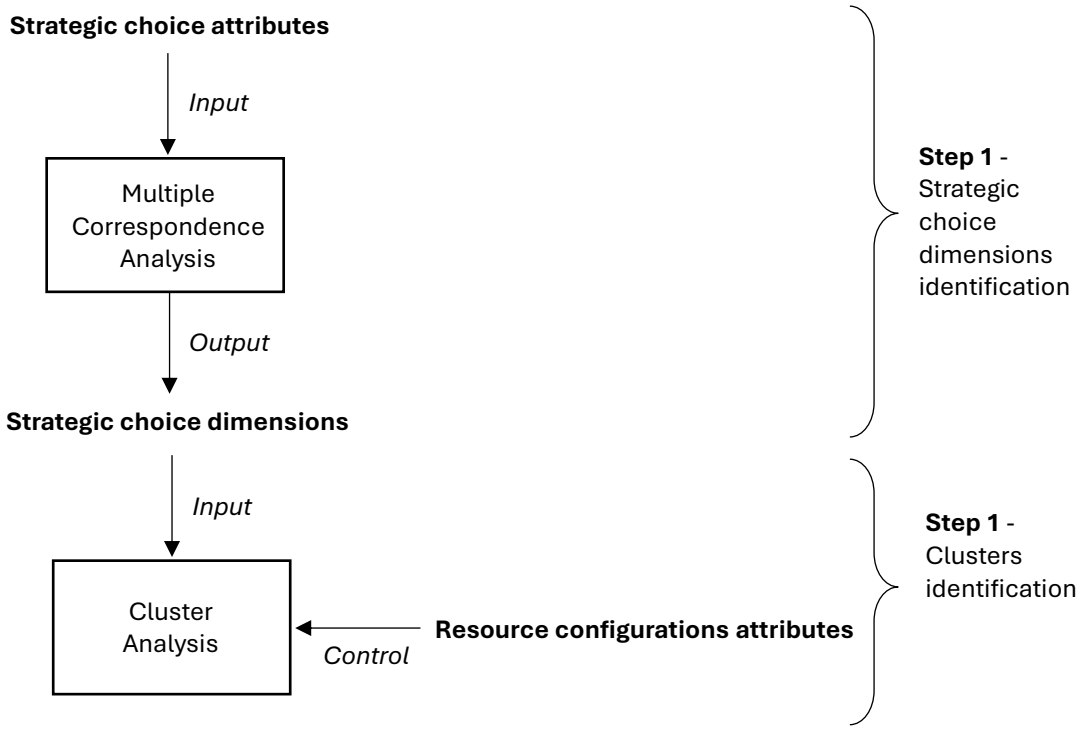
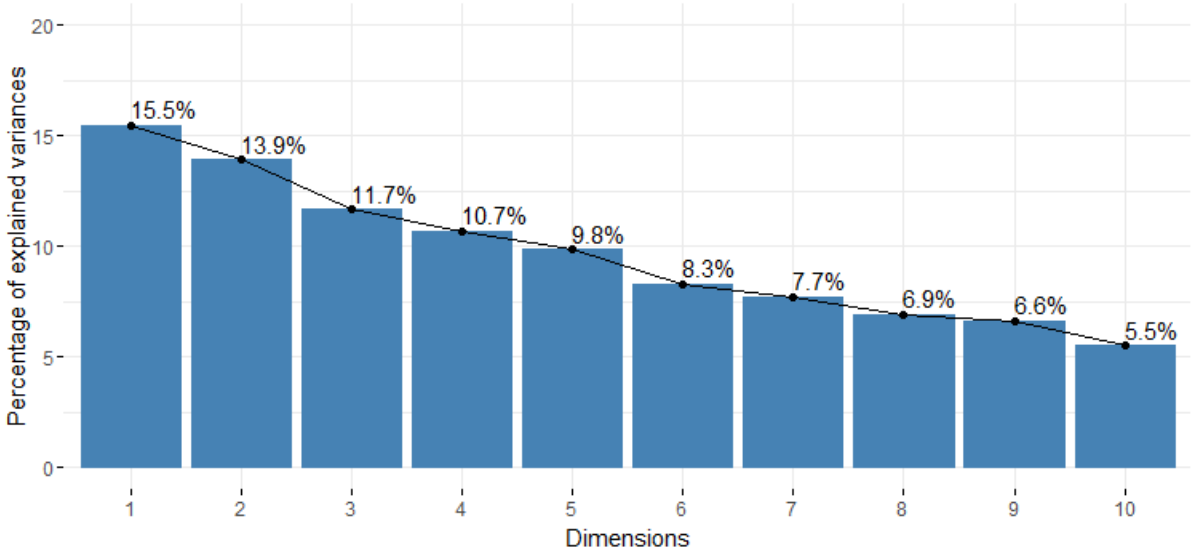


Figure 3. Scree plot showing the decomposition of the total inertia. Values have been corrected using the Greenacre adjustment to the Benzécri (1979) correction.



Based on the distribution of explained inertia, the first five dimensions were retained, accounting for 62.22% of total inertia. This threshold reflects common MCA practice in social sciences to retain around 60% of explained variance (Liontakis & Bogdani, 2025), where inertia

is more evenly distributed across dimensions, and balances analytical depth with parsimony, as additional dimensions contribute limited incremental information while increasing analytical complexity (Hjellbrekke, 20118; Husson et al., 2017). Figure 3 presents the decomposition of explained variance across dimensions, and Table 1 reports the coordinates, contributions, and cos² values of the strategic choice attributes.

Table 1. MCA outputs for the strategic modalities. Bold values indicate Top 5 values.

Strategic modalities	**Coordinates**		**Contribution**		**cos2**		
	Dim 1	Dim 2	Dim 1	Dim 2	Dim 1	Dim 2	Total
Long ROI	-0.08	1.04	0.09	**17.06**	0.00	0.34	0.34
Mid ROI	-0.08	-0.27	0.24	3.11	0.01	0.14	0.15
Short ROI	0.70	-0.73	2.88	3.50	0.05	0.06	0.11
All three goals	-0.67	-0.23	**12.61**	1.67	0.41	0.05	**0.46**
Environmental goals	1.84	3.25	5.05	**17.51**	0.09	0.27	0.36
Financial goals	0.98	-0.80	**11.47**	8.57	0.24	0.16	0.40
Financial and environmental goals	0.66	1.08	3.86	**11.66**	0.08	0.21	0.29
Financial and social goals	-0.41	0.22	1.23	0.42	0.02	0.01	0.03
Social goals	2.16	-0.12	3.48	0.01	0.06	0.00	0.06
Both changes	-0.86	0.07	**18.68**	0.13	0.56	0.00	**0.56**
Organisational change	0.90	-0.58	**12.00**	5.54	0.27	0.11	0.38
Technological change	0.45	0.37	3.77	2.84	0.09	0.06	0.15
Both solutions	-0.93	0.30	**15.56**	1.77	0.38	0.04	**0.42**
Customised solution	0.70	0.79	7.97	**11.23**	0.19	0.24	**0.43**
Standard solution	0.21	-0.74	1.12	**14.99**	0.03	0.39	**0.42**

In the second step, the retained dimensions were used as input for a hierarchical cluster analysis to identify groups of SMEs with similar strategic choices. The resulting clusters were subsequently characterised using resource configuration attributes to identify the factors shaping these strategic choices.

4. Results

This section presents the empirical results in two steps. First, we report the patterns of strategic choices identified through the MCA. Second, we present the results of the hierarchical cluster analysis.

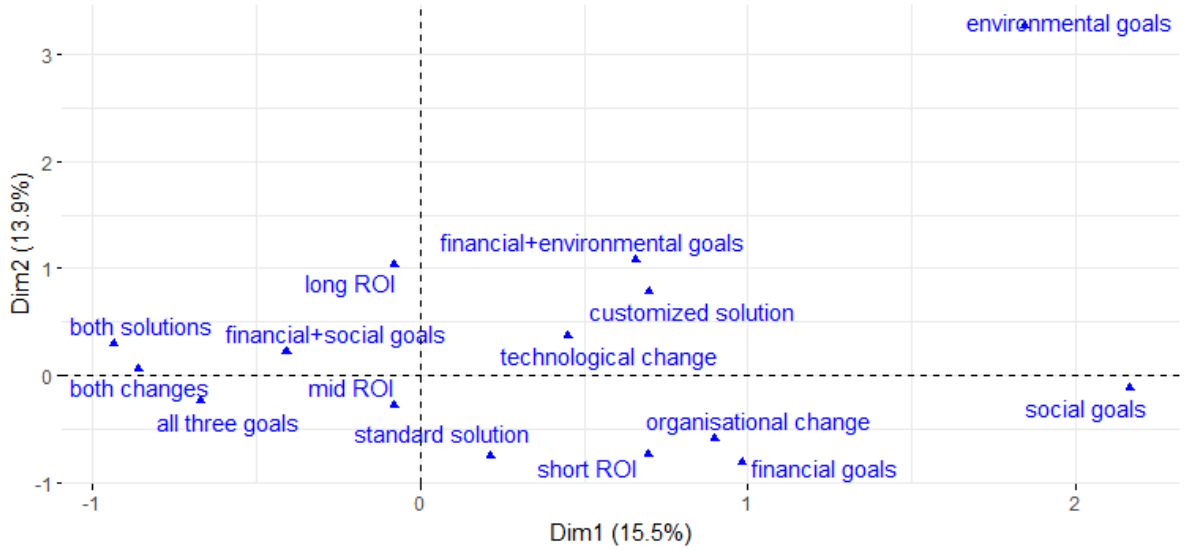
4.1. Patterns of Strategic Choices

The MCA reveals two dominant dimensions structuring SMEs' strategic choices for I4.0 implementation. Table 1 highlights the attributes that most strongly contribute to each dimension, with the top contributors indicated in boldface. The first dimension is mainly shaped by attributes of *all three goals*, *financial goals*, *both changes*, *organizational change* and *both solutions*. The second dimension is primarily structured by attributes of *long ROI*, *environmental goals*, *financial* and *environmental goals*, *customised* and *standard solutions*.

Figure 4 displays the distribution of the attributes mapped on the first two dimensions. The first dimension reflects *the scope of strategic choices,* ranging from broad to narrow. As we move

left on the graph, broader strategic choices, including both types of solutions and changes, are favoured. Moving right, the focus narrows to specific goals and solutions, such as technological changes and financial goals. The second dimension reflects *the radicality of strategic choices*, ranging from risky to cautious. Further from the origin, riskier and more discriminating choices such as environmental goals and customised solutions are highlighted. Lower, more cautious strategies, focusing on short-term ROI, standard solutions and financial goals, become prominent.

Figure 4. MCA map of the modalities with principal normalization for dimensions 1 and 2.



4.2. Identification of Clusters

Building on the five strategic choice dimensions identified through the MCA, a hierarchical cluster analysis was conducted to group SMEs based on the proximity of their managers' responses across these dimensions. Companies whose managers expressed similar combinations of strategic priorities were clustered together, resulting in six statistically distinct groups.

Figure 5 displays the cluster map projected onto the first two MCA dimensions, illustrating the relative positioning of clusters in terms of the scope and radicality of strategic choices. Among the six clusters, four clusters each account for more than 10% of the sample and therefore allow for meaningful empirical profiling. The remaining two clusters reflect highly discriminating strategic choices, primarily oriented toward environmental and social goals, and include only three respondents each. Since their limited size prevents robust profiling, the following analysis focuses on the four dominant clusters.

Table 2 reports the strategic choice and resource configuration attributes identified in the literature review and operationalised in the analytical framework, showing how their distribution differentiates the clusters, based on v-test statistics. Positive (negative) values indicate attributes that are over-represented (under-represented) within a given cluster. Over-represented attributes therefore capture the distinctive features that most strongly differentiate one cluster from others, while under-represented attributes indicate dimensions that are comparatively less salient for that group. The next sub-sections present an in-depth interpretation of these four clusters.

Figure 5. Hierarchical classification of the SMEs based on strategic choice dimensions.

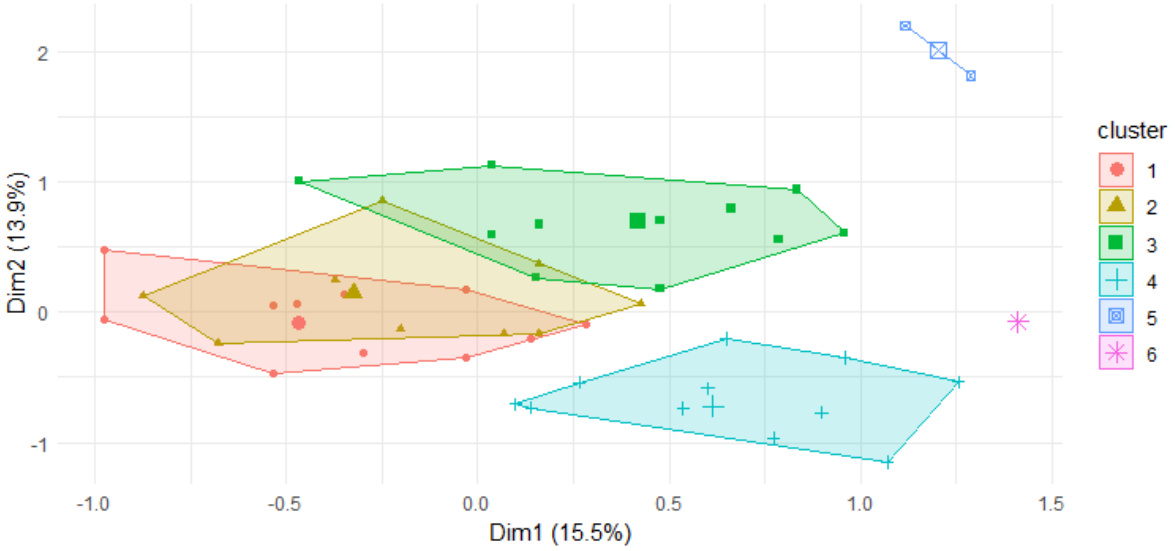


Table 2. Representation of modalities and contextual factors in clusters. Boldface values indicate significance at a level of 5%.

Resource configuration attributes	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
High budgetisation experience	-0.58	**2.71**	-0.37	-1.01
Low change management experience	-0.09	-1.77	-1.04	**2.43**
High collaboration among operators	-1.48	**2.95**	0.77	-1.88
Low collaboration among operators	0.07	-1.11	-1.11	**2.06**
Medium collaboration among operators	1.55	**-2.15**	0.18	0.24
Cybersecurity checks (Once a year)	**-2.06**	0.97	**2.27**	-0.25
High involvement decision-making (future)	0.61	1.43	0.25	**-2.32**
High involvement decision-making (work organisation)	-0.10	**2.08**	0.84	**-2.62**
Low involvement decision-making (work organisation)	-0.76	-1.45	-1.45	**3.44**
Low digital technologies knowledge	-0.29	-1.14	-0.47	**2.28**
Low digital skills (managers)	-0.94	-1.23	-0.22	**2.55**
Low digital skills (operators)	-0.28	**-2.27**	1.31	0.78
Medium digital skills (operators)	-0.38	**2.23**	-1.67	-0.28
Low financial resources	-1.08	-1.77	**2.11**	0.75
Low adaptability to changes	0.40	0.89	**-2.60**	0.75
Low hierarchy	**-1.99**	0. 97	1.62	0.00
Medium hierarchy	**2.61**	-0.94	-1.67	-0.89
International ownership	**2.35**	-1.17	0.30	-1.65
Medium size (less than 50 employees)	**2.61**	**-2.18**	-0.34	-0.16
Micro size (less than 10 employees)	**-2.37**	**2.39**	-0.61	1.19
Strategic choice attributes				
Both solutions	0.95	**3.07**	-0.58	**-3.33**

Customised solutions	-1.59	-0.37	**2.71**	-1.65
Standard solutions	0.55	**-2.77**	**-2.08**	**4.33**
Both changes	**4.48**	0.82	**-2.18**	**-3.61**
Organisational change	**-2.82**	-0.84	-1.57	**4.44**
Technological change	**-2.15**	-0.05	**3.57**	-0.77
All three goals	**7.21**	**-2.55**	**-3.22**	**-2.24**
Financial goals	**-2.67**	-0.41	-1.17	**4.61**
Financial and Environmental goals	**-3.37**	-1.66	**6.47**	-1.14
Financial and Social goals	**-2.99**	**5.52**	-1.45	-0.86
Long ROI (3 years and more)	0.55	-0.05	1.24	**-2.82**
Short ROI (less than a year)	**-2.58**	0.66	-0.21	**2.55**

4.2.1. Responsible Planners

The first cluster is characterised by the over-representation of broad strategic choices combining financial, social, and environmental goals, alongside both technological and organisational change orientations (column 2 in Table 2). Regarding the resource configurations, most SMEs in this cluster are medium-sized and are part of internationally owned corporate groups. Additionally, managers commonly describe their companies as operating under a relatively centralized hierarchy.

Taken together, the over-represented strategic choices and resource characteristics indicate that managers articulate comprehensive transformation ambitions while relying on established planning and governance capacities. We therefore refer to this cluster as *responsible planners*.

4.2.2. Tactical Players

The second cluster is primarily characterised by the over-representation of strategic choices oriented towards financial and social goals, combined with the use of both standard and customised technological solutions (column 3 in Table 2). In terms of resource configurations, this cluster is dominated by micro-sized firms and is marked by strong budgeting capacity for innovation projects, high levels of operators' collaboration, and their active involvement in decision-making. Operators' digital skills are generally assessed as moderate.

This combination of selective strategic priorities and mobilised internal resources points to a pattern in which managers tactically orchestrate existing capacities to support targeted I4.0 initiatives. Accordingly, this cluster is labelled *tactical players*.

4.2.3. Proactive Transformers

The third cluster is distinguished by the over-representation of strategic choices combining financial and environmental goals, a clear preference for technological change, and the adoption of customised solutions (column 4 in Table 2). From a resource configuration perspective, this cluster is characterised by reported financial constraints alongside regular cybersecurity practices.

Taken together, these attributes indicate that managers proactively leverage selective technological investments to overcome resource limitations and advance transformation. We therefore refer to this cluster as *proactive transformers*.

4.2.4. Resilient Pragmatists

The fourth cluster is characterised by the over-representation of short-term ROI expectations, a primary focus on financial goals, organisational change, and the adoption of standard solutions (column 5 in Table 2). These strategic choices reflect a cautious and efficiency-oriented approach to I4.0. In terms of resource configurations, the cluster is marked by low levels of digital knowledge, limited managerial digital skills, weak collaboration among operators, and their minimal involvement in decision-making. Experience in change management is also frequently reported as limited.

This pattern indicates that managers pursue incremental and practical innovation paths despite significant internal constraints. We therefore label this cluster *resilient pragmatists*, emphasising their capacity to maintain innovation efforts under restrictive conditions.

5. Discussion

Our findings highlight that I4.0 implementation in SMEs cannot be understood through a single explanatory angle focused on either strategy or resources. Adopting a multifaceted perspective, the study shows that while resource configurations shape the conditions under which transformation unfolds, strategic choices reflect how managers interpret and mobilise these conditions in practice.

5.1. Diverse Resource Configurations

Contrary to previous studies that outline specific resources to mobilise and to avoid during I4.0 implementation (Hansen et al., 2024; Kumar Hajoary, 2024), our study highlights different resource configurations through several scenarios. While *responsible planners* and *tactical players* deal with resource configurations dominated by enablers, *resilient pragmatists* illustrate the opposite, and *proactive transformers* navigate both resources and constraints.

Despite previous research highlighting the benefits of horizontal, decentralised structures for I4.0 implementation in SMEs (Cimini et al., 2020), our study shows that relatively centralised hierarchies can also contribute to similar outcomes. Stemming from international ownership (Bosman et al., 2019), this configuration allows *responsible planners* to benefit from a structured approach to managing transformation at multiple levels (Santos et al., 2022). In the same vein, the case of *tactical players* challenges the commonly held negative association between small company size and resource limitations in the context of I4.0 implementation (Brozzi et al., 2020). Although frequently constrained by financial limitations (Cimini et al., 2020), these managers strengthen internal capacities, such as budgeting skills, operators' digital competencies, collaboration, and involvement in decision-making, to leverage them during I4.0 transformation.

While existing studies observe SMEs' financial limitations based on a fixed snapshot (Addo-Tenkorang et al., 2024), the co-existence of financial constraints and annual cybersecurity checks in the case of *proactive transformers* might indicate that their resource configuration is dynamic (Teece et al., 2016). Budget fluctuations may result from changes already undertaken as part of the I4.0 transformation (Cimini et al., 2020), with cybersecurity standing out as a rare resource, especially among SMEs that typically overlook the importance of preventive data management (Arroyabe et al., 2024; Barney, 1991).

Finally, our study challenges previous findings suggesting that digital, managerial, and human constraints prevent SMEs from implementing I4.0 (Sony et al., 2024). The case of *resilient pragmatists*, whose resource configuration consists exclusively of constraints, demonstrates

that limitations, such as limited digital knowledge and lack of change management experience, can be strategically compensated by managers through specific strategic choices (Dolmans et al., 2014).

5.2. Specific Strategic Choices

This study moves beyond deterministic strategic roadmaps for I4.0 implementation (Arroyabe et al., 2024; Pozzi et al., 2023) by identifying four distinct strategic scenarios adopted by SMEs' managers. In contrast to typologies that describe SMEs' engagement with I4.0 through progressive managerial orientations and increasing levels of organisational and business model integration (Müller et al., 2018), or that classify firms according to implementation outcomes and resource readiness conditions (Estensoro et al., 2021), the proposed scenarios capture how managers enact distinct strategic responses under heterogeneous and evolving resource configurations. Moreover, the four strategic scenarios identified in this study should be interpreted as snapshots of the interplay between organisational resource configurations and managerial decision logics observed at a given point in time. From a DC perspective (Teece, 2007), changes in internal resources, organisational learning, or managerial profiles may prompt firms to reorient their strategic choices over time and move across scenarios. In this sense, the typology reflects flexible strategic logics rather than stable categories, emphasising managerial agency in navigating I4.0 under changing conditions.

Although scholars consider a broad strategic approach to I4.0 transformation difficult for SMEs due to resource constraints, they often overlook the influence of ownership structure, focusing primarily on family-owned businesses (Santos et al., 2022). Our study reveals that, in the case of *responsible planners*, being part of an international group helps managers to overcome these constraints due to access to structured innovation practices and additional support mechanisms. As resource sensing and seizing often occur at higher levels within the group (Bosman et al., 2019), managers are thus enabled to innovate and adopt strategic choices that are rare among SMEs. Beyond achieving cost reduction and technical upgrades, they recognise the broader potential of I4.0 to improve environmental sustainability, workers' well-being and professional development (Cimini et al., 2020; Santos & Sant'Anna, 2024).

By leveraging the strengths of their resource configuration, *tactical players* practice another strategic thinking that remains uncommon among SMEs. Their budgeting capacity and digitally empowered operators' involvement in decision-making reinforce managers' confidence to invest in both customised and standard solutions (Amatta & Shaker Ali Agha, 2024; Zoppelletto et al., 2023). This advanced technological mix enables not only cost reduction but also reinforces existing operators' collaboration by fostering a safer and more ergonomic working environment (Santos & Sant'Anna, 2024).

Faced with limited financial resources, *proactive transformers* make risky choices by opting for costly customised solutions. Having already invested in cybersecurity, they appear confident in the payback of these initiatives and remain focused on improving their companies technologically (Da Roit & Iannuzzi, 2023). By prioritising financial and environmental goals, they pursue a long-term innovation vision, where investments in waste management and responsible resource consumption gradually reduce costs and help overcome financial constraints (Zabudkina et al., 2024).

Given their resource configuration, *resilient pragmatists* respond to existing limitations by making cautious and practical strategic choices. With limited experience in change management and gaps in digital knowledge and skills, they prioritise quick wins by reducing

costs and production time through standard solutions that are easier to implement (Havsgård et al., 2024; Sony et al., 2024). This strategic prudence tends to limit their engagement with the long-term philosophy of I4.0, which promotes continuous and cross-functional transformation (Pozzi et al., 2023). Yet, by investing in organisational changes such as training and upskilling, they actively mitigate weak operators' collaboration and limited involvement in decision-making, thereby challenging the dominant techno-centric narrative in research on I4.0 implementation in SMEs (Da Roit & Iannuzzi, 2023; Ietto et al., 2024).

These strategic scenarios differ less by the presence or absence of specific resources than by how managers define the *scope* and *radicality* of their strategic engagement with I4.0. This perspective helps to explain why *responsible planners* adopt broad and transformative strategic orientations, *tactical players* favour targeted technological responses with limited organisational change, while *proactive transformers* combine risky technological investments with environmental ambitions, and *resilient pragmatists* prioritise cautious, efficiency-oriented strategies under constraint.

5.3. Contributions

From a theoretical perspective, this study contributes to the literature by offering a new perspective on how SMEs' managers strategically engage with I4.0 implementation. The proposed typology of strategic scenarios demonstrates that managers do not follow a sequential or uniform path, nor rely on a fixed set of goals, solutions, or change priorities. Instead, they design their own strategy for I4.0 by either leveraging existing strengths or compensating for limitations within their companies' current resource configurations (Keupp & Gassmann, 2013). Our findings also challenge the dominant view that resource abundance in SMEs is a prerequisite for I4.0 implementation, while constraints act as barriers (Horváth & Szabo, 2019; Sony et al., 2024). Drawing on RBV and DC perspectives, we highlight the strategic role of managers in navigating internal resource configurations, including those shaped by constraints (Barney, 1991; Teece et al., 2016).

This study also offers actionable insights for SMEs' managers considering I4.0 implementation. Our findings show that specific resource configurations shape specific strategic choices, when actively navigated by managers. In the cases of *resilient pragmatists* and *proactive transformers*, financial and managerial constraints – common among SMEs – are strategically compensated by combining specific goals with carefully selected change priorities. The proposed analytical framework can support managers in two ways: diagnosing their current resource configurations and guiding the definition of strategic decisions for I4.0 transformation. By mobilising the scenario typology as use cases, managers can better anticipate the interplay between configurations and strategic choices, tailoring their own I4.0 trajectory accordingly.

5.4. Limitations and Future Research

We acknowledge several limitations in this study, creating opportunities for future research. First, the small, region-specific sample constrains both the generalisability of findings and the range of strategic scenarios. Future research should test the robustness of the proposed configurations and choices across larger and more diverse contexts. Second, the analytical framework (see Figure 1) focuses solely on internal resource configurations, overlooking external factors such as institutional settings, policy incentives, and industry dynamics. Exploring these influences could enrich the understanding of the strategy-context interplay. Finally, given the dynamic nature of I4.0 technologies, longitudinal studies are needed to

explore how SMEs adapt their strategies and resource configurations over time, and whether such adaptations generate sustained competitive advantages.

6. Conclusion

This study demonstrates that SMEs' managers actively shape I4.0 strategies by navigating diverse resource configurations rather than being dictated by them. The four identified strategic scenarios illustrate how managers mobilise financial, managerial, and human resources and constraints through context-specific decisions. These findings highlight the importance of combining resource-centric views with managerial agency at the core of strategic decision-making in SMEs implementing I4.0. By moving beyond prescriptive success factors, the study reveals that even resource-limited SMEs can achieve meaningful transformation through tailored strategies. The diversity of these strategies and the dynamic nature of resource configurations highlight managers central role in orchestrating strategic responses to I4.0 implementation.

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Paper 4. Go Your Own Way: Managerial Engagement with Regional Innovation Ecosystems for Industry 4.0 Transformation in Belgian SMEs[7]

Abstract. While Industry 4.0 (I4.0) has led to the proliferation of policy-driven innovation ecosystems aimed at supporting small and medium-sized enterprises (SMEs) in their digital transformation, limited attention has been paid to how managers engage with these environments in practice. This study examines how SMEs' managers interpret, evaluate, and mobilise external support within I4.0 Regional Innovation Ecosystems (I4.0 RIE). Drawing on 25 semi-structured interviews with managers of industrial SMEs in Belgium, we adopt a sense-making perspective to analyse engagement as an interpretive process. The findings show that managers approach these ecosystems as overlapping support mechanisms, which they evaluate in terms of accessibility and usability and enact through selective, adaptive, and sometimes reversible patterns of access and use. These findings suggest that engagement with I4.0 RIE is not driven by the availability of support alone, but by how managers interpret and position it in relation to their firms' needs and constraints. By foregrounding these dynamics, the study offers a processual view of how SMEs engage with innovation ecosystems under digital transformation.

1. Introduction

Industry 4.0 (I4.0), initially introduced in Germany at the Hannover Fair in 2011 as part of a national strategy to revitalise manufacturing (Pfeiffer, 2017; Reischauer, 2018), is commonly associated with the fourth industrial revolution, characterised by the integration of digital technologies such as cyber-physical systems, the internet of things, artificial intelligence, and advanced data analytics into industrial production systems (Culot et al., 2020; Frank et al., 2019). Beyond its technological dimension, I4.0 has been institutionalised through a wide range of policy initiatives and support programmes designed to foster its diffusion, particularly among small and medium-sized enterprises (SMEs), which constitute the backbone of most industrial economies (Hervas-Oliver et al., 2021; Teixeira & Tavares-Lehmann, 2022). Across Europe and more particularly in Belgium, this has resulted in the emergence of complex configurations of public and private actors – including governmental agencies, competence centres, research institutions, industry associations, and technology providers – mobilised to support firms' digital transformation.

These configurations have been increasingly conceptualised through the lens of innovation ecosystems (IE), which emphasise the interdependence of heterogeneous actors aligned around a shared value proposition (Adner, 2017; Jacobides et al., 2018), and through regional innovation systems (RIS), which highlight the role of territorially embedded institutions, governance structures, and knowledge infrastructures in shaping innovation processes (B. Asheim et al., 2016; Cooke, 2001). In the context of I4.0, these perspectives converge in describing environments where multiple actors, activities, and resources are coordinated to support firms' technological upgrading through funding schemes, advisory services, training programmes, and collaborative initiatives (Benitez et al., 2020; Hafeez et al., 2025; Jiang et al., 2020). However, while this literature provides important insights into how such environments are structured and how they are intended to support firms, it largely treats engagement as a function of access to external resources and the expected benefits of participation.

[7] This chapter reproduces an article currently under revision (Out for Review (2nd round)) at the journal *Technovation*.

This structural perspective remains insufficient to capture how engagement actually unfolds in practice. Existing research typically conceptualises SMEs as unified organisational actors interacting with external support environments, and explains engagement through firm-level characteristics such as resources, capabilities, or technological maturity (Ietto et al., 2024; Menten et al., 2025; Vereycken et al., 2024). While these factors are important in shaping the conditions of engagement, they provide limited insight into how support is actually interpreted, prioritised, and mobilised within firms. Empirical studies on SMEs' I4.0 transformation consistently report difficulties in accessing and using support – such as identifying relevant actors, navigating institutional arrangements, or aligning external offers with firm-specific needs (Hansen et al., 2024; Müller et al., 2024). Rather than reflecting only structural barriers, these challenges point to a deeper limitation in the literature: the lack of an actor-centred understanding of how such constraints are interpreted and acted upon in firms' engagement with external support. In particular, existing research pays limited attention to the role of managers, despite their central position in strategic decision-making and innovation processes within SMEs (Lanzolla et al., 2021; Mintzberg, 1980; Zoppelletto et al., 2023).

This gap is further reinforced by conceptual ambiguities in how external support environments for I4.0 transformation are defined. Prior studies alternately refer to IE (Benitez et al., 2020), RIS (Sandulli et al., 2021), or sets of intermediaries and support organisations (Hervas-Oliver, 2022), without systematically integrating I4.0-related technological, organisational, and policy dimensions. As a result, the environments supporting I4.0 transformation are often described in fragmented ways. In response, this study conceptualises these environments as I4.0 Regional Innovation Ecosystems (I4.0 RIE), defined as geographically embedded constellations of actors, activities, and artifacts organised around the collective objective of enabling I4.0 transformation.

Building on this reconceptualisation, we argue that understanding engagement with I4.0 RIE requires shifting the analytical focus from firms as homogeneous actors to managers and processes through which they interpret and enact these environments. In SMEs, decision-making is highly centralised and closely tied to managers' cognition, experience, and evaluative judgments (Harney & Alkhalaf, 2021; Mintzberg, 1980), suggesting that engagement with external support is not simply a matter of access, but of interpretation and action (Gavetti et al., 2005; Weick, 1995). To capture this dynamic, we adopt a sense-making perspective, which conceptualises engagement with I4.0 RIE as an ongoing process through which managers select, interpret, and enact elements of their environment in relation to their SMEs' I4.0 transformation (Maitlis & Christianson, 2014; Weick, 2004, 2009).

Against this background, the study addresses the following research question:

How do SMEs' managers engage with I4.0 Regional Innovation Ecosystems in the course of I4.0 transformation?

To answer this question, we draw on qualitative data from 25 managers across 22 industrial SMEs in Wallonia (Belgium), a particularly relevant empirical setting characterised by a strong policy orientation towards digital transformation and a particular institutional configuration shaping the organisation of innovation support (Faniel et al., 2021; SPW & Agence du Numérique, 2021). This context enables us to examine how engagement unfolds within a dense and policy-driven ecosystem, where multiple actors and initiatives coexist.

The study makes three contributions to technology and innovation management research. First, it reconceptualises SMEs' engagement with I4.0 RIE as an interpretive and situated process, moving beyond structural views of ecosystems (Granstrand & Holgersson, 2020) to show how engagement is constructed through managerial evaluation and action. Second, it demonstrates that engagement unfolds through selective, adaptive, and reversible practices, captured in a typology of access and use tactics that challenge linear and cumulative views of ecosystem participation (Menten et al., 2025). Third, it shows that the fragmentation of innovation ecosystems is not only structural (Sandulli et al., 2021) but enacted, as managers' patterns of partial access, selective use, and disengagement shape how ecosystems are experienced and mobilised in practice.

The remainder of the paper is structured as follows. Section 2 reviews the literature on SMEs' I4.0 transformation, external support environments, and sense-making. Section 3 presents the methodology and empirical setting. Section 4 reports the findings. Section 5 discusses the theoretical and practical implications. The paper concludes with limitations and avenues for future research.

2. Literature Review

2.1. I4.0 Transformation and the Need for External Support in SMEs

I4.0 can be understood as a manifestation of digital transformation, aiming to improve industrial companies through *"a fundamental change process, enabled by the innovative use of digital technologies accompanied by the strategic leverage of key resources and capabilities"* (Gong & Ribiere, 2021, p. 12). Frequently associated with the fourth industrial revolution, I4.0 transformation reflects the disruptive effects of digitally connected and data-driven production paradigms (Cefis et al., 2023; Smith & Beretta, 2021) through a set of key technologies such as the internet of things, cyber-physical systems, cloud computing, big data analytics, artificial intelligence, and additive manufacturing (Bortolini et al., 2022; Klingenberg et al., 2019). These technologies allow industrial companies to enable real-time data exchange and make their operational systems more flexible, efficient, and intelligent (Culot et al., 2020; Frank et al., 2019).

In the case of SMEs[8], I4.0 transformation represents a complex and demanding process that exposes firms to multiple technological, organisational, and managerial challenges (Zabudkina et al., 2024). Compared to large firms, SMEs often face limited financial resources, shortages of digital skills, and lower technological capabilities, which restrict their ability to invest in advanced technologies and integrate them strategically into their operations (Horváth & Szabo, 2019; Kumar et al., 2023). Reinforced by difficulties in managing organisational change, developing digital strategies, and aligning technologies with business models (Črešnar et al., 2022; Hansen et al., 2024), these constraints often lead SMEs to early stages of I4.0 maturity, which refers to their quite low level of digital readiness and necessary preconditions in terms of resources and skills (Amaral & Peças, 2021; Estensoro et al., 2021). Because many of the required resources and capabilities cannot be developed internally, SMEs are encouraged to rely on external collaborations, knowledge networks, or institutional support mechanisms to access technological expertise and strategic guidance for their I4.0 transformation (Ghobakhloo et al., 2022; Khin & Hung Kee, 2022; Stentoft et al., 2021).

[8] SMEs are defined as those organisations with less than 250 employees (European Commission, 2003).

2.2. SMEs' Engagement with External Support for I4.0 Transformation

When examining how SMEs engage with external support for I4.0 transformation, existing research remains fragmented and largely outcome-oriented, focusing on isolated aspects such as technology adoption, while overlooking the concrete practices through which managers mobilise such support (Kim & Park, 2024; Vereycken et al., 2024). Across these studies, a first pattern emerges in the selective mobilisation of support actors and resources. SMEs frequently rely on consultants and technology providers to support the adoption of I4.0 solutions (Hansen et al., 2024; Santos et al., 2022), while more experienced firms also engage with public support schemes, particularly financial incentives, to sustain their transformation efforts (Kumar et al., 2023; Santos et al., 2022). In some cases, this engagement extends to collaborations with external partners in both research and development (R&D) and non-R&D activities, enabling firms to access complementary knowledge and resources and to embrace the commercialisation of innovation outcomes (Kim & Park, 2024). However, this mobilisation remains uneven, as many SMEs report difficulties in accessing public support due to bureaucratic constraints or limited awareness of available programmes (Cugno et al., 2021; Horváth & Szabo, 2019). They also struggle to identify suitable providers or experts, particularly in low-technology sectors (Estensoro et al., 2021; Müller et al., 2024) due to important expenses and prioritised short-term benefits (Hafeez et al., 2025; Zabudkina et al., 2024). Similar patterns can be observed in training-related support, where SMEs tend to privilege internal learning or technology-driven training over broader capability-building programmes, potentially limiting the development of their operators' long-term competences (Antonazzo et al., 2023; Da Roit & Iannuzzi, 2023).

Beyond these observations, only a limited number of studies analyses how SMEs concretely engage with external support, pointing towards emerging patterns of access and use practices. For instance, SMEs often approach competence centres with vague expectations and limited prior knowledge, seeking orientation, training, and opportunities for technological experimentation (Ietto et al., 2024). Their access to support may follow diverse and often informal paths, such as participation in networking events, recommendations, or encounters at regional fairs (Vereycken et al., 2024). More systematically, Menten et al. (2025) identify three modes of engagement with external resources: *external pursuing*, referring to targeted search for specific support; *external browsing*, reflecting exploratory scanning of available opportunities; and *internalising*, describing the integration of externally acquired knowledge within the firm. Far from occurring in isolation, these practices may be combined and sequenced over time depending on firms' evolving needs and levels of experience.

Taken together, these findings suggest that while SMEs actively engage with external support, these practices remain only partially and unsystematically analysed, unfolding within environments that are conceptualised in heterogeneous and often inconsistent ways, thereby limiting our understanding of their structure and functioning.

2.3. Conceptualising External Support Environments: from Fragmented Notions to I4.0 Regional Innovation Ecosystems

Building on these observations, while existing studies provide partial insights into how SMEs access and use external support, these studies rely on heterogeneous and often inconsistent conceptualisations of the environments in which these access and use practices unfold. Some scholars focus on specific organisations involved in supporting firms, such as competence centres and training institutions, that provide experimentation facilities, advisory services and capability-building programmes enabling SMEs to adopt I4.0 technologies (Antonazzo et al.,

2023; Prodi et al., 2022). Others examine them through innovation intermediaries – actors such as research institutes, technology providers, industry associations, and government – who identify digital transformation opportunities for SMEs and mobilise the knowledge, actors, and resources needed to realise them (Hafeez et al., 2025; Leckel et al., 2020). Another stream of research goes a step further, framing these environments through the notion of innovation ecosystems (IE), built on interdependent relationships among diverse actors who interact within a collaborative community aimed at generating shared value (Benitez et al., 2020; Boyer & Kokosy, 2024; Jiang et al., 2020). Yet, while these approaches highlight different dimensions of external support – whether the actors involved, the functions they perform, or the interactions connecting them – they rarely conceptualise this environment in relation to the policy origins of I4.0.

First introduced at the 2011 Hannover Trade Fair as a strategic vision for German manufacturing and later institutionalised through the "Platform Industrie 4.0" initiative, I4.0 sought to coordinate key innovation actors in supporting industry through advanced manufacturing technologies (Pfeiffer, 2017; Reischauer, 2018). As the narrative of the *fourth industrial revolution* gained global visibility, it progressively diffused beyond Germany and inspired similar innovation policies in other countries, where I4.0 was adjusted to local technological infrastructures and institutional contexts (Hervas-Oliver et al., 2023; Lund & Vildåsen, 2022). Within the European Union (EU), this diffusion translated into diverse national strategies combining public–private partnerships, digital infrastructures and capability-building programmes aimed at supporting firms – especially SMEs, given their economic importance – in I4.0 transformation (Hervas-Oliver et al., 2021; Teixeira & Tavares-Lehmann, 2022). Reflecting the growing mobilisation of EU structural funds for regional development (B. T. Asheim et al., 2011), Digital Innovation Hubs emerged to foster collaboration among local actors, facilitating I4.0 transition through aligning industrial interests, negotiating policies, and developing solutions (Hervas-Oliver et al., 2021; Sandulli et al., 2021). In line with this logic, some I4.0-oriented studies interpret external support environments through the lens of regional innovation systems (RIS), emphasising how regional institutions, knowledge infrastructures and industrial actors collectively shape the diffusion of digital technologies within specific local contexts (Hervas-Oliver, 2022; Sandulli et al., 2021).

Taken together, these observations suggest that conceptualising the environments supporting I4.0 transformation requires integrating insights from both IE and RIS perspectives (Gamidullaeva, 2018; Martins & Singh, 2023). The IE literature emphasises how heterogeneous actors, activities, and artifacts – including products, services, and tangible or intangible resources – align around a shared value proposition, highlighting the importance of their interdependence in materialising complex innovations (Adner, 2017; Granstrand & Holgersson, 2020; Jacobides et al., 2018). While relevant to I4.0's paradigm combining digital technologies and processes requiring coordinated stakeholder contributions, this perspective overlooks how such collaborations emerge and sustain. In contrast, the RIS literature explicitly addresses the role of regional institutions, governance arrangements and knowledge infrastructures in structuring innovation processes, emphasising how different sub-systems interact within territorially embedded spaces of learning and capability development (B. Asheim et al., 2016; B. Asheim & Gertler, 2005; Cooke, 2001). While aligned with I4.0's logic of diffusion strongly embedded in regional and national policy initiatives aimed at supporting SMEs' technological upgrading, this perspective pays less attention to I4.0 technological aspects through which emerging innovation fields evolve. Building on these complementary insights

and added values, this study conceptualises the external support environment of I4.0 transformation as an I4.0 Regional Innovation Ecosystem (I4.0 RIE) – a geographically embedded constellation of actors, artifacts, and activities organised around the collective objective of enabling I4.0 transformation.

Following Adner's (2017) perspective, ecosystem value is defined relative to a focal actor, which serves as the reference point for its analysis. In the context of I4.0, SMEs are typically positioned as the primary beneficiaries of such environments, as support mechanisms are largely designed to enable their technological upgrading (Hervas-Oliver et al., 2023; Lepore et al., 2023). However, studies often treat SMEs as relatively homogeneous actors, overlooking how their engagement with external support is enacted in practice. In SMEs, decision-making is often highly centralised and largely shaped by managers (Harney & Alkhalaf, 2021; Mintzberg, 1980), who play a key role in initiating and guiding innovation and digitalisation efforts (Lanzolla et al., 2021; Zoppelletto et al., 2023). This suggests that understanding how the value of I4.0 support environments materialises requires shifting attention from firms as abstract actors to the managerial processes through which these environments are engaged with.

2.4. Sense-Making Perspective on Managerial Engagement with I4.0 RIE

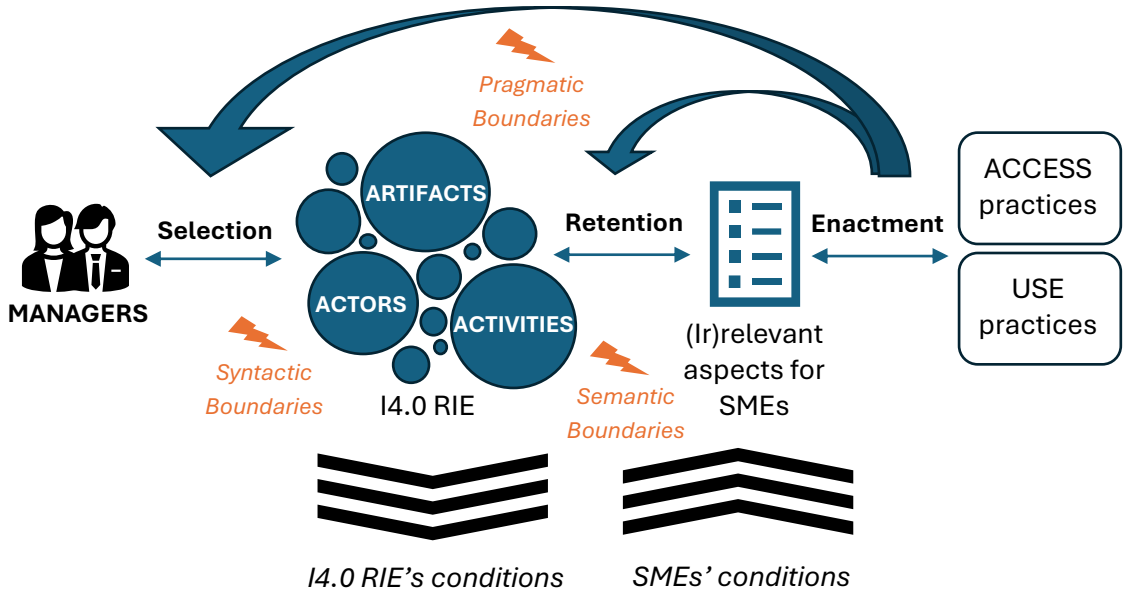
Adopting a managerial perspective on engagement with I4.0 RIE shifts the focus away from viewing this process as a set of predefined and predictable steps, towards understanding it as an interpretive and situated activity, in which the meaning and value of external support emerge through practice (Weick, 1995). Consequently, I4.0 RIE is treated as an environment that is continuously enacted through ongoing processes of sense-making, rather than as a fixed structure to which actors simply respond (Maitlis & Christianson, 2014; Weick, 1995). Sense-making can be analytically decomposed into three interrelated processes: selection, through which individuals extract cues to interpret their environment; retention, through which these interpretations are stabilised, adapted, or reconfigured in light of prior knowledge and organisational context; and enactment, through which interpretations are translated into concrete actions (Weick, 2004, 2009). While analytically distinguishable, these processes remain recursive and intertwined, as managers continuously move between interpreting, evaluating, and acting in response to evolving situations shaped by both SMEs' and I4.0 RIE's conditions (Cristofaro, 2022; Glynn & Watkiss, 2020). From this perspective, managers' engagement with I4.0 RIE can be understood as the ongoing and iterative sense-making process.

At the same time, such engagement rarely unfolds under homogeneous conditions, since managers' interactions with I4.0 RIE involve a diversity of actors, domains, and forms of expertise, which create discontinuities in how external support is provided and used (Martins & Singh, 2023; Weick, 1995). In innovation contexts, these discontinuities have been conceptualised as knowledge boundaries, stemming from the differentiated and specialised nature of knowledge distributed across actors (Caccamo et al., 2023; Martins & Singh, 2023). Prior research distinguishes syntactic, semantic, and pragmatic boundaries, associated respectively with challenges of transfer, translation, and transformation of knowledge (Carlile, 2002), and emphasises their role in shaping coordination across heterogeneous actors and domains. Concretely, syntactic boundaries relate to differences in language and information formats; semantic boundaries reflect divergent interpretations of the meaning and relevance of this information; and pragmatic boundaries arise from differences in interests, constraints, or priorities related to this information (Carlile, 2002, 2004). These boundaries introduce

varying degrees of complexity, ambiguity, and contestation (Carlile, 2004), which constantly influence how managers identify I4.0 RIE, assess its meaning and value for their SMEs, and translate these assessments into concrete actions.

Building on these insights, this study conceptualises managers' engagement with I4.0 RIE as a sense-making process continuously shaped by knowledge boundaries, SMEs' internal conditions and ecosystem dynamics (see Figure 1). This engagement emerges through iterative movements between selection – when managers identify and interpret existing actors, activities, and artifacts of I4.0 RIE; retention – when managers stabilise, adjust, or question these understandings by assessing their relevance for the SMEs; and enactment – when they translate these understandings into actions of accessing and using these understandings. These processes may evolve through the time and remain interrelated, as interpretations inform action, while enacted experiences, in turn, reshape subsequent interpretations (Weick, 1995). This conceptualisation provides the analytical framework for examining how managers engage with I4.0 RIE in the context of I4.0 transformation in SMEs.

Figure 1. Sensemaking-based analytical framework of SME managers' engagement with I4.0 RIE.



3. Methodology

3.1. Wallonia as an Empirical Setting

The Walloon Region (or Wallonia), located in the southern part of Belgium, provides a relevant empirical setting to illustrate I4.0 RIE's functioning, combining strong policy orientation towards digital and industrial transformation, and highly differentiated institutional architecture. As an example of *'multinational'* state where the delineation of innovation is rarely straightforward (Lundvall, 2016, p. 87), Belgium can be characterised as a coordinated market economy (Soskice, 1999), yet one in which coordination is distributed across multiple layers of governance. This configuration results from successive state reforms that have transformed a formerly unitary state into a federal system governed on federal, regional, and community levels, thereby generating a dense distribution of competences and often opaque institutional

landscape (Faniel et al., 2021). In Wallonia, this plays out through the coexistence of the French- and German-speaking Communities, alongside the Region itself (Faniel et al., 2021), which makes policy design for I4.0 dependent on both territorial and linguistic logics. The implementation of I4.0-orietned policies ensured through the Digital Wallonia strategy, with the public limited company Agence du Numérique coordinating initiatives under the Walloon Government and ensuring their alignment with regional strategies and European priorities (Gouvernement Wallon, 2025). More targeted programmes, such as *Industrie et Construction du Futur*, translate this strategy into sector-specific support combining different actors, activities and initiatives like *Made Different*[9] and *StartIA*[10] (SPW & Agence du Numérique, 2021).

This institutional configuration unfolds within a regional economy historically shaped by industrial development, which long positioned Wallonia as one of Europe's major manufacturing centres (Vandermotten, 1998). Industry still remains crucial for regional activity, particularly in the metalworking and metal processing sectors, the food industry, the glass, ceramics, brick and cement industries and the chemical industry (Vincent & Wunderle, 2002). This productive system is characterised by a dense entrepreneurial fabric composed of more than 80,000 private firms, of which 99.6% qualify as SMEs (AKT, 2024). At the same time, this industrial fabric is marked by a significant degree of external dependence, as many SMEs operating in Wallonia are integrated into multinational groups, leading to a partial dissociation between local production and centres of strategic decision-making (Vincent & Wunderle, 2002). This context justifies defining SMEs in this study primarily by their organisational size, with fewer than 250 employees, while recognising that their strategic autonomy may vary depending on their integration into larger corporate groups. Finally, recent evidence indicates that the adoption of I4.0 technologies like internet of things, artificial intelligence or robots among Walloon SMEs remains uneven and largely limited to isolated applications, with advanced and system-wide integration of these technologies still marginal (Agence du Numérique, 2025).

3.2. Data Collection

To examine how managers engage with I4.0 RIE, we were interested in capturing the practices they develop in Walloon industrial SMEs to select, interpret, and enact this external support environment. To do so, we decided to focus on managerial discourses by conducting semi-directive in-depth interviews. Organisational discourse analysis conceives discourse as a tool for meaning construction, where language is not just descriptive of social reality but instrumental in producing it (Fairhurst & Cooren, 2018; Grant & Hardy, 2004). In-depth interviews are thus widely recognised as suitable means for exploring sense-making (Fairhurst & Uhl-Bien, 2012; Johnson, 2002).

To structure the data collection, we developed an interview guide consisting of predominantly open-ended questions within a predefined set of themes (Djamba & Neuman, 2002). These covered the firms' I4.0 transformation experiences, their interactions with the external support, and the outcomes of these interactions. Respondents were primarily invited to narrate their experiences and perceptions about these themes. When the accounts remained implicit or

[9] Made Different is a public initiative funded by the government that supports companies through a pre-adoption programme focused on seven key transformation pillars. To be recognised as a Factory of the Future (FoF) or to win an award, a company must achieve a minimum score across each of these seven dimensions.
[10] Start IA is an initiative designed to help companies prioritise, assess the feasibility of their AI projects, and develop a tailored action plan with support from specialised experts.

insufficiently detailed, additional probing questions were used to clarify the types of support considered, the ways in which they were approached, and the reasons underlying their engagement or non-engagement. This approach allowed the collection of rich empirical data while ensuring sufficient analytical depth regarding how support mechanisms were identified, evaluated, and acted upon. In line with ethical standards, all participants were fully informed about the aims of the study, the voluntary nature of their participation, and the confidentiality of their responses. The informed consent was obtained prior to data collection, and data were handled in compliance with institutional and legal requirements.

The interviews lasted approximately 50 minutes and were conducted either face-to-face or online, depending on participants' availability. We adopted a purposive sampling strategy focused on companies employing fewer than 250 employees, operating in industrial sectors and being at different stages of I4.0 transformation rather than focusing exclusively on already advanced adopters. To capture this variation, companies were selected across different levels of I4.0 maturity, understood as the extent to which I4.0 technologies are adopted and integrated into organisational practices, ranging from initial exploration (beginning) to partial and non-systemic adoption (emerging), to sustained and coordinated implementation (advanced). This categorisation was informed by prior project data on firms' technological practices and iteratively refined through interview material, allowing for cross-validation of each firm's I4.0 maturity.

Within each firm, respondents were selected based on their involvement in strategic and operational decision-making, primarily targeting CEOs and senior managers, as these actors play a central role in shaping digital transformation in SMEs. This focus was aligned with the study's analytical prism, where the engagement with I4.0 RIE unfolds through managers' interactions with support mechanisms (Adner, 2017). Where possible, multiple managerial perspectives were sought within the same firm to capture intra-organisational variation in interpretations. However, access to more than one respondent depended on companies' organisational characteristics such as size, hierarchical structure, and participants' availability, resulting in two respondents being interviewed in three firms. Aligned with the study's focus on managerial sense-making, this pragmatic approach (Bryman, 2013) was privileged to capture potentially divergent interpretations within the same organisational context. These accounts were therefore analysed as complementary rather than aggregated into a single firm-level position. Data collection continued until no new patterns emerged regarding managers' ways of engaging with I4.0 RIE, indicating empirical saturation. The final sample comprised 25 respondents from 22 SMEs (see Table 1).

Table 1. Sample of the study.

Participants		**Companies**			
Name	**Function**	**Size**	**Sector**	**Ownership**	**I4.0 maturity**
Manager 1	CEO	75	38 Waste collection, treatment and disposal activities	Family	Advanced
Manager 2	CEO	45	33 Repair and installation of machinery and equipment	International	Advanced
Manager 3	Manager	130	22 Manufacture of rubber and plastic products	International	Advanced

Manager 4	CEO	115	20 Manufacture of chemicals and chemical products	International	Advanced
Manager 5	CEO	135	20 Manufacture of chemicals and chemical products	International	Advanced
Manager 6	CEO	85	21 Manufacture of basic pharmaceutical products and pharmaceutical preparations	Family	Emerging
Manager 7	CEO	44	25 Manufacture of fabricated metal products	Family	Beginning
Manager 8	CEO	50	21 Manufacture of basic pharmaceutical products and pharmaceutical preparations	Family	Advanced
Manager 9	Manager				
Manager 10	CEO	90	39 Remediation activities and other waste management services	International	Emerging
Manager 11	CEO	33	26 Manufacture of computer, electronic and optical products	Family	Advanced
Manager 12	Manager	100	22 Manufacture of rubber and plastic products	Family	Advanced
Manager 13	CEO	70	27 Manufacture of electrical equipment	Family	Advanced
Manager 14	CEO	18	26 Manufacture of computer, electronic and optical products	International	Advanced
Manager 15	CEO	45	25 Manufacture of fabricated metal products	Family	Emerging
Manager 16	Manager				
Manager 17	Co-CEO	45	25 Manufacture of fabricated metal products	Family	Advanced
Manager 18	Co-CEO				
Manager 19	CEO	8	38 Waste collection, treatment and disposal activities; materials recovery	Family	Advanced
Manager 20	CEO	59	10 Manufacture of food products	Family	Beginning
Manager 21	CEO	20	38 Waste collection, treatment and disposal activities	Family	Beginning
Manager 22	CEO	15	25 Manufacture of fabricated metal products	Family	Beginning
Manager 23	CEO	125	27 Manufacture of electrical equipment	Family	Advanced
Manager 24	CEO	100	28 Manufacture of machinery and equipment	International	Advanced
Manager 25	CEO	19	38 Waste collection, treatment and disposal activities; materials recovery	International	Beginning

3.3. Data Analysis

In line with organisational discourse analysis, interviews were recorded, transcribed, and coded through a combination of thematic, membership, and narrative techniques (Boje, 2001;

Fairhurst & Uhl-Bien, 2012; Jayyusi, 2014). The analysis followed an abductive and iterative logic, allowing us to move back and forth between empirical material and theoretical constructs, in line with the Gioia methodology (Gioia et al., 2013) and sense-making processes (Weick, 2004, 2009). Coding was structured around the three interrelated processes of selection, retention, and enactment, which underpin the analytical framework of this study for examining managers' engagement with I4.0 RIE (see Figure 1). To capture each process as a *"static picture of a dynamic phenomenon"* (Gioia et al., 2013, p. 22), we focused on analysing its outcomes, moving iteratively from in-vivo expressions to first-order concepts, second-order themes, and aggregate dimensions, thereby allowing patterns to emerge while remaining theoretically informed (see Table 2). To enhance reliability and consistency of the analysis, the first author conducted the full coding, which was iteratively discussed with two co-authors throughout the analysis process (Gioia et al., 2013; Saldaña, 2016). These discussions primarily focused on the interpretation and selection of illustrative quotes, particularly for retention and enactment processes, where meanings were more complex and context-dependent (Cristofaro, 2022; Weick, 1995). In cases where interpretations required further clarification, co-authors referred back to the full transcripts of the corresponding interviews. Discrepancies were discussed and resolved through consensus, ensuring consistency in the elaboration of the final coding structure.

Table 2. Data structure of managers' engagement with I4.0 RIE.

1st Order Concepts ***(quotes/experiences)***	**2nd Order Themes** ***(evaluation logics)***	**Aggregate Dimensions** ***(Sense-making process outputs)***
"subsidies", "grants", "calls for projects"; "consultants", "clusters", "training centres"; "ERP", "robots", "audit tools"	Actors, activities, and artifacts of I4.0 RIE	Support mechanisms (selection outcomes)
"extremely complicated", "so daunting for SMEs, "are not necessarily ready", "some things available", "need one point of contact"	Positive and negative experiences of accessing support mechanisms	Accessibility of support mechanisms (retention outcomes)
"experienced and bring great added value", "the centres cannot be ready to train us", "they don't listen", "good training", "hundreds of forms to fill out"	Positive and negative experiences of using support mechanisms	Usability of support mechanisms (retention outcomes)
"I found a coaching service", "I was offered a free 5-6 day analysis of my SME", ", we always go through our external service provider", "A friend recommended it to me"	Patterns of approaching and entering support mechanisms	Access tactics (enactment outcomes)
"we are working with a consultant on our processes to generate data", "instead of filling out forms, I take a look, show it to him", "Their solution proposal was not …That's why we turned to…", "I tried for a day, couldn't figure it out"	Patterns of mobilising and exploiting support mechanisms	Use tactics (enactment outcomes)

To capture selection, we examined how managers identified and interpreted relevant elements of I4.0 RIE through their references to actors, activities, and artifacts. Drawing on membership categorisation analysis (Jayyusi, 2014), these references were first coded as first-order concepts reflecting how managers identified different elements of the ecosystem in their discourse. These concepts were then grouped into second-order themes based on shared purposes and functions, leading to aggregate dimensions corresponding to distinct support mechanisms. The support mechanisms were conceptualised as analytical groupings to organise heterogeneous elements of the I4.0 RIE according to the nature of support associated with them in managers' accounts.

Retention was analysed, focusing on how managers stabilised, adjusted, or questioned their initial interpretations by assessing the meaning and relevance of support mechanisms for their SMEs. Building on thematic analysis, first-order concepts captured discourse statements regarding managers' experiences, which were then grouped into second-order themes reflecting recurring logics of positive and negative evaluation (Braun & Clarke, 2012). These evaluations were structured along two interrelated dimensions – accessibility and usability – capturing how managers assessed both the ease of approaching support mechanisms and their perceived effectiveness once engaged. This allowed us to identify consistent patterns of positive and negative perceptions across support mechanisms.

Finally, enactment was examined, focusing on how managers recounted sequences of action, focusing on how interpretations were translated into concrete practices of access and use of I4.0 RIE (Boje, 2001). First-order concepts captured the accounts of concrete actions of approaching and entering support mechanisms. These were grouped into second-order themes reflecting common patterns of action, which were then aggregated into two sets of dimensions corresponding to access tactics and use tactics. Access tactics refer to patterned ways through which managers approach and activate support mechanisms, while use tactics capture how managers mobilise these mechanisms in practice.

4. Results

Managers' accounts reveal that engagement with the I4.0 RIE develops through concrete experiences with actors, activities, and artifacts encountered over time, rather than through a predefined understanding of the ecosystem. Across cases, managers identify familiar elements of the ecosystem – often linked to specific needs or prior interactions. These elements are progressively evaluated in terms of their accessibility and usability for the firm, before being mobilised in distinct ways depending on the situation. The following sections trace this progression by examining how managers organise these elements into support mechanisms, how they assess their relevance, and how they translate these assessments into practices of access and use.

4.1. Support Mechanisms of I4.0 RIE

The understanding of the I4.0 RIE appeared heterogeneous across cases, reflecting the variety of elements managers encountered in their experience. In most instances, managers referred to familiar actors, activities, or artifacts, describing the needs they address and how they operate in practice. These elements were rarely considered in isolation, but rather evoked through concrete situations and prior interactions. To capture this diversity while making it analytically tractable, these references were regrouped into five distinct support mechanisms, introduced below, defined as analytical groupings of I4.0 RIE elements based on the nature of support associated with them in managers' accounts. As such, these mechanisms reflect the

outcomes of the selection process, through which heterogeneous elements of the ecosystem are organised into functionally meaningful categories.

A first recurrent set of references relates to activities aimed at fully or partially covering companies' expenses related to I4.0 transformation. Almost all respondents mentioned such activities, typically provided by public and private bodies in the form of subsidies, grants, incentives, or reimbursement of consultancy costs, notably through public funding schemes, Proof-of-Concept funding, or regional programmes. Conceptualised as a financial support mechanism, this grouping targets specific costs associated with technology acquisition, solution development, or consultancy services.

Alongside this, managers frequently referred to activities supporting the development and acquisition of digital and technological solutions. Regardless of their SMEs' I4.0 maturity level, a majority of respondents reported engaging with such support, most often in the form of consultancy, but also through solution design, prototyping, testing environments, or system integration services provided by technology providers, suppliers, and integrators. Conceptualised as a technical support mechanism, this grouping is mobilised at different stages of transformation, from identifying relevant tools to implementing automation solutions or developing customised applications.

For managers at earlier stages of I4.0 or engaged in partial and non-systemic transformation, the ecosystem was often associated with activities aimed at structuring decision-making and guiding transformation efforts. These less technology-oriented forms of support were typically provided by consultants, independent advisors, or organisations designated by public programmes. Conceptualised as a guiding support mechanism, this grouping includes audit programmes, diagnostic services, digital maturity assessments, and the development of transformation roadmaps.

In contrast, managers engaged in more advanced stages of I4.0 transformation more frequently associated the ecosystem with opportunities to connect and exchange with other actors. These activities, aimed at fostering knowledge sharing and collaboration, were mainly ensured by clusters, professional associations, and other public and private organisations involved in regional innovation. Conceptualised as a networking support mechanism, this grouping includes events, workshops, fairs, peer exchanges, collaborative projects, as well as recommendations and referrals. It is distinguished by the possibility of membership, particularly in clusters and professional associations, which provides access to more sustained interactions.

Finally, some managers referred to activities aimed at developing skills and knowledge related to I4.0. These activities, often tailored to specific needs – such as process-related learning, technological training, or soft skills development – were provided by vocational training centres, competence centres, technology vendors, and other organisations involved in regional innovation. Conceptualised as an educational support mechanism, this grouping includes seminars, certifications, forums, and structured programmes.

Importantly, these mechanisms go beyond reflecting discrete components of the ecosystem. Initiatives such as *Made Different* illustrate how a single artifact can be associated with multiple forms of support in managers' accounts, as it brings together financial, guiding, and educational components. Similarly, consultants and technology providers may be associated with several forms of support, as their interventions often combine technical, guiding, and

educational dimensions in the context of solution integration. Taken together, these findings highlight the inherently fragmented and overlapping nature of the I4.0 RIE in Wallonia, where the same actors, activities, and artifacts can be associated with multiple forms of support depending on the context of engagement.

4.2. Perceptions of I4.0 RIE Support Mechanisms

Managers' accounts further reveal how these support mechanisms are evaluated in practice, based on their accessibility and usability. Reflecting the outcomes of the retention process, these evaluations vary depending on prior experiences, organisational conditions, and the specific context in which support is encountered.

4.2.1. Perceived Accessibility

Access to support mechanisms was most frequently described as challenging, particularly in the case of financial support. While one manager referred to *"small grants that are easy to get" (Manager 19),* many others described it as *"extremely complicated"* (Manager 25). Managers often highlighted the difficulties to identify *"who to contact"* (Manager 17), explaining that they *"don't get enough assistance for that"* (Manager 7). Legal constraints regarding European definition of SME[11] created further barriers. This was particularly emphasised by managers of more advanced firms integrated into international groups, as one manager explained: *"Even though we are a Belgian SME, because we are part of an international group, there are many things we are not entitled to"* (Manager 4). Others criticised the rigidity of local authorities being *"too strict about these things, since in France, the interpretation of the rule is different"* (Manager 2), adding with frustration that public authorities *"always want to be more Catholic than the Pope"* (Manager 13). Although some agreed with this logic, as their group provides internal financial support, others pointed to unfairness: *"In everyday life, it's not a group, it's just me, and I can just look up and ask them for permission to do this or that"* (Manager 13). Calls for proposals were also as difficult to access. These concerns were especially expressed by managers of smaller firms at earlier stages of I4.0 transformation, describing them as *"so daunting for SMEs, that not many of them go for it"* (Manager 21), with concerns about fairness in allocation, since managers are *"always informed at the end"* (Manager 7) and feel that *"it's always the same companies that get as much aid as possible"* (Manager 21).

Beyond financial support, access to technical support revealed more contrasted experiences. When solutions were standardised and locally available, managers described access as relatively straightforward. One noted: *"It's easy, when you are looking for an ERP system: the market is dominated by two or three companies"* (Manager 6), while another highlighted the advantage of proximity: *"Having them just a stone's throw away is fantastic – it's quick and efficient"* (Manager 19). However, these positive experiences contrasted with the difficulties encountered when seeking tailored solutions. Managers reported challenges in identifying *"companies that customise their products to make it suitable for the application you want"* (Manager 1), sometimes spending *"hours trying to find programmes compatible with what we do"* without success (Manager 21). In some cases, access was further constrained by a mismatch between available solutions and SMEs' maturity levels, as some firms *"are not necessarily ready"* (Manager 5) or *"have not yet gone through all the previous stages"* (Manager 15) to benefit from *"high-quality 4.0 services"* sold by regional actors (Manager 3).

[11] The European Union classifies a business as a SME if it employs fewer than 250 people and meets at least one of the following financial criteria: an annual turnover of up to €50 million or a balance sheet total of no more than €43 million (European Commission, 2003).

While these difficulties relate to the availability and suitability of solutions, access to guiding support was more often described as structurally fragmented. Most managers described the access as overwhelming because of *"different people [are] all offering the same thing"* (Manager 3), with *"the same projects going through two different organisations"* (Manager 21), creating a sense of dispersion. This led to a perceived need for simplification, as they *"need one point of contact, not twenty-five"* (Manager 10). For some, this situation was reinforced by the lack of proactive outreach, since *"the information is available if manufacturers seek it out"* (Manager 23), yet many *"don't seek it out"* themselves (Manager 24). This fragmentation was often related to the complexity of the Belgian institutional system, described as involving *"many structures and layers that clash a little and create this effect"* (Manager 20), with *"lots of things being decided at lots of levels", which is "typically Belgian"* (Manager 11). As a result, managers often faced difficulties similar to those encountered with financial support, expressing willingness to *"find a company that can guide me"* but struggling *"know who the right people are to talk to"* (Manager 6).

In comparison, access to networking support was described as both enabling and overwhelming. Some managers referred to an excess of information, explaining that they receive *"three emails about three different workshops"* (Manager 2), which creates the impression that *"everyone does everything"* (Manager 19). At the same time, others emphasised that access becomes easier once familiarity with the ecosystem is established, particularly among managers of more advanced SMEs with prior engagement in the ecosystem. For these managers, it is a matter of learning how the system works – *"the more I participate, the more I know who I need to continue working with"* (Manager 9) – and being recognised within it, since *"when you are well known in the ecosystem, there is a lot of networking going on"* (Manager 2).

Finally, access to educational support was less frequently discussed, as many managers explained that learning activities were primarily organised internally, often in collaboration with long-term technology suppliers or driven by managerial initiatives, and oriented towards the use of newly implemented solutions. When mentioned, however, access revealed specific territorial and contextual barriers. Some managers pointed to regional imbalances, particularly between French-speaking and German-speaking communities. One explained that *"there are some things available to the rest of Wallonia, but not in the German-speaking part, it's a shame"* (Manager 11). Another described cultural and linguistic barriers, noting the difficulty of *"integrating people who have been trained in another city"* when company is *"in a French-speaking region but have a German-speaking mentality"* (Manager 18).

4.2.2. Perceived Usability

Use of support mechanisms revealed more contrasted experiences, depending on how they were mobilised in practice. In this context, financial support was often described as a key enabler for initiating I4.0 projects, particularly by reducing the cost barrier associated with early investments, as highlighted by several managers. One recalled: *"We started thanks to incentives at the regional level"* (Manager 1), while another insisted on the importance of *"the analysis offered free of charge by the Walloon Region",* explaining: *"If tomorrow someone told me I had to spend €3,000 or €4,000 on an analysis, I don't know if I would do it"* (Manager 21). These positive experiences were accompanied by strong criticisms regarding how financial support is used and distributed. Some managers argued that *"this whole constellation of consultancies"* became the main beneficiaries (Manager 5), leaving firms with limited direct value, since *"the budget is spread across schools and universities to do all the analysis"*

(Manager 19). Others doubted the system itself, describing certain initiatives as *"just empty shells run exclusively by politicians to put together a package of subsidies"* (Manager 20), or suggesting that government involvement was *"just to make money"* (Manager 22). Practical aspects of using funding schemes were also perceived as burdensome, with submission processes described as *"truly horrific"* (Manager 10) and *"disturbing because of the changes to the rules of the game midway through"* (Manager 2). Managers referred *to "hundreds of forms to fill out"* (Manager 22). These often required *"to send paper letters with a handwritten signature",* sometimes requiring *"easily lose 3–6 months"* (Manager 19). As one noted: *"They encourage us to digitalise, but perhaps they should do the same"* (Manager 17).

While financial support primarily shaped the conditions for initiating projects, the use of technical support raised issues related to the actual integration of solutions. A recurrent concern among managers was the misalignment between proposed solutions and SMEs' specific needs, a difficulty more frequently reported by managers from firms that had not yet reached advanced levels of I4.0 integration. Some explained that *"the real needs of the company are not sufficiently taken into account"* (Manager 15), as experts *"don't listen, and they work a lot with big companies"* (Manager 21). As a result, managers described situations where they invested time and resources into solutions that were *"not really suited to the company's needs"* (Manager 5), leading to tools with which they *"won't do anything"* (Manager 3), or more broadly *"without anything coming of it"* (Manager 9).

In parallel, the use of educational support revealed a more ambivalent pattern. On the one hand, managers appreciated programmes that provided tangible demonstrations of *"what AI, IoT and Industry 4.0 can offer"* (Manager 23) included in certain educational programs, particularly given that *"SMEs don't have time to keep up with technological developments"* (Manager 15). On the other hand, several respondents expressed strong criticisms of existing training structures. Despite being described as *"well equipped"* and staffed with *"well-trained teachers"*, vocational training centres were sometimes seen as reflecting *"the failure of the education system in Belgium"* (Manager 20), particularly in their inability to align programmes with industry needs. Their educational offers were criticised for lacking knowledge of profession-specific issues – *"they don't know anything"* because *"it is very complex"* (Manager 22) – or for being outdated, as they *"cover things"* already implemented in firms (Manager 22). In this context, some managers preferred to rely directly on technology suppliers, explaining that *"the centres cannot be ready to train us on things that came out two days ago and that no one knows about yet"* (Manager 11).

Compared to these tensions, guiding support was more consistently perceived as valuable when effectively mobilised. Many managers highlighted the benefits of audit programmes, which provided an opportunity to *"step back a little to decide what our next priorities will be"* (Manager 3), especially in situations where *"there are many things you don't see anymore"* when *"you have your nose to the grindstone"* (Manager 13). The perceived usefulness of this support, however, depended strongly on the profile of consultants involved. Managers valued experts who are *"experienced and bring great added value"* (Manager 3), *"experienced and pragmatic"* (Manager 13), preferably *"at the end of their careers, in tune with what is happening today"* (Manager 21). In contrast, younger consultants were sometimes viewed as lacking credibility, as they *"think they know everything, but end up with dubious theories"* (Manager 3) and *"never got their hands dirty"* (Manager 13). Beyond experience, managers were attentive to consultants' intentions, noting that some *"offer a diagnosis to propose their own solutions*

and not those of their competitors" (Manager 1) or *"include people who sell programmes and automation systems"* (Manager 21).

Finally, networking support stands out as the only category unanimously described as beneficial in use. Managers consistently referred to it as a key resource for identifying relevant contacts, enabling them to be *"in touch with lots of other companies"* (Manager 2) and *"identifying stakeholders who are available to assist us in developing specific area"* (Manager 23). For many, this became a turning point, as when they *"have questions about one project or another"* (Manager 12), they can *"call five or six people to find another contact"* (Manager 19). Beyond facilitating connections, networking was also valued for *"benchmarking, sharing knowledge, and undertaking joint projects"* (Manager 24), and for making the decision to start I4.0 transformation *"much easier"* (Manager 13).

Across cases, these evaluations rarely converged towards a uniformly positive or negative view of the ecosystem. Instead, managers described mixed perceptions shaped by sequences of uneven experiences across different forms of support. For instance, one manager appreciated the availability of regional diagnostics while criticising the lack of fairness and transparency in access to funding schemes (Manager 21). Another described the proximity of technical providers as efficient, et regretted the difficulty of finding solutions adapted to specific needs (Manager 1). Similarly, one manager considered vocational centres well equipped, while simultaneously criticised for their inability to prepare younger generations for industrial work (Manager 20). Other managers valued awareness-raising initiatives but found them poorly aligned with the complexity of their activity (Manager 13) or described networking as a valuable source of contacts while feeling overwhelmed by fragmented communication channels (Manager 19). Across these accounts, a recurring pattern emerges: access may appear open, yet remain constrained by information gaps, eligibility conditions, or administrative burdens, while use generates value only when support is adapted to firms' needs and sustained over time, resulting in uneven and sometimes inconsistent experiences across support mechanisms (Table 3).

Table 3. Managerial perceptions of I4.0 RIE support mechanisms' accessibility and usability.

Support mechanism	Perceived accessibility	Perceived usability
Financial	(+) Presence of multiple grants easy to get (-) Lack of assistance in finding the right person (-) Limited access because of European definition of SMEs (-) Inequal access to calls for proposals	(+) Useful starting point (-) Wrong targets to be supported financially (-) Ambiguous intentions of budgets (-) Laborious and insufficiently digitalized process of application
Technical	(+) Reachable standard and local solutions (-) Lack of customisable tools suppliers (-) Gap between solutions and SMEs' maturity	(-) Lack of attention to the needs, leading to incomplete or abandoned outcomes
Educational	(-) Regional mismatch in terms of information spreading	(+) Practical demonstrations of new technologies

	(-) Linguistic and cultural mismatch of training programs	(+) Well-equipped programs of vocational training centres (VTC) (-) VTC are the sign of failed education system (-) Lack of programs tailored to profession particularities in VTC (-) Lack of knowledge about cutting-edge technologies in VTC
Guiding	(-) Redundant and fragmented offers (-) Lack of proactive offers (-) Difficulties in finding the right contact person to guide	(+) Audits as a chance to step back and rethink priorities (+) Experienced experts as consultants (-) Young and inexperienced consultants (-) Biased offer of expertise, pushing to buy the solutions
Networking	(+) Familiarity with the ecosystem makes access easier (-) Too much information (-) No mapping or guidance for newcomers entering the ecosystem	(+) Point of contact to find right solution (+) Tracking tool for novelties (+) Starting point in I4.0 transformation (+) Source of joint projects

4.3. Practices of Accessing and Using I4.0 RIE Support Mechanisms

Beyond how support mechanisms are identified and evaluated, managers also describe how they access and use them in practice, reflecting the outcomes of the enactment process. These practices do not align systematically with specific types of support mechanisms. Instead, similar ways of accessing and using support were observed across different mechanisms, suggesting that these practices are transversal rather than tied to the nature of a given support.

4.3.1. Access Tactics

The following access tactics capture how managers engage with the I4.0 RIE when initiating contact with support mechanisms, reflecting diverse situations, intentions, and ways of accessing support in practice.

4.3.1.1. Aligned Problem-Solving

The most frequently observed access tactic corresponds to an aligned problem-solving logic, in which managers engage with the I4.0 RIE to address a clearly identified internal issue. In such cases, support is sought when a direct match exists between a predefined need and the assistance provided by a given mechanism.

This logic was particularly visible when firms faced specific skill gaps that constrained technological progress or daily operations. In these situations, educational support was mobilised as a targeted response. For instance, Manager 3, faced with the burden of digital transformation, searched for structured guidance in vocational training centre: *“An IT project has a beginning but never an end – it's hell. So, I found a coaching service that helped me get organised”.* Similarly, Manager 7 engaged with a training programme to address recruitment challenges: *“We decided to participate at a support programme that trains machinists who we take on as interns and then, if they are suitable, we recruit them”.* In both cases, the aligned problem-solving logic was triggered by a clearly defined gap, and the selected support directly corresponds to that need.

A similar pattern could be observed in the mobilisation of guiding and technical support, often involving consultants or integrators. Here, managers first identified a precise technical limitation – such as difficulties in data usage, process automation, or system integration – and then sought external expertise offering a fit-for-purpose solution. As Manager 6 explained regarding ERP data usage: *"Since we didn't know how to retrieve it, we decided to work with a consultant to address this issue".* This illustrated a sequence in which problem identification preceded engagement, and support was selected based on its ability to resolve that specific issue.

Financial support was also accessed through this aligned logic, particularly when it enabled the implementation of already defined projects. Rather than being sought in abstraction, funding instruments were mobilised to support targeted actions, such as feasibility analyses or solution development. For instance, one SME entered the *Proof-of-Concept (POC)* programme primarily to partially reimburse expert costs, with Manager 17 explaining: *"We went through a POC subsidised by Digital Wallonia, to get funding to test our idea for AI application, because otherwise it would have been too much for us to finance ourselves".* In another case, after failing to identify a suitable provider for waste detection, Manager 21 initiated the development of a solution through a publicly supported consortium: *"I decided to apply for an incentive to develop the programme, as I had not succeeded to find it anywhere".* In these cases, financial support operated as a pragmatic enabler of a predefined course of action.

Finally, this logic also extended to more complex forms of engagement, such as participation in public programmes combining several types of support. Initiatives such as *Made Different* were mobilised when managers sought to address a clearly articulated strategic question, such as assessing transformation priorities. As Manager 8 explained: *"It started with a need on our part to understand whether we were investing in the right strategic actions."* Even in these multi-actor configurations, access remained anchored in a predefined problem, with support mechanisms selected for their perceived ability to provide a direct and relevant response.

4.3.1.2. Pragmatic Repurposing

In contrast to aligned problem-solving, pragmatic repurposing refers to situations in which managers engage with the I4.0 RIE without an initial direct match between their needs and the intended purpose of available support mechanisms. While a concrete problem or objective may be present, the support is accessed and subsequently adapted or selectively followed to serve firm-specific priorities not originally foreseen by its providers.

This logic was particularly visible in the mobilisation of combined support mechanisms offering guidance, knowledge, and funding. In many cases, managers reinterpreted these programmes by prioritising specific components – most often financial incentives – over their intended focus on guidance or capacity building. Reflecting on his decision to engage with the *Made Different* program, Manager 21 admitted that the financial incentive was the main driver: *"It was because I was offered a free 5-6 day analysis of my SME that I agreed to do it".* Manager 9 joined the *Start IA* program primarily to secure funding, despite already having a defined idea and technical partner, explaining: *"Let's be honest, it was to get funding, because I had been asking for this for a year".* Similarly, several others cited the opportunity to access free audits, engineer time, or pilot subsidies as their main reason to participate was accessing these programmes to test ideas or reduce internal resource commitments rather than to follow their original logic.

In other cases, support mechanisms were repurposed to serve objectives unrelated to their initial design, such as employer branding and visibility in a competitive labour market. Manager

7 explained that the main motivation for participating in *Made Different* was to receive the Factory of the Future (FoF) label in order to attract new workers: *"It was free publicity in the region to encourage people to come and work here. Since it's difficult to find operators, the label will send a message: 'They're investing, the team is young, it's great, we have fun, it was fantastic'".* In this case, the initiative was accessed as a tool to strengthen the company's local image and recruitment capacity, rather than as a transformation pathway.

Finally, some managers enrolled in institutional programmes to access a complementary external perspective rather than to initiate or structure transformation process. Here, support was used as a validation or benchmarking device for processes already underway. Manager 14 described that participation in *Made Different* provided *"a complementary way of looking at our transformation, which was already well underway, and of obtaining expertise and an audit of what we had done",* with the FoF label perceived as *"the icing on the cake".* These cases illustrated how support mechanisms' pre-existing trajectories were reinterpreted and reoriented, with managers creating a functional match ex post rather than relying on an initial alignment.

4.3.1.3. Relational Prioritising

SMEs' managers who followed relational prioritising logic accessed support from the I4.0 RIE primarily through existing relationships, relying on confidence built through prior collaboration – a pattern more frequently observed among managers with prior experience and established relationships in the ecosystem. While a need could still be identified internally, the choice of support was driven by the availability of proven partners rather than by a search for the best operational or technical fit.

This logic was particularly visible in the mobilisation of technical support. Managers deliberately chose to work with service providers they had already known and relied on for specific projects. In one case, Manager 18 explained how their ERP-related developments were always assigned to a proven external partner who was a former colleague: *"For everything related to our ERP programming, we always go through our external service provider, with whom we have worked extensively. He was the workshop manager at our company at the time, which means he is familiar with the production constraints we may encounter. He is not an IT specialist".* Here, faith in the individual's knowledge of the company's operations outweighed formal expertise or alignment with I4.0 standards. Similarly, Manager 7 described adapting their ERP with the original supplier: *"To develop very specific features for our ERP, we work with the company that provides the ERP. We have a very good understanding with them".* Rather than searching for providers offering new solutions, these managers prioritised relational continuity with actors who understood their context.

In some cases, these relationships even reversed the direction of engagement, with proven partners initiating projects. As Manager 19 explained, a long-standing partner directly proposed collaboration to test new digital capabilities: *"When our partner learned about our situation, he directly reached out to us, as he wanted to try out digital process and product twins on us".* A similar dynamic appeared in the case described by Manager 24, where process revision was initiated by a subcontractor: *"Our subcontractor, with whom we have a long-standing relationship, began working with a private consulting firm to review their manufacturing process. As our two businesses are closely linked, we took this step with them".* In these situations, relational proximity acted as the primary entry point into new projects, with access shaped less by internal search than by the continuity of existing ties.

4.3.1.4. Exploratory Search

In contrast to the previous access tactics, exploratory search refers to situations in which managers engage with the I4.0 RIE without a clearly defined project or solution in mind. In these cases, support is accessed to explore possibilities, stimulate reflection, or generate new directions when the problem remains ambiguous or evolving.

This logic was often associated with the mobilisation of combined support mechanisms offering guidance, funding, and educational resources. Managers engaged proactively with such programmes to test assumptions or initiate reflection processes. As Manager 1 explained: *"We responded to a call from the Walloon Region's 'StartIA' programme with the aim of conducting a diagnosis within the company to see if AI could bring something to the company".* Here, support was accessed as a diagnostic device, enabling managers to explore potential opportunities without a predefined strategy.

In other cases, exploratory engagement emerged more reactively, triggered by external stimuli rather than deliberate search. Managers described engaging with maturity assessments, digital audits, or research initiatives after being exposed to them, often without prior intention. Manager 2 recalled how an unsolicited self-assessment tool prompted internal reflection and subsequent engagement: *"We received an online self-assessment to gauge our maturity, and we saw that there were a whole series of things we didn't have. We said to ourselves that if we wanted to improve the company, we had to do it".* In this case, the support made the problem visible, initiating a process of internal realignment. Similarly, exploratory engagement could be driven by informal recommendations or low-cost opportunities. Manager 22 described joining a technology-oriented network following a friend's suggestion: *"A friend recommended it to me, so I decided to give it a try. Plus, it was not very expensive".* Here, the decision to access support was triggered by a willingness to explore, learn, and remain connected to emerging opportunities, rather than a defined need.

Table 4. Managerial tactics to access I4.0 RIE support mechanisms.

Ecosystem access path	Manner of access	Reasons	Managers' motto	Examples of support
Aligned problem-solving	Support is accessed to address a clearly defined internal need, with managers seeking mechanisms that directly match this need and align with their intended purpose.	Fill internal skills gap Resolve identified technical issues Access fit-for-purpose funding	*"We access the support for exactly what it is meant to do."*	Vocational training programmes Technology providers and integrators Subsidies and incentive schemes Public audit and diagnostic programmes
Pragmatic repurposing	Support is accessed without an initial direct match to a defined need, and is then adapted to serve firm-specific priorities.	Enhance employer branding Reduce project costs Validate internal transformation efforts	*"We access the support and make it fit our needs."*	Public audit and diagnostic programmes

Relational prioritising	Support is accessed primarily through proven, long-term partners, with decisions driven by loyalty or familiarity rather than technical relevance.	Rely on proven service providers Respond to partner-led initiatives Maintain relational continuity	*"We access the support because we have confidence in its actors."*	Technology providers Digitalisation programs
Exploratory search	Support is accessed to explore options, reflect, or assess potential directions in situations where the problem is still undefined or emerging.	Identify opportunities Trigger reflection Test potential use of technologies	*"We access the support because we're not sure what we need and this helps us think."*	Public IA assessment initiative Public digital audit programs Professional networks

4.3.1.5. Towards typology of managerial access tactics

Across cases, these access tactics show that engagement with the I4.0 RIE can be driven by either clearly defined needs or more exploratory intentions. While some managers access support to address specific problems in alignment with the intended purpose of support mechanisms, others adapt available support to their own priorities, rely on steady relationships, or engage with support as a way to explore and reflect. These different logics reflect a variety of underlying motivations, ranging from operational constraints and financial considerations to reputation-building, relational continuity, and experimentation. They are also associated with diverse forms of support, including training programmes, consultancy audits, funding schemes, networks, and collaborative pilot projects, illustrating how support mechanisms are interpreted and accessed in different ways by SMEs' managers (Table 4).

4.3.2. Use Tactics

The following use tactics capture how managers engage with support mechanisms in practice, reflecting distinct ways in which accessed support is mobilised within their firms.

4.3.2.1. Plug-and-Play

The most widespread tactic mobilised by SMEs' managers to use support mechanisms corresponds to a plug-and-play logic. In these situations, managers accept and use support as it is provided, following predefined procedures and formats designed by support providers.

This logic was particularly visible in the mobilisation of educational support. When facing specific skill gaps, managers turned to vocational training programmes whose content directly matched their needs, without attempting to modify their structure. For Manager 3, it was a perfect solution to be formed to manage digital transformation: *"I found a coaching programme that helped me get organised and create a roadmap to follow step by step".* Similarly, Manager 7 described how participation in a predefined training pathway enabled recruitment: *"They went to [vocational training centre], completed the programme, came here for an internship, and then stayed on".* In these cases, the structured nature of the support was perceived as efficient and time-saving.

A similar pattern emerged in the use of combined technical and guiding support, where managers relied on expert-led services and directly implemented proposed solutions. Manager 6 described how her firm relied on the consultant's proposal to introduce a solution to improve

data monitoring: *"And now we are working with a consultant on our processes to generate data so we can monitor them more effectively. He is looking into what can be done and has suggested we develop an artificial intelligence plug-in".* Likewise, Manager 23 explained how his company, new to digitalisation, followed entirely what was offered to them: *"They were the ones who provided us with the data they could give us, because we were a bit new to the field".* Here, reliance on external expertise and limited internal capabilities reinforced a logic of direct adoption.

This tactic was also evident in the use of structured programmes combining guiding, financial, and educational components. While managers sometimes expressed critical reflections on the content or scope of these interventions, they nevertheless followed the prescribed format. For Manager 8, the report with the highlights on the ups and downs of his firm was not informative enough to keep on with the transformation: *"It was the consultant who came to carry out the diagnosis and then gave us a final report. I think it could have been more incisive, clearer, telling us 'this is what needs to be done'".* Similarly, Manager 13, although appreciated the approach, criticised its narrow scope: *"The consultant took us by the hand and helped us. The person stayed for a whole week to conduct an audit. However, I find it extremely unfortunate that it was limited to production, when we made changes in sales".* In both cases, the firms accepted the standard audit format, but their reflections highlighted a mismatch between the delivered content and their internal capacities and transformation goals.

By engaging with financial and guiding schemes, such as business vouchers or small-scale subsidies, managers applied through formal procedures, followed the steps required, and used the funding as prescribed. In one typical case, Manager 17 described calling on digital experts through a voucher scheme: *"As part of a business voucher scheme, we call on digital experts, they are assigned a task lasting a few days or a few hours, and then, we recover 50–75% of the cost of these services".* Almost the same logic was described by Manager 9 regarding his engagement with *Start IA program*: *"We had to submit a form with our project idea. Once it was accepted, we were awarded €4,000 in funding and a few hours of support".* These schemes involved clearly defined timelines, deliverables, and formats that were followed with little negotiation.

4.3.2.2. Mutual Tailoring

Contrary to managers who engaged with the I4.0 RIE seeking ready-to-use solutions, SMEs' managers who followed the mutual tailoring tactic valued the co-creation of support, allowing them to shape the solution through sustained interaction with the provider. This a dynamic was more frequently observed among SMEs with more advanced level of I4.0 transformation.

In some cases, although the support was encouraging plug-and-play tactic, mutual tailoring emerged naturally. For instance, Manager 17 described the process behind *Made Different program* as building a joint roadmap rather as receiving a diagnosis: *"We were supported by a consultant with whom we were able to exchange ideas and get their point of view. We carried out an initial pre-audit on the seven pillars. We identified our strengths and weaknesses. We came up with a plan to work on different stages to achieve the FoF objective".* Here, the support process became a shared design effort, integrating both external expertise and internal coordination.

In other cases, faced with the misfit of the proposed guiding or technical support from technology providers, managers opted to adapt it collaboratively, shifting from passive to active engagement with desire to make the solution operationally relevant. For instance, Manager 1

explained that while the proposed solution was technically solid, it lacked the contextual specificity they required: *“We saw that their solution, which is standard for the industry as a whole, was good, but that it could be better if we did something more customised. So we have now been working together for several months on something that will be specific to cogeneration and our site”.* In another example, adaptation emerged through an ongoing, iterative collaboration marked by testing and revisions. Manager 7 described the process not as a single intervention but as an evolving dialogue: *“We really wanted to adapt their solution to our needs. We had one or two meetings. We ran some tests. Then more meetings, because it wasn't quite working. But it was truly collaborative work”.* In both cases, a mutual tailoring tactic gradually replaced the initial plug-and-play logic as the managers sought a more targeted and effective outcome.

The mutual tailoring tactic often unfolded within long-standing collaborations. Within intra-organisational contexts, Manager 18 explained his experience of updating the existing ERP system with the long-standing service provider: *“It became a really close partnership, because as soon as there's something bothering me, instead of filling out forms, I take a look, show it to him, we look at it together and try to integrate it into other systems”.* Within inter-organisational contexts, Manager 24 recalled when his SME engaged alongside their subcontractors in transformation processes: *“We reviewed our manufacturing processes together with our subcontractor in collaboration with a private Lean Manufacturing company”.* Here, co-creation went beyond bilateral exchanges with support providers, by extending to triangular arrangements involving external experts and partner firms.

Finally, the tailoring tactic was applied by some managers whose SMEs took part in multi-actor projects. In one such project aiming to create a standardised solution to collect the same information from different machines regardless of their size or age, Manager 7 emphasised the joint nature of a technical development process: *“We are part of a steering committee with other companies: there are people who manufacture parts, there are people who work in IT, and there are people who develop communication processes”.* Rather than entering the project with a fixed solution in hand, these firms participated in building one, positioning themselves as both beneficiaries and contributors.

4.3.2.3. Selective Leveraging

The logic of assessing the fit of the external support was central among managers who applied the selective leveraging tactic to use support mechanisms. By drawing on external input to the extent it aligned with internal priorities, managers – mostly from SMEs with advanced level of I4.0 transformation – appropriated support in different ways without engaging in full co-creation.

In several cases, managers, confronted with the plug-and-play logic of the support, switched to provider because of a lack of contextual diagnosis or insufficient framing. Manager 5 recounted an unsatisfactory first engagement with a provider who failed to account for the company’s specificities: *“To develop 4.0, we first contacted a 4.0 company. Their solution proposal was not accompanied by an on-site analysis of what we do and what we can improve. That's why we turned to a consulting firm that spent more than six months on site working on all the pillars to put in place working methods that would last”.* The move from a poorly contextualised offer to a deep on-site collaboration illustrates how managers reoriented their engagement to ensure that support produced lasting change. Manager 7 described evaluating two providers of the same support type and selecting the one with a more suitable offer, despite

its higher cost: *“We contacted several companies. One company offered us a very cheap, plug-and-play solution. Another offered us a much more expensive solution, but it was much better suited to our business; they had really thought it through. So, we entrusted them with the entire project, and they got it up and running without us having to lift a finger”.* While reactive in the first case and proactive in the second, both managers pursued the same logic of securing a better fit for their SMEs’ needs and priorities.

In other cases, support was reframed rather than replaced to serve internal strategic purposes. Manager 2, faced with the guiding support limited to a diagnostic report, decided to transform it to a source of internal motivation through timelines and milestones: *“The diagnostic support gave us an initial analysis, but we still did everything ourselves, as the consultant only came to one or two meetings. So, it was good to have the guidelines and the deadline, as it meant we knew we had to be ready to show him what we'd done in three months' time”.* Here, the shift happened in the support’s function rather than in its provider, strategically reoriented to generate internal motivation.

4.3.2.4. Boundary-Setting

Finally, some managers followed a boundary-setting tactic when navigating the I4.0 RIE. Faced with a mismatched offer, they chose to set clear limits by abandoning or refusing the support, rather than trying to adapt it or seeking an alternative.

In financial support mechanisms, boundary-setting often stemmed from procedural barriers or inadequate timelines – a pattern particularly visible among smaller firms and those at earlier stages of I4.0 transformation. Manager 7 described the experience of discovering a funding opportunity too late to act: *“We were notified a week before we could make the final submission for the project. We are a small company, we can't do anything in a week, it was too late”.* Manager 25 reported abandoning the effort altogether after repeated failures to navigate an online application system: *“I tried for a day, couldn't figure it out, and asked two IT experts for help”.* In both cases, although the support was technically available, it turned out to be inaccessible in practice due to infrastructural constraints.

Boundary-setting within combined support programmes was sometimes the result of disrupted leadership continuity. In two separate accounts, managers explained that projects were abandoned following the departure of a key individual who had initiated the engagement. Manager 13 recalled: *“My predecessor, who has now retired, was involved in Made Different. They started doing things, but then it kind of petered out”.* Similarly, Manager 2 shared an experience she observed from the outside: *“The CEO of another company visited us and was clearly going to drive the project forward. But she later resigned, and I thought the project might be cancelled – her successor would need the same commitment but could have different priorities”.* In such cases, the commitment to follow through was personal rather than collaborative, and once that anchor was gone, the project lost its driving force.

Technical and guiding support was also declined when it failed to align with immediate operational realities. Manager 15, for instance, set boundaries because the support offer felt disconnected from their everyday concerns: *“Connecting my machines to sophisticated systems does not motivate me at all, because I have everyday problems such as finding staff”.* Manager 23 described declining a project proposal despite its technical potential due to time constraints: *“We received a proposal from the cluster, but it requires a significant time commitment and availability, and we already have a major investment plan to implement over*

the next two years". For these firms, even well-designed offers failed to compete with more pressing strategic demands.

Finally, boundary-setting occurred when managers suspected misaligned interests. Managers 22 explained walking away from a project after questioning the real intentions behind it: *"They came to us with a great idea, but once we got to the meeting, I realised it was just [nonsense], because all they want to do is put together a team that they're going to pay with my money, while they reap all the benefits".* This statement illustrates how the suspicion of being taken advantage of can undermine technically sound proposals.

4.3.2.5. Towards typology of managerial use tactics

Across cases, these use tactics show that managers engage with the I4.0 RIE in ways that range from direct adoption to deliberate disengagement. While some accept predefined support to gain rapid access or compensate for limited internal capacity, others co-develop it with providers to ensure alignment with evolving needs. In between, managers selectively mobilise specific elements of available support or choose to disengage when it does not fit their priorities or constraints. These different approaches reflect a variety of underlying considerations, including operational urgency, convenience, the search for contextual fit, and the need to preserve strategic focus. Taken together, these findings illustrate how managers not only apply but also adapt, filter, or refuse support, enacting their agency through different tactics of use (Table 5).

Table 5. Managerial tactics to use I4.0 RIE support mechanisms.

Ecosystem use tactic	Manner of use	Reasons	Managers' motto	Examples of support
Plug-and-play	Support is used as provided, without modification. Managers follow the structure, content, and process predefined by the support provider.	Time-saving logic Lack of internal capacity Perceived credibility of external expertise	*"We follow the instructions"*	Vocational training centres Technology consultants Public digital audit programs Business vouchers & small-scale subsidies
Mutual tailoring	Support is developed collaboratively through sustained interaction between the firm and the provider, resulting in adapted or co-created solutions.	Standard offer misfit Need for contextualization Long-standing or commitment-based partnerships	*"We co-create the instructions"*	Technology consultants Multi-actor R&D projects Lean transformation with subcontractors
Selective leveraging	Support is strategically appropriated according to its fit with the firm's needs, without engaging in full co-creation.	Lack of technical support Competing offers Limited guiding support	*"We choose what fits and make it work for us"*	Technology consultants Public digital audit program

Boundary-setting	Support is explored but ultimately abandoned when it proves misaligned with the firm's operational context, priorities, or constraints.	Timing or procedural barriers Leadership changes Mismatch with operational realities Perceived pursuit of benefits by external actors at the expense of the firm	*"We know when to say no"*	Late-stage calls for proposals Digital subsidy platforms Consulting-led assessments Cluster-led collaborative offers

5. Discussion

This study contributes to understanding how SMEs' managers engage with I4.0 RIE by examining the interpretive processes through which support mechanisms are made meaningful and enacted in practice. Building on the results, the discussion advances three interconnected contributions. First, it reconceptualises I4.0 RIE by shifting attention from their structural configuration towards how they are experienced and constructed through managerial sense-making. Second, it shows that engagement unfolds through selective, evolving, and sometimes reversible tactics, driven by continuous managerial evaluation of support accessibility and usability. Third, it demonstrates that fragmentation, widely documented as a structural characteristic of innovation systems, acquires its practical significance through managerial enactment.

5.1. Reconceptualising SMEs' Engagement with I4.0 RIE

This study contributes to existing research on SMEs' engagement with external support for I4.0 transformation by shifting attention from the structural properties of innovation (eco)systems to the managerial processes through which these environments are interpreted and mobilised in practice. Previous studies have predominantly conceptualised such environments either as structured configurations of actors and resources (Adner, 2017; Lundvall, 2016), or through the specific roles played by intermediaries, institutions, and policy instruments in enabling SMEs' access to knowledge, capabilities, and innovation opportunities (Hafeez et al., 2025; Howells, 2006; Ietto et al., 2024). Within this perspective, analytical attention is primarily directed towards how these environments are organised and how their components support firms, while engagement tends to be implicitly treated as a function of access to and availability of external resources.

By adopting a sense-making perspective, our study extends this work by conceptualising engagement as an interpretive and situated process, through which managers identify, evaluate, and enact elements of I4.0 RIE in relation to their firms' conditions and needs (Cristofaro, 2022; Weick, 1995). Existing research has predominantly conceptualised ecosystems as enabling structures that provide firms with access to resources, knowledge, and support mechanisms (Hafeez et al., 2025; Menten et al., 2025; Shen et al., 2024), thereby emphasising their structural properties and functional roles. This perspective shifts the focus from ecosystems as enabling structures to engagement with them as a process of managerial construction, in which external opportunities are actively interpreted and selectively mobilised rather than simply accessed or used. More specifically, we show that engagement unfolds through iterative movements between selection, retention, and enactment, which connect

managers' understanding of I4.0 RIE and interpretations of its accessibility and usability with concrete tactics of accessing and using support (see Figure 2). This also implies that engagement cannot be reduced to firms' exposure to available support (Menten et al., 2025; Vereycken et al., 2024), but depends on how managers construct the boundaries of what is considered relevant, accessible, and actionable within the ecosystem. In doing so, this perspective complements research on firms' external knowledge search, which highlights the importance of drawing on diverse external sources to enhance innovation (Bogers et al., 2018; Laursen & Salter, 2006; Ricci et al., 2021), but tends to treat such openness as a strategic orientation rather than as an interpretive process shaped by managerial sense-making.

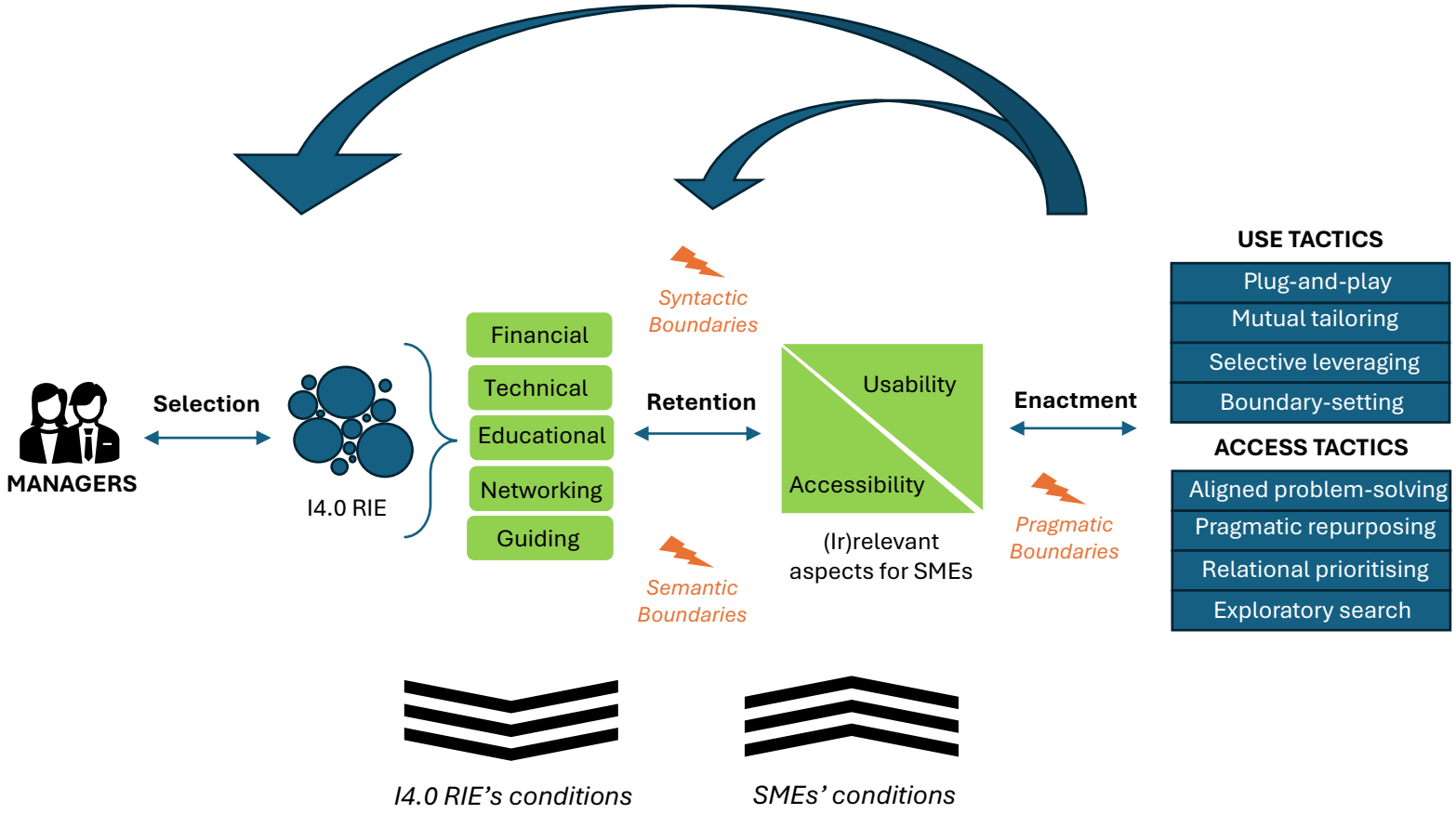
Moreover, our results suggest that ambiguity constitutes a defining feature of how I4.0 RIE is encountered and made sense of by managers, rather than a contextual factor to be evaluated or overcome (Gioia et al., 2012; Sandulli et al., 2021). Rather than stemming solely from identifiable constraints, this ambiguity reflects the interpretive nature of engagement, where the relevance, accessibility, and usability of support remain open to multiple meanings. This phenomenon can be understood through the presence of knowledge boundaries between managers and I4.0 RIE actors (Carlile, 2002, 2004). First, syntactic boundaries may emerge through differences in language – particularly across institutional and linguistic communities in Belgium – which shape how support mechanism is provided and accessed by SMEs' managers. Second, semantic boundaries may arise from divergent interpretations of support accessibility and usability, as managers make sense of these mechanisms based on their prior experiences and firm-specific contexts. Finally, pragmatic boundaries become visible in action, as differences in interests and priorities shape how support is mobilised – for instance, when managers adapt solutions to their context, prioritise alternatives offering better fit, or disengage due to perceived misalignment between providers' commercial intentions and SMEs' needs. In line with research on managerial cognition and strategic decision-making (Gavetti et al., 2005), managers thus rely on prior experiences, evaluative judgments, and simplified representations to navigate novel configurations of opportunities.

5.2. Selective and Reversible Engagement tactics with I4.0 RIE

While the previous section conceptualises engagement as an interpretive process, our findings further show that such engagement takes the form of selective, evolving, and sometimes reversible tactics, instead of unfolding uniformly across SMEs. Contrary to dominant assumptions that position engagement with IE as a progressive process of increasing participation and integration – where firms are expected to align with coordinated sets of actors and resources organised around shared value creation (Adner, 2017; Jacobides et al., 2018) – SMEs' involvement in I4.0 RIE appears contingent upon continuous managerial evaluation. This assumption of progressive engagement is also reflected in research on external knowledge sourcing, which frames openness as a strategic orientation towards accessing and combining multiple knowledge sources, while often overlooking how such engagement is enacted in practice through specific tactics (Dahlander & Gann, 2010; Laursen & Salter, 2006).

From this perspective, entry into the I4.0 RIE, rather than occurring automatically, emerges from managerial evaluations of the perceived alignment between available support and the SMEs' immediate needs and capabilities. While prior research has largely interpreted limited engagement through the lens of structural barriers – such as lack of awareness, administrative complexity, or difficulties in identifying appropriate partners (Horváth & Szabo, 2019; Müller et al., 2024) – our findings show that these elements are not determinative, but become

Figure 2. SMEs' engagement with I4.0 through managerial sense-making.



meaningful only through managerial interpretation, shaping decisions to engage, adapt, or disengage. In this sense, non-engagement goes beyond constrained accessibility or usability of I4.0 RIE, reflecting less visible organisational and relational dynamics, including leadership discontinuity, perceived lack of energy, or misaligned interests between providers and beneficiaries (Ocasio, 1997). Far from being a passive avoidance or a reflection of misunderstanding of I4.0 opportunities (Ietto et al., 2024), this *boundary-setting* tactic reflects a form of protective agency: when faced with constraints, managers conserve internal resources and maintain strategic coherence.

Engagement itself then takes the form of selective and adaptive use of support, rather than full participation in ecosystem initiatives. This finding contrasts with approaches that emphasise SMEs' need to rely on a broad range of external actors and support mechanisms – such as consultants, technology providers, institutional programmes, and collaborative networks – to access the resources and capabilities required for I4.0 transformation (Khin & Hung Kee, 2022; Stentoft et al., 2021). While this literature highlights the importance of external support, it tends to assume that firms benefit from expanding their engagement with available sources. In contrast, our findings show that managers do not mobilise these mechanisms uniformly, but continuously filter, combine, and reinterpret them based on their perceived relevance and usability, making engagement a process of selective appropriation rather than cumulative process of open innovation (Dahlander & Gann, 2010; Ricci et al., 2021).

Importantly, these engagement patterns with I4.0 RIE vary across SMEs depending on how contextual conditions are interpreted and mobilised in practice. While existing research emphasises the role of structural constraints such as limited resources, skills shortages, or technological maturity (Hansen et al., 2024; Kumar et al., 2023), our findings show that these factors only contribute to differentiated engagement trajectories rather than uniformly constraining them. In particular, variations in technological maturity and resource availability shape how managers perceive the accessibility and usability of support, leading to distinct modes of engagement. For instance, less experienced firms tend to rely on established norms of use, such as plug-and-play solutions, while managers from more advanced firms engage more selectively and strategically, combining and adapting support or relying on long-term partnerships. This variation highlights how differences in perceptual filters enable managers to redefine what support mechanisms represent in practice – as shortcuts, exploratory tools, or co-development opportunities (Weber & Glynn, 2006; Weick, 1995). Altogether, these patterns show that the volatility of I4.0 RIE engagement process is incremental and evolving rather than *"immediate and final"* (Weber & Glynn, 2006, p. 1648).

5.3. Engaging with I4.0 RIE under Conditions of Fragmentation

The findings presented above point to a fundamental tension in how I4.0 RIE are experienced by SMEs' managers, emerging from fragmentation phenomenon. On the one hand, the coexistence of multiple actors, initiatives, and support mechanisms reflects an attempt to accommodate the diversity of SMEs' needs by offering a wide range of entry points, services, and collaborative opportunities, in line with studies on the enabling role of heterogeneous and complementary actors within ecosystems and RIS (Adner, 2017; B. Asheim & Gertler, 2005). On the other hand, this same multiplicity generates a fragmented landscape, in which overlapping initiatives, weakly connected actors, and heterogeneous forms of support complicate SMEs' engagement and reduce the overall readability of I4.0 RIE, echoing empirical observations of loosely coordinated and weakly integrated innovation systems

(Sandulli et al., 2021). The Walloon case provided a particularly illustrative configuration of this tension. In line with research on multi-level governance and institutional layering in regional innovation systems (B. Asheim & Gertler, 2005; Lundvall, 2016), the coexistence of regional, national, and European initiatives contributes to the multiplication of actors and programmes, while making their articulation only partially visible from the perspective of firms. Similar tensions have been observed in the Catalan innovation system is characterised by a dense landscape of heterogeneous actors connected through weak and unstable ties, resulting in limited coordination and short-term interactions between initiatives (Sandulli et al., 2021). Contrary to the previous studies that define these institutional characteristics as defining structure of firms' innovation (Adner, 2017; B. Asheim et al., 2016), our findings demonstrate that the fragmentation can be enacted in different ways through managerial sense-making (Weick, 1995).

These dynamics can be understood by linking engagement practices to managers' perceptions of accessibility and usability, which are stabilised or challenged through retention processes (Weick, 2004). When retention is credited, managers tend to confirm their expectations of support mechanisms, relying on familiar procedures or opportunistic exploration, particularly when lacking internal expertise (Horváth & Szabo, 2019; Müller et al., 2024) or facing unclear mapping of available support (Menten et al., 2025; Müller et al., 2021). In such cases, perceived accessibility and usability are reinforced, leading to engagement patterns that prioritise existing routines and low-risk experimentation. By contrast, when retention is discredited, perceived misalignment between support and SMEs' needs prompts managers to actively navigate around I4.0 RIE constraints. This involves relying on trusted contacts to compensate for limited or fragmented visibility of potential partners, selecting a provider offering several support mechanisms and intentionally revisiting their purposes, or changing providers offering the same support mechanism to get better technical assistance. In this sense, engagement practices reflect ongoing re-evaluations of what support is considered accessible and usable, rather than direct responses to structural conditions.

5.4. Theoretical Implications

This study contributes to technology and innovation management research by revisiting how SMEs' engagement with I4.0 RIE is conceptualised, moving beyond structural and resource-based explanations towards a processual and practice-based understanding grounded in managerial sense-making. A first contribution lies in reconceptualising engagement with I4.0 RIE as an interpretive and evaluative process. Research on external knowledge sourcing and open innovation has highlighted the importance of accessing diverse external actors and knowledge sources to support firms' innovation (Dahlander & Gann, 2010; Laursen & Salter, 2006), often framing openness as a strategic orientation towards expanding external interactions. However, this literature tends to assume that available resources can be mobilised once firms decide to engage. Our findings refine this view by showing that engagement is contingent upon prior evaluations of accessibility and usability relevance for SMEs, through which managers determine whether support mechanisms are worth accessing or using. As such, openness translates into selective processes of filtering and prioritisation shaped by managerial attention and judgement, rather than into broad or cumulative engagement (Gavetti et al., 2005; Ocasio, 1997). This perspective shifts the focus from the availability of support to the conditions under which it becomes meaningful and actionable according to SMEs' managers.

A second contribution concerns the nature of engagement tactics, which are shown to be selective, adaptive, and reversible. Innovation ecosystem literature often implicitly assumes that firms progressively increase their participation in ecosystem activities as they integrate into networks of complementary actors and resources (Adner, 2017; Jacobides et al., 2018), while research on SMEs' digital transformation emphasises the importance of expanding external collaborations to overcome resource constraints (Hafeez et al., 2025; Stentoft et al., 2021). In contrast, our findings demonstrate that managers regulate their SMEs' engagement with I4.0 RIE through continuous evaluation, leading to patterns of partial participation, selective use, and disengagement. This suggests that engagement unfolds as an iterative sequence of adjustments shaped by evolving perceptions of usefulness, constraints, and priorities, rather than following a linear trajectory of increasing integration. By conceptualising disengagement through boundary setting tactic as an integral component of engagement, rather than as its absence or failure, this study extends existing work on engagement with external support (Menten et al., 2025; Vereycken et al., 2024) by highlighting the reversible and contingent nature of firms' interaction with external support environments.

A third contribution relates to the understanding of fragmentation in I4.0 RIE, and more broadly in IE and RIS. Prior research has associated fragmentation with weak coordination, institutional layering, or loosely connected actors within regional innovation systems (B. Asheim & Gertler, 2005; Cooke, 2001; Sandulli et al., 2021). Our findings extend this perspective by showing that fragmentation becomes meaningful through managerial engagement practices, and is enacted through interactions with overlapping support mechanisms whose boundaries and purposes are not always clearly distinguishable. In this sense, fragmentation is not only a condition of the ecosystem, but an outcome of how firms selectively access, use, and combine available forms of support. The fragmentation phenomenon identified in this study highlights that efforts to diversify and tailor support to heterogeneous SMEs – through the multiplication of actors, programmes, and initiatives, often encouraged in IE and RIS literature as a way to enhance complementarities (Adner, 2017; B. T. Asheim et al., 2011) – simultaneously increase complexity and limit effective use, as firms engage with only a subset of available mechanisms. This shifts the analytical focus from fragmentation as a coordination failure to fragmentation as an enacted condition of engagement.

5.5. Practical Implications

The findings of this study suggest practical implications for both managers and policymakers involved in I4.0 transformation of SMEs, by highlighting how engagement with I4.0 RIE unfolds through selective access, differentiated use, and continuous evaluation of support mechanisms.

For managers, the typology of access and use tactics provides a structured framework to reflect on how they engage with available support mechanisms in practice. Rather than approaching external support as a predefined set of opportunities to be accessed, the findings suggest that managers benefit from explicitly recognising their own patterns of engagement – whether driven by immediate problem-solving, exploratory intentions, relational anchoring, or adaptive repurposing. This reflexive awareness enables managers to better align their engagement with their firm's priorities, capabilities, and constraints. In particular, distinguishing between how support is accessed and how it is used allows managers to move beyond passive adoption, and to actively shape support through selective leveraging, mutual adaptation, or deliberate disengagement when expected value is not realised. In this sense, rather than

prescribing optimal behaviours, the typology supports more informed and strategic decision-making regarding when, how, and to what extent external support should be mobilised in the context of I4.0 transformation.

For policymakers, the findings call for a reconsideration of how I4.0 RIE are designed, coordinated, and evaluated. While many regional and national policies aim to foster SMEs' digital transformation through the multiplication of programmes, intermediaries, and funding instruments, the results suggest that policymakers should pay closer attention to how such fragmentation of support mechanisms is experienced in practice, particularly in terms of clarity of roles, entry points, and expected outcomes. This implies shifting from a logic of expanding support provision towards improving its readability and usability for SMEs' managers. Besides simplifying procedures and increasing transparency, addressing these issues requires also ensuring continuity in relationships and interactions between SMEs and support providers. In this regard, policy efforts should prioritise the design of support ecosystems that, in addition to being comprehensive in scope, are also interpretable, accessible, and adaptable from the perspective of firms. By doing so, policymakers can enhance the practical usability of I4.0 support mechanisms, without necessarily reducing their diversity, but by improving how this diversity is structured and coordinated in practice.

Another key implication concerns the articulation between policy orientations and the practices of professional support providers, such as consultants, technology suppliers, and intermediary organisations. The findings show that, when poorly articulated, overlapping or competing support mechanisms can become difficult to interpret for SMEs' managers, for instance when similar services are offered without clear differentiation or when policy-driven programmes and market-based services pursue partially converging objectives. Rather than enforcing uniformity or coherence to mediate this fragmentation, the results suggest clarifying the positioning of different actors, improving the visibility of complementarities between support mechanisms, and facilitating more transparent transitions between them. By making the diversity of support more intelligible and actionable from the perspective of managers, such efforts contribute to supporting the enactment of fragmented I4.0 RIE, instead of mediating it.

Importantly, these implications should be understood in relation to the specific institutional context in which I4.0 RIE are embedded. Given the Walloon empirical setting of the study, the coexistence of regional strategies, national institutional arrangements, and European funding programmes contributes to the layering of support initiatives, which shapes both their diversity and their fragmentation. Such configurations are particularly salient in multinational states (e.g., Canada, Switzerland) or coordinated market economies (e.g., Germany, Sweden), where overlapping institutional layers and distributed responsibilities structure firms' access to support (B. Asheim & Gertler, 2005; Cooke, 2001; Lundvall, 2016). While these dynamics share similar institutional features, the precise configuration of actors, instruments, and coordination mechanisms remains context-dependent. As such, the recommendations derived from this study should be understood as context-sensitive insights into how support environments can be made more actionable for SMEs within specific institutional settings, rather than as universally applicable prescriptions.

5.6. Limitations and Future Research

The insights generated by this study are bounded by several methodological and contextual considerations that should inform future research. The empirical material derives from a set of Belgian industrial SMEs embedded in a particular multi-level policy and institutional

environment (Faniel et al., 2021). This context not only determines the range of supports available for I4.0 transformation but also shapes the fragmentation, duplication, and coordination challenges managers encounter when navigating them. Comparative studies across regions and sectors – especially where institutional ecosystems are more centralised or more market-driven – would help assess the transferability of the proposed typologies of framings, access paths, and use tactics.

The study provides a snapshot of managerial sense-making of I4.0 RIE engagement at a given stage of their I4.0 transformation process. As technological, market, and policy conditions evolve, so too may the perceived legitimacy, accessibility, and usability of ecosystem support (Weber & Glynn, 2006). This dynamic is likely to intensify with the transition towards Industry 5.0 (Valette et al., 2023; Zhang et al., 2023), where support mechanisms increasingly incorporate human-centric, sustainable, and resilience-oriented objectives alongside technological ones, further expanding the interpretive demands placed on managers. Longitudinal research following the same SMEs over time could reveal how these evolving expectations reshape managerial interpretations, how access and use tactics are reconfigured, and whether I4.0 RIE engagement trajectories stabilise or end.

The analytical framework was developed through a qualitative, interpretive approach, privileging depth over breadth. While this has allowed us to capture the hybridity and contextual embeddedness of engagement practices, it also means the findings reflect both the accounts of participants and the interpretive lens of the researchers (Fairhurst & Uhl-Bien, 2012). Complementary studies using survey-based or mixed designs could test the stability of the typologies, quantify their prevalence, and examine how different combinations of access and use tactics relate to I4.0 transformation outcomes achieved by SMEs.

6. Conclusion

This study advances understanding of how SMEs' managers engage with I4.0 RIE by showing that such engagement unfolds through interpretive and action-oriented processes, rather than through access to a coherent system of support. Managers interact with overlapping support mechanisms, which they interpret, evaluate, and enact through differentiated access and use tactics. Engagement thus emerges as a situated and evolving process, through which fragmented support is translated into firm-specific actions. By identifying distinct access and use tactics, the study shows that engagement can be selective, adaptive, and sometimes reversible, depending on how managers perceive their SMEs' organisational conditions and I4.0 RIE fit with their needs. This shifts the understanding of engagement with external support environments from linear support mobilisation to a complex process of sense-making, where managers actively shape how support is accessed and used.

Finally, the transition towards Industry 5.0 may further amplify the dynamics identified in this study. As support mechanisms increasingly integrate social, environmental, and organisational dimensions alongside technological ones, SMEs' managers are likely to face even greater interpretive complexity in engaging with external support. This suggests that the role of managerial sense-making may become even more central, as firms will need to navigate not only technological options, but also broader value-oriented and societal objectives embedded in emerging support frameworks. Future research could therefore examine how the evolution from Industry 4.0 to Industry 5.0 reshapes the nature of support mechanisms and the ways in which SMEs interpret, prioritise, and enact them.

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Discussion

This discussion brings together the insights developed throughout the thesis to address its overarching research question: *How do managers perceive and strategically navigate I4.0 transformation in industrial SMEs?* As established in the introduction, this question emerged from the recognition that I4.0 is a socially constructed and interpretively negotiated process, rather than a neutral or fixed technological reality. The thesis therefore adopted an interpretivist stance, progressively shifting from structural explanations of context influencing I4.0 transformation towards an analysis of managerial agency and its interaction with organisational and institutional environments. Building on the multi-level structure introduced in the thesis, it bridges the micro level of strategic vision, the meso level of resource mobilisation, and the macro level of ecosystem engagement, thereby integrating the analytical perspectives of each empirical study.

Following this logic, the discussion unfolds in four main parts. It first revisits the key findings of the four studies to show how their complementarity converges into a multi-level analytical framework that conceptualises I4.0 transformation as a process of structuration. Building on this foundation, the second part introduces trade-offs and navigation practices as the two central modalities through which structuration unfolds in action – respectively capturing how managers make sense of tensions and how they enact situated responses within and across different levels. The third part extends these insights to discuss the thesis's main theoretical contributions and practical implications. Finally, the section concludes by recognising the limitations of the thesis and by outlining future research avenues.

Recall of Results

This thesis provides four distinct yet complementary responses, emerging from four papers, on how SMEs' managers perceive and strategically navigate I4.0 transformation. Table 2 summarises the constituent elements of each paper, supporting the cross-reading of their analytical focus and contribution.

The first paper, which analyses the literature on contextual enablers and barriers influencing SMEs' strategic choices (see Table 2), outlines the scope of SMEs' I4.0 transformation. This scope emerges as challenging environment in which managers are pressured to make I4.0-oriented decisions regarding profitability, goals, change, technology, and solutions (Estensoro et al., 2021; Horváth & Szabo, 2019). These decisions depend on how managers handle trade-offs between enablers and barriers arising from SMEs' inner and outer contexts (Greenwood & Hinings, 1996; Scott, 2014). To better understand this context-specific decision-making, the second paper zooms in at micro level of I4.0 transformation, by investigating how SMEs' managers engage with the conceptual diversity of I4.0 to orient action. By analysing I4.0 definitions from survey and managers' discourses from interviews, we revisit I4.0 conceptual diversity to highlight it as the condition shaping how managers understand and enact I4.0 into transformation within their SMEs (Weick, 1995). In such a context, managers bracket the conceptual diversity of I4.0 through three interpretative dimensions, anchor it in managerial and organisational contexts (Penttilä et al., 2020; Sharifi & Zhang, 2009), and stabilise it through strategic actions (see Table 2). To obtain a more detailed representation of such approaches, the third paper turns to the meso level of I4.0 transformation, by investigating how managers mobilise SMEs' resource configurations to make strategic decisions. The four strategic scenarios obtained due to survey data analysis (see Table 2) illustrate that SMEs possess diverse combinations of resources and constraints (Barney, 2021). Instead of framing

these configurations as fixed enablers or barriers, managers recombine and strategically mobilise them through specific strategic choices (Teece et al., 2016). To complete these scenarios portraying SMEs' internal transformation, the fourth study zooms out to the macro level of I4.0 transformation, examining how managers engage with external support from I4.0 regional innovation ecosystems (RIE). The analysis of interviews captures this engagement through sense-making process (Weber & Glynn, 2006; Weick, 2004), where managers' understanding of I4.0 RIE – captured through five support mechanisms – and interpretations of its accessibility and usability are enacted through concrete access and use tactics (see Table 2).

By moving beyond the deterministic stance of the first paper, which captured I4.0 transformation more as a reaction to internal or external context, the following three empirical papers deliver distinct perspectives on managerial agency shaping this transformation. Altogether, the papers demonstrate that managers perceive and navigate I4.0 transformation in uneven ways – through their personal interpretations of I4.0 concept, strategic mobilisation of internal resources, or distinct engagement practices with I4.0 RIE. By illustrating that *"there is no single Industrie 4.0"* (Pfeiffer, 2017, p. 111), this thesis highlights the power of managerial perceptions and actions regarding the appropriation of I4.0 to the contextual specifics of their SMEs. At the end, the concept of I4.0 becomes an adjustable framework for transformation (Meyer, 2019), empowered through the constant interaction between managerial agency and SMEs' context, through which managers actively orient and reshape the directions of change followed by their firms.

Table 2. Overview of key constituent elements from the four papers composing this thesis.

Papers	Findings	Constituent elements
1	Strategic choices for I4.0 transformation depend on trade-offs between enablers and barriers arising from SMEs' inner and outer contexts.	• Inner context: organisational structure, technological resources, financial resources, human resources, managerial and organisational culture, and business strategy. • Outer context: market conditions and stakeholders. • Strategic choices: *profitability* (short, mid, or long-term ROI), *purpose* (financial, operational, or Triple Bottom Line), *focus* (technological or human capital), *technology* (basic or advanced), and *solution* (standard or customised).
2	Managers bracket the conceptual diversity through interpretative dimensions, anchor it in contextual factors, and stabilise it into actions.	• Perceptions typology: *means* (technology and data), *purpose* (transformation, performance, and human), and *challenge* (conceptual, normative, and resource-related). • Contextual factors: *managerial* (background, role, mindset and interests), *company* (technology and operations, finances, workforce, innovation), *environment* (labour cost and market, sector, institutional support), • Strategic actions: technological, human-centred, ecosystem-based.
3	In SMEs with diverse resource configurations, managers leverage	Strategic scenarios typology: • Responsible planners: combine structured managerial and organisational systems with balanced financial, social, and environmental goals,

	resources and constraints to shape strategic choices for I4.0 transformation.	driving both technological and organisational transformation. • Tactical players: leverage strong managerial and human capital to allocate resources flexibly towards financial and social goals through standard and customised solutions. • Proactive developers: transform financial constraints into innovation drivers by focusing on environmental and financial improvements and favouring technological change through customised solutions. • Resilient pragmatists: navigate limited managerial and human resources by prioritising financial goals and organisational change through short-term ROI and standard solutions.
4	In a fragmented I4.0 RIE, managerial engagement is shaped by how support is interpreted, evaluated, and enacted through diverse access and use tactics.	• Ecosystem support typology: financial, technical, educational, guiding, and networking. • Access paths: aligned problem-solving, pragmatic repurposing, relational prioritising, and exploratory search. • Use tactics: plug-and-play, mutual tailoring, selective leveraging, and boundary setting.

Understanding I4.0 Transformation as a Process of Structuration

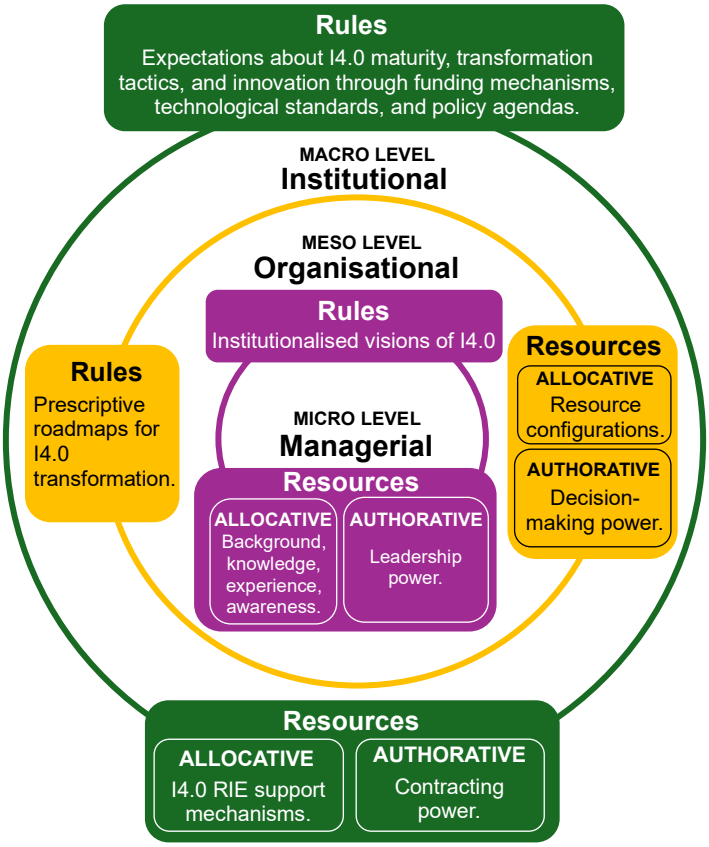
Following the logic stemming from the results of this thesis, I4.0 transformation within SMEs can be understood as a process of structuration, in which managerial agency and contextual structures are mutually dependant as they continuously interact (Busco, 2009; Giddens, 1987). In this recursive interplay contextual structures refer to elements of social systems in which managers intervene during I4.0 transformation, whereas agency refers to managers' actions over these structures (Giddens, 1987; Whittington, 2010). Structures represent sets of rules and resources[12] inherent to multiple and overlapping social systems, which, in this thesis, correspond to the micro, meso, and macro levels of I4.0 transformation (Whittington, 2010). Whittington (2010, p. 149) compares these structures to language, providing managers with *"at the core, sufficient stability to allow the effective storing of knowledge over time; at the margins, the creation of new words and usages to accommodate changing needs and circumstances".* Thus, managers act as *"powerful agents"* who draw upon these structures (Whittington, 2010, p. 149) to interpret, mobilise, and engage with the systems in which they operate, sustaining I4.0 transformation across time and contexts (Busco, 2009; Giddens, 1987).

At the micro level, managers construct and enact their understanding of I4.0 within a context nurtured by grand narratives legitimising techno-centred and performance-oriented visions of I4.0 (Lyotard & Brugger, 2001; Oesterreich et al., 2020), which function as *interpretative schemes* (Giddens, 1987; Whittington, 2010). This repertoire of institutionalised and diffused visions generally constitutes one of the managers' first contact points with I4.0 conceptual diversity (Culot et al., 2020), affecting their sense-making of I4.0 transformation (Weick, 1995).

[12] Rules refer to interpretive schemes shaping meaning and to normative expectations defining appropriate action, both emerging from multiple actors within I4.0 RIE. Resources, in turn, refer to allocative capacities through which managers exercise power over objects and to authoritative capacities through which they exercise power over people (Giddens, 1987; Whittington, 2010).

Managers thus rely on *allocative resources* – such as their educational and professional background, mindset and interests – and their awareness of SMEs' context, and *authoritative resources* embodied in their leadership power (Harney & Alkhalaf, 2021; Zoppelletto et al., 2023). These elements shape the structure of the managerial system (see Figure 2), through which managers draw on I4.0 conceptual diversity to form and enact their understanding of I4.0 transformation in situated decisions (Pfeiffer, 2017; Weick, 1995).

Figure 2. Social systems as dimensions of I4.0 transformation.



At the meso level, managers are often encouraged to rely on prescriptive roadmaps indicating success and failure factors for I4.0 transformation (Pozzi et al., 2023; Sony et al., 2024), articulating *normative expectations* about how I4.0 transformation should be conducted (Barney, 2021). Conceived with the aim of delivering expected outcomes, these frameworks generally offer a standard vision of SMEs' internal context, often highlighting existing constraints and overlooking resources' dynamic nature (Hansen et al., 2024; Teece, 2007). Our study shows that managers exercise their agency by mobilising and sometimes recombining *allocative resources* – SMEs' resource configurations shaped by financial, digital, organisational, and human resources and constraints – and by activating *authoritative resources* through their decision-making power (Teece et al., 2016). Altogether, these elements shape the structure of the organisational system (see Figure 2), where managers design adaptable approaches to I4.0 transformation. They do so by assessing how evolving internal factors – such as budget or technologies – may alter strategic priorities, while emerging priorities – such as environmental goals or organisational change – can, in turn, influence resource mobilisation (Eisenhardt & Martin, 2007; Teece, 2007).

At the macro level, managers engage with a broader environment in which *normative expectations* about I4.0 maturity, transformation tactics, and overall technological innovation are produced and stabilised through policy agendas, technological standards, and funding mechanisms. These elements contribute to defining what I4.0 is and how it should be implemented, shaping both the meaning and the legitimate scope of action (Meyer, 2019; Oesterreich et al., 2020; Pfeiffer, 2017). Although these rules define the legitimate scope of action, managers mobilise existing support for I4.0 transformation by actively engaging with it in different ways (Weber & Glynn, 2006; Weick, 2004). They do so, by drawing upon *allocative resources* offered by the ecosystem – captured in this thesis through support typology – and mobilising *authoritative resources* through their contracting power of interacting with support providers (Menten et al., 2025). These elements shape the institutional system structuring the I4.0 RIE (see Figure 2), through which managers may conform to support providers' conditions via a plug-and-play tactic or reshape them through selective leveraging.

Taken together, these dynamics reveal I4.0 transformation as a multilevel structuration process linking managerial, organisational, and institutional dimensions of change. While this section mostly focused on the portrayal of contextual structures, the following ones introduce *trade-offs* and *navigation practices* as the two main modalities through which structuration unfolds in action. The first represent the arenas where managers confront tensions between normative expectations and existing resources, while the second capture the situated practices through which managers shape their SMEs' strategic technological trajectories for I4.0 transformation.

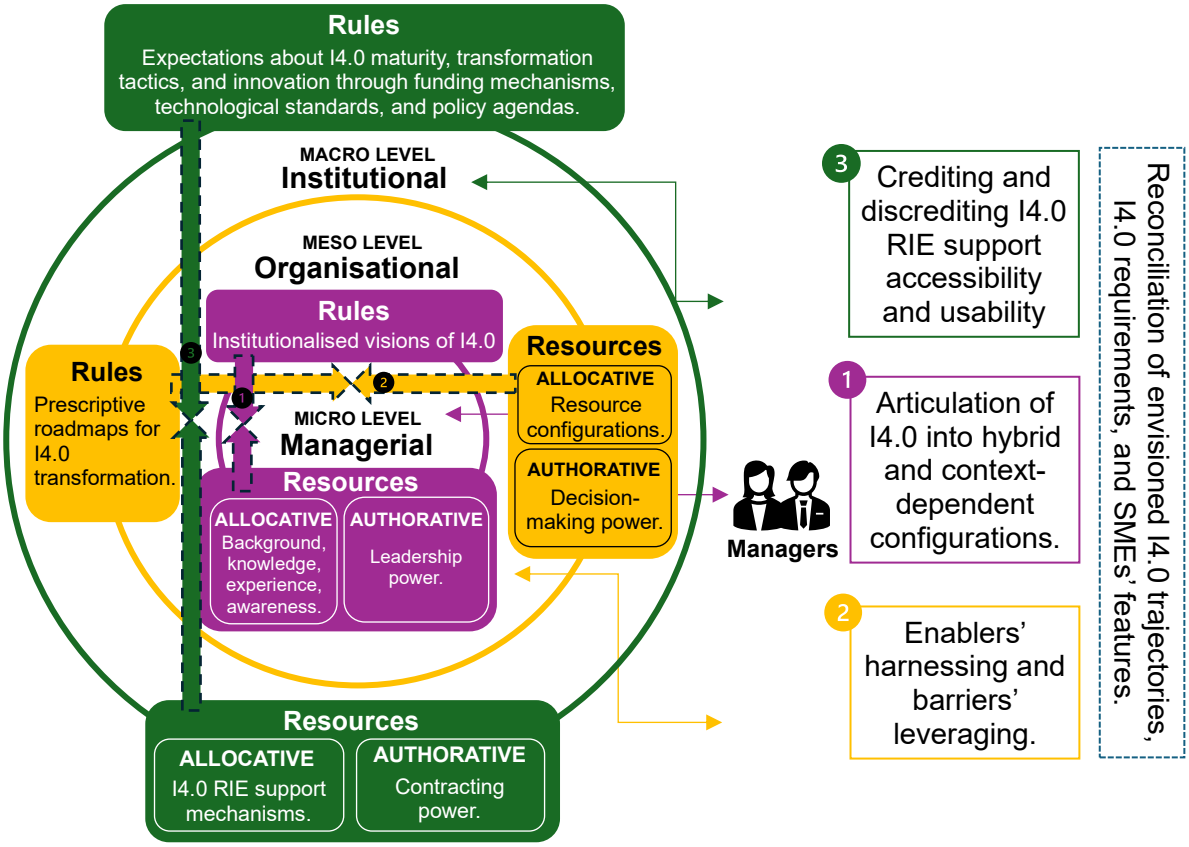
Trade-offs as Arenas of Structuration

While existing studies have identified a diversity of internal and external conditions which can enable or hinder I4.0 transformation (Hansen et al., 2024; Sony et al., 2024), this thesis offers a novel perspective on their interplay. Rather than treating these factors as separate causal forces, the findings reveal how institutional rules – generally presented as enabling – and resources of SMEs – often presented as hindering – collide across levels of I4.0 transformation, producing trade-offs. These trade-offs highlight the cognitive dimension of agency that plays invisible yet crucial role in shaping how managers reason about and decide on I4.0 transformation.

At micro level, while the concept of I4.0 is articulated as a vision of an innovative industrial future (Lyotard & Brugger, 2001; Pfeiffer, 2017), its meaning remains diverse. This results from its diffusion through the plurality of sources and its shaping by different policy and industrial realities that combine technological and societal expectations (Culot et al., 2020; Oesterreich et al., 2020). SMEs' managers are thus confronted with a plural institutionalised visions of I4.0, which collides with their perceptual filters. These filters are shaped by managers' educational and professional background, roles within SMEs, mindset and interests regarding I4.0 transformation as well as their sensitivity towards SMEs' contexts (Weick, 1995). In this sense, the trade-off emerges from the collision between I4.0's broad institutional framings and the resources at the disposal of managers to make sense of I4.0 conceptual diversity (see *trade-off 1* in Figure 3). In response to this trade-off, managers articulate I4.0 into hybrid and context-dependent configurations by bracketing it through interpretative dimensions and anchoring it in managerial and organisational contexts (Meyer, 2019; Yunus, 2021). Depending on their leadership style, some emphasise human-related purposes alongside data-driven means, whereas others adopt more critical stances towards the I4.0 discourse and prioritise performance-oriented goals. These variations illustrate that the embracing of I4.0 is far from

uniform: different priorities emerge depending on organisational setting and managerial framing, challenging explanations that link I4.0 perceptions solely to SMEs' digital maturity (Tortorella et al., 2021) or managers' technological affinity (Wilkesmann et al., 2018).

Figure 3. Trade-offs within and across social systems of I4.0 transformation.



At the meso level, the existing prescriptive roadmaps often encourage SMEs to establish a balanced set of enabling resources – such as financial capacities, digital maturity, or change managerial competences – to succeed in I4.0 transformation (Barney, 1991; Pozzi et al., 2023). Yet SMEs' internal contexts rarely comply with these normative expectations, as this thesis reveals highly heterogeneous resource configurations: some composed exclusively of enablers, others only of barriers, and many combining both in varying proportions (see *trade-off 2* in Figure 3). Thus, instead of focusing on harnessing enabling factors, managers can similarly leverage existing barriers (Arroyabe et al., 2024; Keupp & Gassmann, 2013), unlocking even more creative forms of innovation. Within centralised hierarchies, often seen as obstacles (Cimini et al., 2020; Da Roit & Iannuzzi, 2023), managers can nonetheless develop comprehensive approaches to I4.0 transformation, particularly under international ownership structures. Within micro-sized SMEs, typically constrained with limited resources (Brozzi et al., 2020; Cimini et al., 2020), managers cultivate an organisational culture grounded in collaboration, which enhances digital knowledge and fosters rare capacities of budgeting for innovation. Even when facing financial constraints, managers can sustain specific practices, such as systematic cybersecurity checks, that are often presumed absent in such contexts (Arroyabe et al., 2024; Machado et al., 2021). This trade-off highlights that resource constraints form an integral part of SMEs' I4.0 transformation dynamics, putting managers at strategic position of sensing, seizing, and configuring these factors (Teece, 2007).

At the macro level, the institutional narrative positions I4.0 ecosystems as uniformly supportive environments, designed to provide SMEs with expertise and guidance (Hervas-Oliver et al., 2020; Scott, 2014). Our findings, however, reveal that these ecosystems are experienced by managers in mixed ways with the available support often described as fragmented, overlapping, and misaligned with companies' specific needs. Faced with this trade-off between how I4.0 RIE is designed and approached by companies, managers can credit or discredit perceptions of the accessibility and usability of existing external support through access and use tactics (see *trade-off 3* in Figure 3). In this thesis, credited retention appears when managers' interactions with the ecosystem confirm their previously held views (Weick, 2004) – either by reinforcing trust in its usefulness or by normalising its limitations. Those perceiving I4.0 RIE support as accessible and supportive (Kumar et al., 2023; Santos et al., 2022) validate these framings by relying on familiar administrative channels or established procedures to secure grants and standard solutions. Others, who see it as fragmented or bureaucratic (Horváth & Szabo, 2019; Orzes et al., 2020), also credit their retained perceptions: they use support cautiously or instrumentally, confirming the idea that external help is necessary but cumbersome. In contrast, discredited retention arises when new experiences contradict these assumptions and trigger a cognitive reassessment (Weick, 2004). Managers confronted with perceived dysfunctions of the ecosystem can reinterpret them as opportunities to act differently by reconsidering the value of institutional support or turning a mismatched offer into a self-defined resource. Through these shifts, managers' tactics reflect a process of framing and reframing, where I4.0 RIE is not simply accepted or rejected but continuously interpreted through situated actions (Weber & Glynn, 2006; Weick, 2004).

Since social systems corresponding to each level of I4.0 transformation often overlap (Whittington, 2010), trade-offs arise not only within each system but also at their intersections. Tensions can appear between managerial and organisational systems, when managers' perceptions of I4.0 transformation collide with their SMEs' resource configurations. Although previous research often portrays contexts still reliant on paper-based routines, obsolete machinery, or limited digital literacy as detrimental to innovation (Hansen et al., 2024; Sony et al., 2024), this thesis shows that such contexts do not prevent managers from innovating. Instead, managers draw on these challenges to define data-centred and performance-driven priorities for I4.0 transformation. Trade-offs can also emerge between managerial and institutional systems, when managers' perceptions of I4.0 RIE support are misaligned with the way its institutional frameworks are designed. Our findings show that most managers were highly critical of financial support, citing poorly digitalised application processes, unclear budget criteria (Ghobakhloo et al., 2022; Horváth & Szabo, 2019), or restrictions linked to EU definitions of SMEs. Nevertheless, managers still mobilised these mechanisms, often describing them as essential to sustain the ongoing I4.0 transformation, thus accepting to comply with the existing misalignments. Finally, tensions occur between organisational and institutional systems, when SMEs' internal configurations fail to align with I4.0 RIE support mechanisms. We demonstrate that, beyond administrative burdens and limited digital maturity – commonly identified as key barriers to benefiting from external support (Estensoro et al., 2021; Horváth & Szabo, 2019) – factors such as RIE institutional configurations and companies' I4.0 maturity can produce similar constraining effects. Indeed, some managers struggled to access educational support because the communication language – tied to different linguistic communities – differed from that used within the company, while the offered programs were outdated compared to the technologies already in SMEs' practice.

Across these three interfaces, the observed trade-offs illustrate the central role of managers in acting upon existing contextual structures (Giddens, 1987; Whittington, 2010) through their cognitive capacity to bridge envisioned I4.0 trajectories with the organisational and institutional constraints surrounding them (see Figure 3). This logic of reconciliation cuts across all levels of I4.0 transformation: managers continuously align I4.0 requirements with the realities of their social systems through leadership to enact perceptions into actions (Sharifi & Zhang, 2009), decision-making to match needs and challenges (Keupp & Gassmann, 2013), and contracting power to shape external partnerships (Harney & Alkhalaf, 2021). These trade-offs become the underlying mechanism upon which navigation practices emerge, as managers turn their perceptions into concrete actions axed on I4.0 transformation (Weick, 1995).

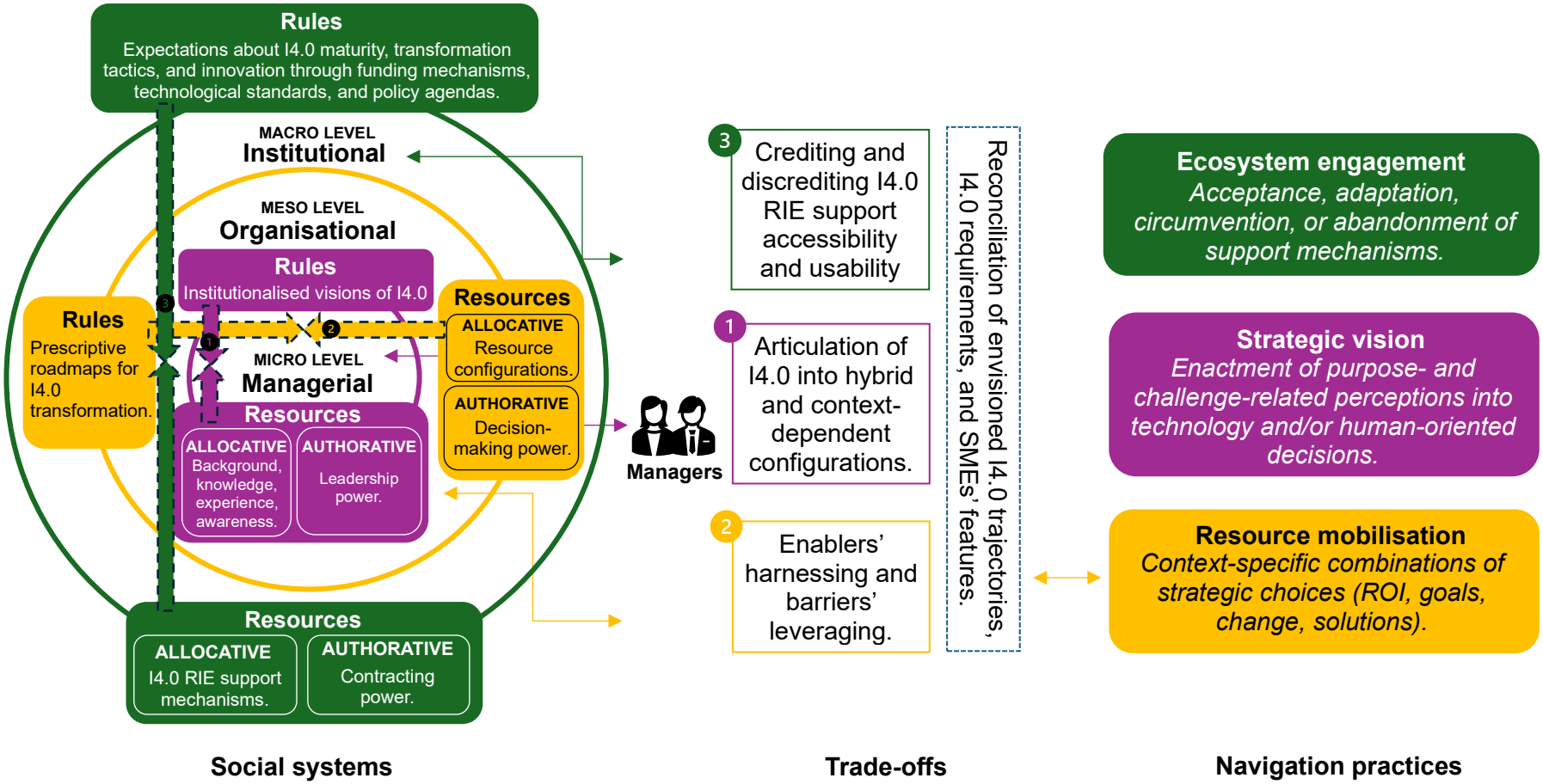
Navigation Practices Emerging from Trade-Offs

Existing research often illustrates SMEs' I4.0 transformation through maturity models (Estensoro et al., 2021; Müller, Buliga, et al., 2018), staged progressions (Mittal et al., 2020; Vereycken et al., 2024), or descriptive case studies (Cimini et al., 2020; Machado et al., 2021). While these approaches document milestones and patterns of change, they rarely capture the strategic decision-making processes behind SMEs' actions (Menten et al., 2025). Despite SMEs being widely recognised as managerially driven organisations (Harney & Alkhalaf, 2021), the role of managerial agency in I4.0 transformation remains underexplored, appearing mostly in general accounts of digitalisation (Zoppelletto et al., 2023) or in narrow analyses of particular technologies (Tortorella et al., 2021). This thesis advances the debate by conceptualising navigation practices as the ways managers enact their cognitive responses to trade-offs into situated courses of action across three levels of I4.0 transformation (Weick, 1995).

At the micro level, navigation unfolds through the ways managers enact their perceptions of I4.0 in strategic decisions, conceptualised in this thesis as strategic vision (see Figure 4). By articulating I4.0 interpretative dimensions into hybrid configurations, managers frequently focused on purpose and challenge-oriented perceptions, mobilising them as a foundation for their context-specific strategic decisions (Sharifi & Zhang, 2009; Viitala et al., 2022). For example, when I4.0 was perceived as costly and technically complex for employees, managers opted for subsidised diagnostics and expertise. When it was seen as another passing fashion, some reframed it as *"continuous improvement"* to make it accessible to operators and avoid ambiguity (Ivanova & Torkkeli, 2013). These patterns illustrate that technology-oriented framings could coexist with organisationally sensitive practices, such as adapting communication and accompanying operators through puzzling situations (Balogun et al., 2015; Boje, 2001). Conversely, although being sensitive to *"keeping the human face of the company"*, some managers privileged automation over recruitment to avoid labour costs associated with I4.0 (Ietto et al., 2022; Stentoft et al., 2021). In this sense, micro-level navigation reflects how managers anchor purpose- and challenge-related perceptions through organisational contexts to undertake multidimensional and sometimes paradoxical decisions.

At the meso level, navigation takes shape through the ways managers mobilise SMEs' resource configurations to make strategic choices for I4.0 transformation (see Figure 4). Given the heterogeneity of internal contexts, managers leverage enablers and barriers by combining priorities related to goals, ROI, change, and solutions to align with their companies' specific needs (Barney, 1991; Teece et al., 2016). Being part of an international group allowed some managers to embed I4.0 for their SMEs within a structured multi-level approach, extending

Figure 4. Interplay of managerial agency and SMEs' contextual structures during I4.0 transformation.



attention beyond financial and technological objectives to include sustainability and workers' well-being (Bosman et al., 2019; Cimini et al., 2020). Other managers pursued incremental approaches by allocating limited budgets across multiple projects, implementing standard I4.0 technologies that encourage responsible resource use and waste management, helping cut costs and manage budgets more effectively (Martinetti et al., 2024; Santos & Sant'Anna, 2024). Even in SMEs dominated by human resource constraints, managers privileged organisational transformation to mediate to these issues, challenging portrayals of SMEs' orientation towards I4.0 transformation as primarily techno-centric (Cimini et al., 2020; Ietto et al., 2024). These scenarios illustrate that managerial agency lies in reworking current resource configurations, rather than in awaiting optimal conditions for I4.0.

At the macro level, managers' engagement with I4.0 RIE appears far more nuanced than the commonly assumed sequence of predictable steps of fixing a goal, finding a support provider, and adopting or internally adjusting received support (Menten et al., 2025; Vereycken et al., 2024). When RIE design clashes with SMEs' organisational contexts, managers selectively engage with support mechanisms by accepting, adapting, bypassing, or abandoning them (see Figure 4). Some managers – especially from SMEs lacking internal expertise or digital maturity – conform with the standardised supplier procedures to compensate for these limitations. When external support proves mismatched with the needs of SMEs (Estensoro et al., 2021; Orzes et al., 2020), some managers engage in support co-creation with institutional actors, turn to alternative providers, or reframe existing initiatives as internal motivational levers. In other cases, managers bypass structural difficulties by relying on trusted partners, maintaining relational continuity instead of navigating formal entry points (Menten et al., 2025; Vereycken et al., 2024). Still others, discouraged by the administrative burden or the misfit of proposed solutions (Horváth & Szabo, 2019; Orzes et al., 2020), withdraw from engagement altogether to preserve limited time and resources. Moreover, when facing a similarly perceived dysfunction of the I4.0 RIE – such as the lack of technological solutions aligned with SMEs' operational or business specificities (Estensoro et al., 2021; Müller et al., 2024) – managers mostly respond in different ways. Some switch partners, others co-create solutions together with providers, while some seek funding to develop in-house solutions or postpone projects that required resources already overstretched by concurrent initiatives.

By representing I4.0 transformation as a structuration process, this thesis stresses the importance of continuous co-evolvement between managerial agency and SMEs' contextual structures (see Figure 4). This dynamic interplay unfolds across the micro, meso, and macro levels, showing that transformation rarely results from managers simply adopting I4.0-related requirements. Instead of framing I4.0 through Triple Bottom Line that aligns social, economic, and environmental goals (Jayashree et al., 2021; Santos & Sant'Anna, 2024), chasing resource configurations empowered by digital or financial enablers (Ghobakhloo et al., 2022; Sony et al., 2024), or getting institutional support to innovate (Benitez et al., 2022; Ietto et al., 2024), managers constantly navigate the trade-offs. These emerge between normative expectations prescribing how to navigate I4.0 and the resources available to managers, that the latter interpret, mobilise, and reshape within and across different levels. While the observed trade-offs expose the cognitive dimension of agency, where managers make sense of contradictions and craft meaning, navigation practices reveal its enactive dimension, through which these meanings materialise in strategic practices (Weick, 1995). By bridging these two layers, managers neither simply comply with institutionalised I4.0 frameworks (Oliver, 1991; Scott, 2014) nor act in isolation – they reconcile their vision of I4.0 transformation with the

existing resource configurations and ecosystem designs through series of context-specific decisions, choices, and engagement tactics. This perspective advances existing research by re-centring the manager as a reflexive actor who structures and is structured by the I4.0 environment (Giddens, 1987; Weick, 1995), approaching I4.0 transformation within SMEs as an open, negotiated, and continuously reconstructed process.

Theoretical Contributions

This thesis advances management and innovation studies by proposing a structural and processual lens to explain how managers navigate complex technological transformations within SMEs. Moving beyond deterministic views of I4.0 as a linear technological progression driven by predefined resources or policy support (Ghobakhloo et al., 2022; Pozzi et al., 2023), it conceptualises such transformations as strategic technological trajectories that emerge through the recursive interplay between managerial agency and contextual structures (Dosi, 1982; Giddens, 1987). While conceived as being driven by technological possibilities and structured through institutional arrangements – including policies, standards, norms, and shared expectations that orient and legitimise directions of change (Fogaça et al., 2024; Scott, 2014) – these trajectories become strategic due to differences in how they are translated and enacted across firms. Within this perspective, transformation does not result from the alignment of SMEs' pre-existing conditions with I4.0 requirements (Ietto et al., 2024; Sony et al., 2024) – but from the ways managers interact with conceptual diversity of I4.0, their SMEs' internal resources and I4.0 RIE to orient, enact and stabilise their perceptions of I4.0 transformation over time (Weick, 1995). In doing so, the thesis advances digital innovation research by shifting the understanding of transformation from technological paradigm anchored into systemic conditions (Adner, 2017; Dosi, 1982) and driven by capability-based adaptations to environmental (Eisenhardt & Martin, 2007; Teece, 2007), towards strategic technological trajectories that are actively shaped through I4.0 meaning enactment, resource mobilisation, and ecosystem engagement.

Conceptual Diversity as a Generative Mechanism of Managerial Sense-Making

The first contribution lies in shifting the role of conceptual diversity of I4.0 from an analytical problem for scholars to a generative condition for managerial action under I4.0 transformation, extending sense-making and strategic ambiguity research (Gioia et al., 2012; Weick et al., 2005). While prior work has shown that ambiguity enables multiple interpretations and supports alignment among actors, it remains largely silent on how such interpretive plurality becomes organised into actionable orientations. Addressing this gap, the means–purpose–challenge typology developed in this thesis shows how managers actively structure conceptual diversity into configurations of meaning that orient action. Rather than resolving ambiguity, managers engage with it by organising different dimensions of I4.0 – *what* it enables, *why* it matters, and *how* it challenges their context – into coherent orientations for transformation. In this sense, cognitive and enactive agency are intertwined: managers simultaneously construct meaning and act upon it, progressively stabilising selected interpretations through strategic decisions. In doing so, the thesis contributes to managerial cognition and dynamic capabilities literature (Helfat & Peteraf, 2015; Hodgkinson & Healey, 2011; Teece, 2007) by showing that in addition to informing decision-making, interpretive processes also generate orientations that underpin strategic choices under conditions of ambiguity. This provides micro-foundations for understanding how strategic action emerges from meaning, highlighting the stabilisation of interpretation as a key mechanism linking cognition to capability development.

More broadly, this contribution extends innovation literature by repositioning conceptual diversity as a generative mechanism of strategic decision-making rather than a limitation to be resolved. Indeed, many central but ambiguously defined concepts in organisational change research – such as sustainability (Bansal & Song, 2017; Hahn et al., 2015), resilience (Duchek, 2020; Linnenluecke, 2017), or open innovation (Bigliardi et al., 2021; Bogers et al., 2018) – are often treated as stable constructs, while in practice they encompass multiple and competing logics that actors must actively organise to act. By showing how such multiplicity is structured and stabilised through managerial action, the thesis suggests that these concepts can be understood as evolving strategic trajectories shaped through ongoing processes of interpretation and enactment. In this sense, I4.0 illustrates a broader mechanism through which organisational change unfolds under conditions of conceptual diversity.

From Enablers and Barriers to Enacted Resource Configurations

The second contribution lies in challenging the dichotomous view of enablers and barriers by reconceptualising them as dynamic configurations of pressures, opportunities, and constraints that managers actively interpret and reconcile, rather than as static determinants of I4.0 transformation success. Earlier research often described these factors as dichotomous – either supportive or obstructive (Ghobakhloo et al., 2022; Hansen et al., 2024; Horváth & Szabo, 2019) – adopting a deterministic logic that links abundant resources to success and their scarcity to failure. By contrast, this thesis demonstrates that SMEs' managers frequently operate under mixed configurations, where positive and negative conditions coexist and require arbitration (Zabudkina et al., 2024). This shift moves the analysis from identifying which factors enable or hinder transformation to understanding how managers actively construct the strategic relevance of these factors in practice. This construction unfolds through cognitive and enactive agency, through which managers face trade-off situations, by actively reconciling I4.0-related expectations and requirements with resources across different levels of transformation.

From a theoretical standpoint, this approach reinterprets the resource-based view (Barney, 1991) and dynamic capabilities theories (Teece et al., 2016) by showing that instead of possessing inherent strategic value, resources acquire meaning through managerial interpretation and action. The same factor – such as limited budget, underdeveloped organisational culture, or rigid hierarchy (Cimini et al., 2020; Črešnar et al., 2022) – can hinder or enable I4.0 transformation depending on how managers frame and mobilise it. Rather than treating SMEs' resource configurations as objective states, this thesis interprets them as situated enactments of managerial agency, through which constraints can be actively transformed into strategic drivers of action instead of remaining limitations to overcome (Arroyabe et al., 2024). Consequently, I4.0 transformation becomes compatible with asymmetric resource profiles that combine both enablers and constraints, while strategic decision-making no longer depends on ideal preconditions, but on how managers creatively mobilise their SMEs' internal strengths and limitations to orient ongoing transformation paths. This reframing contributes to management and innovation research more broadly by questioning the prescriptive notion of *readiness* that fuels many models of technological change and digital transformation (Appelbaum et al., 2012; Roos & Nilsson, 2020; Weiner, 2009). These models often capture change through a sequential path of steps with measurable preconditions to fill in order to succeed. By demonstrating that SMEs can progress through the creative recombination of both enablers and constraints, this thesis shifts the analytical focus from assessing resource availability to examining the processes through which managers

actively enact, recombine, and assign strategic meaning to them (Giddens, 1987; Weick, 1995).

I4.0 RIE as Selectively Enacted Engagement Spaces

Finally, this thesis advances the theorisation of innovation environments by repositioning them from coordinated systems of support towards selectively enacted spaces of engagement. Innovation ecosystem (Adner, 2017; Jacobides et al., 2018) and regional innovation system (Asheim et al., 2016; Cooke, 1992) literatures commonly conceptualise these environments as structured configurations of interdependent actors and institutions that collectively enable innovation and transformation. Within this perspective, coherence, alignment, and complementarities across actors are treated as key conditions for effective support. However, these perspectives rely on heterogeneous and partially disconnected conceptualisations of such environments, variously emphasising actors, intermediary functions, or system-level interdependencies, while rarely accounting for their policy-driven construction in the context of I4.0 (Pfeiffer, 2017). Building on this insight, the thesis conceptualises these environments as I4.0 RIE – a geographically embedded and institutionally shaped constellations of actors, activities, and artifacts organised around supporting SMEs' transformation. Building on empirical findings, this thesis shows that managers engage with I4.0 RIE through processes of selection, retention, and enactment (Weber & Glynn, 2006; Weick, 2004), defining what is relevant, usable, and worth mobilising based on their interpretations, priorities, and constraints. Through this process, ecosystems take shape as partial and situated configurations rather than fully integrated systems.

This perspective extends institutional theory by clarifying how institutions operate as components of support mechanisms within I4.0 RIE and how their effects materialise in practice. While institutional approaches typically conceptualise policy instruments, funding schemes, and institutional programmes as pressures to which companies can respond strategically (Oliver, 1991; Scott, 2014), the findings show that these pressures are mediated through managerial sense-making and enacted via access and use tactics. In this view, instead of directly shaping actions, institutions become effective only through the ways managers engage with, reinterpret, and mobilise them within their firm's context (Weiner, 2009). Managerial enactment thus constitutes the mechanism through which macro-level institutional arrangements are translated into differentiated organisational responses for specific strategic trajectories.

This contribution also informs boundary-work research (Langley et al., 2019; Murray, 2010) by showing how managerial enactment of I4.0 RIE relies on the ongoing configuration and negotiation of boundaries between managerial, organisational, and institutional systems. In line with the selective engagement processes described above, the observed access and use tactics illustrate that collaboration unfolds through both connecting and rearranging these domains. Practices such as *pragmatic repurposing* and *selective leveraging* reflect a configurational use of boundaries, through which actors restructure existing mechanisms to create new alignments while maintaining institutional coherence (Bucher & Langley, 2016; Langley et al., 2019; Oldenhof et al., 2016). In contrast, *mutual tailoring* and *relational prioritisation* exemplify collaborative boundary work, where actors engage in reciprocal adjustments and relational continuity to sustain cooperation without erasing distinctions (Kellogg et al., 2006; Langley et al., 2019; Levina & Vaast, 2005). Together, these practices illustrate that boundaries serve as flexible coordination, enacted through *"the skillful activities*

of particular people managing the ambiguities of belonging to and navigating different worlds" (Langley et al., 2019, p. 35).

Practical Implications

The findings of this thesis invite both managers and policymakers to reconsider how I4.0 transformation is approached in practice. Rather than treating it as a linear process of technological upgrading, this transformation is approached as an evolving process shaped through the interaction between managerial interpretation, organisational dynamics, and institutional design. In this perspective, transformation develops through the ways managers clarify meaning, work with available resources, and find and shape relevant ecosystem support, while policymakers contribute by structuring coherent and accessible support environments. This interaction becomes particularly salient in contexts where multiple actors and initiatives coexist, requiring both managers and policymakers to organise and align diverse elements over time. Accordingly, the following practical implications address both sides of this interaction, outlining several recommendations derived from the empirical results.

Implications for Managers

The findings of this thesis reflect a specific managerial reality, particularly in micro and small firms, where limited time, resources, and organisational support structures constrain the possibility of developing formalised and comprehensive transformation strategies. In this context, managers should simultaneously manage day-to-day operations, explore technological opportunities, and interact with multiple ecosystem actors. Building on these insights, this thesis suggests the idea of a methodological guide[13], composed of a set of practical and adaptable tools that managers can mobilise at different moments of their transformation process. These tools support ongoing navigation by helping managers structure their decisions, adjust their actions, and progressively shape context-specific transformation trajectories under conditions of uncertainty. Rather than being applied sequentially, they can be combined, revisited, and adapted over time, in line with the iterative nature of SMEs' transformation practices (Harney & Alkhalaf, 2021).

Clarifying What I4.0 Means for Your Company

A first lever for action consists in clarifying what I4.0 represents for the organisation. Rather than starting directly from technological solutions, managers can use the means–purpose–challenge typology developed in this thesis to guide this reflection.

In practice, this tool helps managers to:

- identify the means they want to mobilise (technologies, data, etc.),
- clarify the purpose of their transformation (performance, organisational change, human aspects, etc.),
- recognise the challenges they may face (normative, organisational, resource-related, etc.).

[13] This proposal constitutes a first structured formulation of a methodological guide grounded in the empirical findings of the thesis. Its further development is currently envisaged through a more systematic design, incorporating dedicated formats, facilitation methods, and practical exercises to support SMEs' managers in navigating transformation processes.

The findings show that these dimensions often coexist and interact. This requires managers to keep a balance between them, instead of focusing mainly on technologies while leaving aside organisational or human implications.

Managers can use this typology as a collective discussion tool with their teams. By involving employees in defining what I4.0 means for the company, they can align strategic intentions with daily practices and reduce gaps between discourse and operations (Balogun et al., 2014; Denis et al., 2007). Storytelling practices can further support this process by turning abstract ideas into shared narratives that foster understanding and ownership (Boje, 1991; Brown et al., 2005). This reflection can be revisited over time through regular exchanges and discussion moments, allowing managers to adjust and stabilise a shared understanding as the transformation evolves.

To support its practical use, the means–purpose–challenge typology has been translated into an operational format through a training programme co-designed with colleagues from the LENTIC research centre, within the international project “Industry.4.h” launched by the Cat Foundation in cooperation with Grenoble Institute of Technology, Polytechnic University of Milan, and Technical University of Darmstadt. Within this programme, the typology was reinterpreted as a visual tool – a pie chart-like model – used during interactive group discussions to help participants explore diverse perceptions of I4.0 and refine their internal communication and storytelling towards employees (see Appendix B). To highlight differences in priorities and viewpoints, personas based on the thesis’ empirical findings were introduced to support dialogue and mutual understanding within teams (see Appendix C). At the end of the programme, participants can reuse these tools within their organisations to co-construct, together with their teams, a shared narrative of their I4.0 transformation trajectory (Boje, 1991; Brown et al., 2005).

Clarifying what I4.0 means for your company brings:

- creates a shared understanding across the organisation,
- connects strategic intentions with everyday practices,
- supports decision-making in situations where directions remain unclear.

Working With Available Resources in a Flexible Way

A second lever consists in approaching the firm’s resources and constraints as flexible and evolving, rather than as a fixed set of strengths and weaknesses.

Managers can rely on two complementary tools:

- the repertoire of internal and external factors identified in Study 1, which provides a structured basis for assessing their SMEs’ context,
- the four strategic scenarios (responsible planners, tactical players, proactive developers, resilient pragmatists), which illustrate different ways of using resources and setting priorities.

In practice, managers can:

- regularly review their available resources (financial, technological, organisational, human),

- identify how existing constraints can be used as levers and how current strengths can be mobilised differently,
- explore alternative ways of using their resources by discussing the scenarios during workshops or strategy sessions.

These scenarios can also be translated into a canvas model, structured around the firm's situation (resources, constraints, strategic choices), and updated over time to track progress and adjust directions.

To support this approach, managers can establish simple routines such as project reviews or team feedback sessions, helping them identify which choices create learning and which lead to bottlenecks or rigidity.

What working with available resources in a flexible way brings:

- turns constraints into actionable levers,
- supports continuous adaptation without waiting for ideal conditions,
- helps visualise and adjust strategic directions over time.

Finding and Shaping the Right Ecosystem Support

A third lever consists in approaching I4.0 ecosystems as sources of support that managers can explore and adapt depending on their needs.

The findings show that available support often appears fragmented, with multiple actors, overlapping initiatives, and unclear entry points. Managers can therefore benefit from structuring their approach around three practical axes.

Managers can first clarify what kind of support they are looking for, based on the typology identified in this thesis:

- financial support (subsidies, funding programmes),
- technical support (technologies, expertise),
- educational support (training, skill development),
- guiding support (diagnostics, advisory services),
- networking support (connections with partners and peers).

This helps focus attention on what is most relevant and avoid spreading efforts across too many initiatives.

Managers can then consider different ways of reaching this support. The findings identify several access tactics:

- aligned problem-solving: using known programmes or contacts to address a clearly identified need,
- pragmatic repurposing: using an existing programme for a purpose different from its initial design,

- relational prioritising: relying on trusted partners or existing relationships rather than formal entry points,
- exploratory search: actively looking for new opportunities or partners.

These approaches can be combined depending on the situation, the urgency of the need, and the manager's familiarity with the ecosystem.

After accessing support, managers can decide how to use it so that it fits their SMEs. The findings highlight several ways of doing so:

- plug-and-play: using a solution as it is, with minimal adjustment,
- mutual tailoring: working with the provider to adapt the solution to the firm's context,
- selective leveraging: using only the parts of the support that are useful,
- boundary setting: setting limits to keep control over internal processes or decisions.

These different approaches help managers ensure that external support remains aligned with their companies' priorities and capacities.

Managers can support this process by keeping track of their interactions with external actors and regularly reviewing how each initiative contributes to their transformation. This helps maintain continuity over time, especially when contacts or projects evolve.

What finding and shaping the right ecosystem support it brings:

- helps organise actions in complex and fragmented environments,
- offers different ways to find and use external support,
- strengthens alignment between external opportunities and internal priorities,
- supports more consistent and controlled transformation over time.

Implications for Policymakers and Ecosystem Actors

For policymakers, the findings call for a rethinking of how I4.0 ecosystems are designed, governed, and evaluated, particularly in multinational states (e.g., Belgium, Canada, Switzerland) or coordinated market economies (e.g., Germany, Sweden, Switzerland), where overlapping institutional layers and distributed responsibilities shape firms' access to support (Asheim & Gertler, 2005; Lundvall, 2007; Soskice, 1999). The results highlight a structural tension that can be understood as a fragmentation phenomenon: the coexistence of multiple programmes, agencies, and intermediaries reflects an effort to address the diversity of SMEs' needs, yet this same multiplicity creates fragmented landscapes that remain difficult for managers to navigate. In practice, this fragmentation reduces the readability of available support and leads managers to rely on partial, selective, and sometimes discontinuous use of ecosystem support. In this context, policy efforts would benefit from shifting their focus from the expansion of instruments towards the coordination and articulation of existing mechanisms. The typology of I4.0 RIE supports identified in this thesis – *financial, technical, educational, guiding,* and *networking* – could serve as a foundation for this coordination. Once tested and adjusted to regional or national specificities, it could be used to cluster existing support mechanisms according to their dominant purpose and function, thereby stabilising the entry points available to SMEs and improving the visibility of relevant programmes. This

categorisation would also help policymakers identify overlaps, address gaps, and align different actors, activities, and artifacts with firms' diverse transformation needs. Complementary to this, cross-agency working groups that include both support providers and SMEs' representatives could function as assessment and coordination platforms, promoting collective reflection on redundancies, clarifying roles, and ensuring long-term coherence in I4.0 ecosystem design.

Policymakers can also build on the typologies of access and use tactics developed in this thesis to rethink how existing I4.0 support mechanisms are designed, communicated, and followed up. The findings show that managers interact with I4.0 RIE through diverse logics of access, ranging from the most conventional – such as *aligned problem-solving* and *exploratory search* – to the least ones – such as *pragmatic repurposing* and *relational prioritising*. The same can be observed among use tactics, where *plug-and-play* and *boundary-setting* are the most familiar use scenarios, whereas *mutual tailoring* and *selective leveraging* are more experimental ones. These patterns reveal that access and use could be difficult to resume into uniform administrative steps, since they represent social processes shaped by perceived familiarity, trust, and relevance. To translate these insights into practice, support policies could focus on making access and use more intuitive. Given that the experience in I4.0 RIE navigation was crucial in getting familiar with its rules and potential flaws, simplification of entry procedures can help by making them more user-friendly. This can include allowing companies to contact designated support providers rather than navigating generic portals and introducing guided application paths that correspond to distinct experience-oriented profiles (for instance, "first-time applicants", "experienced innovators", or "advanced users").

The findings of this thesis emphasise the importance of relational continuity for effective I4.0 ecosystems, illustrated through *relational prioritising* paths that cultivate long-term partnerships and through *boundary-setting* tactics where managers withdraw from projects following internal rotations. The frequent turnover of programmes and personnel at both organisational and institutional levels (Harney & Alkhalaf, 2021) often causes SMEs to lose contact with initiatives or support providers, weakening trust and discouraging engagement. Rather than relying on individual contacts, policymakers could promote systemic continuity through mechanisms that preserve the history of interactions, even when actors change. This could include secured tracking systems documenting firms' participation across programmes, confidential institutional memory databases accessible only to authorised intermediaries, and coordination platforms that allow companies to reconnect easily with relevant support actors as their situation changes. Such mechanisms would ensure relational consistency without compromising confidentiality or managerial autonomy. In addition, cross-programme mentoring networks could link firms facing similar challenges, providing flexible relational support that complements formal assistance. By focusing on continuity of information and relational quality rather than fixed contact points, public initiatives can foster trust while maintaining SMEs' autonomy to explore diverse partnerships within the ecosystem.

Finally, the evaluation of I4.0 ecosystem effectiveness should evolve beyond quantitative indicators such as the number of supported firms or technology adoptions. These metrics often overlook how companies sustain transformation, reframe their understanding of it, and develop relationships with ecosystem actors. Policymakers are encouraged to integrate qualitative evaluation criteria that record how firms experience and use support, allowing these insights to inform the continuous adaptation of offers. For this matter, while the collection of success stories (Khin & Hung Kee, 2022; Mittal et al., 2018) remains valuable for increasing the visibility

of support mechanisms and spreading awareness about existing programmes, it should not be the sole source of evaluation. To gain a fuller picture, policymakers and support providers are encouraged to facilitate the sharing of diverse experiences, including those highlighting difficulties or unmet expectations. This process requires creating trust-based and confidential feedback environments where companies can speak openly about their experiences. To make this feedback collection both meaningful and feasible, light and embedded participation formats can be envisioned. Instead of lengthy workshops or standard online surveys, feedback could be gathered through brief post-programme reflection calls or periodic check-ins coordinated by intermediaries already familiar with the firm. Another option is to offer micro-feedback tools – such as digital diaries connected to the support mechanism's interface – that can be used to write down quick reflections at key moments of a project, capturing impressions while they are still fresh. Accompanied by a clear explanation of how the feedback will be protected and used for future improvements, these low-effort mechanisms can encourage honest input while minimising the administrative burden. By turning evaluation into a continuous learning dialogue, policymakers can improve the responsiveness of I4.0 ecosystem programmes and build stronger trust among participating SMEs.

Towards a Shared Approach to Transformation

The implications of this thesis invite to take the understanding of I4.0 transformation as structuration (Giddens, 1987) a step further, unfolding it as a continuous and reciprocal process of interaction between firms and their ecosystems. Managers contribute by creating shared narratives of I4.0, embracing their resource configurations' dynamics, and tracking relevant support mechanisms, while documenting their engagement practices. Policymakers, in turn, can reinforce these dynamics by designing I4.0 RIE that evolve through clarifying access points, fostering relational continuity through coherent coordination, and establishing feedback mechanisms that transform firms' experiences into collective intelligence. When these perspectives converge, I4.0 transformation becomes a shared practice: managers translate institutional frameworks into context-specific strategies, while policymakers draw from firms' lived experiences to refine governance and support. This reciprocal dynamic contributes to the gradual shaping of transformation trajectories, where meaning, resources, and support are continuously adjusted through interaction between firms and their environment. This duality allows both sides to confront and reconcile the inherent tensions of I4.0 transformation through negotiating (Langley et al., 2019; Whittington, 2010). This negotiating happens between institutional prescriptions and organisational realities, between the need for coordination and the preservation of autonomy, and between Belgium's historically complex institutional configuration and the pursuit of coherent support mechanisms, aligned with SMEs' needs.

Limitations and Future Research

This thesis, while offering a multi-level and interpretive understanding of how SMEs' managers perceive and navigate I4.0 transformation, inevitably bears several limitations. These can be grouped into three main categories related to empirical scope and generalisability, research design and temporality, and analytical and conceptual boundaries. Recognising them allows situating the scope of this work and outlining fruitful directions for future research[14].

[14] In this perspective, Appendix A outlines a prospective research direction through which I would like to extend this work, illustrating how I position my future research in relation to the theoretical and empirical avenues opened by this thesis.

Empirical Scope and Generalisability

The empirical material primarily stems from Walloon manufacturing SMEs, situated in an institutional context marked by overlapping competences and a dense network of policy support initiatives (Faniel et al., 2021). This regional and sectoral anchoring ensured contextual richness and enabled fine-grained analysis of managerial navigation within a complex I4.0 ecosystem of support mechanisms. However, this very complexity also constrains the transferability of findings. Managerial sense-making and engagement with external support may unfold differently in regions where support systems are more centralised and unified, more market-driven, or still emergent (Benitez et al., 2020; Da Roit & Iannuzzi, 2023; Hoffmann et al., 2022). Future research could therefore adopt a comparative perspective, analysing how the degree of governance centralisation, policy maturity, or public–private coordination affects managers' interpretive agency and strategic choices regarding I4.0 RIE support. Cross-regional studies across European or non-European contexts could reveal how variations in institutional design shape SMEs' navigation practices of I4.0 ecosystems.

Within this research, attention was also paid to ensuring industrial representation by including firms from diverse manufacturing branches as well as from waste management and construction-related sectors, all of which are inevitably affected by I4.0 transformation (Galizia et al., 2023; Müller et al., 2018). This heterogeneity enabled a transversal understanding of managerial agency across different environments but also aggregated sectoral specificities that may nuance how I4.0 transformation unfolds in different sectors. Future studies could thus adopt a more focused sectoral lens, exploring how I4.0 practices interact with operational logics, supply chain dependencies, and regulatory pressures specific to individual industries. Such in-depth sectoral inquiries would encourage refined insights more tightly aligned with the industrial realities and institutional particularities of each sector.

Research Design and Temporality

The second limitation concerns the temporal design. The cross-sectional design of both quantitative and qualitative empirical studies captures managerial interpretations at a specific moment in time, without observing how perceptions and strategies evolve. Yet this thesis demonstrates that I4.0 transformation is an ongoing, recursive process shaped by adaptation, reinterpretation, and changing contexts. Without longitudinal observation, it remains difficult to trace how managerial sense-making evolves when SMEs experience shifts in resources, leadership or policy changes. Future research could therefore adopt processual and longitudinal designs – combining repeated interviews, ethnographic observation, and time-sequenced case studies – to follow how narratives regarding I4.0 transformation evolve, stabilise, mutate, or fade. Such approaches would extend the temporal reach of the current analysis and elucidate how short-term trade-offs arise into long-term navigation practices, revealing the cumulative structuration of I4.0 strategic trajectories.

Analytical and Conceptual Boundaries

The third limitation concerns the analytical and conceptual framing of the thesis, which shapes both its depth and its scope.

First, the multi-level design of this thesis – linking managerial, organisational, and institutional systems – offers a comprehensive lens on I4.0 transformation as structuration process, fostering the interplay between agency and structure on different levels. Yet the integration across levels remains primarily theoretical rather than empirical: each level was studied through distinct datasets and analytical frameworks, and their convergence was reconstructed

and discussed in synthesis. Future research could adopt embedded multi-level case designs connecting these levels in real time. Following the same SMEs across different levels of their strategic technological trajectories would provide direct empirical grounding for the recursive interactions theorised here. In particular, it could show how trade-offs identified across different levels unfold, illustrating how institutional shifts reshape both resource configurations and interpretive frames within firms and vice versa. Such research would operationalise the multi-level structuration of I4.0 transformation more explicitly, offering evidence of how managerial perceptions, organisational resources, and ecosystem support co-evolve through concrete navigation practices.

Second, the focus on managers as central actors introduces a single-actor perspective. While consistent with the research question, this approach excludes the voices of employees, policymakers, unions, and other stakeholders who co-construct transformation in practice (Pichault, 2013). The findings already suggest that many observed phenomena – such as I4.0 narratives, ecosystem framings or engagement practices – result from co-constructive processes of sense-making and navigation. Future research could thus adopt multi-actor designs, integrating voices from different positions. Comparative discourse analyses or joint workshops could reveal how different actors co-construct, negotiate, and reconcile meanings and practices

Finally, anchoring the thesis within the discourse of I4.0 provided conceptual focus and relevance to contemporary industrial policy debates, yet it also narrows the analytical scope to one paradigm of technological change. As frameworks such as Industry 5.0, sustainability transitions, or circular economy models gain prominence (Bansal & Song, 2017; Fratini et al., 2019; Leng et al., 2022), and as broader notions such as digitalisation, digital transformation or technological innovation continue to evolve (Plekhanov et al., 2023; Radicic & Petković, 2023), the central notions of this thesis – particularly trade-offs, strategic sense-making, and ecosystem engagement – may evolve or reconfigure. Future research could therefore extend this inquiry by applying the structuration and sense-making-oriented lens developed in this thesis (Giddens, 1987; Weick, 1995) to these adjacent and more generic transformation concepts. Examining how alternative paradigms introduce distinct institutional rules, normative expectations, or cognitive frames into companies' strategic technological trajectories would reveal whether the same dynamics of strategic vision, resource mobilisation, and ecosystem engagement hold beyond the I4.0 label.

Conclusion

This thesis aimed to understand how SMEs' managers perceive and strategically navigate the transformation associated with I4.0. When this research began, I4.0 had already become a dominant topic in policy and academic circles, often presented as a driver of industrial renewal through digital technologies. Yet this discourse was fragmented, marked by conceptual diversity and a technological determinism that framed transformation as a technical, linear, and controllable process. SMEs were often portrayed as resource-constrained systems, struggling to follow trajectories designed for larger firms. Against this backdrop, this thesis re-examined I4.0 transformation through an interpretive lens, showing that it is less a fixed process of technological upgrading than an evolving and situated course of action shaped through the interaction between managerial agency and contextual structures.

The thesis unfolded through four complementary studies, each addressing a different level of this interaction. The first study identified the dominance of enabler–barrier dichotomies in the literature and the absence of managerial agency in explanations of I4.0 transformation, suggesting a new perspective of trade-offs leading to strategic choices. The second showed that instead of simply reproducing existing definitions of I4.0, managers engage with its conceptual diversity by bracketing, anchoring, and stabilising meanings in relation to their organisational contexts. The third revealed that SMEs' resources are better represented as evolving and asymmetric configurations of resources and constraints that managers actively mobilise and sometimes recombine through strategic choices than fixed determinants of failure or success. The fourth examined how managers navigate fragmented I4.0 RIE, showing that this process requires interpreting available support through five support mechanisms and enacting it through access and use tactics. Taken together, these studies trace a conceptual and empirical shift of my position as a researcher from structural explanations – where change results from internal and external enablers or barriers – to interpretive exploration, where I4.0 transformation emerges as co-construction of meaning, action, and engagement between managers and their contexts.

By bridging these perspectives, the thesis conceptualises I4.0 transformation as a process of structuration – a continuous interplay between contextual rules and available resources on the one hand, and managerial agency on the other. Rather than merely reacting to institutional or technological imperatives, managers act upon them, translating I4.0-related requirements into firm-level narratives of purpose, means, and challenges. These narratives function as interpretive anchors that align managerial, organisational, and institutional dimensions of transformation, guiding strategic decisions. The findings highlight that I4.0 transformation further unfolds through trade-offs and navigation practices – the two modalities through which agency and structure meet in practice. Trade-offs capture how managers reconcile misalignments between institutional requirements, SMEs' resource configurations, and organisational priorities. Navigation practices translate these reconciliations into situated strategies, whether through strategic vision, resource mobilisation, or ecosystem engagement. Together, they highlight how managers maintain coherence in contexts characterised by shifting priorities and ambiguous institutional environments.

Beyond its empirical contributions, the thesis also advances theoretical understanding of I4.0 transformation in SMEs, explaining that it requires moving beyond static models of enablers and barriers and adopting a perspective where resources, perceptions, and institutional frameworks are co-constituted through managerial practice. It extends structuration theory to the field of technological transformation, demonstrating how recursive interactions between agency and structure generate context-specific and strategically oriented courses of change. More broadly, the thesis contributes to management and innovation studies by showing that complex technological transformations can be approached as strategic technological trajectories actively shaped through strategic vision, resource mobilisation, and ecosystem engagement. For SMEs' managers, this means that transformation is less about following ready-made and readiness-oriented technological roadmaps than about clarifying what I4.0 means for their organisation, working with available resources in a flexible way, and finding and shaping the right ecosystem support over time. For policymakers, it means recognising that I4.0 RIE represent living systems shaped by the very actors they seek to support, rather than established infrastructures, prescribing how to succeed in I4.0 transformation. Together, managers and policymakers are encouraged to co-construct the trajectories through which I4.0

transformation unfolds, transforming what initially appeared as a techno-centric and performance-oriented agenda into a context-specific process of strategic sense-making, whose evolution may also resonate with adjacent paradigms such as Industry 5.0.

Ultimately, this thesis argues that I4.0 – and by extension other ambiguously defined and policy-driven concepts such as sustainability, resilience, or open innovation – is a dynamic construct that evolves through the meanings and practices of those who interpret and enact it. Understanding transformation therefore requires studying how actors make sense of change, how they balance contradictions between institutional pressures and organisational specificities, and how they navigate the boundaries of fragmented ecosystems. Through this interpretive and multi-level perspective, the thesis repositions I4.0 transformation as a co-constructed process – where progress stems not from ideal conditions or perfect alignment, but from the ability of managers and institutions to engage reflexively, learn collectively, and sustain continuity across evolving environments.

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Appendix A

Positioning Future Research: Extending Strategic Technological Trajectories

Building on the insights and research avenues identifies in this thesis, I would be interested in exploring how the notion of strategic technological trajectories applies to contexts where technological transformation interacts more directly with sustainability imperatives and human constraints. Given the current EU Industry 5.0 agenda, this perspective appears particularly relevant in the context of waste management and recycling firms, which have long operated at the intersection of sustainability, human constraints, and operational resilience, and may face new tensions associated with the acceleration of emerging technological solutions.

First, it raises the question of how managers make strategic decisions when technological solutions are available but perceived as inadequate or misaligned with operational needs. During my fieldwork, I was particularly struck by the way managers in waste management and recycling sectors question the effectiveness of available technologies and, in some cases, develop their own solutions or rely primarily on human expertise to sustain operations. These situations point to the need to examine how such misalignments are perceived and negotiated across actors, including managers, operators who confront these technologies in daily practices, and technology providers whose assessment of the applicability of their solutions to companies' operational realities may diverge.

Second, these contexts invite a closer analysis of how workforce characteristics shape organisational change and work practices within these firms. In sectors where jobs are physically demanding, require low formal qualifications, or involve linguistic diversity, the introduction of advanced technologies may redefine skill requirements in ways that are difficult to absorb. This calls for examining how these transformations are experienced and mediated across multiple actors, including managers, operators, labour unions, and training institutions, each contributing to the definition of what constitutes a "workable" transformation.

Third, the strong integration of sustainability objectives in these sectors calls for examining how environmental goals interact with technological and organisational choices. Rather than assuming alignment between digitalisation and sustainability, future research could benefit from analysing how these priorities are framed, enforced, and negotiated across actors such as managers, regulators, and certification bodies, whose requirements shape both the direction and feasibility of transformation efforts. This includes examining situations where compliance constraints, validation processes, or environmental standards influence technological choices, potentially reinforcing certain solutions while limiting others, and how firms navigate these tensions in practice.

Appendix B

Visual support used during the training program in the scope of “Industry 4.h” project to facilitate perception sharing and internal communication on I4.0 transformation.

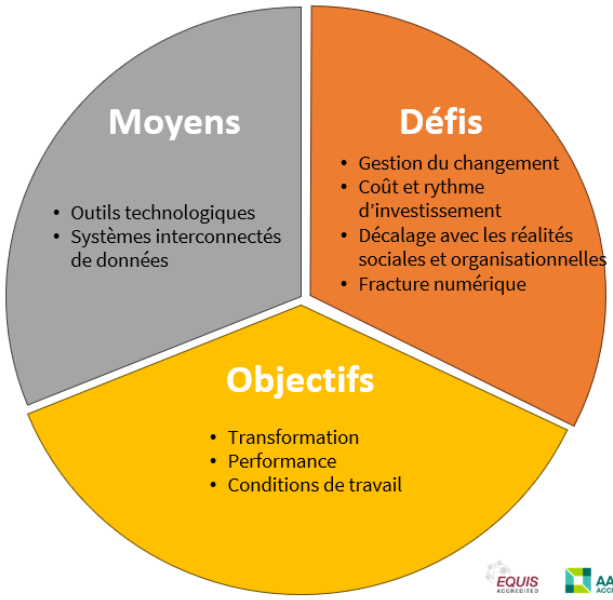
Bâtir un récit "inspirant" sur l'Industrie du Futur

- Comment comptez-vous présenter l’Industrie du futur à vos collaborateurs? Sur quels éléments mettriez-vous l’accent pour les embarquer?

- Animation :
  - Chacun met un mot clé sur un post-it
  - Sur la base des post-it, construction d’un bref pitch par entreprise (2 minutes maximum) pour expliciter le projet de transformation en cours

LENTIC Industry 4.h — EQUIS AACSB HEC LIÈGE

L’Industrie du Futur perçue par les managers des PME industrielles



LENTIC Industry 4.h — EQUIS AACSB HEC LIÈGE

Appendix C

Personas used during the training program in the scope of “Industry 4.h” project to foster dialogue and recognition of multiple I4.0 visions and priority-settings.

Antoine

Responsable Technique

Microentreprise de l'usinage

Pour moi, l'Industrie du Futur, c'est ...

Un terme « fourre-tout », souvent utilisé à des fins politiques. Je préfère investir uniquement dans des technologies offrant des gains mesurables, tout en préservant les méthodes artisanales.

Mes motivations :

- Améliorer l'efficacité tout en préservant la qualité.
- Investir dans des solutions avec un retour rapide.
- Maintenir la transparence pour les partenaires et clients.

Mes craintes :

- Investir dans des technologies coûteuses qui ne sont pas adaptées à la complexité des processus.
- Choix politiques déconnectés des réalités industrielles

Claire

Chef de Projet Transformation Digitale

Moyenne entreprise d'électronique industrielle

Pour moi, l'Industrie du Futur, c'est ...

Un moyen d'améliorer la gestion des données et d'automatiser les tâches répétitives. Je compte sur l'interconnectivité des machines qui rendra la production plus fluide et offrira l'autonomie aux employés.

Mes motivations :

- Faciliter le travail des équipes grâce à l'automatisation et la maintenance prédictive.
- Exploiter les données en temps réel pour optimiser les décisions de production.
- Suivre la croissance de l'entreprise en restant agile.

Mes craintes :

- Devoir adopter des technologies imposées par les fournisseurs, plutôt que choisies librement.
- Marginaliser des employés avec des compétences manuelles, dépassés par la complexité des nouveaux systèmes.

Marc

Manager en Optimisation des Processus

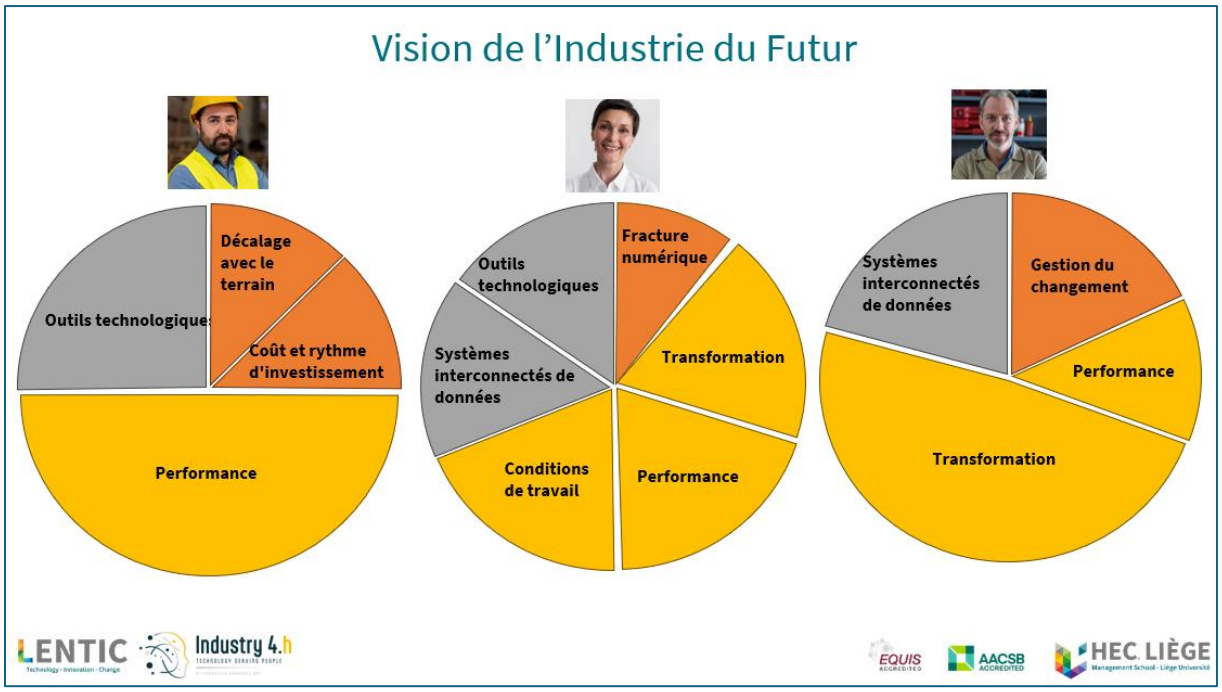
Petite entreprise spécialisée dans le recyclage

Pour moi, l'Industrie du Futur, c'est ...

Un levier technologique essentiel pour automatiser les processus et maximiser l'efficacité avec des ressources limitées. Je prévois d'utiliser des capteurs et l'IA pour optimiser la production et surveiller les équipements.

Mes motivations :

- Améliorer la productivité tout en réduisant les coûts et les erreurs humaines.
- Améliorer le processus de planification pour mieux répondre aux besoins des clients.
- Rester compétitif face aux grandes entreprises.

Mes craintes :

- Délais de formation trop longs pour les équipes, ralentissant la production.
- L'usine en arrêt à cause de la défaillance d'un composant des systèmes interconnectés