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Proposal of a conceptual framework for the digital transformation of companies: analysis of the French mechatronic industrial context

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Dedicated to my beloved family, my dear parents and my awesome brother, for their endless love and unconditional support of all my projects and dreams.

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Résumé

La Transformation Digitale (TD) représente un véritable défi pour les entreprises du monde entier, non seulement en raison de sa complexité due à l'évolution rapide de la technologie, mais aussi en raison du manque de guides appropriés. Une TD entend préparer les entreprises à profiter des nombreuses opportunités offertes par les technologies digitales. Néanmoins, la revue de la littérature révèle que les modèles et cadres digitaux actuels qui visent à fournir des orientations pour les TD des entreprises semblent déconnectés de l'objectif réel d'une TD, encore aujourd'hui mal connu. Leur inexactitude dans la représentation des réalités du scénario de la TD provient du manque de connaissance du contexte de l'entreprise, ainsi que du manque de considération de tous les éléments impliqués dans la transformation et de leurs interactions. Les limites identifiées dans les propositions actuelles ont initié une analyse de la TD dans son concept et son application et à en proposer une nouvelle vision, globale et systémique. A travers la proposition d'un cadre conceptuel pour la TD, cette thèse adopte en effet une vision holistique des éléments qui prennent part à une TD, de leur rôle et leurs interactions. Fondé sur des principes sociotechniques, le cadre développé (1) identifie cinq dimensions de l'entreprise impliquées dans le processus de transformation : la technologie, les processus, la structure, les compétences et la culture ; (2) reconnaît le rôle clé de la stratégie et de la mesure et du management de la performance en tant qu'éléments structurants de la TD et (3) reconnaît l'influence du contexte sur la TD. La méthode de recherche par étude de cas est utilisée pour valider l'applicabilité de la proposition dans sept entreprises industrielles françaises, du secteur mécatronique.

Abstract

Digital Transformation (DT) represents a real challenge for companies around the world, not only because of its complexity due to technology's fast evolution, but also because of the lack of appropriate guidance. A DT aims to prepare companies to take advantage of the many opportunities offered by digital technologies. Nevertheless, the review of the literature reveals that current digital models and frameworks that intend to provide guidance for companies' DTs seem disconnected from the real objective of a DT, which is still not fully understood. Their inaccuracy in representing the realities of the DT scenario derives from the lack of acknowledgment of the company's context, as well as the lack of consideration of all the elements implicated in the transformation and their interactions. The limitations identified in the current proposals led this work to analyze the DT in its concept and application and to propose a new, global and systemic vision. Through the proposal of a conceptual framework for the DT, this thesis adopts a holistic view of all the elements that take part in a DT, their role and the interactions between them. Based on socio-technical principles, the framework developed (1) identifies five business dimensions involved in the process of transformation: technology, processes, structure, competencies and culture; (2) recognizes the key role of strategy and performance measurement and management as structuring elements of the DT; and (3) acknowledges the influence of the context on the DT. The case study research method is used to validate the applicability of the proposal in seven French industrial companies in the mechatronics sector.

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Glossary

Assessment: refers to the wide variety of methods or tools that are used to evaluate, measure, and document the readiness or maturity progress of companies (adapted from the Glossary of Education Reform).

Business: a commercial organization such as a company, shop or factory (Oxford Advanced Learner's Dictionary, n.d.).

Business process: a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer (Hammer & Champy, 1993).

Company: a business organization that makes money by producing or selling goods or services (Oxford Advanced Learner's Dictionary, n.d.).

Competency: the ability, encompassing knowledge, skills, and attitudes of an individual to perform adequately in a job (Rosas, 2006).

Concept: an idea or a principle that is connected with something abstract (Oxford Advanced Learner's Dictionary, n.d.).

Conceptual Framework: identifies the main concepts that explain a phenomenon and the relationship between them (Miles and Huberman, 1994).

Context: the situation or set of circumstances in which something happens and that helps to understand it (Oxford Learner's Dictionary, n.d.).

Digital: using a system of receiving and sending information as a series of the numbers one and zero, showing that an electronic signal is there or is not there (Oxford Learner's Dictionary, n.d.).

Digital maturity: the state of advancement or development of the Digital Transformation in a company (adapted from the Cambridge English Dictionary, n.d.).

Digital readiness: the willingness of a company or a state of being prepared for beginning a Digital Transformation (adapted from the Cambridge English Dictionary, n.d.).

Digital Transformation: the profound and accelerating transformation of business activities, processes, competencies, and models to fully leverage the changes and opportunities brought by digital technologies and their impact across society in a strategic and prioritized way (Demirkan et al., 2016).

Digital Technologies: the electronic tools, systems, devices and resources that generate, store or process data (Victoria State Government Education and Training, 2019).

Digitalization: the fundamental changes made to business operations and business models based on newly acquired knowledge gained via value-added digitization initiatives (Schalmo and Williams, 2018).

Digitization: the technical process of converting analogue signals into a digital form, and ultimately into binary digits (Legner et al., 2017).

Dimension: an aspect, a particular feature of something; a way of thinking about something (Oxford Learner's Dictionary, n.d.).

Element: a necessary or typical part of something; one of several parts that something contains (Oxford Advanced Learner's Dictionary, n.d.).

Factor: one of several things that cause or influence something (Oxford Advanced Learner's Dictionary, n.d.).

Firm: a company offering a professional service (Cambridge English Dictionary, n.d.).

Framework: the systems of rules, ideas, or beliefs that are used to plan or decide something (Cambridge English Dictionary, n.d.).

Holism: the idea that the whole of something must be considered in order to understand its different parts (Oxford Advanced Learner's Dictionary, n.d.).

Holistic: considering a whole thing or being to be more than a collection of parts (Oxford Advanced Learner's Dictionary, n.d.).

Index: a sign or measure that something else can be judged by (Oxford Advanced Learner's Dictionary, n.d.).

Maturity Model: consists of a sequence of maturity levels for a class of objects (e.g., organizations, processes) that represent an anticipated, desired, or typical evolution paths of these objects shaped as discrete stages in which the highest stage represents a conception of total maturity (Becker et al., 2009).

Mechatronics: the synergistic integration of mechanical, electrical, and computer systems (Bishop, 2008).

Notion: an idea, a belief, or an understanding of something (Oxford Advanced Learner's Dictionary, n.d.).

Organization: a consciously coordinated social unit, composed of two or more people, that functions on a relatively continuous basis to achieve a common goal or set of goals (Robbins and Judge, 2017).

Organizational culture: the pattern of shared beliefs and values that give members of an institution meaning and provide them with the rules for behavior in their organization (Davis, 1984).

Organizational structure: defines how job tasks are formally divided, grouped, and coordinated (Robbins and Judge, 2017).

Performance: how successful an investment, company, etc., is and how much profit it makes (Cambridge English Dictionary, n.d.).

Phenomenon: a fact or an event in nature or society, especially one that is not fully understood (Oxford Advanced Learner's Dictionary, n.d.).

Roadmap: an overall plan for the deployment of new technologies, containing organizational change, that explains the main phases that need to be taken (Daim and Oliver, 2008; Issa et al., 2018).

Skill: a special ability to do something (Cambridge English Dictionary, n.d.).

Smart manufacturing: systems that are fully integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs (National Institute of Standards and Technology NIST, n.d.).

Smart products: complex systems that combine their physical nature composed of mechanical and electrical parts with hardware, sensors, data storage, microprocessors, software and connectivity in multiple ways (Porter and Heppelmann, 2014).

Smart services: the use of data and analytics by a provider to support a customer's decision-making process with the intent to create value for the customer (Schüritz et al., 2019).

Smart supply chains: have the capability for extensive information availability and enable superior collaboration and communication across digital platforms resulting in improved reliability, agility and effectiveness (Raab and Griffin-Cryan, 2011).

Strategy: the creation of a unique and valuable position involving a different set of activities (Porter 1996).

System: a group of things, pieces of equipment, etc. that are connected or work together (Oxford Advanced Learner's Dictionary, n.d.).

Terminology: the set of technical words or expressions used in a particular subject (Oxford Advanced Learner's Dictionary, n.d.).

Theoretical Framework: consists of the theoretical principles, constructs, concepts and tenants of a theory (Grant and Osanloo, 2014).

Introduction

General context

In today's environment, companies around the world are finding themselves in a race against the relentless technological evolution. Digital technologies' exponential improvement and widespread availability are democratizing their use and accelerating innovation, offering companies amazing opportunities for efficiency and growth.

Companies that have taken the first steps towards the adoption of digital technologies are not only improving their competitive position but also constantly rising customer expectations. In consequence, the highly competitive pressure adds up to the technological challenges for the companies that have not made the change.

Preparing the company for a successful introduction of digital technologies implies an important degree of organizational change. Since the nature of this change is radical, it often requires a re-evaluation of the companies' business and operational model: a business transformation. Although traditionally, technology has been an important source of transformation, the digital challenges have proved more complex for companies than previous technological developments.

The continuous and exponential growth of processing power, storage capacity and communication bandwidth are changing the way the world operates and shaping the characteristics of the digital era we are living in. At the business level, the overwhelming quantity of technological options and their constant evolution translate into a complex environment with a high degree of uncertainty.

To recognize the particularities of this scenario, a technology-driven transformation is required for companies to succeed. This new type of business transformation induced by the adoption of digital technologies is widely known as Digital Transformation (DT). This notion refers to the changes companies are required to implement to pursue technological opportunities successfully (see Figure 1). More specifically, it can be defined as follows:

"DT is the profound and accelerating transformation of business activities, processes, competencies, and models to fully leverage the changes and opportunities brought by digital technologies and their impact across society in a strategic and prioritized way" (Demirkan et al., 2016).

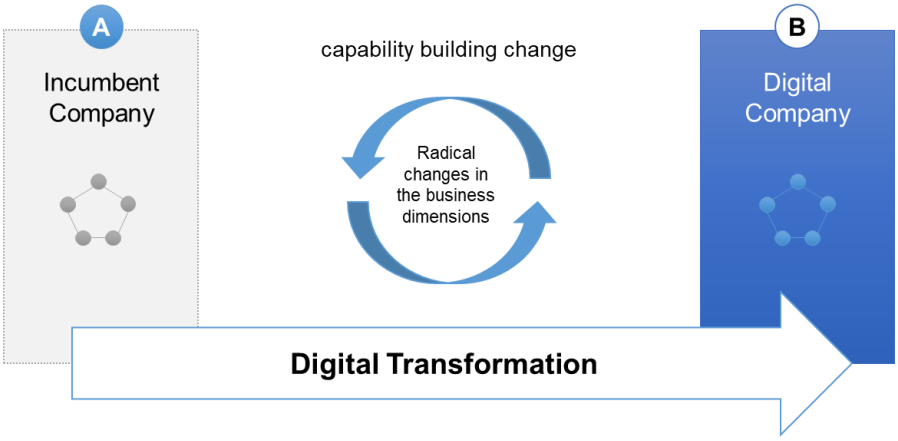


Figure 1 DT representation (author's own creation).

The path for transformation, however, is not always clear as DTs are highly contextual, and the scope of their implications is extensive. Indeed, taking advantage of technology introduction, either by streamlining operations and processes or enhancing products and services, requires changes beyond the technical aspects. Processes and competencies, among other business dimensions, are also required to adapt. Managing this type of change demands a careful analysis of the knowledge of an organization's starting point to define the gap towards the objective.

Research problem

In this context, companies find themselves in need of specific guidance as choosing the right approach to take on a journey towards a DT is paramount for success. For those with the resources, access to the services of consulting firms that can develop solutions for their specific needs is the answer. The rest must rely on other sources, and literature is a viable resource to get help for guiding their efforts.

The need to guide companies in their DT appears to be clear for academics and practitioners alike. Numerous works have been produced related to the concept, its strategic options, the technologies to use, as well as the models and frameworks to guide its application. These works generally produce a vision of the DT that intends to act as a reference during its development and implementation phases.

It appears, however, that the available solutions are often found to be out of sync with some of the companies' requirements regarding the subject. Indeed, current proposals, unfortunately, show that DT remains a subject poorly understood as the produced works often fail to provide practical guidance. A generic view of a diverse process and a shortened view of the transformation effects on all company aspects prevent current approaches from fulfilling their objective.

The challenges are numerous, and the urgency and complexity of digitally transform a company are only increasing as the speed of technological change is quickly leading to a Fourth Industrial Revolution. In these conditions, pressure is particularly high for the industrial sector due to the fast evolution of the technologies that digitalize the means of production as well as what is being produced.

The urgency of a DT is also enhanced due to the relevance of its many benefits, not only for companies but also for nations around the world that see it as a path to economic growth. In this sense, multiple countries have implemented actions to incentive the transformation of their industrial sectors, following the example of the well-known German program: Industry 4.0 platform.

Europe is aware of the need for digitalization of the industry and is accelerating its transition toward a digital economy that allows companies to compete globally. In France, particularly the Factory of the Future (Usine du Futur) program has targeted the performance improvement of its industrial sector as well as its ability to innovate with several initiatives and financial programs. With the mechanical branch at the center of the strategy, substantial resources are focused on an agile and coordinated transformation of the sector.

Recent studies have found, however, that in Europe, the slow pace of companies in adopting digital technologies is threatening the region's ability to compete at the global level (Candelon et al., 2020). The European industry sector is lagging behind other important players such as China and US in what is labeled as "digital maturity" by the BCG Digital Acceleration Index (see Figure 2).

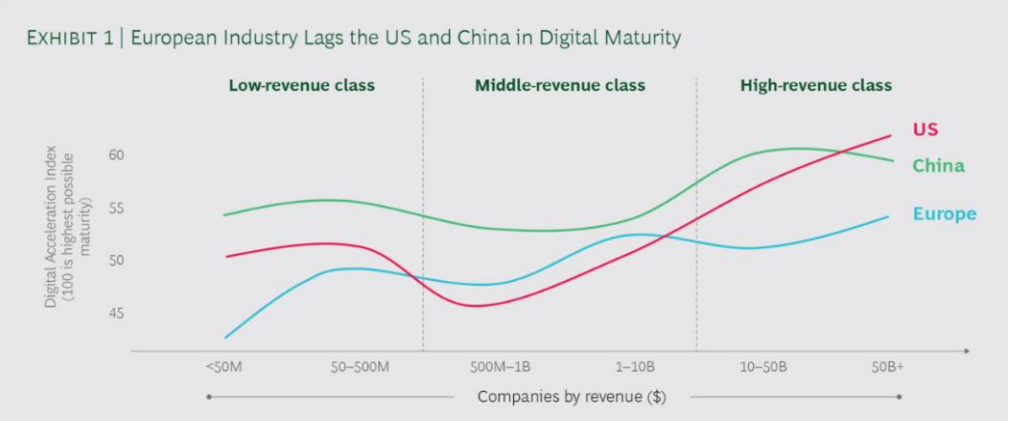


Figure 2 Digital Maturity of Europe, US and China (Candelon et al., 2020).

As the implications of not providing appropriate guidance to companies go far beyond the consequences at the business level, the relevance of accompanying the companies' DT has become more critical. Unfortunately, as new proposals to guide their DT efforts continue to be published, criticism keeps surrounding the same issues. The consensus especially revolves around one main problem: works are not capturing the whole scope of the implications of the DT in a company. New approaches are then needed to propose better and more effective solutions.

Research aims and questions

The identified problem highlights the unfulfilled mission of current literature to ***provide companies with the necessary guidance to achieve successful DTs***. In view of this assessment, this work takes a step back to address the level of knowledge of this phenomenon to propose a new and more comprehensive vision. With this strategy, this research aims to develop a Conceptual Digital Transformation Framework (CDTF). The objective of the CDTF is to serve as a frame of reference for the whole scope of the implications of a DT for a company by answering the following main question:

- *What does it imply for a company to digitally transform?*

Contributing with an answer to this fundamental question means equally addressing the following research questions:

1. *What is a DT, and what is the objective that it pursues?*
2. *What are its main elements and their role during a DT?*
3. *What are the business dimensions that are involved in a DT and their interactions?*
4. *What is the process that it follows and its trajectory toward a successful DT?*
5. *How does a company's context influence the development of a DT?*

The answer to these research questions will draw a better picture of the DT complexities. Moreover, a more accurate characterization of the DT phenomenon and the identification of its components and dynamics intends to become a stronger foundation for further research.

Nevertheless, in pursuing this specific thesis, a choice was made regarding its nature. A preliminary review of current literature led to the realization that regardless of the relevance of the topic, a holistic view has not been widely addressed. Even though this approach entailed a high-level risk

to the depth of the work when dealing with a topic of such complexity, the objective was to provide a holistic view of the phenomenon. This thesis then aims to produce a conceptual contribution of the knowledge of the subject.

Research Method

A research method of three stages has been designed to answer the fundamental questions about the DT phenomenon stated in this work (see Figure 3). The stages have the following objectives:

1. review the current state of the literature through a Systematic Literature Review (SLR) to identify the models and frameworks that provide DT guidance and determine their main limitations;
2. propose a holistic view of the DT phenomenon by building a conceptual framework of its main elements based on a theoretical foundation;
3. validate the applicability of the CDTF's main propositions by conducting case studies of French companies that belong to the mechatronic industrial sector.

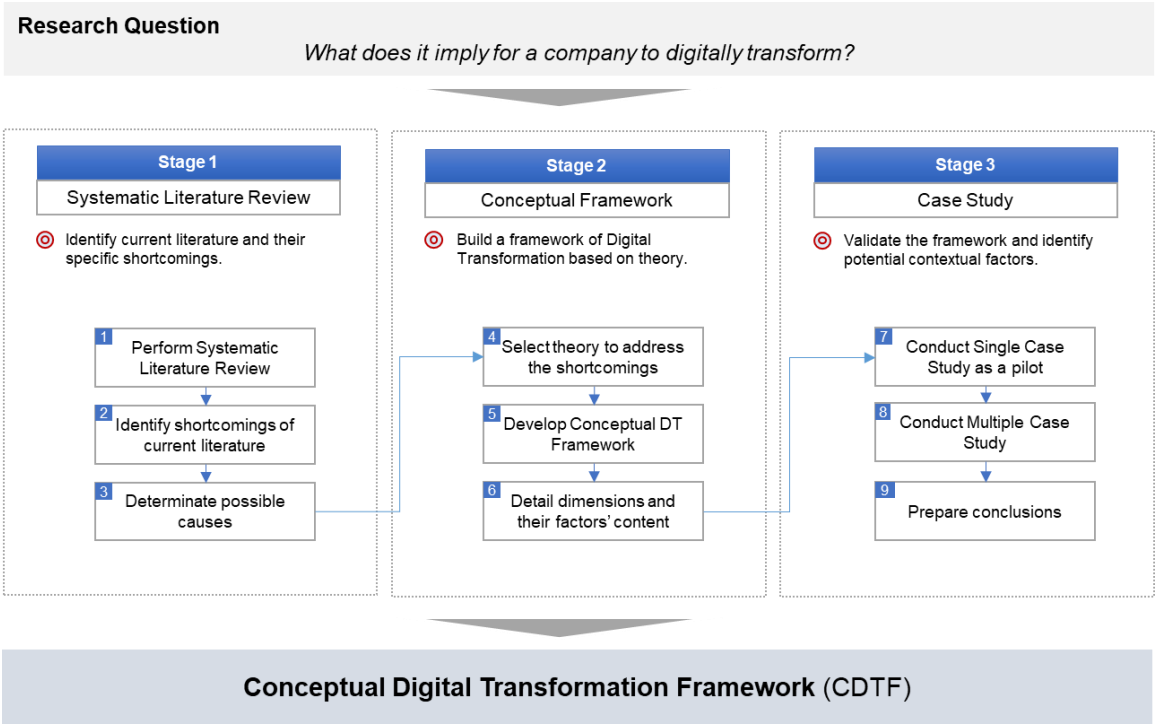


Figure 3 Description of the general stages of the research design defined to answer the main research question.

In the first stage, an SLR was proposed to identify the relevant works in literature that offer DT guidance. The choice of a systematic approach (i.e., SLR) to deliver a state-of-the-art intended for the review to be as exhaustive as possible in identifying the relevant works. Through this approach, the works identified in academic literature were combined with those coming for practice. A thorough evaluation of both sets of proposals targeted the identification of the reasons behind the lack of effectiveness regarding their objective.

In the second stage, a conceptual framework is built based on the results of the critical review of the literature and the resulting limitations of current Digital Models and Frameworks (DMFs) according to the requirements of the DT scenario. As a holistic and theoretical approach was missing in current proposals, the development of the Conceptual Digital Transformation Framework (CDTF) was built on that premise. Accordingly, the design takes advantage of the Socio-Technical Systems (STS) theory and available models on organizational change, in particular, those based on the content of change and the elements that compose it.

In the third stage, the case study research method is used to validate the applicability of the CDTF's main propositions. As the CDTF's condition of being a theoretical answer to the research questions is acknowledged, this last stage was planned to compare the proposal with the realities of industrial settings. The aim was to validate the CDTF's elements and their role in real case scenarios and to identify the effect of a company's context on the development of the DT.

The case research method was used with single and multiple case study layouts to benefit from a cross-case analysis. First, the case of a French manufacturer served as a pilot case to validate and improve the data collection instruments that were to be used with a more extensive sample. Next, a multiple case study was performed using a sample of six French industrial companies in addition to the pilot case. The companies selected, manufacturers or assemblers of the mechanical branch of the sector, participate in highly technological markets and are using mechatronics as a way to digitize their core products.

Thesis Structure

This thesis is structured in four chapters organized as follows.

Considering the novelty of the domain and the lack of formal definitions, the first part of **Chapter 1** is devoted to introducing the terminology surrounding the DT notion. The aim is to identify the different uses of similar terms that will facilitate the review of literature as well as position the definitions that are used throughout this work to achieve clarity. In the second part, as criticism of current DMFs is focused on their level of coverage of the scope of a DT, **Chapter 1** reviews the existing literature on the subject. By using an SLR, the relevant DMFs are identified and reviewed to reveal their limitations.

Later, **Chapters 2 and 3** focus on building a holistic and conceptual view of the DT. **Chapter 2** introduces the Conceptual Digital Transformation Framework (CDTF), a holistic view of all the elements of a DT based on a theoretical approach that answers to the limitations identified in current DMFs. **Chapter 3** details the content of the business dimensions proposed to identify the relevant factors that contribute to a company's DT, along with a view of the interactions between them.

Afterward, **Chapter 4** presents through an empirical approach the validation of the applicability of the proposed CDTF in real case scenarios. **Chapter 4** confronts the CDTF's main propositions with companies' DT in industrial settings. By using both, single and multiple case studies, this work validates the presence of the elements and their roles and explores the effect of context on the DT.

Finally, the last section presents the main **conclusion** of this research work. Theoretical and Practical implications, along with the limitations of the study and perspectives of future research, conclude this section.

Chapter 1: Literature review

In the introduction, today's relevance of digital technologies was stated, and Digital Transformation (DT) was positioned as the strategic requirement for companies facing the challenges of technology introduction. Nevertheless, the full scope of this transformation is yet to be completely understood, and consequently, this work seeks to propose a new and more comprehensive vision of the DT phenomenon.

To build this view, in this chapter, the objective is to determine the state of the art of current Digital Models and Frameworks (DMFs) that offer guidance during the company's DT efforts. To achieve this objective, first, the main concepts surrounding the DT notion are identified and positioned to overcome the challenges that represent a novel subject without a common terminology. Afterward, the different DMFs available in the literature are identified through a Systematic Literature Review (SLR) by using the previously defined DT terminology. Finally, an analysis of their methods to create their content and a critical review of the findings are performed to identify the limitations that inhibit them from fulfilling their purpose.

This chapter is structured as follows. Section 1.1 introduces and positions the terminology related to the DT concept. Section 1.2 identifies the current DMFs available in the literature that intend to provide guidance to companies' DTs. Section 1.3 reviews and discusses the findings identified in the literature. Section 1.4 presents the conclusion and a summary of the chapter.

1.1 Digital Transformation (DT) terminology

Understanding the complexity of the current technological landscape is a challenge, a challenge that only gets heightened by the lack of a common terminology related to the "digital" terms. The importance of positioning the definitions for the main concepts surrounding Digital Transformation (DT) is critical to ensure clarity in this work and to avoid any overlapping between notions that creates confusion.

Additionally, establishing a DT terminology for this work was fundamental for understanding the uses of different notions and for identifying the terms to use in the search strategy of the Systematic Literature Review (SLR) that is presented in the second part of this chapter.

After a preliminary search for literature related to the DT notion, a first review of the body of knowledge on the subject allowed to define the following categories of concepts that help to better understand the DT terminology:

- types of digital change,
- types of digital initiatives,
- types of digital tools,
- types of digital indicators,
- types of digital programs.

In the next sections, the main definitions of each term are introduced, and possible misunderstandings and confusions are discussed. Afterward, a definition for each concept is selected based on their ability to represent the concept with simplicity and avoid overlapping with the other concepts in the same set.

1.1.1 Types of digital change

The notions of digitization, digitalization, and digital transformation have been the target of many efforts of researchers and practitioners that have attempted to differentiate them formally. The reason behind these efforts lies in the fact that their use in the literature is not standardized and sometimes overlaps (Imran et al., 2021).

1.1.1.1 Digitization

The term digitization is defined by Tilson et al. (2010) as *"the process of converting analogue signals into a digital form, and ultimately into binary digits (bits)."* In their adaptation of Tilson's definition, Legner et al. (2017) made a small precision and added *"the technical process of converting..."*, which allowed the concept to stand out from confusion. Generally, everybody seems to agree on the basics of this definition. However, even though most definitions center on the physical process of conversion from a purely technical perspective, some authors have presented other views that add more business sense to the notion. Schallmo and Williams (2018), for example, define it as *"digitally enabling analogue or physical artefacts for the purpose of implementing into said artefacts into business processes with the ultimate aim of acquiring newly formed knowledge and creating new value for the stakeholders."* The perspective of this last definition of this technical concept, however, is not common in literature.

1.1.1.2 Digitalization

The Oxford English Dictionary (n.d.) defines digitalization as *"the adoption or increase in the use of digital or computer technology by an organization, industry, country, etc."* More specifically, digitalization is defined in Gartner's IT Glossary (n.d.) as *"the use of digital technologies to change a business model and provide new revenue and value-producing opportunities."* The same source though also refers to digitalization as *"the process of employing digital technologies and information to transform business operations"* (Bloomberg, 2018).

Following this line of thought, Schallmo and Williams (2018) define digitalization as *"fundamental changes made to business operations and business models based on newly acquired knowledge gained via value-added digitization initiatives"*. This definition is at the same time more specific than the first one proposed by the Oxford English Dictionary and covers the two very valid proposals by Garner's IT Glossary.

1.1.1.3 Digital Transformation

Given its current relevance, DT, like some other contemporary concepts, has been widely defined in the literature. In one interesting effort, Vial (2019) conducted an extensive review that identified a total of 23 definitions of the concept proposed in the literature. Vial's review then and other recent analyses have found that the number of proposed definitions, unfortunately, does not mean that there is "conceptual clarity" regarding the meaning of the term (Schallmo et al., 2017; Vial, 2019). This situation, and especially the lack of a formal definition of the term, has been addressed by several authors. Consensus is yet to be achieved, and at the moment, the literature still presents an array of different visions.

Before exploring some examples of those definitions, it is important to remind that the DT notion is originated from the Business Transformation (BT) concept. A BT is defined as *"a fundamental change in organizational logic, which resulted in or was caused by a fundamental shift in behaviors"* (Muzyka et al., 1995) that most likely will require "rethinking" the business (Philip and McKeown, 2004). In this scheme, digital technologies are the critical element that triggers a digital (business) transformation. With this frame of reference in mind, next, three different types of definitions are presented.

To start, one popular and simple definition regards the DT as *"the use of technology to radically improve performance or reach of enterprises"* (Westerman et al., 2011). This definition, however, can be misleading, as it can be argued that using technology for "improving performance" cannot necessarily be classified as a real transformation. Another similar perspective is proposed by Berghaus and Back (2016). The authors consider that *"DT encompasses both process digitization with a focus on efficiency, and digital innovation with a focus on enhancing existing physical products with digital capabilities."* Though this proposal is specific in its purpose of using digital technology to "digitize" or "digitalize" processes or products, it still lacks the transformational factor from the company's perspective.

In searching for a definition that reflected the organizational change perspective and the transformational level of that change, two definitions were identified. First, Matt et al. (2015) describe a DT as *"a blueprint that supports companies in governing the transformations that arise owing to the integration of digital technologies, as well as in their operations after a transformation"*. More concretely, Demirkan et al. (2016) propose that DT is *"the profound and accelerating transformation of business activities, processes, competencies, and models to fully leverage the changes and opportunities brought by digital technologies and their impact across society in a strategic and prioritized way."* Unlike the previous ones, this type of definition associates the concept of DT with a proactive and strategic process. A process that is concerned with preparing the organization to deal with the challenges of today's continuous technological change.

1.1.1.4 Positioning the digital change's terms

After analyzing the three previous terms, it is evident that the variety and sometimes closeness of some of their definitions are the reason they are often used interchangeably in the literature. These terms are closely related; therefore, an integral perspective is needed to position their definitions.

This work will therefore limit the notion of digitization to the traditional technical stance for the sake of clarity by using the definition by Legner et al. (2017). For digitalization, the perspective of the definition proposed by Schallmo and Williams (2018) is followed. Finally, by choosing the conceptualization of the DT by Demirkan et al. (2016), a vision based on the company's business transformation is ensured. Table 1.1 presents the summary of the perspective proposed.

Table 1.1 Types of digital change and their selected definition.

Concept	Definition	Author(s) & Year
Digitization	The technical process of converting analogue signals into a digital form, and ultimately into binary digits.	Legner et al., 2017
Digitalization	The fundamental changes made to business operations and business models based on newly acquired knowledge gained via value-added digitization initiatives.	Schalmo and Williams, 2018

Concept	Definition	Author(s) & Year
Digital Transformation	The profound and accelerating transformation of business activities, processes, competencies, and models to fully leverage the changes and opportunities brought by digital technologies and their impact across society in a strategic and prioritized way.	Demirkan et al., 2016

1.1.2 Types of digital initiatives

To realize the potential of digital technologies, several initiatives are set in motion inside a company. These initiatives, when implemented, determine a company's trajectory toward DT. Digital initiatives generally imply the digitization or digitalization of the company's processes, products or services.

Given the relevance of the industrial sector in the digital context, many digital initiatives have been designated with a specific label. That is the case with initiatives like Smart Manufacturing (SM) or Smart Products (SP), among others. The label "smart" is related to the fact that the introduction of digital technologies enables a certain level of intelligence or "smartness" to their functionality. Here the four main initiatives in the industrial sector are introduced and defined, as they will be used in this work.

1.1.2.1 Smart manufacturing

The Smart Manufacturing (SM) concept is constantly expanding along with the possibilities that are enabled by technology's fast evolution. There are, however, definitions that reflect the general idea of this notion. A first definition of the term considers that SM *"blends information technology (IT) with operations technology (OT) to enable greater productivity, efficiency, quality, and customization within factory operations"* (Weiss et al., 2016).

Another perspective presents SM as *"systems that are fully integrated, collaborative manufacturing systems that respond in real-time to meet changing demands and conditions in the factory, in the supply network, and in customer needs"* (National Institute of Standards and Technology NIST, n.d.). Even though both are characterized by the simplicity in which they present an overly complex subject, the one by NIST is more specific in listing the characteristics of the system and, therefore, the one chosen.

1.1.2.2 Smart supply chain

The enhancement of the traditional supply chain with the introduction of digital technologies is commonly labeled as Smart Supply Chain (SSC). SSCs are defined *"as the new interconnected business system which extends from isolated, local, and single-company applications to supply chain-wide systematic smart implementations"* (Wu et al., 2016).

In SSCs, interconnections with all the participants in the value chain are a reality and go beyond the company to reach customers and suppliers. Also known as Digital Supply Chains (DSC), SSCs have *"the capability for extensive information availability, and enable superior collaboration and communication across digital platforms resulting in improved reliability, agility, and effectiveness"* (Raab and Griffin-Cryan, 2011). From the two definitions proposed, this last definition represents a clearer vision of the SSCs' objectives.

1.1.2.3 Smart products

Smart products (SP), also called smart and connected products, are very closely related to the conceptualization of smart objects. All these concepts at their origin were influenced by Weiser's (1991) notion of "ubiquitous computing," in which every object either contains or has access to a computer. Today, his vision is becoming a reality in the SPs through the increasing processing power and device miniaturization, among other technological developments (Porter and Heppelmann, 2014). These developments enable several functionalities that add many levels of intelligence and connectivity to physical products.

More formally, the concept of SP has been defined from two perspectives. Initially, SPs were seen as part of the components that enabled smart manufacturing. In this context, SPs' capabilities serve to actively support the manufacturing process as they "knew" how they were manufactured and how they were intended to be used (Kagermann et al., 2013). Now, SPs are seen from a customer value perspective in which products become autonomous on control tasks that were before the responsibility of their users (Thiesse and Köhler, 2008).

Defined as *"products that are capable to do computations, store data, communicate and interact with their environment"* (Mühlhäuser, 2008; Miche et al., 2009; Schmidt et al., 2015), SPs keep evolving to realize many commercial opportunities. Today, SPs have become *"complex systems by combining its physical nature of basic mechanical and electrical parts with hardware, sensors, data storage, microprocessors, software and connectivity in miryad of ways"* to offer many possibilities to their users (Porter and Heppelmann, 2014).

1.1.2.4 Smart services

In the current digital context, the value from the large amount of data collected goes beyond its internal use inside the company to support the decision-making to deliver additional value for customers (Davenport, 2013). Through the data collected by the SPs, it is now possible to provide valuable data to the customers and enhance the service offerings of a company (Porter and Heppelmann, 2014).

These new service offerings, known as Smart Services (SSs), are contributing to the creation of new business models that commercialize data in two forms, raw data and data analytics (Chen et al., 2012; Schüritz et al., 2017). In this sense, SSs are defined as *"the use of data and analytics by a provider to support a customer's decision-making process with the intent to create value for the customer"* (Schüritz et al., 2019). SSs, also called data-driven or digital services, offer value for the customer but also value for the company as it is expected that they generate new value streams through the innovation in their business models (Kaiser et al., 2021).

1.1.2.5 Positioning the digital initiatives' terms

In a detailed view of these previous terms, it would be more challenging to isolate each concept as they are often components of more complex systems: smart factories, product-service solutions, or systems, among others. This simplified view intends to serve only as a reference of their global meaning to facilitate the comprehension of the propositions of this work. As there is no overlapping to solve with this strategy, the most suitable definition for each term is presented in Table 1.2.

Table 1.2 Types of digital initiatives and their selected definition.

Concept	Definition	Author(s)
Smart manufacturing	Smart Manufacturing are systems that are fully integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs.	National Institute of Standards and Technology (NIST), n.d.
Smart supply chain	Smart Supply Chain has the capability for extensive information availability and enables superior collaboration and communication across digital platforms resulting in improved reliability, agility and effectiveness.	Raab and Griffin-Cryan, 2011
Smart products	Smart Products are complex systems that combine their physical nature composed of mechanical and electrical parts with hardware, sensors, data storage, microprocessors, software and connectivity in multiple ways.	Porter and Heppelmann, 2014
Smart services	Smart services are the use of data and analytics by a provider to support a customer's decision-making process with the intent to create value for the customer	Schüritz et al., 2019

1.1.3 Types of digital indicators

In literature, when discussing the performance of the DT process, two types of indicators are often found: digital maturity and digital readiness. Frequently both terms are used interchangeably; therefore, positioning them is crucial for understanding their role during a DT.

1.1.3.1 Digital readiness

In contemplating a change of the magnitude and complexity of a DT, companies question themselves if they are ready to start such a challenge. Readiness is defined as *"the willingness or a state of being prepared for something"* (Cambridge English Dictionary, n.d.). In the digital context, this "something" could be translated as "beginning a DT effort." However, the notion of digital readiness is not always associated with the beginning of the journey. In literature, sometimes, it is also used during the process of the DT (e.g., Lichtblau et al., 2015). In those very common cases, referring to the highest level of digital readiness means to be digitally transformed.

1.1.3.2 Digital maturity

Maturity is a term extensively used in the digital context. Considering the definition of the term "Maturity" as a *"very advanced or developed form or state"* (Cambridge English Dictionary, n.d.), it is assumed that reaching the highest level of digital maturity can equal being digitally transformed. To measure digital maturity, however, a specific definition of what represents *"being digitally transformed"* (maturity) in a specific context is essential (De Bruin et al., 2005). In consequence, the concept of digital maturity is considered dynamic and should be assessed regarding the goals of the DT.

1.1.3.3 Positioning the digital indicators' terms

To avoid overlapping the two previous terms, it is better to follow Schumacher et al.'s (2016) point of view, in which the concepts of maturity and readiness are differentiated according to their objective. In this sense, an assessment of digital readiness will look to establish if an organization is ready to engage in a maturity process. Along the same line, assessing digital maturity will measure the current state of the maturing process. In the digital context, logically, this "maturing process" is represented by the DT of the company. Consequently, digital readiness will measure if the initial state or condition of a company is favorable to begin a DT, and digital maturity will be focused on measuring the advancement towards a successful DT. Table 1.3 presents the chosen definitions for both terms.

Table 1.3 Types of digital indicators and their selected definition.

Concept	Definition	Author(s)
Digital Readiness	The willingness of a company or a state of being prepared for beginning a DT.	Adapted from the Cambridge English Dictionary
Digital Maturity	The state of advancement or development of the DT in a company.	Adapted from the Cambridge English Dictionary

1.1.4 Types of digital tools

The type of DT guidance provided to companies by current Digital Models and Frameworks (DMFs) found in the literature varies according to the tool used to display the different proposals. The tools that can be identified are classified as follows:

- maturity model,
- roadmap,
- framework,
- assessment,
- index.

It is possible to divide these tools first by type of function. While Maturity Models (MMs), roadmaps, and frameworks are tools for guiding a company's DT, assessments and indices provide analyses or formulas for measuring the state of a company regarding the progress of its DT. Consequently, in the literature, assessments and indices often contain in their proposals one of the other three tools as those are a reference to the evaluation they made (e.g., Azhar et al., 2021; Lakmali et al., 2020). Figure 1.1 shows a graphical representation of the types of tools available to provide guidance for the companies' DT, respectively, divided by their use: tools that guide the company's DT or that evaluate the progress of a company's DT.

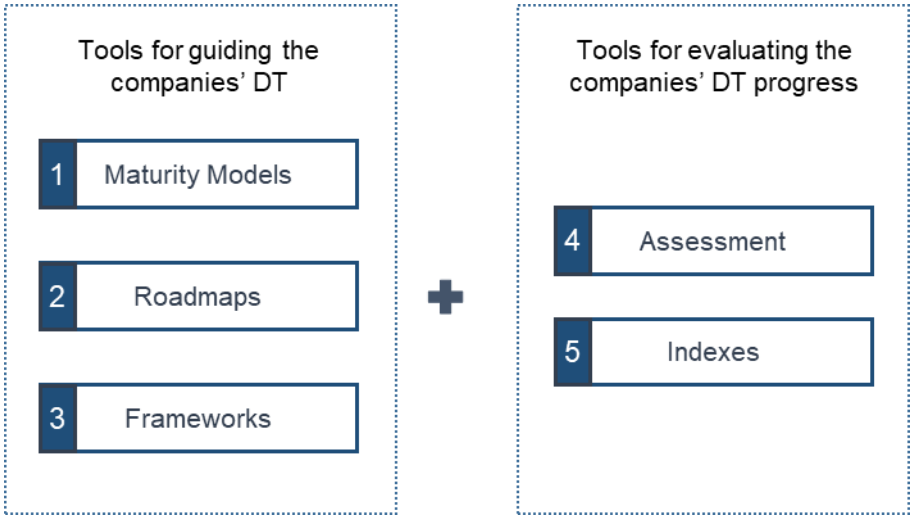


Figure 1.1 Types of tools for guiding the DT and their objectives (author's own creation).

Figure 1.1 shows how assessments and indices complement the other three tools. A description of each of these tools follows to understand their use in the digital context.

1.1.4.1 Maturity model

Maturity Models (MMs), not really models per se, are tools that were conceived to assess the degree of competence in a certain domain based on a defined set of criteria (De Bruin et al., 2005; Pöppelbuß and Röglinger, 2011). These instruments depict an evolutionary path towards an objective when predictable patterns exist (Pöppelbuß and Röglinger, 2011). This characterization then becomes the base for positioning a company in a given maturity stage and setting a further objective for improvement (Becker et al., 2009; Mettler, 2009). Originally built for software development, its application has quickly grown to other domains (Pöppelbuß and Röglinger, 2011). Figure 1.2 shows a graphical view of the main components of MMs.

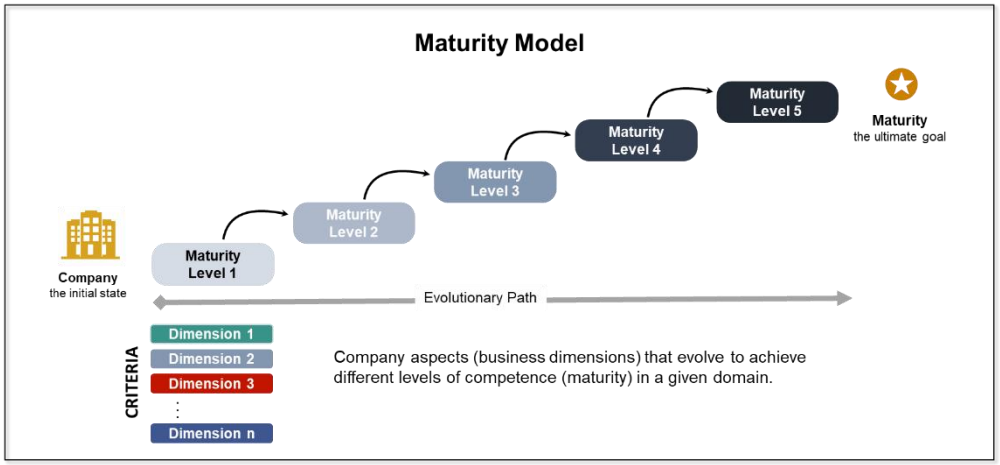


Figure 1.2 Generic characterization of a maturity model (author's own creation).

In the digital context, the concept of maturity in the models is relative to the objective of the DT chosen by its creator: mainly the digitalization of a process (e.g., smart manufacturing) or the digitization of products and services (e.g., smart products). Based on that choice, the milestones towards the objective are characterized as maturity stages and detailed from different business dimensions (see Figure 1.3). There is also a choice in their design regarding their intended audience. In the wide variety of MMs, some authors choose to present generic solutions while others intend to be more specific towards a particular audience, like industrial companies.

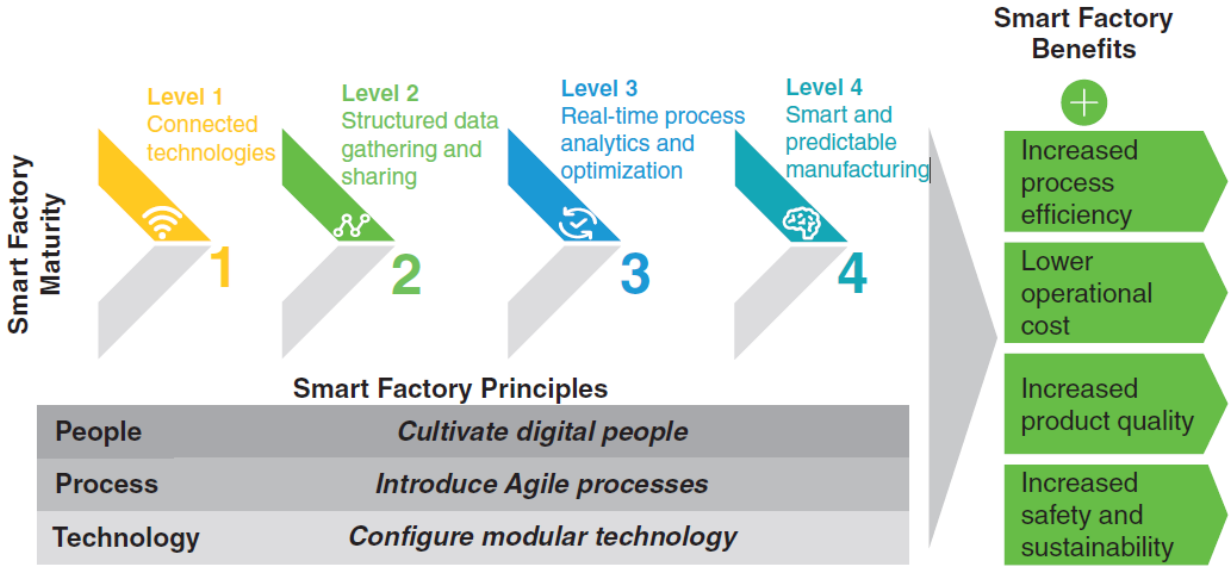


Figure 1.3 Example of a maturity model in literature.

In this MM, the different levels of maturity towards achieving a Smart Factory are defined according to three dimensions: people, process, and technology (source: Smart Factory Maturity Model by Sjödin et al., 2018).

Though MMs lack a clear definition and are often positioned between the conceptualizations of model and method (Mettler, 2009), MMs are indeed fixed representations of "predictable patterns" (Pöppelbuß and Röglinger, 2011). More specifically, MMs are defined as *"a sequence of maturity levels for a class of objects (e.g., organizations, process) that represent an anticipated, desired or typical evolution paths of these objects shaped as discrete stages in which the highest stage represents a conception of total maturity"* (Becker et al., 2009).

1.1.4.2 Roadmap

Roadmaps understood as *"a plan for how to achieve something (objective)"* (Cambridge English Dictionary, n.d.), are used in the digital context to display the stages required to successfully achieve a DT. Roadmaps have been frequently used in technology planning and implementation (Garcia and Bray, 1997). In the literature related to the DT, however, the application of the term goes beyond technology planning to include other aspects (see Figure 1.4).

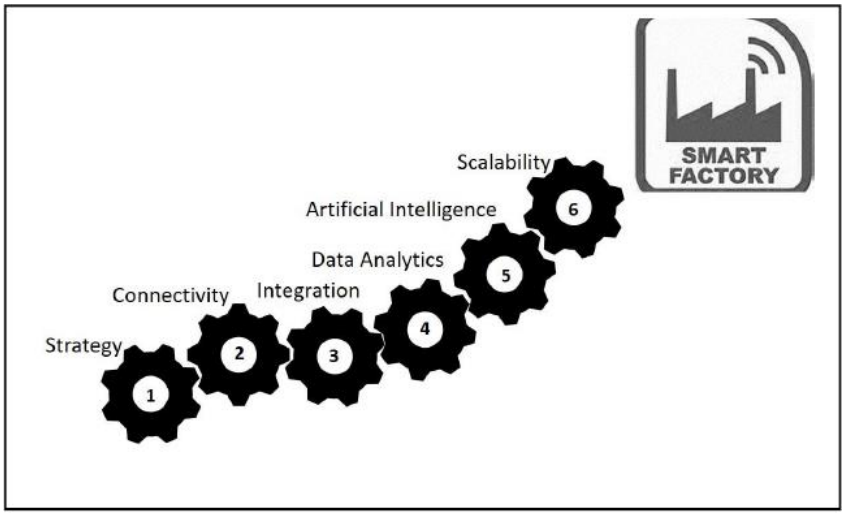


Figure 1.4 Example of a roadmap in literature.

In this roadmap the "road" towards a Smart Factory follows six main phases: from strategy to scalability (source: A six-gear roadmap for the Smart Factory Journey by Sufian et al., 2019).

Considering MMs' criticism of being generic, roadmaps are seen as the tools that can be used to design customized plans for companies based on MMs' content (Mittal, Khan et al., 2018; Colli et al., 2019). The approach to the development of roadmaps in the digital domain is to enable companies to develop their own paths towards a DT (Pessl et al., 2020). A path to DT, as Gard et al. (2016) state: is *"where to start, what to change, how much to invest, and how to make it all happen."* Based on that, it is possible to define roadmaps as *"an overall plan for the deployment of new technologies, containing organizational change, that explains the main phases that need to be taken"* (Daim and Oliver, 2008; Issa et al., 2018).

1.1.4.3 Framework

Frameworks, in general, are *"systems of rules, ideas, or beliefs that are used to plan or decide something"* (Cambridge Dictionary, n.d.). There are two types of frameworks, conceptual and theoretical. In the digital domain, both types can be found, even though they both present conceptual representations of the DT. There are, however, significant differences between these two types. Conceptual Frameworks *"identify main concepts that explain a phenomenon and the relationship between them"* (Miles and Huberman, 1994). Theoretical Frameworks, on the other hand, are *"the theoretical principles, constructs, concepts, and tenants of a theory"* (Grant and Osanloo, 2014).

In the digital context, conceptual frameworks are the most used to display the concepts related to a DT, to one or more of the digital initiatives, or to assess the DT (see Figure 1.5).

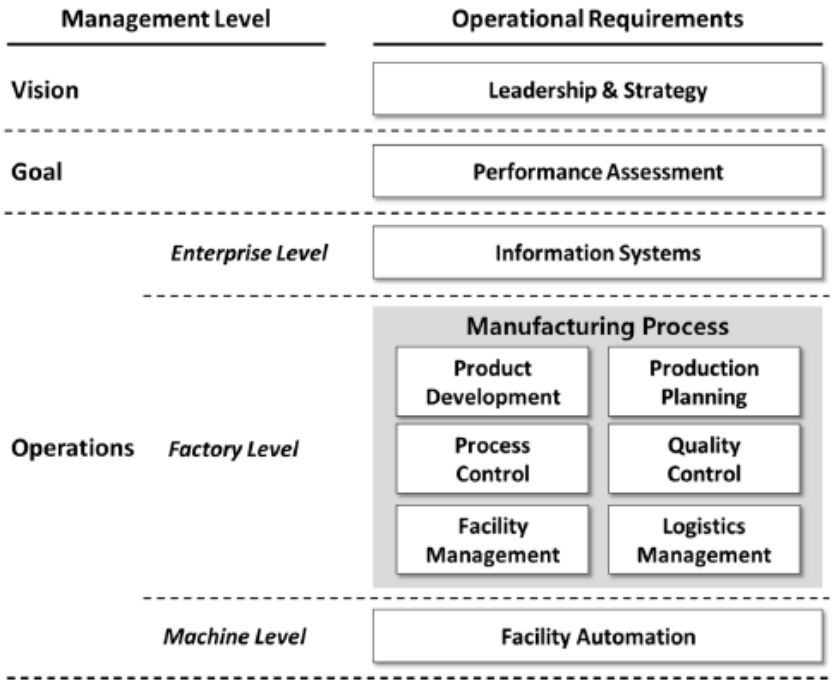


Figure 1.5 Example of a conceptual framework in literature.

In this framework, management and operational requirements are considered to assess the level of "smartness" of manufacturing companies towards the achievement of the characteristics of a Smart Factory (source: A smartness assessment framework for Smart Factories by Lee et al., 2017).

1.1.4.4 Assessment

A more accurate definition of assessments for the digital context is found in the education domain. The Glossary of Education Reform (n.d.) defines them as *"a wide variety of methods or tools that educators use to evaluate, measure, and document the academic readiness, learning progress, skill acquisition, or educational needs of students."* In the digital context, assessment methods and tools take the form of questionnaires that measure two concepts, either the evolution of the DT of a company or its readiness for starting one. The use of Likert scales is frequent to evaluate answers in the defined dimensions of the DT. The assessment presented in Figure 1.6 is based on a 4-point scale that goes from level one "beginner" to level four "expert" to measure a company's digital readiness.

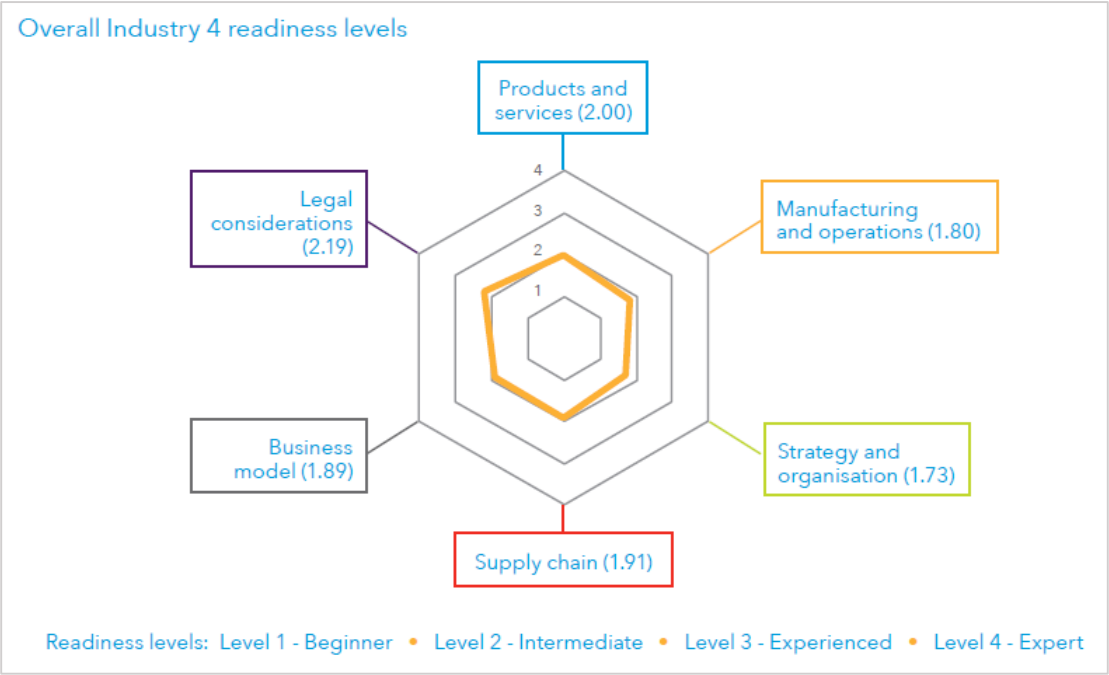


Figure 1.6 Example of an assessment in literature.

In this assessment, a survey of 35 variables in six core dimensions is evaluated by using a 4-point Likert scale that corresponds to four levels of maturity. The objective of this assessment is to define a company's readiness to take advantage of the potential of the cyber-physical age (source: An Industry 4.0 readiness assessment tool by Agca et al., 2017).

Assessments are most of the time accompanied by a definition of the milestones towards a DT, provided by a MM, a roadmap, or a framework. The role of assessments is to evaluate a company so it can be placed in one of those milestones. In consequence, assessments are the complement of MMs, roadmaps, or frameworks.

1.1.4.5 Index

An index is defined as *"a sign or measure that something else can be judged by"* (Oxford Advanced Learner's Dictionary, n.d.). Indices in the digital context appear as tools used for calculating either the maturity of a company during a DT or the readiness to start one by calculating a simple factor (see Figure 1.7).

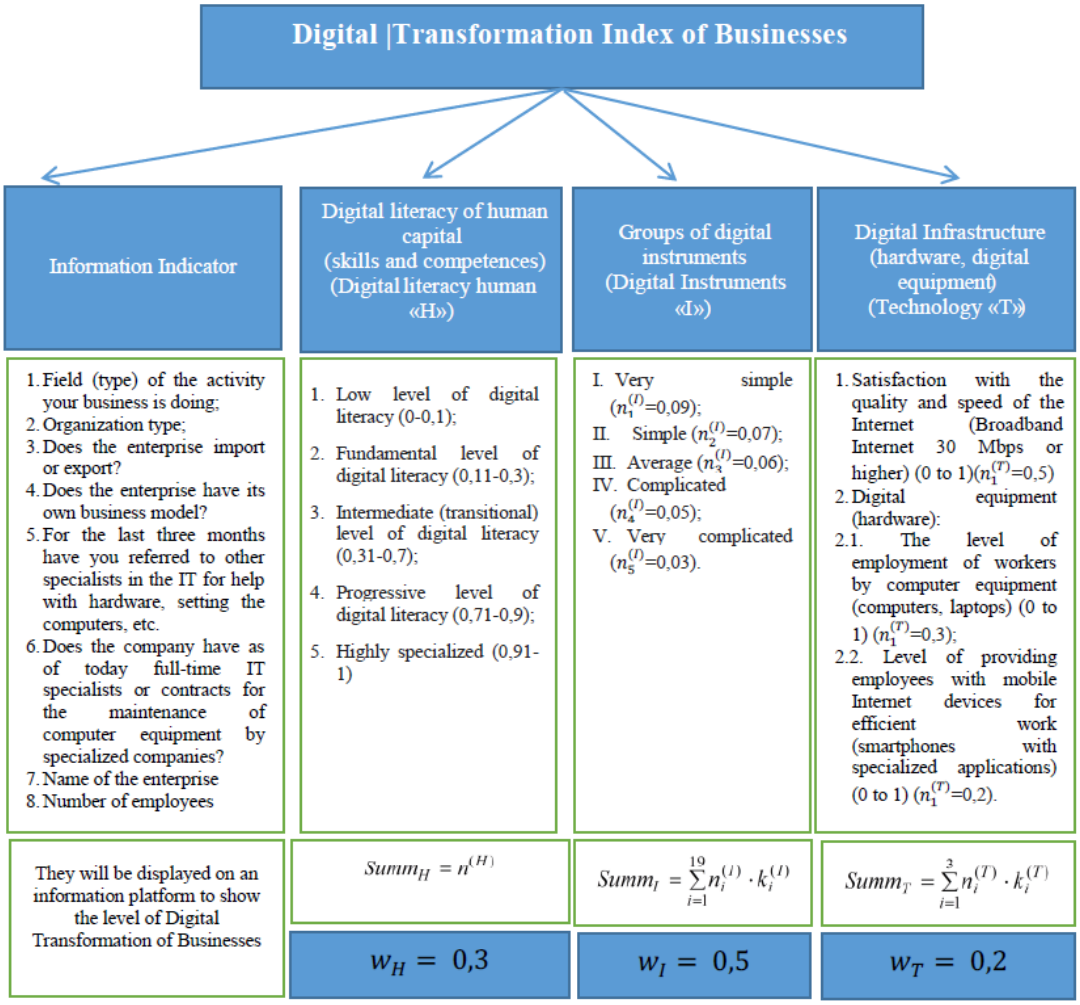


Figure 1.7 Example of an index in literature.

In this index, a weighted average score is calculated to define the level of digital maturity of a particular enterprise or industry as a whole through three criteria: digital literacy of human capital, digital instruments integrated into the business process, and the digital infrastructure of the company (source: DT Index of businesses by Strutynska et al., 2020).

An index is used to indicate the result of an evaluation of different company aspects defined in an associated MM, for example. The index represents the result that will place the company on a specific maturity stage of the MM just as an assessment. That is the reason why both tools are used interchangeably in some research works. The difference between them, however, lies in that the assessment is the tool of evaluation, and the index is the result of an evaluation. In the end, these tools include an assessment and a result of such assessment.

1.1.4.6 Positioning the digital tools' terms

In this set, the reviewed concepts do not overlap except for the last two evaluation tools: assessments and indices. To differentiate them, assessments will refer to the evaluation tool, and indices will refer to a specific measurement. Table 1.4 presents the chosen definitions for all five concepts.

Table 1.4 Types of digital tools and their selected definition.

Concept	Definition	Author(s)
Maturity Model	A maturity model consists of a sequence of maturity levels for a class of objects (e.g., organizations, processes) that represent an anticipated, desired or typical evolution paths of these objects shaped as discrete stages in which the highest stage represents a conception of total maturity.	Becker et al., 2009
Roadmap	A roadmap is an overall plan for the deployment of new technologies containing organizational change that explains the main phases that need to be taken.	Daim and Oliver, 2008; Issa et al., 2018
Conceptual Framework	A conceptual framework identifies the main concepts that explain a phenomenon and the relationship between them.	Miles and Huberman, 1994
Theoretical Framework	A theoretical framework consists of the theoretical principles, constructs, concepts and tenants of a theory.	Grant and Osanloo, 2014
Assessment	An assessment refers to the wide variety of methods or tools that are used to evaluate, measure, and document the readiness or maturity progress of companies.	Adapted from the Glossary of Education Reform
Index	An index is a sign or measure of maturity that companies can be judged by.	Adapted from the Oxford Advanced Learners' Dictionary

The identification and definition of the different tools used to represent the companies' evolution toward a DT are highly relevant for the execution of the search strategy of the literature review. However, given the variety of methods and to simplify the report and discussion of the main findings, in this work, they will be grouped under the label "Digital Models and Frameworks" (DMFs).

1.1.5 Industry 4.0 and other digital programs

1.1.5.1 Industry 4.0

Industry 4.0 is a term that originated in 2011 from a key initiative of the High Tech Strategy 2020 of the German government that looked to explore the potential of a new type of industrialization (Kagermann et al., 2013). The principles of the Industry 4.0 were then described in what was later called "Industrie 4.0 Platform", a program of the German government whose objective is "to secure and expand Germany's leading international position in the manufacturing industry" (see Figure 1.8).

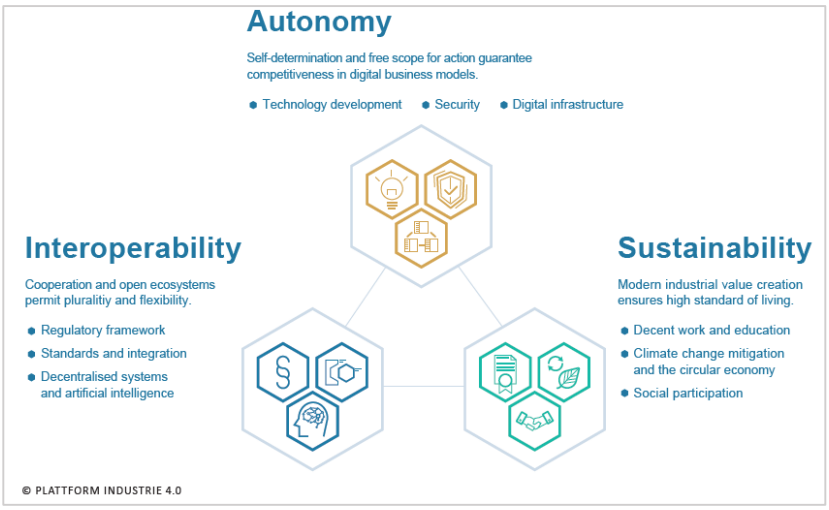


Figure 1.8 Main principles of the Platform Industrie 4.0, Germany government program.

(source: https://www.plattform-i40.de)

Since then, the pervasiveness of this concept around the world has been impressive. Nowadays, Industry 4.0 is a synonym for the Fourth Industrial Revolution, the most recent stage of technological development triggered by emergent technologies (Schwab, 2017). Logically, given the relevance of the subject for economic growth, a growing number of countries around the world have created similar programs to incentive the DT of their industrial sectors. A sample of some of these programs in Europe and other selected countries, leaders in manufacturing, are shown in Table 1.5.

Table 1.5 A selection of government programs created to incentive the DT of the industry.

Country	Program name	Year of creation
Germany	Platform Industrie 4.0	2011
Great Britain	High value manufacturing catapult	2011
Italy	Factory of the Future (Fabbrica del futuro)	2012
France	Factory of the Future (*Usine du Futur*)	2013
USA	Advanced Manufacturing Partnership	2014
China	Made in China 2025	2014
Japan	Society 5.0	2016

1.1.5.2 Positioning the digital programs' terms

More recently, Industry 4.0 is not only used for industrial scenarios, but it has also become a synonym for digital change, and many efforts related to new technologies are then labeled or referred to as Industry 4.0 or 4.0. In this sense, DT is also sometimes referred to as Industry 4.0, not only for DT in industrial contexts but also in other sectors. Its growing popularity and association with other terms, such as smart manufacturing, create significant confusion.

Given the relevance of the industrial sector and the interest in developing tools to accelerate their DT, this work takes into consideration the many uses of the term in the literature search. Nevertheless, in the rest of the manuscript, Industry 4.0 will be used only to refer to the German platform to promote the DT of the industrial sector.

1.1.6 Definition of search terms

Part of the importance of setting the DT terminology was to determine the search terms for achieving a thorough review of the literature. The objective of identifying the DMFs available in literature led us to a search strategy based on two components. The first one is composed of the different types of tools that present a proposal intended to provide companies with guidance in their DT efforts. All five tools are included here, given that assessment and indices may have a MM included in their proposal. The second part is composed of the different names that can represent an objective related to a DT. Considering the limitations of search engines, in this part, the terms "smart," "digital," and "digitalization" are included to represent the digital changes and initiatives. The term "Industry 4.0" is also considered as it can sometimes be used as a synonym for DT, as mentioned before.

1.1.7 Conclusions

In a preliminary search, it was identified in the research literature that most of the terms to name the proposals to guide companies' DT were not standard. As one of the objectives of this section, discussion of the use of different terminologies allows for the construction of a combination of terms that will focus the literature search and make it more efficient.

The positioning of definitions for all the relevant concepts will also allow having a glossary of the "digital" terms that becomes the reference for establishing the language to use along the content of this work. In Appendix 1.1, a consolidated view of the complete list of selected terms is available.

1.2 Systematic Literature Review (SLR)

A literature review is a critical stage of research projects to help provide a strong foundation for advancing the knowledge of a subject (Webster and Watson, 2002). The concern of this review of literature is the identification and analysis of the available Digital Models and Frameworks (DMFs) proposed to guide companies in their Digital Transformation (DT) efforts. The aim is to determine their adequacy to fully represent the implications of a DT for a company. This literature review set in the digital context, however, implies many challenges. Literature on the subject and its related terms is extensive. This richness, which speaks for the current relevance of the subject, presents some challenges when combined with its novelty. As discussed previously, official definitions of the term and the related terminology are not yet available in the academic literature, which has an impact on the use of the different notions and their analysis. Search strategies that consider the multidisciplinary nature of the subject are required, given the criticism of the limited views of the available works in literature. That situation implies performing a wider search that covers many perspectives and different levels of detail to provide a complete vision of the state of the art.

1.2.1 SLR method

In searching for a strong foundation for building a proposal, this work adopts a Systematic Literature Review (SLR) as its method. A systematic review is *"a review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyze data from the studies that are included in the review"* (Moher et al., 2009).

The SLR performed for this work is driven by the following research questions:

1. What are the DMFs available in the literature?
2. What are the methods used to develop them and generate their content?
3. What is the objective they pursue and the scope of the DT their content currently covers?
4. Is the guidance proposed adapted to the particularities of companies' context?

Through an SLR, this thesis intends to identify the relevant works to answer these questions. To achieve this objective, this review first presents the method followed to perform the literature search. Next, the sections are focused on answering each of the questions. The review ends with the presentation and discussion of the main findings.

The quality of SLRs relies upon the transparency of the search of the literature, its analysis, and reporting procedures (Booth, 2016). To accomplish the required quality, this section was built following the main guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement (Page et al., 2021).

The PRISMA statement was originally created as a series of guidelines to ensure the quality of reporting of systematic reviews as they started to become key in health care research (Moher et al., 2009). Lately, its application has expanded into other domains that look to ensure a literature review that is valuable by using reporting guidance (Page et al., 2021).

To accomplish the first requirement of a systematic search, that is, its coverage, a combination of multidisciplinary and domain-specific databases was selected. The databases used for this purpose were Scopus, Web of Science (WoS), IEEE Xplore, EBSCO, and Science Direct (SD). Given the multidisciplinary nature of the subject and the domain of application (industrial sector), these databases were considered the most adequate as they count for an important amount of quality research literature (Scopus, WoS, SD) or they are renowned in the fields of engineering (IEEE) or business (EBSCO). See Appendix 1.2 for the full details of the search strategy.

The first exploratory research of the works available in the research literature and the definition of the DT terminology helped in identifying more accurate terms for the systematic search. Two main components were identified, a combination of the aim of the DT (smart, digital, Industry 4.0, or digitalization) and the tool used to depict the transformation process (maturity model, index, framework, roadmap, or assessment). Considering the lack of a common DT terminology, this structure allowed for the definition of a more effective search strategy. Therefore, the search was performed by using the following combination of terms:

("smart" OR "digital" OR "Industry 4.0" OR "digitalization") AND ("maturity model" OR "index" OR "framework" OR "roadmap" OR "assessment")

The search was performed in October 2021 and updated in December 2021, considering the exponential growth of literature on the subject. Results were retrieved only in English and the period considered for the search was from 2010 to 2022 (2022 to include preprints), as the subject is very time-sensitive due to the fast evolution of technology (see Figure 1.9).

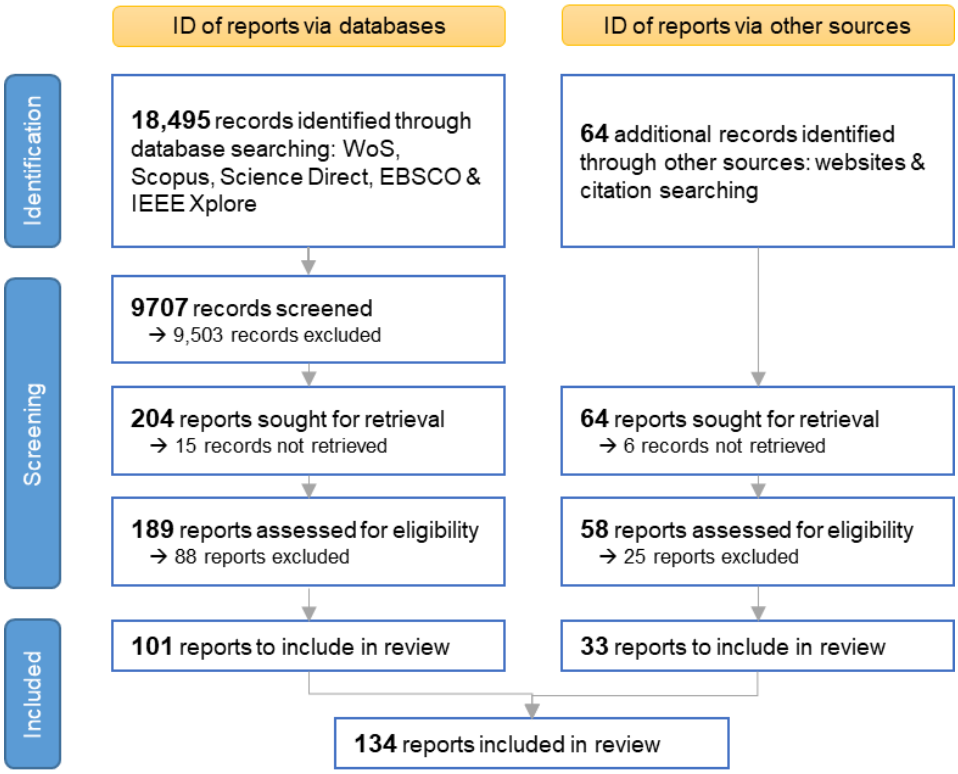


Figure 1.9 PRISMA procedure for SLR (adapted version from Page et al., 2021).

The search in the chosen databases reported a total combined 9707 sources after removing duplicated records. Most of them were not the objective of the review, but this design assured an exhaustive search of the type of sources required, though it complicated the stage of screening.

During the screening stage, the exclusion criteria of the sources comprise the following reasons:

- the DMF's objective is not to present a model or framework to guide the DT or a digital initiative (e.g., narrow approaches focused on only one dimension such as technology, competencies, etc.);
- the DMF focuses on other types of DTs that do not share the same characteristics as those of business organizations, such as the DT for medical or utilities industries and smart cities.

This filter reduced the number of sources to 204 works, which were assessed according to the following inclusion criteria:

- the DMF has a clear objective related to the DT or at least one of the main types of initiatives discussed earlier;
- the DMF is intended to have a scope beyond technology;
- the DMF's development is deemed to be complete;
- the DMF's content and procedure of development are available with at least a minimum of detail for the evaluation.

The SLR of the current DMFs resulted in 101 works. Nevertheless, as it is generally known that electronic searches have gaps, and there is always the possibility of missing some important works, 33 additional DMFs were also located through websites or reference searching through the reference lists of relevant papers, a method commonly referred to as snowballing (Hiebl, 2021).

Those additional articles that complemented the ones found through the academic databases came from the practice community that has also produced highly referenced works on relevant research papers, hence their inclusion. See Appendix 1.3 for a complete list of the 134 DMFs identified through the SLR.

In the next section, the DMFs identified are reviewed in terms of their general characteristics, the methods used for their development and the scope of the DT their content covers.

1.2.2 Digital Models and Frameworks (DMFs) available in the literature

Multiple DMFs are proposed in the literature to assist companies in their DT. The nature of those identified through this SLR is presented here through three main criteria: the year of their publication, their country of origin, and the type of publications available. The objective is to provide a general view of how the identified DMFs are constituted.

1.2.2.1 Year of publication

The first thing to note is the exponential growth of the number of works produced in the last years. Just as an example, more than 40% of the DMFs identified were produced between 2020 and 2021, which can be an indication of the relevance of a subject and a need that possibly has not been fulfilled. Figure 1.10 shows the number of DMFs identified by their year and type of publication.

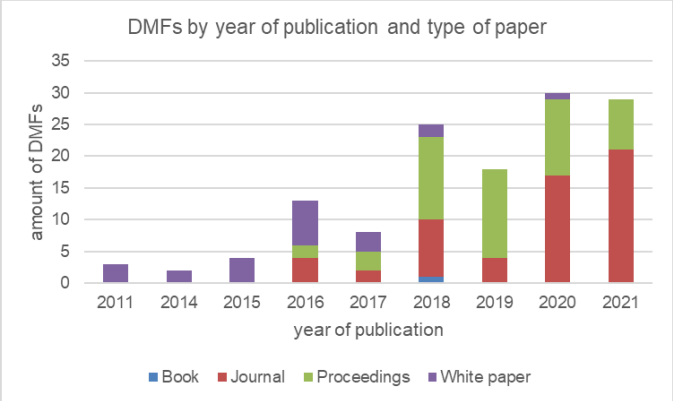


Figure 1.10 DMFs by year and type of publication.

The graph also presents the type of publications created each year. It can be observed that the first publications were white papers coming from practice or government agencies, especially those related to manufacturing (e.g., Lichtblau et al., 2015). Those DMFs were identified throughout reference searching, as they were highly cited by research works. Figure 1.11 presents a more detailed view of their composition.

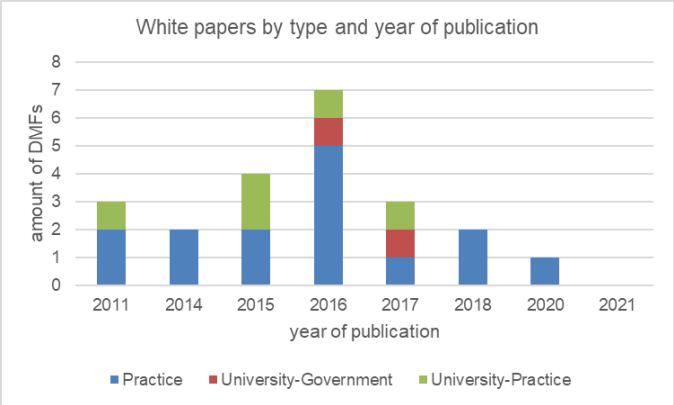


Figure 1.11 White papers by type and year of publication.

There is evidence of the influence of these first works, as they inspired the more recently developed DMFs. Though there are many more DMFs available coming from practice, this review only considered those cited in research works.

1.2.2.2 Country of origin

Another interesting characteristic of the DMFs identified is their country of origin (see Figure 1.12).

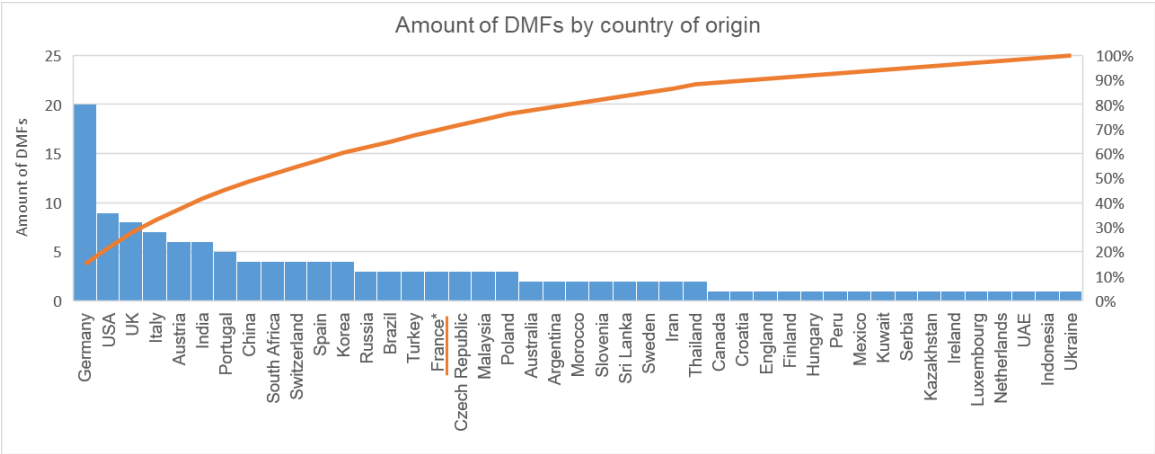


Figure 1.12 Amount of DMFs by country of origin.

Germany leads in the number of DMFs proposed with 15%, even though the works are coming from many different countries as the digitalization initiatives of the industrial sector are becoming a priority in government agendas all over the world.

1.2.2.3 Origin and type of publication

The origin of the works is diverse; while the vast majority come from research (82%), there is a key contribution from practice of influential DMFs (11%). The rest of the identified DMFs (7%) come

from collaborations between practice, represented in its majority by consulting firms, and government or academic institutions, such as engineering faculties or associations. Figure 1.13 shows the composition of the sample regarding this attribute.

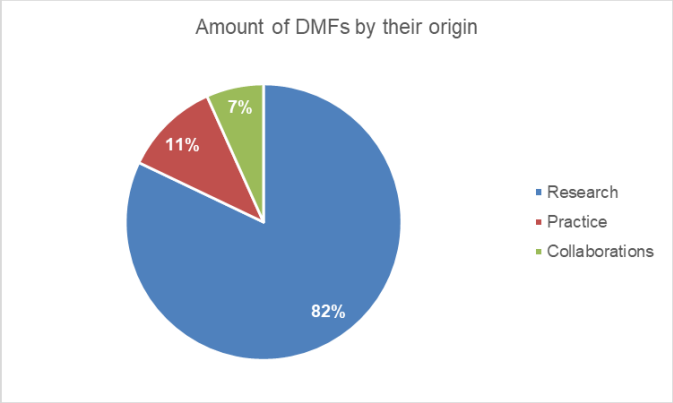


Figure 1.13 Amount of DMFs by the origin of their publication.

In Figure 1.14, it is observed that the majority of the DMFs, mostly from research, are coming from peer-reviewed journals, with 43% and 39% from conference proceedings.

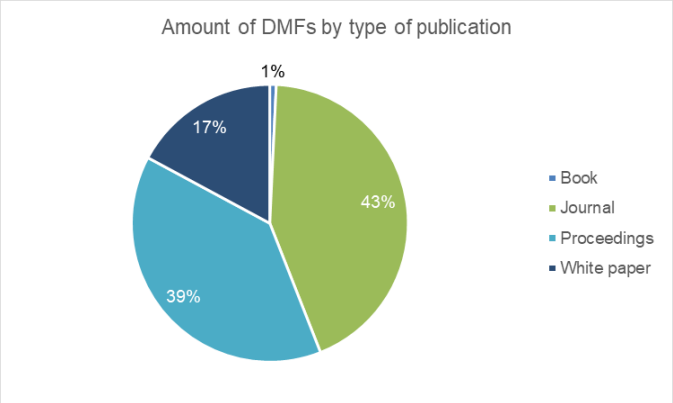


Figure 1.14 Amount of DMFs by the origin of their publication.

There is also 17% of DMFs that are white papers. White papers are reports that are prepared to show results of surveys or case studies, or web pages containing self-assessments for companies. However, it seems evident that these works are designed to give a sample of the services offered by the consulting firms that proposed them. In the case of collaborations, the white papers showcase industry case studies that aim to incentivize the digitalization of companies in a given country or industry sector.

1.2.3 DMFs' method of development

The last part of the presentation of the available DMFs focuses on the methods used to develop them. Two aspects are considered key to providing a global view of the works regarding this variable: the type of tool used to create the DMF, and the method used to generate its content.

1.2.3.1 Type of tools used to develop DMFs

An interesting detail of the selected works is the variety of the tools used for illustrating the DT. They are present either in the form of frameworks (e.g., Lee et al., 2017; Scremin et al., 2018), indexes (e.g., Schuh et al., 2017), readiness assessments (e.g., Exner et al., 2018; Jung et al., 2016) or the popular MMs (e.g., Schumacher et al., 2016; Akdil et al., 2018; Chonsawat and Sopadang, 2021). Figure 1.15 shows the proportion of each type of tool used to present the DMFs.

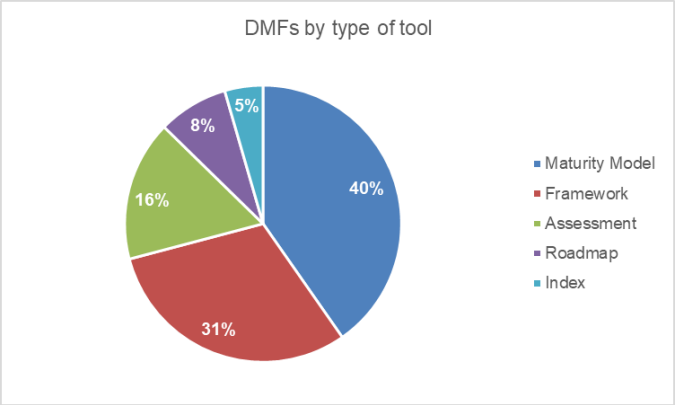


Figure 1.15 DMFs by type of tool used in their development.

The results show that the predominance of the MMs and frameworks above other methods, such as roadmaps, indices, or assessments, is overwhelming. However, between MMs and frameworks, MM characteristics are more suitable to provide companies with the guidance of their DT efforts (see Section 1.1.4.1). The MMs are proposed either as a reference for a maturity path or accompanied by a tool for the assessment or self-assessment of a company's maturity. These works, coming from research and practice, are mostly focused on describing the path a company must follow to achieve a DT. As the road towards a DT implies an evolution of the organization to reach a business objective, MMs seem to be a natural choice for many of these proposals.

In the results of the SLR, it is clear that MMs' presence in the digital domain is rather important; however other tools such as frameworks are also greatly used in the DT representations. MMs and frameworks, however, represent a static view of a phenomenon known for having a dynamic nature due to its dependence on many contextual factors.

The level of detail of the works is, in most cases, very limited, as reported by previous analysis. Even though there are truly remarkable works with operational level detail, most of the works, regardless of their origin, do not seem to have the level of detail required to be used in a DT implementation. This situation can logically be expected from the works coming from practice, as the consulting firms aimed to attract the attention of companies' executives to acquire their services (see Figure 1.16), but the situation is no different for the rest of the DMFs (see Figure 1.17).

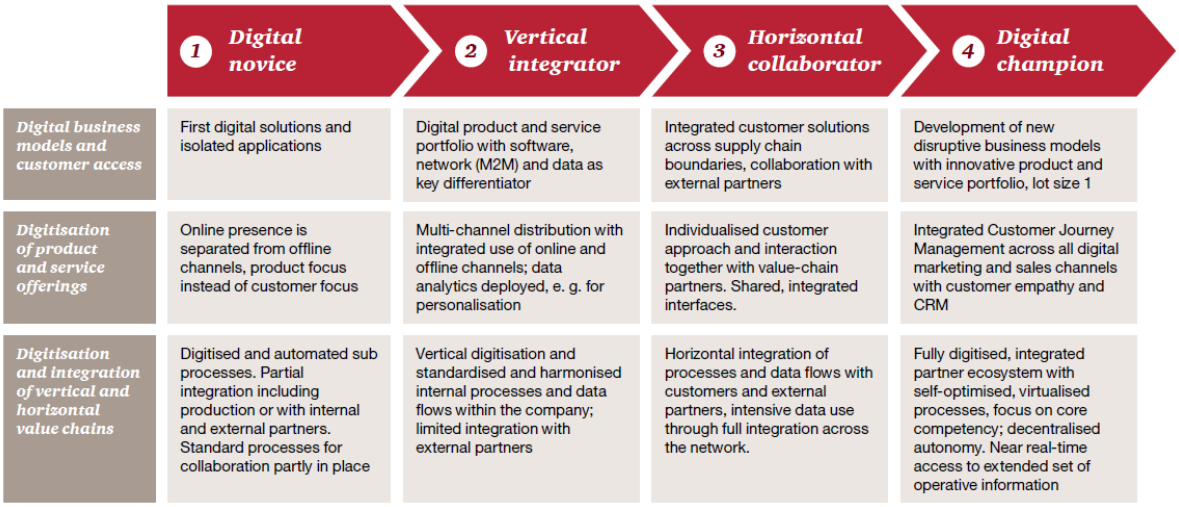


Figure 1.16 Extract of PwC's Maturity Model originated in practice (Geissbauer et al. 2016).

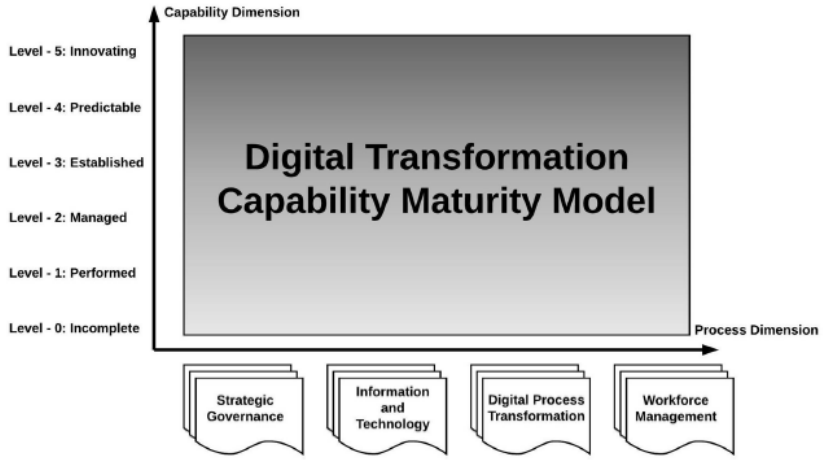


Figure 1.17 Maturity Model originated in research (Gökalp and Martinez, 2021).

Table 1.6 presents a selection of DMFs describing their origin, the digital initiatives and the type of companies they target, along with the number of business dimensions and maturity levels they cover, as an illustration of these types of proposals.

Table 1.6 Main information of a selection of DMFs.

#	DMF's name	Year	Origin	Source of content	Digital initiative targeted	Number of dimensions	Maturity levels
01	Industrie 4.0 Readiness (Lichtblau et al., 2015)	2015	Practice	Industry Case studies	Smart Products & Services	6	6
02	PwC Maturity Model (Geissbauer et al., 2016)	2016	Practice	Industry Survey	Smart Products & Services	7	4
03	Industry 4.0 Maturity Model (Schumacher et al., 2016)	2016	Research	Literature Review	Smart Manufacturing	9	5

#	DMF's name	Year	Origin	Source of content	Digital initiative targeted	Number of dimensions	Maturity levels
04	Industrie 4.0 Maturity Index (Schuh et al., 2017)	2017	Practice	Industry Case studies	Smart Manufacturing	4	6
05	Adoption Maturity Model (Scremin et al., 2018)	2018	Research	Literature Review	Smart Products & Services	3	5
06	Smart Factory Maturity Model (Sjödin et al., 2018)	2018	Research	Industry Case studies	Smart Manufacturing	3	4
07	Digital Readiness Level 4.0 Model (Pirola et al., 2020)	2020	Research	Literature Review	Smart Manufacturing	5	5
08	Company Compass 2.0 (Nick et al., 2020)	2020	Research	Literature Review	Smart Manufacturing	7	5
09	DX-CMM (Gökalp and Martinez, 2021)	2021	Research	Literature Review & Experts' Input	Smart Manufacturing	4	6
10	Extended Maturity Model for DT (Soares et al., 2021)	2021	Research	Extension of current MMs	Smart Manufacturing	6	5

The results of the SLR show that the quantity of proposals to guide the companies' DT is overwhelming; however, deficient documentation raises many questions about the rigor of their method of development and validation. MMs, for example, do not have a well-established and accepted framework to guide their development and assessment, a condition that can affect the quality of their contribution. Additionally, the lack of a common DT terminology complicates the evaluation and comparison of different proposals.

The characteristics of the tools currently used for the proposals do not seem a good fit to portray the complexity of the DT phenomenon and provide companies with the much-needed guidance. The inadequacy of the tool, along with a methodological framework still in development, can be the reason why the number of new models keeps growing.

1.2.3.2 Methods used to define the DMFs

The variety of results that were obtained by reviewing the company's aspects considered by the DMFs found in the literature review led this work to consider the methods used to define them (see Table 1.6, DMFs' number of dimensions and maturity levels). In this regard, three were the main methods identified as the source of the definition of the business dimensions and maturity levels in each DMF:

1. literature reviews,
2. industry case studies or companies' surveys,
3. experts' interviews.

Literature reviews are the methods recommended by the most used methodologies for developing MMs. This means, for example, literature reviews of the content of existing DMFs. This type of content creation, along with the extension/combination of existing DMFs, only inherits the same problems that the previous works may already have.

Industry case studies and companies' surveys are regularly found as the preferred method for the proposals coming from practice or collaborations between academic or government institutions and

practice. In this type of method, the information originating from real case scenarios is summarized to create a guide for pursuing a DT. Beyond the issues raised by this type of generalization, information on the effectiveness of the proposal is rarely available.

Experts' interviews are frequently a complement to confirm the soundness of a proposal and are therefore often used in combination with the other two methods. In this method, the content of the proposal is validated by an expert(s) in the domain. Given that DT is a multidisciplinary subject, this method of validation would require several experts in different domains and sectors, which is not necessarily the case in the available works.

1.2.4 DMFs' coverage of the DT implications

A central interest of this review is to investigate if the content of the DMFs available in the literature covers all the implications of a DT for a company. In organizing the analysis of the DMFs coverage of those implications, this section followed the defined research sub-questions as a guideline to define the following topics:

- their objective;
- the targeted companies;
- the DT process portrayed;
- the company's aspects considered;
- the level of detail presented.

1.2.4.1 DMFs' objective

Identifying the objective of the models was the first thing to determine in order to have a sense of the type of guidance proposed by the works. Figure 1.18 presents a view of the different objectives stated by the authors of the DMFs in the study's sample. This view is combined with the type of tool used to present them to give an idea of the type of information provided regarding the objective.

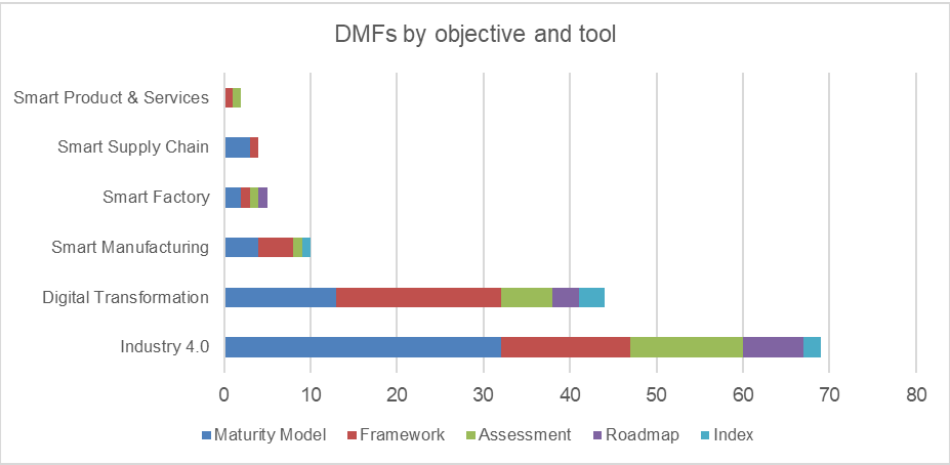


Figure 1.18 DMFs by objective and tool of creation.

In this figure is possible to identify, for example, that 32 maturity models present a proposal for realizing the goals of Industry 4.0.

In the results, it can be identified that the majority of the DMFs are focused on digital initiatives and not the transformation of the company. Only those that identify their objective as “Digital Transformation” and especially those coming from practice give an idea of a focus on the company instead of a technology introduction project. However, the lack of detail in most of the works inhibits a complete appraisal of that situation (e.g., Santiago da Costa et al., 2018, Zhang and Zhang, 2021). To measure the evolution of this objective, DMFs’ authors use either digital maturity or digital readiness as an indicator of the company state. In most cases, the difference is not made, and both terms are used interchangeably (see Figure 1.19).

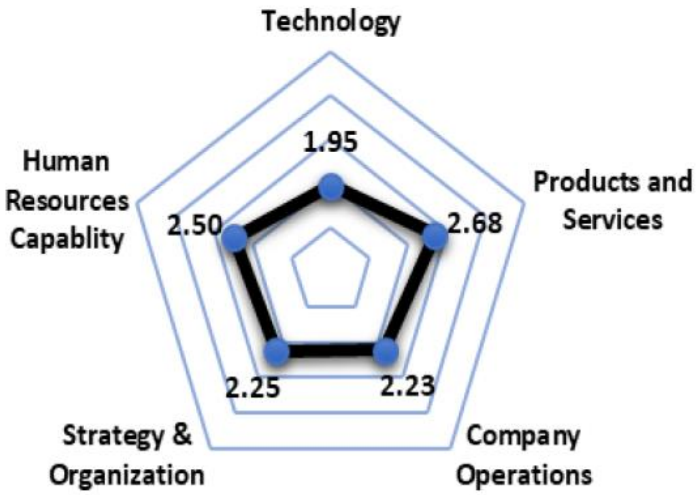


Figure 1.19 Example of companies’ “readiness” measurement.

This figure shows the assessment of a 5-dimension MM with six levels of maturity, where level five represents the highest state of achievement of the Industry 4.0 concept (source: Maturity Model to Assess the Smart Indonesia Manufacturing Companies 4.0 Readiness by Almamalik, 2020)

As it is observed in the DMF in Figure 1.19, both concepts, readiness and maturity, are combined in one maturity model. In this case, readiness is associated with being compliant with the principles of Industry 4.0, that for the author, is also synonymous with smart manufacturing.

1.2.4.2 DMFs’ targeted companies

In the analysis of the identified DMFs, it is evident that the current offer of works is focused on Industry 4.0, and consequently, 67% of the works are conceived for the manufacturing sector (see Figure 1.20). There is also an emphasis on manufacturers that belong to the category of Small and Medium Enterprises (SMEs), as they are at a disadvantage in the face of the challenges that the new digital context presents (Mittal, Khan et al., 2018).

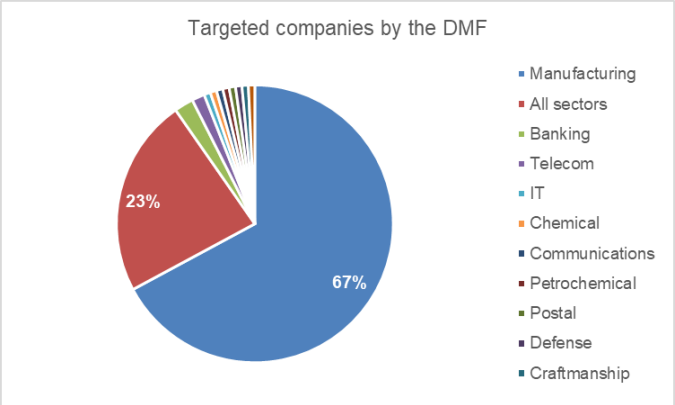


Figure 1.20 Proportion of companies' types targeted by the DMFs.

As can be expected, DMFs addressed to a wide audience tend to be generic and superficial since they do not look to cover the specificities of users (see Figure 1.21).

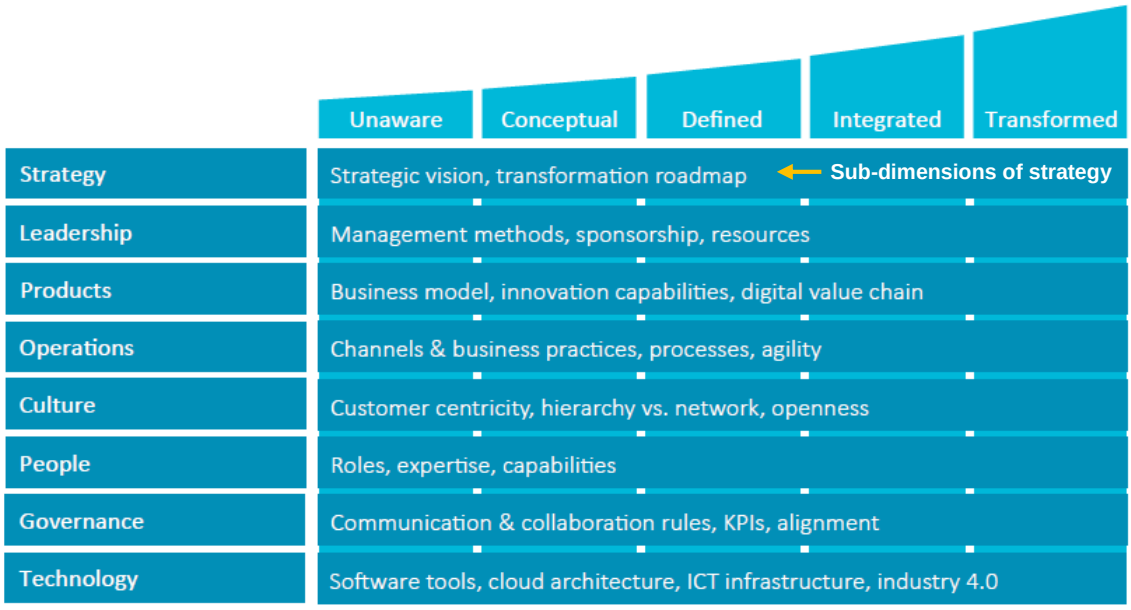


Figure 1.21 Example of a DMF targeting all companies.

This MM proposes eight dimensions divided into sub-dimensions that are detailed according to five maturity levels (source: Digital Maturity Model by Azhari et al., 2014).

Surprisingly, the same issues were identified in those DMFs addressed to specific audiences such as manufacturers or Small and Medium Enterprises (SMEs) (see Figure 1.22).

	1	2	3	4
Processes and infrastructure	Some of our internal processes are rudimentarily digital, some manual.	Internal processes are digital and in some cases interconnected.	Internal processes are digital and in most cases interconnected.	All processes are on a single digital platform.
Digital sales	We have a standardised website for sales.	We have accompanying measures and digital services augmenting online sales.	We use big data to create offerings for individual customers.	We have used digitisation to fundamentally change our business model.
Customer involvement	Customers can give feedback on a standardised basis via digital channels.	Customer feedback is automatically processed and analysed.	Customers are involved digitally in isolated business processes (e.g. sales and development).	Customers are involved digitally in all business processes (sales, development, etc.).
People and culture	Digitisation hardly concerns our staff.	We make sure staff use digital tools.	We provide training and experts to further the digital development of our staff.	We promote innovation by including digital skills in our hiring criteria.

Figure 1.22 Example of a DMF targeting SMEs in Switzerland.

This MM proposes four main dimensions that are detailed into four maturity levels (source: Rating scale for calculating degree of digitisation by Greif et al., 2016).

They present a characterization of a DT more suitable for industrial companies. Nevertheless, the DMFs do not acknowledge that even between companies of the same sector, there are particularities of their context that can affect the development of their DT efforts, such as their size and available resources.

1.2.4.3 DMFs' portray of the DT process

Given the type of tools used to represent the DT, only the content of MMs and roadmaps present something that can resemble more to a process. Frameworks are mostly conceptual representations of the phenomenon. Assessments and indices are either questionnaires or formulas. The issue with MMs is that they present maturity stages rather than a progression of steps towards a DT. In this sense, roadmaps can be closer to what a process is; however, they are more superficial and lack the detail that MMs most commonly have.

Going into deeper detail, it is possible to characterize the content of the MMs as static. They represent a tool that displays one solution that implies that all companies follow the same path regardless of their context (see Figure 1.23).

Level / Dimension	Initial (I)	Repeatable (II)	Defined (III)	Managed (IV)	Optimizing (V)
Strategy	To improve productivity	Keeping up with industry benchmark	Suitable for enterprise's overall strategy	Long-term strategy	Collaborative strategy
Process	Information to support	Continuous improvement	To match the production task	Implementation of the flexibility	Service oriented and customer requirements
Personnel	High technical competencies	Inter-disciplinary talent demand gradually	Rising to the requirement of management	Focus on the professional training and scientific evaluation	Efficient talent can fuse with the machine and environment friendly

Figure 1.23 Extract of Smart Manufacturing Capability Maturity Initial Model (Peng et al., 2016).

Regarding the roadmaps, the process usually is presented as a series of steps toward an objective. The level of detail of the steps proposed varies as well as the objective pursue. It is accurate to say that the roadmaps found in the SLR are something resembling more a checklist than a process. The proposals present general solutions without the detail on how to follow the suggested path (see Figure 1.24).

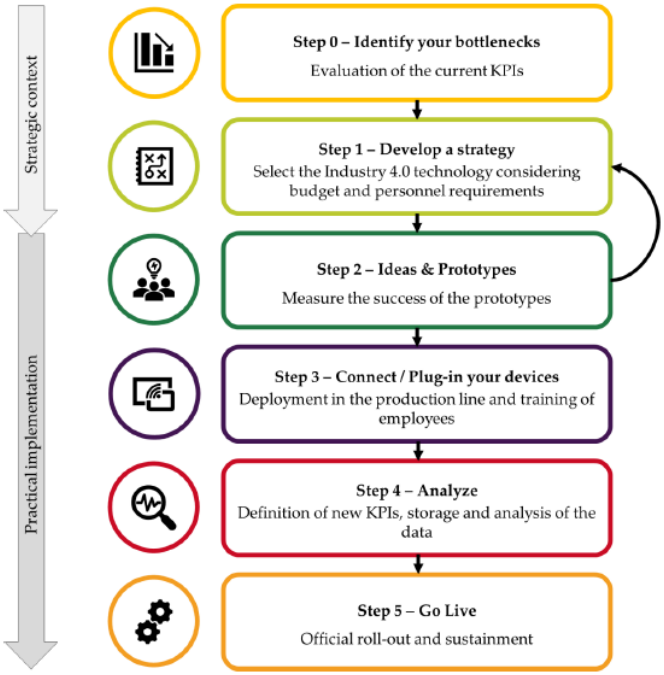


Figure 1.24 Roadmap for the 4th Industrial Revolution for SMEs (Cotrino et al., 2020).

Considering DT as a process of organizational change, it is observed that this process is not being portrayed in its completeness on the DMFs that are conceived for guiding it.

1.2.4.4 Company's aspects considered by the DMFs

The coverage of the DT phenomenon by the DMFs is represented by the company's aspects they considered in their design. To facilitate the review of these aspects, a standardized catalog was defined based on the content of the selected works. A total of 15 aspects were identified as follows. Strategy, business model, investment, customer, partners, product, services, process, governance, culture, leadership, employee competencies, organizational structure, technology and performance measurement.

The content of the DMFs was then classified, considering the company's aspects defined. This organization allowed a homogenization of the names of the concepts to enable the comparison of the DMFs with the same criteria from a high-level perspective. After working on a standardization of the aspects, the analysis started by identifying the ones considered by the DMFs selected during the SLR. Figure 1.25 shows the company's aspects considered in the selected works and the number of times they are included by the DMFs.

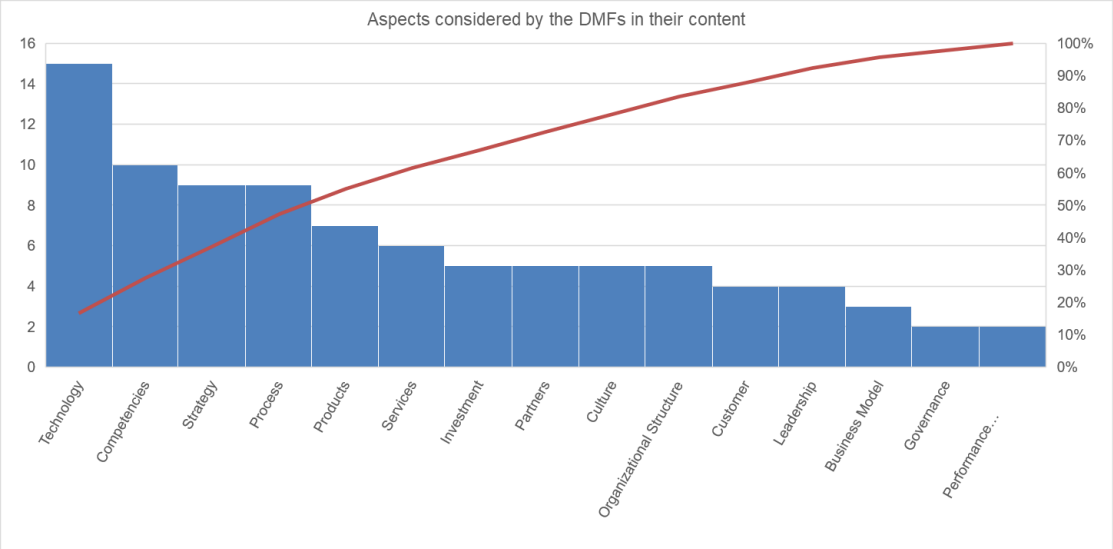


Figure 1.25 Company's aspects considered by DMFs.

Long criticized because of a predominantly technological perspective (Schumacher, 2016; Mittal, Khan et al., 2018), recently developed DMFs have started to include other organizational elements. Nevertheless, perhaps because of the multidisciplinary condition of the DT, it is difficult to find a well-documented holistic view when most of the authors' background is focused on only one discipline, mainly engineering. This situation continues to lead the different proposals to present a predominantly technological perspective even when considering other aspects based on different justifications. A closer view of the differences in the scope of the works can be attested in Table 1.7 by reviewing the company's aspects considered by the DMFs presented previously in Table 1.6 in section 1.2.3.

Table 1.7 A selection of DMFs and the company's aspects they considered in their content.

Company's aspects	DMF 01	DMF 02	DMF 03	DMF 04	DMF 05	DMF 06	DMF 07	DMF 08	DMF 09	DMF 10	Total count
Strategy	●		●		●		●	●	●	●	7
Business Model		●								●	2
Investment	●		●		●					●	4
Customer		●	●				●			●	4
Partners		●	●				●			●	4
Products	●	●	●		●			●		●	6
Services	●	●			●			●		●	5
Process		●	●			●	●	●	●	●	7
Governance		●	●								2
Culture		●	●	●				●	●		5
Leadership			●							●	2
Employee Competencies	●	●	●		●	●	●	●	●	●	9
Organizational Structure		●		●					●	●	4
Technology	●	●	●	●	●	●	●	●	●	●	10
Performance Measurement					●						1
Total count	6	11	11	3	7	3	6	7	6	12	

In this sense, DMFs proposed by researchers with an engineering background have a strong focus on technology. On the contrary, DMFs coming from practice or from collaborations with consulting firms present more emphasis on organizational aspects in the aspects proposed. Beyond these polarities based on the background of the authors of the DMFs, there is still an understandable agreement on the predominance of the technological perspective, given the nature of the DT. Additional to the technological dimension, there is a high consideration of the employee competencies and processes as a critical part of the change.

This result is quite understandable, considering an important number of the DMFs are focused on the manufacturers' transition to Industry 4.0, and process digitalization is a core part of its principles. This high-level view of the company's aspects considered by the DMFs, however, can be misleading as it only represents a partial analysis of the coverage of the DT phenomenon. By going deeper in this analysis, though the works do not have an operational level available, it was immediately clear that the details covered by the same aspect in different DMFs can also vary enormously.

Taking the technological dimension as an example, one that is included in each of the selected works, can explain this argument better. In the content of the models, it can be observed that for some, the maturity in the technological dimension is measured by the level of automation, and for others, by their capability of data & analytics or the presence of an agile IT architecture (see Table 1.8). In fact, almost each of the selected models has a different appreciation of this very same business dimension, making a comparison impossible.

Table 1.8 Criteria covered by the Technology aspect of the DMFs sample.

#	DMF's name	Criteria included in the technology aspect of the DMF
01	Industrie 4.0 Readiness (Lichtblau et al., 2015)	**Smart Factory** Digital modelling, Equipment infrastructure, Data usage, IT systems **Smart Operations** Information sharing, Cloud usage, IT security, Autonomous processes

#	DMF's name	Criteria included in the technology aspect of the DMF
02	PwC Maturity Model (Geissbauer et al., 2016)	**Data & Analytics as core capability** Central use of predictive analytics for real-time optimization and automated event handling with intelligent database and self-learning algorithm enabling impact analysis and decision support **Agile IT architecture** Single data lake with external data integration functionalities and flexible organization. Partner service bus, secure data exchange
03	Industry 4.0 Maturity Model (Schumacher et al., 2016)	**Technology** Technology for information exchange; Utilization of cloud technology; Mobile devices on shop floor; Decentral information storage; Sensors for data collection; Integrated computers in machines; Integrated computers in tools; Additive manufacturing; Utilization of robots
04	Industrie 4.0 Maturity Index (Schuh et al., 2017)	**Information systems** *Information processing:* Data analysis, Contextualized data delivery, Resilient IT infrastructure, Application-specific user interface *Integration:* Horizontal and vertical integration, Data governance, Standard data interface, IT security
05	Adoption Maturity Model (Scremin et al., 2018)	**Technology** The decision-making model for the selection of infrastructure, standards and technologies related to I4.0. The growing threat of cyber risk. **Networking and Integration** The scope of the introduction of I4.0 in an organization Three levels of integration: Horizontal, Vertical and E2E **Infrastructure** An evaluation of the smart technologies adopted, the ICT systems that enable their integration, and the cyber security system to ensure a high level of safety in data management and integrity
06	Smart Factory Maturity Model (Sjödin et al., 2018)	**Technology - Configure Modular Technology** Accuracy of data collection, automated processes for data mining, real-time performance analysis, simulation systems, monitor and visualize critical operational analytics, supply chain predictability.
07	Digital Readiness Level 4.0 Model (Pirola et al., 2020)	**Technology** Analyses the current adoption of the Industry 4.0 enabling technologies. **Integration** Analyses the digitalization level and the integration with other actors of the value chain.
08	Company Compass 2.0 (Nick et al., 2020)	**Virtual world** Utilization of collected data, Applied technologies, Automatic, adaptive control of production, Degree of automation, Digital mapping and intervention, Level of IT development and Vertical integration, Visualization, IT security.
09	Digital Transformation Capability Maturity Model (Gökalp and Martinez, 2021)	**Information and Technology** IT strategy Management, Requirement definition, Enterprise Architecture Development, Infrastructure Management, Data Governance, Agile Software Development, Security Management, Enterprise Architecture Integration, Data Analytics, Enterprise Architecture Maintenance.
10	Extended Maturity Model for DT (Soares et al., 2021)	**Smart Factory** Equipment infrastructure, Digital Model, Data collection and usage, IT systems **Smart Operations** Integration, Autonomous processes, Control & Monitoring, IT Security, Cloud usage

In the general view, it was also clear that there are organizational aspects that are still less explored in the DMFs. This is particularly evident in the low presence of the organizational structure and culture aspects. In the case of organizational culture, this aspect is almost absent from the DMFs that are coming from research even when in the literature is one of the critical success factors in scenarios of organizational change of the characteristics of the DT.

In the analysis of different works, it was also identified that in the design of the content of different aspects, the links that exist between them during the DT are not considered and properly portrayed

in the proposals. They also fail to recognize the role of the organizational context during the transformation, and they seem to ignore the particularities of the scenarios of certain types of companies.

This situation validates the main questions of this research work as they clearly show that there is not a common understanding of what represents digital maturity in a DT and what are the changes in the company's aspects (business dimensions) that impact that measure. In the end, the consequences of these limitations are models that take the form of generic characterizations that do not accurately represent the path an organization must follow to a successful DT.

1.2.4.5 DMFs' level of detail

The level of detail of the information provided about the DMFs is critical to fulfilling their objective of providing guidance to companies that are looking to digitally transform. Achieving this objective is a challenge, considering that of the 82% of DMFs coming from research, 46% are conference proceedings with a page limit between 4 and 10. Even for the remaining 54%, journal papers or book chapters of 20 or 30 pages may seem a challenging task given the complexity of the subject (see Section 1.2.2.3). In these conditions, attempting to trigger action with a high-level vision is hardly viable. The research works end up being reference works for other researchers or strategic-level information for practice.

1.3 Critical review

The previous analysis presented a global view of the available guidance for companies looking to digitally transform their businesses. In this section, a summary of the findings is presented, and a critical review is conducted to identify the limitations of the DMFs that inhibit them from providing companies with the proper guidance for starting a DT.

1.3.1 Summary of findings

In reviewing the relevant literature, it is observed that the DMFs' content shows that their vision is incomplete and superficial.

1.3.1.1 DMFs available in the literature

The DMFs available in the literature are growing exponentially, with 45% of the ones identified produced between 2020 and 2021. Composed of 82% of research works, there are also seminal works coming from practice from the 2010s (see Section 1.2.2.3). The type of publications chosen to present the DMFs range from conference proceedings to journal papers in research, while practice naturally privileges the use of white papers (reports). With a clear predominance of German contribution, the rest of the works are from countries all over the world, attesting to the global relevance of the subject. This situation also shows how scattered are the research efforts on the subject.

1.3.1.2 Methods used to develop DMFs and generate their content

The methods used to develop the DMFs are varied, and they serve different objectives. Their evaluation here is made considering their representation of the DT that can serve as a guide for the companies' DT. In this respect, though MMs and frameworks account for 71% of the DMFs, MMs are the ones that are able to provide more information about the trajectory toward a DT (or a digital initiative) than frameworks (see Section 1.2.3.1).

Things get more critical regarding the method to generate the content. Results showed that most of the DMFs rely mainly on literature reviews to define their content. When these reviews search existing literature, specifically previous DMFs, to build their content, there is certainly a risk of inheriting the same issues as the source. Only isolated cases rely on theory to build content. It is also interesting to note that the rigor of the methods used to validate the content of the DMFs, such as experts' interviews, may affect the quality of their contribution.

1.3.1.3 DMFs objectives and coverage of DT's implications

The objective of the DMFs generally revolves around digital initiatives. Considering that most of them target the manufacturing sector, Industry 4.0 is a popular objective. Only a fraction of the models targets a DT, but how they characterize its objectives is a piece of information that is not always available due to the lack of detail regarding the DMFs (see Section 1.2.4.1). Given the strong focus on Industry 4.0 and smart manufacturing, a considerable number of DMFs are built to help manufacturing companies in their efforts regarding the digitalization of their production processes. Other DMFs also direct their efforts to support Small and Medium Enterprises (SMEs) or, more specifically, manufacturing SMEs, as they are categorized as a group especially challenged by the prospect of a DT due to the lack of resources (see Section 1.2.4.2).

DMFs' ability to present a representation of a DT for these groups, however, is seriously limited by the tools they choose to use. Only MMs and roadmaps get close to portraying the DT in a series of stages (MMs) or steps (roadmaps) to follow. However, the representation is static and lacks the flexibility to adapt to the companies' context. Evaluating the coverage of the scope of the implications of the DT covered by the DMFs is difficult. The aspects of the company that they consider are numerous, but there is no agreement on the ones chosen by each DMF or a sound justification for their selection. The detailed criteria for the same aspect can also be different from one DMF to the other, an indication of the lack of agreement on the factors that contribute to achieving the DT objectives.

1.3.1.4 DMFs capability to adapt to companies' context

In the analysis of the DMFs, their fitness to adapt to the companies' context is limited not only by the static nature of the tools they used to portray the DT but also by the lack of consideration of the impact of context on companies' DT. The apparent lack of understanding of the factors in the companies' context that have an influence on the successful development of a DT is a serious shortcoming of the DMFs. Even when targeting specific groups, current MMs, for example, are static representations that do not offer any degree of customization.

Previous studies linked to this thesis have explored the impact of characteristic features of companies on their DT efforts (Liborio Zapata et al., 2021), but there is much work to do in this

regard. The need is recognized, as the DMFs are targeting specific groups with their proposals, but a combination of methodological choices and awareness of the implications for building them perhaps are inhibiting a successful result.

1.3.2 DMFs limitations

Based on the findings identified through the performance of the SLR and the particularities and requirements of the DT scenario, it is possible to identify the shortcomings of current works in the literature. This global view of the situation gives the advantage of a better understanding of the root cause of the problem in the search for a better solution.

1.3.2.1 DMFs objective is disconnected from the nature of the DT

In reviewing the models' objectives, it is identified a disconnection between the goals of the models and the objective of achieving a DT. Models aim for the introduction of technology instead of a structural change of the company to better profit from the digital technologies. Short/medium-term objectives target initiatives such as smart manufacturing or its equivalent Industry 4.0 instead of a business transformation enabled by digital technologies.

Even though some DMFs proposed a trajectory comprised of initiatives for companies on specific scenarios (e.g., manufacturing sector), the focus remains on completing projects of technology introduction. As the term DT is frequently used as a synonym for Industry 4.0, it rarely refers to a transformation of the company. Those occasions are mostly present in the DMFs coming from practice, in which consulting firms (e.g., Accenture, Ernst & Young) explain their relevance. Nevertheless, the content of those DMFs is generally superficial as they function as sales material for the services of such businesses.

In consequence, the indicators that the DMFs propose to measure such objectives get affected by this shortcoming. Reaching "digital maturity," most likely, may not mean the same in each of the different DMFs available. To add to the confusion, there is a lack of clarity regarding the meaning of the digital maturity and readiness concepts as they are used interchangeably in measuring the accomplishment of the DMFs' objectives.

1.3.2.2 DMFs offer an inconsistent and incomplete view of the DT

The critical review of the DMFs' content shows an inconsistent and incomplete view of the company aspects involved in a DT. Apart from a predominant focus on technological aspects, there is no consensus on what aspects should be considered in the DMFs, even for those that share the same objective and characteristics. The inconsistent view is present at all levels and is only aggravated by the lack of common terminology.

As the technological aspect covers most of the content offered by the DMFs, the differences in the set of company's aspects proposed by the DMFs analyzed in this review showed that a truly complete and multidisciplinary view is still missing. The lack of completeness is enhanced by the superficial account of the DT that is available because of the type of publications used to present their proposals, mostly articles with a page limit.

The unstandardized and superficial view of the DT also complicates the identification of the specific factors inside the different company's aspects that contribute to the DT's success. Even those DMFs that show some depth in their proposals present an inconsistent and disconnected view of the factors that define the digital maturity of the company. Additionally, the DMFs are not clear on the roles each of the aspects plays in the companies' DT. They present an isolated, totally disconnected view of the individual changes suggested that does not acknowledge relationships and interactions between the company's aspects involved.

1.3.2.3 DMFs present a generic characterization of the DT

Even when addressed to specific groups with a particular context, the characterization of the DT in the DMFs is generic and does not seem to consider the requirements of the companies' context. The low level of detail in the content of the DMFs, and the static representation that tools such as MMs allow, do not give much space to represent an organizational change of such complexity as a DT.

1.3.2.4 The need for a holistic view of the DT based on theory

After performing this critical review of the DMFs available in the literature, it is possible to determine an overall lack of representation of the whole implications of the DT by their authors. The origin of the limitations that led to this general assessment seems to have their origin not only in the tools used for developing and presenting the DMFs but especially in the methods that are used to create their content that lack a theoretical foundation.

As the aim of this work is limited to creating a frame of reference for the whole scope of the implications of the DT, the limitation of the DMFs regarding the tools used to present them will not be addressed in this work. The whole focus will be on building a view of the DT that is complete and consistent with a theoretical basis.

1.3.3 Conclusions

Based on the review of the current situation of DMFs in literature, it is understandable that several research works declare that there is not one in the digital domain that is recognized as official, either from research or practice, despite the overwhelming offer (Cimini et al., 2017; De Carolis et al., 2017; Felch et al., 2019; Gökalp et al., 2017; Scremin et al., 2018). It is also not surprising that their application has been rather limited (Felch et al., 2019) as the vision of the DT they provide is still not sufficiently consistent and complete, as this review has found.

The limitations reviewed show that current DMFs may suffer from the consequences of using tools without a solid methodology to guide a novel and complex concept (DT). Issues then arise in the applied method as well as in the content. But whereas there seems to be much to do regarding the tools and their method of development, this work will focus on addressing the shortcomings regarding their content. Based on those findings, the need for a holistic vision of the DT is needed to understand the whole scope of their implications for companies.

1.4 Chapter's conclusion and summary

This first chapter established the DT terminology for understanding the digital context and identifying current uses of related terms that allowed performing the review of literature efficiently. Afterward, in the analysis of the state of the art, through the performance of a Systematic Literature Review (SLR), the relevant Digital Models and Frameworks (DMFs) that are proposed in the literature to guide the companies' DT were identified. The key findings related to the DMFs' content highlighted the disconnection of their objectives with the nature of a DT, presenting incomplete and inconsistent proposals out of sync with the companies' context. The proposals were also deemed superficial due to a lack of operational detail and short in scope as they are mainly focused on the technology perspective. The inability to represent the realities of the DT scenario has its origin in the lack of awareness of the company's context and the company's aspects that change and their dynamics and interactions. The multiple issues identified in their content, probably a consequence of the lack of theoretical foundation of their method of development, signal a poor understanding of the DT phenomenon that leads this work to propose a new vision. A vision that in a holistic way considers all the elements, internal and external to the company, that contribute to the DT's success.

This new holistic vision, to be built based on theory, will represent a theoretical answer to the main research question of this work:

- *What does it imply for a company to digitally transform?*

Having understood the details of the limitations of current literature, the new vision must accomplish a satisfying answer to the defined research sub-questions:

1. *What is a DT, and what is the objective that it pursues?*
2. *What are its main elements and their role during a DT?*
3. *What are the business dimensions that are involved in a DT and their interactions?*
4. *What is the process that it follows and its trajectory toward a successful DT?*
5. *How does a company's context influence the development of a DT?*

The proposal to represent this new vision of the DT is presented in the two following chapters.

Chapter 2: The Conceptual Digital Transformation Framework

Insights from the literature review presented in the previous chapter unveiled the need for a holistic vision of a company's DT. Such a vision implies identifying its objective, the elements that constitute it, and the process a company should follow to successfully transform. In identifying the DT elements, this proposal distinguishes the specific aspects inside the company whose evolution defines a company's DT. These company aspects, labeled business dimensions, will be briefly identified in this chapter and explored more deeply in Chapter 3 as they are the core of a DT. Having evaluated the limitations of related efforts in current literature, a theoretical foundation became an essential characteristic of this endeavor.

In this chapter, the proposal of the Conceptual Digital Transformation Framework (CDTF) is presented, with a focus on the main elements that take part in the DT and the theoretical foundations that support it. The choice of the use of a conceptual framework allows portraying graphically the concepts representing each element and the relationships between them to provide a comprehensive view of the DT. A high-level process of a DT is also proposed to accompany the CDTF.

This chapter is structured as follows. Section 2.1 details the method followed to build the conceptual framework of the DT and presents the theories that constitute its foundation. Section 2.2 introduces the Conceptual Digital Transformation Framework (CDTF) and explains how it is generally constituted. It also presents a high-level process of a company's DT that derives from the framework. Section 2.3 presents the conclusion and a summary of the chapter.

2.1 Conceptual framework

Throughout the review of current Digital Models and Frameworks (DMFs) that are designed to offer companies guidance to achieve a DT, several shortcomings were identified that prevent them from fulfilling their goal (see Chapter 1, Section 1.3.2). Although the main proposal of this work addresses specifically the gaps related to the content of those proposals and the scope they cover, it also identifies the method used to produce those works as the root cause of their limitations. Therefore, having identified that a formal approach based on theory and a holistic vision was missing, this work first establishes a stronger foundation of the CDTF by building its theoretical basis.

2.1.1 Conceptual framework building method

In this context, it seems only appropriate to approach the task of building a holistic view of the DT phenomenon by using a conceptual framework, as conceptual frameworks are the *"end result of bringing together a number of related concepts to give a broader understanding of the phenomenon of interest"* (Imenda, 2014). DT, like most social phenomena, is complex and requires a multidisciplinary approach for a better comprehension that can be achieved with the building of a conceptual framework (Jabareen, 2009). As the proposed conceptual framework is built on conceptual elements derived from theory, a literature review was not the source of the framework.

In fact, the contribution of this work relies precisely there, in presenting a definition that is supported by existing theory on organizational change. This approach will allow building a broad and structured business view of this type of change and positioning other critical elements involved in a DT. A conceptual framework that acknowledges all the elements in a DT will provide a strong

foundation to guide the digital initiatives and possibly the creation of better Digital Models and Frameworks (DMFs).

Furthermore, the use of a conceptual framework served a double purpose as its design also guides the validation phase of this research work in Chapter 4. The representation of the comprehensive view of the DT also proved helpful in the case selection and data collection phases by clarifying the information needed to be collected to validate the proposal.

Despite the fact that there is not much guidance towards building a conceptual framework and that, in practice, they are built empirically, the development of the Conceptual Digital Transformation Framework (CDTF) follows the procedure proposed by Jabareen (2009). Some modifications were made to the procedure, as the main source of the framework was set to be theory instead of a literature review, as explained before. The method used consists of the following phases:

1. building the theoretical foundation;
2. identifying and naming concepts;
3. categorizing the concepts;
4. synthesizing the concepts into a framework;
5. verifying the conceptual framework's design.

In the next sections, each phase of the method performed is detailed as an introduction to the presentation of the resulting Conceptual Digital Transformation Framework (CDTF).

2.1.2 Building the theoretical foundation

The point of departure in searching for a theory or theories that constitute the basis of this proposal is the limitations of current DMFs available in the literature.

The literature review allowed this work to identify three major limitations of current DMFs (see Chapter 1, Section 1.3.2):

1. DMFs objective is disconnected from the conceptualization of a DT and its objective;
2. DMFs offer an inconsistent and incomplete view of the implications of a DT for a company;
3. DMFs present a generic characterization of the DT that does not consider a company's specific context.

These findings revealed that the available literature does not properly answer the research question defined for this work: *what does it imply for a company to digitally transform?* The findings also highlighted the absence of theoretical background in building the content of the DMFs as a possible reason for their limitations. In the next section, each of the main shortcomings of the DMFs is addressed with related theories to build the foundation of the CDTF (see Figure 2.1).

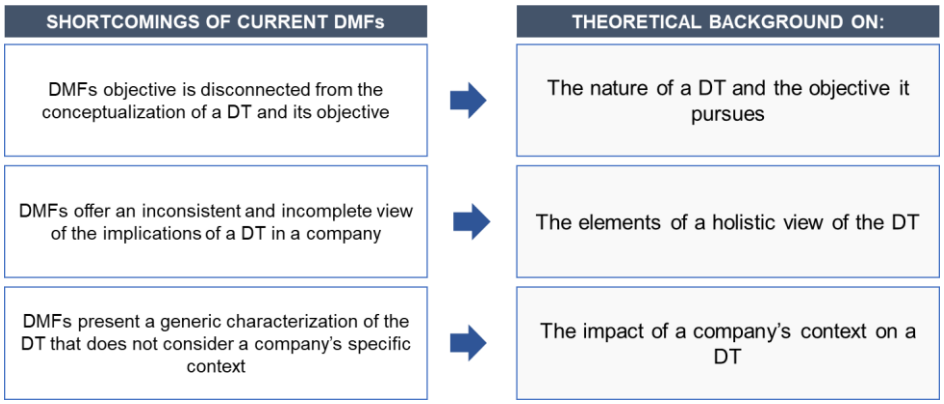


Figure 2.1 DMFs' shortcomings and the related main subjects that require a theoretical background.

First, to address the disconnection between the DMFs' objective and the conceptualization of a DT, this work is remitted to the concept of business transformation to characterize this type of change. Afterward, to attempt to solve a key issue of the current representation of a DT, an analysis of theories on organizational change is performed to define the elements involved in such change. Finally, to consider the effects of companies' context on the development of their DT efforts, a first proposal of the factors that compose the companies' context is defined according to previous studies.

These requirements that mirror the shortcomings identified during the Systematic Literature Review (SLR) represent the specific targets of the vision this work aims to provide.

2.1.2.1 The nature of a DT and the objective it pursues

In current DMFs, a DT is only the objective for 33% of them (see Chapter 1, Figure 1.18). A proportion that is also questionable when reviewing the details of the works. A closer look revealed that even those DMFs that announced DT as their objective were also aiming for some type of digitalization, highlighting the misinterpretation that exists regarding the concept. The finding is surprising, given that the notion of transformation is not new. Since the 90s, "corporate" or "business" transformation has been a recurrent subject in organizational theory and is especially linked to organizational change. Muzyka et al. (1995) presented one of the first attempts to define it when they introduced (business) transformation as a *"fundamental change in organizational logic, which resulted in or was caused by a fundamental shift in behaviors."*

Many authors have agreed on the complexity of this type of change, especially in the fact that it involves *"interrelated system-wide changes"* (Prahalad and Oosterveld, 1999), and have insisted on the need that the elements involved must be clearly identified to manage them effectively (Mintzberg and Westley, 1992). In this sense, perhaps the most relevant definition from that time related to this work is the type of change that represents a transformation in order to succeed. A transformation is not just implementing a change to go from point A to B but to *"enact a long-term sustainable organization"* (Muzyka et al., 1995). The objective for a transformation then is capability-driven, mostly as it is economic-driven (Riasanow et al., 2017).

This characterization of different orders of change has been developed by several authors on different scales emphasizing the features of each type, especially transformations. Whether they call it radical (Abernathy and Utterback, 1978; Tushman and Romanelli, 1985), revolutionary (Mintzberg and Westley, 1992), regenerating (Muzyka et al., 1995), or transformational (Sammut-Bonnici and Wensley, 2003) change, the result point out into a new and more advanced

organization. A clear example is that of Bartunek and Moch (1987) that in their classification of orders of change, the third (and higher) level describes an organization that is so advanced that its members have developed the capacity to adapt even their frames of reference to better respond to changes in the environment.

This vision of a new organization is also present in the definition for DT selected in Chapter 1, in which DT *"is the profound and accelerating transformation of business activities, processes, competencies, and models to fully leverage the changes and opportunities brought by digital technologies and their impact across society in a strategic and prioritized way"* (Demirkan et al., 2016). In the digital context, therefore, a transformed company will have built the capabilities to take advantage of the opportunities digital technologies bring. In this vision, the focus is on creating a highly adaptive organization that is prepared to manage change on an ongoing basis.

Theory on the transformational type of change characterizes it as profound, extensive and, above all, aiming to build a new organization that has the capabilities to deal with continuous change. Following this reasoning, to accomplish the implementation of one or more digital initiatives (e.g., smart manufacturing) cannot be classified as a DT. Certainly, each initiative will contribute to the transformation of the company, but the ultimate objective must be centered on building the capabilities of the transformed company. In consequence, two strands of evolution are required during a DT (see Figure 2.2).

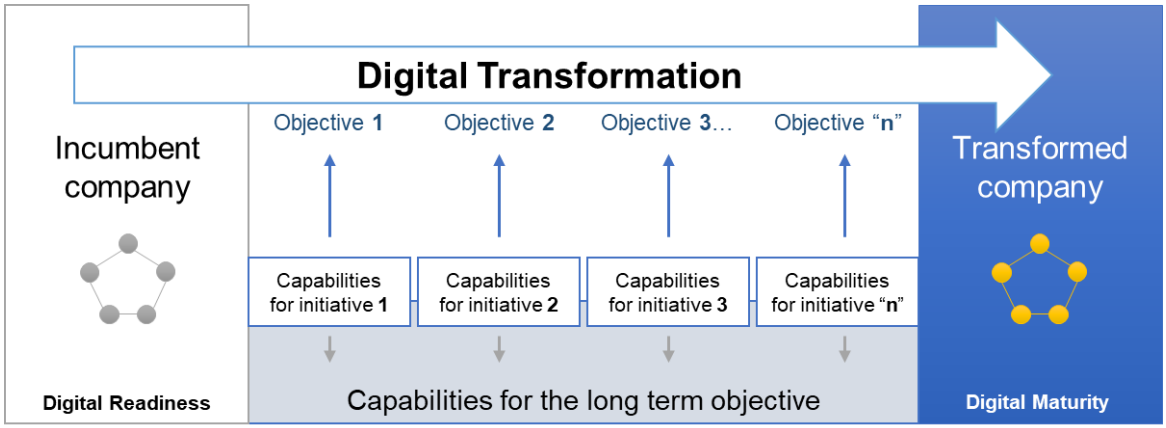


Figure 2.2 A company's capabilities evolution path towards a DT (author's own creation).

The double evolution towards a DT implies that at the same time that an (incumbent) company is building capabilities to achieve the short-term objectives through a series of digital initiatives, it must also build the long-term capabilities that ensure its competitiveness. In consequence, considering that maturity reflects the state of a company's transformation, it should focus on measuring the capabilities a company must develop to remain competitive in the new digital context. Similarly, in order to position the concept of readiness as well, this indicator should measure if the conditions to start an effort to build such capabilities are favorable for success.

2.1.2.2 The elements of a holistic view of the DT

The critical review of the DMFs in Chapter 1 (see Section 1.3) showed that the representation of the DT they provide is inconsistent and incomplete. The origin of this misrepresentation lies in the following limitations:

- a predominant focus on technological aspects and a general lack of consensus on the rest of the elements involved and their roles during the DT;
- a lack of clarity on the specific components of the elements that contribute to the companies' DT;
- an isolated view of the changes that does not acknowledge relationships and interactions between the elements.
- a process to achieve a DT is not identified, just the milestones in each of the criteria defined by the DMFs.

These limitations in current DMFs lead to determining that a holistic view that presents all the implications of a DT for a company is required. The requirements for this new vision, according to the findings of the review of the literature, are the following:

- the elements that are implicated in the process of transformation and their role;
- the specific business dimensions involved in the company's transformation, and their interactions;
- the definition of a high-level process of the transformation of a company.

Building the holistic view of the DT based on theory requires first identifying the elements at different levels that should be considered in a DT. The results should enable the possibility of designing a process that will allow working afterward on the roles of the elements defined and their relationships and interactions. Following the assumption that a DT is an organizational change, the obvious path is to search for a suitable theory within the rich body of literature in this domain.

Literature on the organizational change domain is abundant and varies deeply according to different perspectives. Several authors have reviewed the theories and research on organizational change. Notably, Armenakis and Bedeian (1999) and, more recently, Burke (2017) make an account of theories and research focused on this area. Both analyses are of particular interest to this work as they focus on what Armenakis and Bedeian call "content factors" that are set to predict the performance of change. In Table 2.1, a selection of theories and models of this type are presented, along with a brief description of their content.

Table 2.1 Organizational change theories and models.

Theory	Author(s)	Year	Description
Socio-Technical Systems theory	Trist and Bamforth	1951	A theory that is based on the view of an organization as a system composed of two subsystems (technical and social) that must be jointly optimized to achieve the desired performance.
Six-Box Organizational Model	Weisbord	1976	A model that considers six main categories to diagnose possible problems in an organization's performance: purposes; structure; relationships; rewards; leadership; and helpful mechanisms.
Congruence Model for diagnosing Organization Behavior	Nadler and Tushman	1980	A model based on the open system framework in which the organization's transformation is affected by inputs, such as its history and resources. Outputs will determine the performance of the system by the state of variables such as group behavior and intergroup relations.
TPC (Technical, Political, Cultural) Framework	Tichy	1982	A framework that considers that organizations have interrelated technical, political and cultural aspects that must be handled in order to manage strategic change.
Model of Organizational Performance and Change	Burke and Litwin	1992	Model based on organizational climate studies that proposes a description of the elements of change and

Theory	Author(s)	Year	Description
			suggest causal links between performance and change.
The transformation Imperative	Vollmann	1996	A model that provides a tool to define the magnitude of the impact of organizational change of the transformational type.

In this section, a selective analysis of the content of only one theory and two models is made, considering those whose content is relevant to the aim of this work. The selection is composed of the following works:

- Trist and Bamforth's (1951) Socio-Technical Systems theory,
- Burke and Litwin's (1992) Model of organizational performance and change,
- Vollmann's (1996) The transformation imperative model.

A brief explanation of the three proposals follows.

Socio-Technical Systems (STS) theory

The Socio-Technical Systems (STS) theory is based on the premise that organizational works systems are constituted respectively by social and technical subsystems (see Figure 2.3).

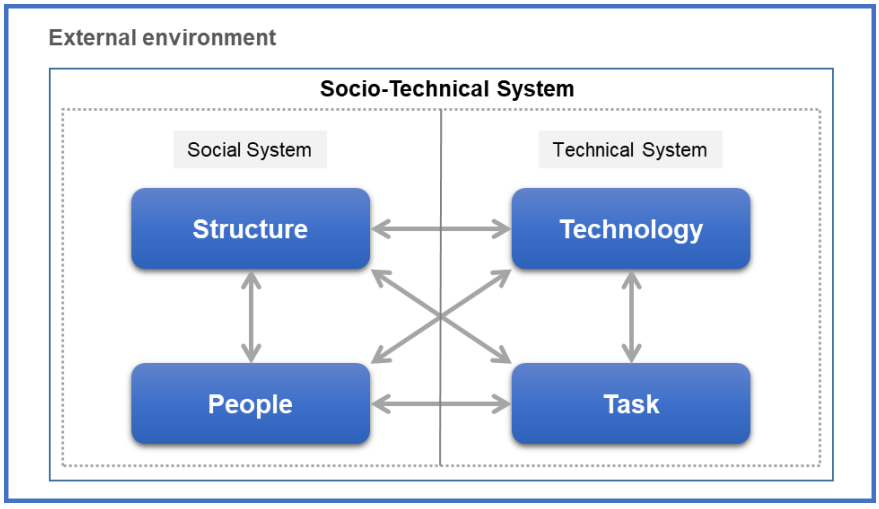


Figure 2.3 Representation of the 4 "interacting variables classes" within a socio-technical system proposed by Bostrom and Heinen (1977a), based on Leavitt (1964).

The interaction between variables intends to acknowledge the relationship and the importance of designing change to complement and reinforce each other.

Both systems have complex interdependencies that need to be jointly optimized to achieve the desired performance (Trist and Bamforth, 1951). Several authors have developed different parts of the STS theory (e.g., Nightingale and Rhodes, 2015), and others have applied their principles to different domains (e.g., Bostrom and Heinen, 1977a; Bostrom and Heinen, 1977b).

Model of organizational performance and change

The model of organizational performance and change (Burke and Litwin, 1992) presents a set of interconnected variables classified into two types: transformational and transactional factors (see Figure 2.4).

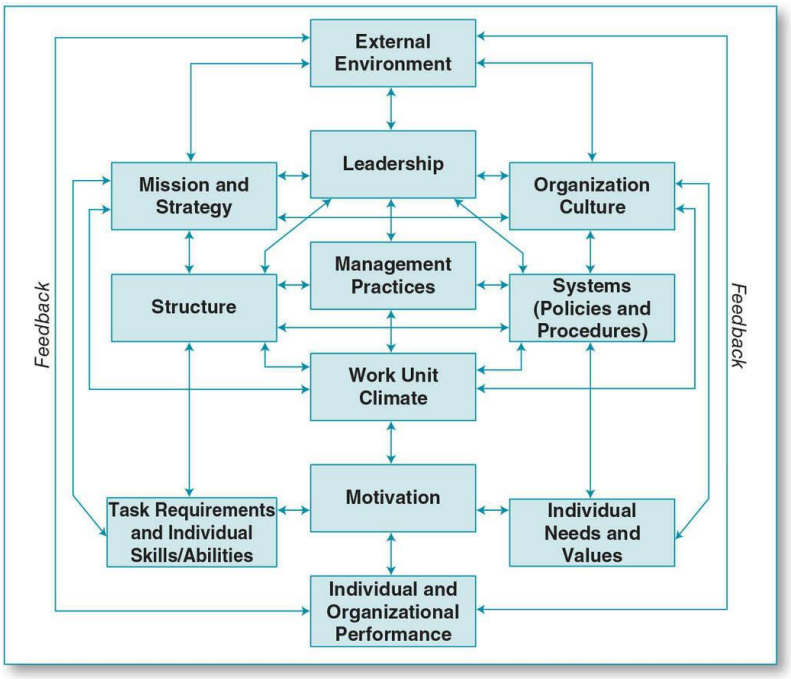


Figure 2.4 Model of organizational performance and change (Burke and Litwin, 1992; Burke, 2017).

Transformational change happens when changes in the environment affect the related factors, such as strategy and mission.

The transformation imperative model

The transformation imperative model intends to define the magnitude of the impact of an organizational change of the transformational type in a given company (Vollmann, 1996). The model consists of a matrix of eight facets that are confronted with three organizational dimensions and three organizational resources (see Figure 2.5). Filling out the matrix implies cross-checking how changes in each facet will impact the dimensions and resources of the company. The analysis of the collective combination of the elements in the matrix has the aim of measuring the magnitude of the effect of an intended business transformation.

	Dimensions			Resources		
Facets	(a) culture	(b) configuration	(c) coordination	(d) people	(e) information	(f) technology
(a) strategic intent						
(b) competencies						
(c) processes						
(d) resources						
(e) outputs						
(f) strategic responses						
(g) challenges						
(h) learning capacity						

Figure 2.5 The transformation imperative model (Vollmann, 1996).

The three proposals of the elements of an organizational change have strong similarities in some aspects and complementarities in others. This argument is made based on the intention of their design. While the STS theory is made to show the functioning of an organization as a system, the models are created either to predict or design performance as a result of organizational changes. This distinction is part of the reason for the differences in the elements included in their proposals (e.g., strategy, performance). Nevertheless, to design the holistic vision of a DT, it is imperative that the vision considers organizational functioning and organizational change, as Burke and Litwin (1992) well put it. In consequence, elements of both the STS theory and the model of performance and change are considered. The design of the CDTF, however, primes the principles of the STS theory.

The reason this proposal relies on the work of Trist and Bamforth (1951) and the premises of their STS theory is that it supports the argument that the business dimensions involved in a technological change, such as a DT, go beyond the technological aspect and consider other important dimensions of the company. Their acknowledgment that organizational systems are constituted by both social and technical subsystems is especially useful to this analysis as it enables the identification of the main elements involved in this type of change. Along with the socio-technical view of the companies, their argument that the social and technical subsystems have complex interdependencies that need to be jointly optimized to achieve the desired performance helps address another important limitation of current approaches.

To this end, Bostrom and Heinen's (1977b) application of the theory to the field of Management of Information Systems (MIS) is of value for proposing an approach in which the technical system requirements are designed to fit the social aspects of the people requirements (joint optimization). It is also here that Bostrom and Heinen's (1977a) definition of a set of "interactive variables classes" that represent the social and technical aspects of an STS is of value. Based on Leavitt's (1964) variables of change, their definition is instrumental in helping to establish a set of the business dimensions involved in a DT with a theoretical approach. In their proposal, paying attention to four variable classes, structure, and people, representing the social subsystem and technology and task, representing the technical subsystem, is considered to produce the best performance outcomes for a company.

Complementing these characteristics of the STS theory are two proposals of socio-technical inspiration. First, it is the work of Burke and Litwin (1992) that in their model proposed elements like strategy and performance that are critical to organizational change and that are not considered by the STS theory. Finally, this work will also be guided by Nightingale and Rhodes' (2015) work regarding the external dynamics and the internal context of the company and its relation to DT success, which will help to complete the view of the DT under a socio-technical perspective and cover the main gaps on the content of current models. A new definition based on a well-known theory that assures a broad business view provides a stronger base for new solution approaches that cover the full scope of the DT and could later be translated to better guidance for companies.

2.1.2.3 The impact of a company's context on a DT

In the review of the previous models, it was possible to start to identify the key elements that can take part in the holistic view of a DT. One element, however, that distinguishes the socio-technical approaches is the characterization of organizations as open systems (Emery, 1959) that interact with the environment that surrounds them. Nightingale and Rhodes' (2015) expanded this understanding in their "enterprise landscape" concept that comprises not only the external environment but also the internal landscape or organization context.

In a scenario of change, they argue that it is important to understand both components of the "landscape." Considering that the environment is constantly changing, and the organization is part of an ecosystem that can be affected by those changes, it is important to understand the factors that must trigger an action in the form of a transformation. Internally, it is critical to understand the conditions in which an organization will face a change, making sure to identify its strengths and its weaknesses. This last argument reinforces the idea of the need for a digital readiness measurement (see Section 1.1.3.3).

2.1.3 Identifying and naming concepts

The previous section allows the identification of the main theoretical sources for determining the concepts or elements that will ultimately constitute the conceptual framework. The analysis comprised three themes:

1. the nature of a DT and the objective it pursues;
2. the elements of a holistic view of the DT;
3. the impact of a company's context on a DT.

From the analysis of the first theme, it can be deduced that the transformative nature of the DT will deliver a completely new version of the company prepared for the digital context, therefore a "digital company." The evolution toward a digital company will require indicators that help ensure the success of the DT by measuring its readiness and maturity.

The analysis of the third theme can also deliver the concepts needed to be considered in this proposal in a very straightforward way. The impact of context on a DT will be considered from the internal and external perspectives.

The first and third themes identify, therefore, the following group of concepts:

- digital company, digital readiness, and digital maturity;
- external environment and internal context,

To complete the list of concepts, the second theme will be analyzed further. The models reviewed in the last section provided different perspectives of the elements that are involved in an organizational change. To build a holistic view, those perspectives will be confronted next to identify where they coincide and where they differ.

In Table 2.2, the elements of the three proposed views on the content of organizational change are also confronted with the elements considered by current DMFs analyzed in the literature review (see Chapter 1, Section 1.2). Similar concepts are displayed in the same row, a "-" symbolizes a lack of a similar concept for a given theory or model.

Table 2.2 Elements considered by three organizational change theories and models and the ones proposed by the DMFs available in the literature.

No	**Socio-Technical Systems Theory** (Trist and Bamforth, 1951; Nightingale and Rhodes, 2015)	**Model of Organizational Performance and Change** (Burke and Litwin, 1992)	**The Transformation Imperative Model** (Vollmann, 1996)	**DT elements proposed by current DMFs in the literature**
1	External Environment	External Environment	-	-
2	Internal Context	-	-	-
3	-	Mission and Strategy	Strategic intent	Strategy
4	-	-	Strategic responses	Products and Services
5	-	-	-	Business Model
6	-	-	Resources	Investment
7	-	Leadership	-	Leadership
8	-	Organizational Culture	Culture	Culture
9	Structure	Structure	Configuration (organization design)	Organizational Structure
10	Task	Systems (policies and procedures)	Processes	Process
11	-	-	Information	-
12	-	Management Practices	Coordination	Governance
13	People	-	People	-
14	-	Tasks and individual skills	Competencies	Competencies
15	-	-	Learning capacity	-
16	-	Individual and Organizational Performance	Outputs	Performance Measurement
17	Technology	-	Technology	Technology
18	-	-	-	Customer and Partners
19	-	-	Challenges	-
20	-	Individual needs and values	-	-
21	-	Work Unit Climate	-	-
22	-	Motivation	-	-

As stated before, the external environment (No. 1) and the internal context (No. 2) are already included as part of the concepts to consider. Leadership (No. 7), customer and partners (No. 18), and challenges (No. 19) can be included as a part of the internal context. Strategy (No. 3), then start the analysis. Strategy is one of the elements missing from the STS theory, but that is indispensable in a representation of organizational change. Associated to that concept are strategic responses such as the creation of products and services (No. 4), the business models to commercialize them (No. 5), and all types of resources to realize them (No. 6). In fact, the digital initiatives can be considered as strategic responses and expand beyond the creation of products and services.

Organizational structure (No. 9), processes (No. 10), and technology (No. 17) are a clear choice and to avoid the generic nature of the “people” label of the STS theory, organizational culture (No. 8) and competencies (No. 14) seem the appropriate concepts to represent this variable. Information (No. 11) is linked with the process element, as are other elements like management practices, coordination, and governance (No. 12); therefore, it can be argued that they are implicit in the process element. Similarly, learning capacity (No. 15) is considered a part of competencies. A

choice is made regarding individual needs and values (No. 20), work unit climate (No. 21), and motivation (No. 22), which are more linked to individual and organizational behavior and, therefore, will be excluded from the proposal of this work.

Finally, a critical element that closes the elaboration of the proposal of the conceptual framework is the performance measurement (No. 17) that is linked to the follow-up of the ultimate objective of the DT, a transformed company: a digital company.

The main concepts that result from building the theoretical foundations for the conceptual framework are:

- external environment and internal context;
- digital company;
- digital readiness and digital maturity;
- (digital) strategy, resources, business models, digital initiatives (products, services);
- technology, processes, competencies, organizational structure, and culture;
- performance management.

In the next section, a final categorization is performed to start organizing the concepts into the first version of the conceptual framework.

2.1.4 Categorizing and synthesizing the concepts into a framework

The exercise in the last section provided a better understanding of the nature of the different concepts that take part in an organizational change. With this understanding, a preliminary classification of the concepts can be performed. Two changes are proposed in this classification. First, the elements related to the strategy are considered as a part of the strategy; therefore, they constitute its sub-elements. Similarly, the elements that mirror the interactive variables proposed by the STS theory are classified as the business dimensions that define the company's DT. In Table 2.3, this classification of the terms is presented.

Table 2.3 Preliminary classification of the elements and sub-elements identified as part of an organizational change.

No	Element	No	Sub-elements
1	External environment		-
2	Internal context		-
3	Digital company		-
4	Digital readiness		-
5	Digital maturity		-
6	Digital strategy	**6.1**	Digital initiatives
		6.2	Business models
		6.3	Resources
7	Business dimensions	**7.1**	Technology
		7.2	Processes
		7.3	Organizational Structure
		7.4	Competencies
		7.5	Organizational Culture
8	Performance measurement		-

Based on that classification, drawing the first version of the framework with the selected concepts is possible. The first version of the Conceptual Digital Transformation Framework (CDTF) is presented in Figure 2.6.

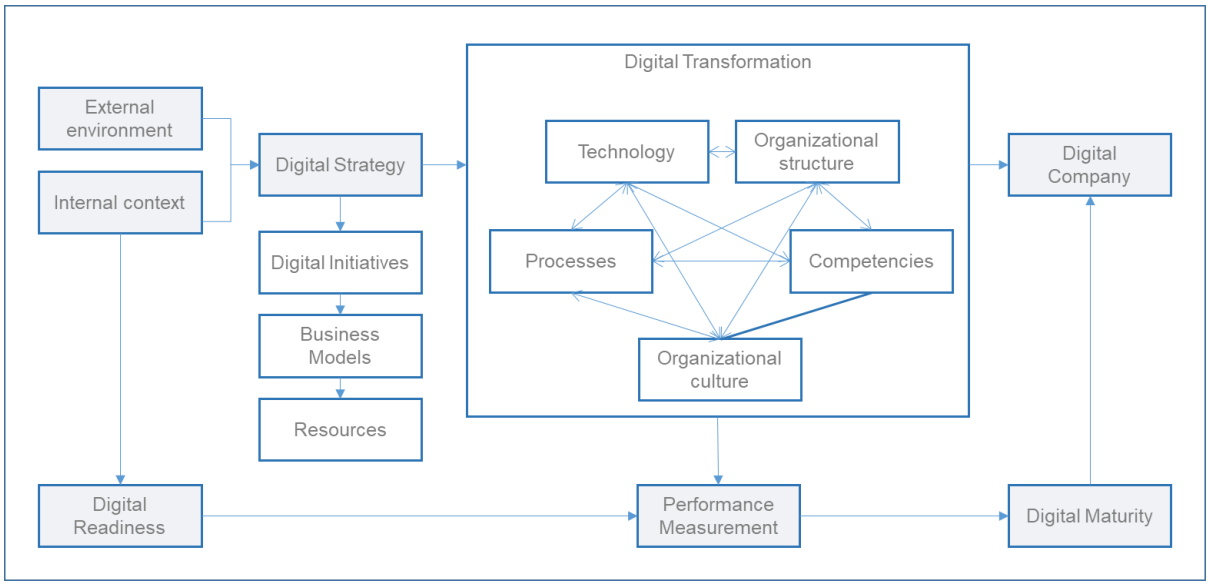


Figure 2.6 First version of the Conceptual Digital Transformation Framework (author's own creation).

This first version represents the elements and the business dimensions involved in a DT and the relationships and interactions between them. Based on the previous analysis, it is possible to place the different elements in this first vision of the DT. The context as an input of the strategy that also defines the digital readiness of a company. The strategy and the information provided by its sub-elements that will give the directions to the DT process. The five business dimensions will evolve following the directions of the strategy to build the necessary capabilities for the company to transform. Performance measurement will determine the digital maturity of the company and ultimately declare when it reaches the status of digital company, the highest level of maturity.

In the next section, the stage of verification of the CDTF design is detailed.

2.1.5 Verifying the conceptual framework's design

The validation of the CDTF was performed in two stages. The first consisted of the verification of the design of the framework with experts to put the assumptions and logic of the framework to the test, taking advantage of the real-life experience of practitioners. The second corresponds to the process of the formal validation of this proposal included in Chapter 4 of this thesis.

Following the development of the CDTF as a proposed solution, the verification of the design was performed with two industry experts in order to assess its soundness regarding the realities of the industrial sector and businesses in general. With this objective in mind, one expert was selected from the engineering domain and the second from the business consulting community. The first professional selected was, at the time of the interview, responsible for the DT projects at the Technical Centre for the Mechanical Industry (CETIM), a specialized center based in France dedicated to providing companies with the means and competencies to improve their competitiveness. The second was the owner of Cazimir Consulting, a business consulting firm also

based in France with experience in DT projects. The choice was intentional and honored the socio-technical spirit of the research project. During this research, a reconciliation of both sides, the technical and the human part, was always searched for.

The industry experts agreed with the selected concepts and validated that the proposal made sense according to their practice. Their feedback highlighted the following subjects:

- the need for a vision, a direction that guides the DT efforts;
- the critical danger of making generalizations regarding company situations;
- the importance of culture and the human factor.

Particularly reassuring was that they both agreed on the critical role of organizational culture as this work has found that traditional organizational change theories insist on it, but somehow is one of the dimensions absent in many of the available DMFs in the literature.

2.1.6 Conclusions

Requirements for building a conceptual framework of a DT were drafted as an answer to the limitations of current Digital Models and Frameworks (DMFs). Addressing the gap between what theoretically an organizational change of these characteristics should comprise and its representation in current literature resulted in a more comprehensive view of a company's DT. A key part of designing the conceptual framework of a DT with a theoretical foundation relied on existing organizational change theories and models. More specifically, the Socio-Technical Systems (STS) theory that has conceptualized the organization as a system allows understanding the elements that have a critical role in the performance or result of an organizational change. In the next section, after the verification of the first version of the conceptual framework of a DT, a more detailed and matured version of the Conceptual Digital Transformation Framework (CDTF) is presented.

2.2 Introducing the Conceptual Digital Transformation Framework

The concepts reviewed in previous sections provided the elements to build a conceptual framework that expanded the current understanding of the DT, adding an emphasis on the components that are an omission from current solution proposals (DMFs). Based on the first version of the CDTF, further exploration of the literature on each individual element allowed this work to build a new version that provides a more balanced and complete view of the DT, that will be explained in the following sections. Figure 2.7 introduces the Conceptual Digital Transformation Framework (CDTF).

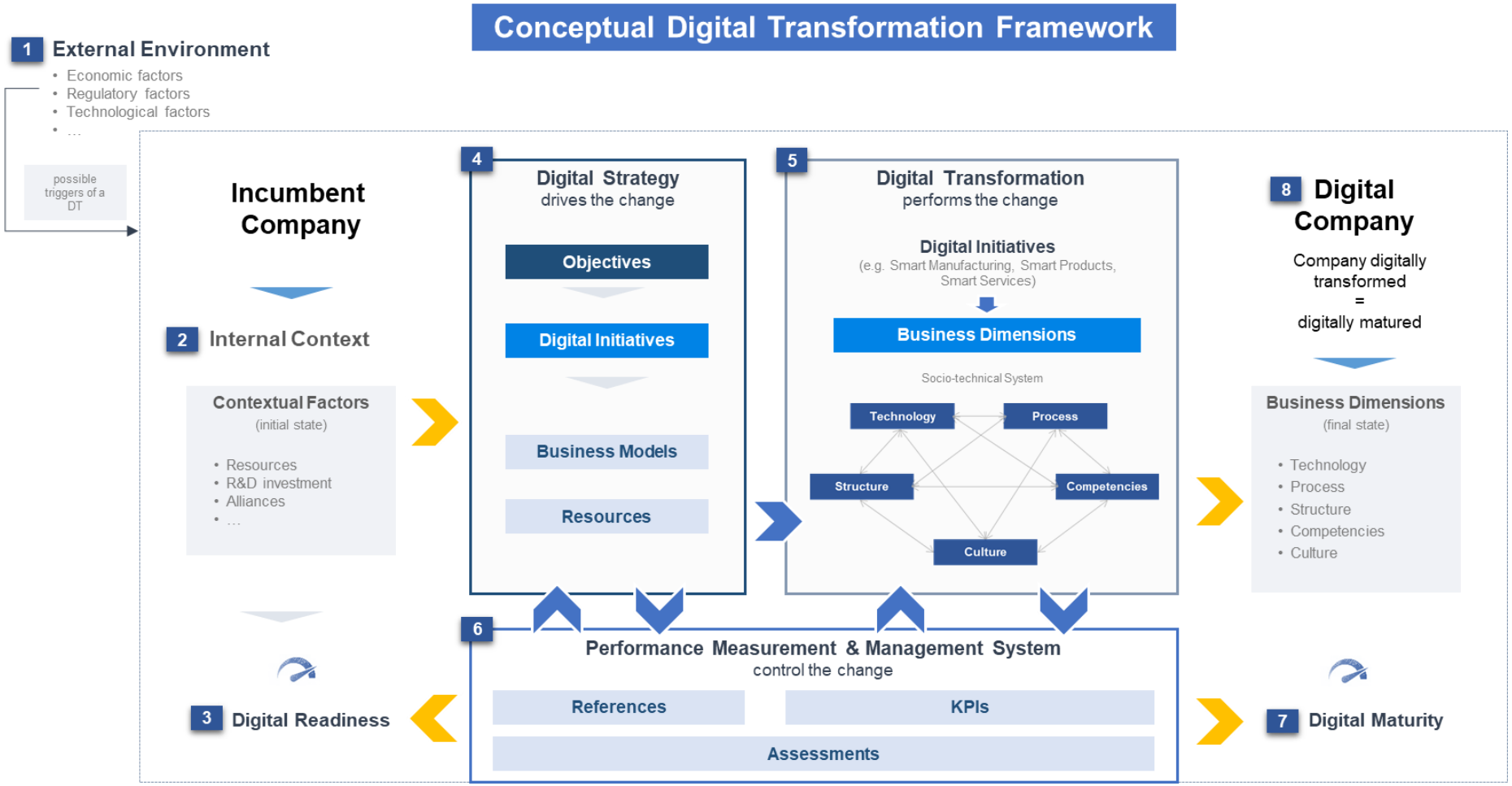


Figure 2.7 Conceptual Digital Transformation Framework (CDTF).

The main concepts of the DT are numbered. The "…" indicates the factors are only a sample of the complete list.

The CDTF is a comprehensive view of all the elements that must be considered during a DT and the interactions between them. The set of elements that comprise the CDTF work together to show a proposal of how a DT should work to take full advantage of its opportunities.

The CDTF starts with the input of the company's context. The external environment factors (No. **1**) may increase the urgency of a DT. The company's internal context (No. **2**) establishes the conditions for such a change. Both have an impact on the digital strategy (No. **4**) that must be defined. Therefore, for a strategy to be effective, it must take them into account when defining the business objectives for the effort. Those business objectives will be the point of departure to determine the digital initiatives to pursue. Business models and resources must be defined and assigned accordingly.

The sub-elements of the digital strategy will give direction to the core of the CDTF, the digital transformation element. The DT element (No. **5**) will perform the transformation by implementing changes inside the company, specifically in the business dimensions implicated. The design of the changes will consider the interactions between these dimensions. In this way, the changes will produce the desired performance or outcome for the DT.

Overseeing this effort from before it starts its planning stage and through the achievement of the DT (digital maturity) is a Performance Measurement and Management System (PMMS). A PMMS (No. **6**) will first determine the company's level of digital readiness (No. **3**) to start a DT. It will provide feedback to the digital strategy, so the strategic planning considers its current status and references for establishing the objectives. Afterward, it will measure the company's progress towards the achievement of the objectives through the digital maturity indicator (No. **7**). Digital maturity represents in this scheme not only the achievement of the digitalization objectives but the status of a digital company (No. **8**), a company better prepared to face the challenges of the digital context, an environment of constant change.

In the following sections, a general description of the proposal is presented to position each element's role in performing a DT.

2.2.1 The external environment

The lack of consideration of context variables on current DMFs is severely criticized by academic literature. Generic solutions presented by the DMFs are believed to fail to fulfill the needs of guidance of companies pursuing a DT. In developing the CDTF, one of the main concerns regarding the companies' context was to analyze if the special characteristics of the current business environment might have a different effect on scenarios of organizational change. The influence of context in processes of organizational change is recognized in several organizational studies, but this context, the digital context, presents the following general conditions to consider:

- the digital environment is still in its infancy, which means regulations and competitive rules, are still in definition; therefore, uncertainty is high in this scenario;
- the speed of change in many aspects, but technologically speaking overall, is redefining the pace and continuity of change that demand a new type of company;
- new variables in the company's internal context start to become more relevant as the nature of the change requires a new lens to face challenges and identify opportunities.

The external environment acts as the trigger of the DT and depending on the factors in play for this scenario, it also dictates the parameters in which the change should happen. In this proposal, the factors of the external context, such as the economic conditions, new regulations or technological

developments, must be monitored and evaluated to define a digital strategy accordingly (see Table 2.4).

Table 2.4 External Environment Factors that precipitate a DT (adapted from Nightingale and Rhodes, 2015).

ID	Factor	Description
EC01	Political	Events in the political landscape or governments that impact the access to financial resources or operations.
EC02	Regulatory or Legal	Changes in laws or regulations that impact the operations of the companies or represent opportunities.
EC03	Economical	Factors in the economy of countries that can impact the companies' competitive position.
EC04	Market	Changes in the market composition can represent opportunities or threats to a company's position.
EC05	Technological	Evolution of technology that presents opportunities or challenges.
EC06	Resources	Actions that impact the availability of resources required for the companies' operations.
EC07	Environmental	Challenges are presented by the evolution of the environmental factors related to the environment.

A DT at the right time and according to a specific strategic intent of a company requires that a proper scanning and reading of environmental factors is continuously performed. In the current digital context, additionally to the technological factors, the changes in the relevant markets or regulatory conditions add pressure to companies to accelerate their DT to remain competitive. Other factors like regulations on the use and application of digital technologies or the availability of resources with the competencies to handle them can impose barriers on the companies' efforts to develop new products or services.

Figure 2.8 shows the detail of the external environment element with one example of each of the seven relevant factors that constitute it, as well as their relationship with the digital strategy element.

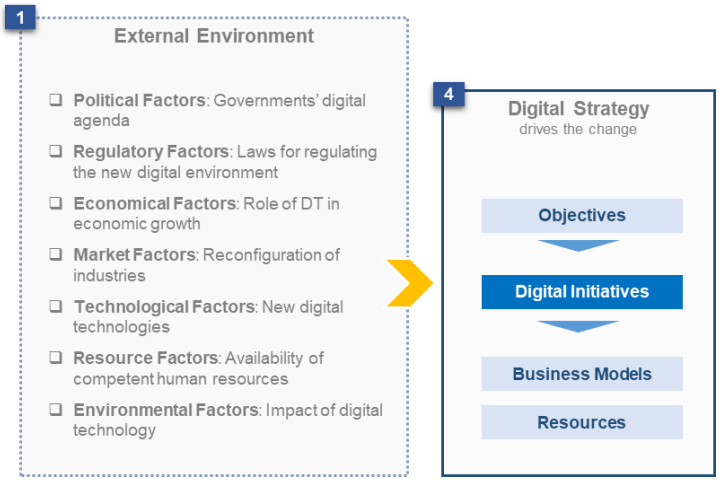


Figure 2.8 Relationship between the external environment and the digital strategy elements (author's own creation).

It is expected, then, that a relationship exists between the relevant factors of the external environment (independent variable) and the urgency to start a DT (dependent variable), and the conditions of such DT (dependent variable). Figure 2.9 shows a graphical view of this relationship.



Figure 2.9 Relationship between the external environment and the digital strategy element.

The way to use the information of an environmental analysis is a decision that each company have to make, but it is critical to understand the underlying importance of the influence of this analysis on DT efforts and, therefore, the importance of monitoring all the factors that are relevant to each company.

2.2.2 The internal context

The internal context of a company is mainly composed of the configuration of the company features (e.g., size, resources, offerings), as well as the initial state of factors that are associated with its business dimensions (e.g., the flexibility of organizational culture) and that are relevant for a DT (see Table 2.5).

Table 2.5 Characteristics of an internal context (adapted from Mittal, Khan et al., 2018).

ID	Characteristic	Description	Value=1 (Worst)	Value =5 (Best)
IC01	Access to resources for transformation and innovation	What is the company's level of resources for digital transformation and innovation?	Insufficient	Sufficient
IC02	Adoption of new technologies	What is the company's level of capacity to integrate new technologies?	Low	High
IC03	Investment in R&D	What is the level of resources invested in R&D activities?	Low	High
IC04	Product Customization Capability	What is the company's level of competence to develop highly customized products?	Low	High
IC05	Consideration of processes and standards	How well does the company take into account processes, standards and norms?	Low	High
IC06	Leadership engagement	How flexible is the company's management to experiment and consider initiatives to implement advanced technologies?	Low	High
IC07	Flexibility of organizational culture	How flexible is the company's culture to experiment and consider initiatives to implement advanced technologies?	Low	High
IC08	Strategy definition	What is the level of formality of the strategy definition process?	Dictated by leadership instinct	Based on market research and analysis
IC09	Decision-making	What is the level of formality in decision-making in the company?	Restricted to the manager	Board of Directors

ID	Characteristic	Description	Value=1 (Worst)	Value =5 (Best)
IC10	Organizational Structure formality	What is the level of formality of the organizational structure?	Low	High
IC11	Organizational Structure agility	What is the level of agility of the organizational structure?	Low	High
IC12	Human Resources engagement	Do employees perform several functions in the company or do they have the opportunity to develop a high level of expertise in a particular field?	Several domains	Specific domain
IC13	Exposure to human resources development (inside the industry)	At what level do employees have the opportunity to be exposed to development within the industry in which the company participates?	Low	High
IC14	Exposure to human resources development (outside the industry)	At what level do employees have the opportunity to be exposed to development outside the industry in which the company participates?	Low	High
IC15	Industry knowledge and experience	Is the knowledge of employees in the industry focused on one specific area or several areas?	Focused on a specific area	Dispersed in different areas
IC16	Alliances with universities	What level of networking with universities does the company have?	Low	High
IC17	Alliances with research institutions	What level of networking with research institutions does the company have?	Low	High
IC18	Performance of key activities	What is the level of outsourcing of the company's core activities?	Outsourcing	Within the company
IC19	Dependence on the collaborative network	What is the level of dependence on its suppliers and vendors?	High	Low
IC20	Customer relationship	How is the company's relationship with its customers?	Weak	Strong
IC21	Supplier relationship	How is the company's relationship with its suppliers?	Weak	Strong

Just as it happens with the external environment, the conditions of these components must be evaluated before starting to plan the strategy of a DT. The assessment of the company features can translate into restrictions for the desired digital strategy, for example, the level of financial resources available to invest in technology.

Figure 2.10 shows the detail of the internal context composition with some of the relevant company's features, as well as the interaction with the digital strategy element. It also shows the relationship of the internal context with the digital readiness, as the factors define the value of this indicator.

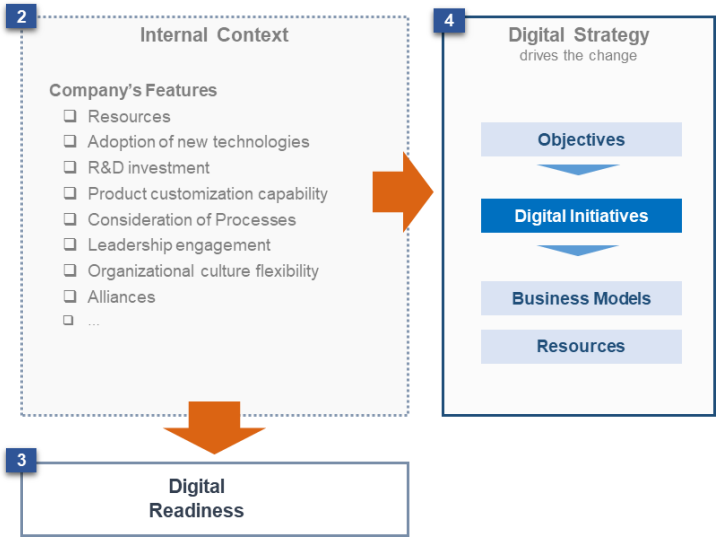


Figure 2.10 Company's internal context (author's own creation).

Regarding the internal context, it is expected that its factors (independent variable) influence the business objectives (dependent variable) as the company needs to assess what objectives are in measure to attain. In the same way, a business model (dependent variable) that is more suitable to the configuration of the company and its ambitions can be designed with a better prospect of success. Resources allocated to the DT (dependent variable) must be aligned with the resources available within the company (see Figure 2.11).



Figure 2.11 Relationship between the company's internal context and the digital strategy element.

Given the presumed effect of the company's context, internal or external, on the development of the DT efforts, a thorough evaluation of these two elements is recommended before beginning a DT. In the next section, a digital readiness indicator is proposed.

2.2.3 The digital readiness indicator

The first indicator that this proposal considers provides a measurement of the readiness of the company to start a transformational change. Digital readiness is considered by some works in literature but frequently mistaken with the digital maturity concept. In this proposal, as discussed in Chapter 1, readiness acts as a forecast of the probability of reaching the desired digital maturity (see Chapter 1, Section 1.1). In this sense, readiness measures the state of the company's internal context and allows identifying if problems may arise by its lack of preparation for a change of this magnitude. For example, if the gap between the current and the desired state is wide beyond what it can be possible for the company to achieve in a determined period of time. The readiness indicator is then proposed as a "sanity check" of the company's digital ambitions.

Digital readiness is measured before starting a DT, and it is composed of an evaluation of the proposed factors of the company's internal context, which are divided into those related to the willingness and preparedness to start a DT (see Figure 2.12).

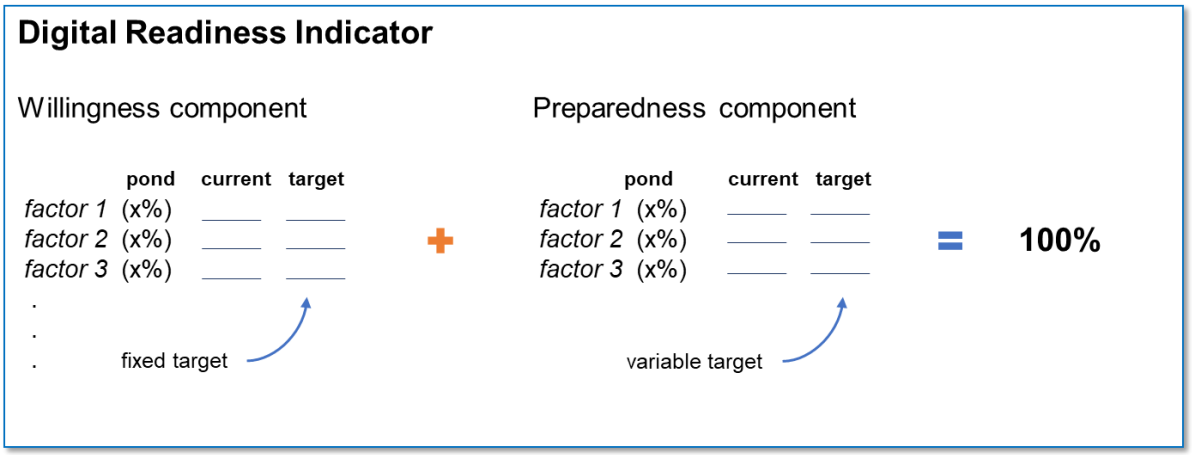


Figure 2.12 Conceptualization of the calculation of the digital readiness indicator (author's own creation).

The willingness component refers to the factors such as the leadership engagement that show the level of commitment of the organization to the change as it is believed that influences the success of the initiatives (see Table 2.6).

Table 2.6 Characteristics of an internal context belonging to the willingness component of the digital readiness indicator.

ID	Characteristic	Description
IC02	Adoption of new technologies	What is the company's level of capacity to integrate new technologies?
IC03	Investment in R&D	What is the level of resources invested in R&D activities?
IC06	Leadership engagement	How flexible is the company's management to experiment and consider initiatives to implement advanced technologies?
IC16	Alliances with universities	What level of networking with universities does the company have?
IC17	Alliances with research institutions	What level of networking with research institutions does the company have?

The preparedness component relates to the more practical side of the readiness indicator and refers to the factors that can facilitate or make difficult the changes required during the company's DT, as can be, for example, the style of decision-making or the consideration of processes (see Table 2.7).

Table 2.7 Characteristics of an internal context belonging to the preparedness factor of the digital readiness indicator.

ID	Characteristic	Description
IC01	Access to resources for transformation and innovation	What is the company's level of resources for digital transformation and innovation?

ID	Characteristic	Description
IC04	Product Customization Capability	What is the company's level of competence to develop highly customized products?
IC05	Consideration of processes and standards	How well does the company take into account processes, standards and norms?
IC07	Flexibility of organizational culture	How flexible is the company's culture to experiment and consider initiatives to implement advanced technologies?
IC08	Strategy definition	What is the level of formality of the strategy definition process?
IC09	Decision-making	What is the level of formality in decision-making in the company?
IC10	Organizational Structure formality	What is the level of formality of the organizational structure?
IC11	Organizational Structure agility	What is the level of agility of the organizational structure?
IC12	Human Resources engagement	Do employees perform several functions in the company, or do they have the opportunity to develop a high level of expertise in a particular field?
IC13	Exposure to human resources development (inside the industry)	At what level do employees have the opportunity to be exposed to development within the industry in which the company participates?
IC14	Exposure to human resources development (outside the industry)	At what level do employees have the opportunity to be exposed to development outside the industry in which the company participates?
IC15	Industry knowledge and experience	Is the knowledge of employees in the industry focused on one specific area or several areas?
IC18	Performance of key activities	What is the level of outsourcing of the company's core activities?
IC19	Dependence on the collaborative network	What is the level of dependence on its suppliers and vendors?
IC20	Customer relationship	How is the company's relationship with its customers?
IC21	Supplier relationship	How is the company's relationship with its suppliers?

The willingness component has a fixed target as it is believed that its objective is not a reference that varies from company to company. On the other hand, the preparedness component must establish a target depending on the type of initiatives the company is planning to pursue.

2.2.4 The digital strategy

In the vision of this work, the digital strategy is a critical component of the CDTF. In this proposal, it is defined as *"the creation of a unique and valuable position, involving a different set of activities"* (Porter, 1996). Accordingly, a digital strategy has the role of defining this unique and valuable position that digital technologies enable. This definition will drive the DT process. The nature of this role makes the digital strategy a pre-requirement for beginning a DT.

Strategy develops a link between the ends or objectives of the business actions and the means or resources to get there (Chandler, 1962; Porter, 1980). This proposal then establishes the following sub-elements of the digital strategy:

- objectives,
- digital initiatives,
- business models,
- resources.

The ensemble of all these strategic choices will give direction to the DT. Figure 2.13 shows in detail the composition of the digital strategy element in the CDTF and the relationships with the other main elements proposed.

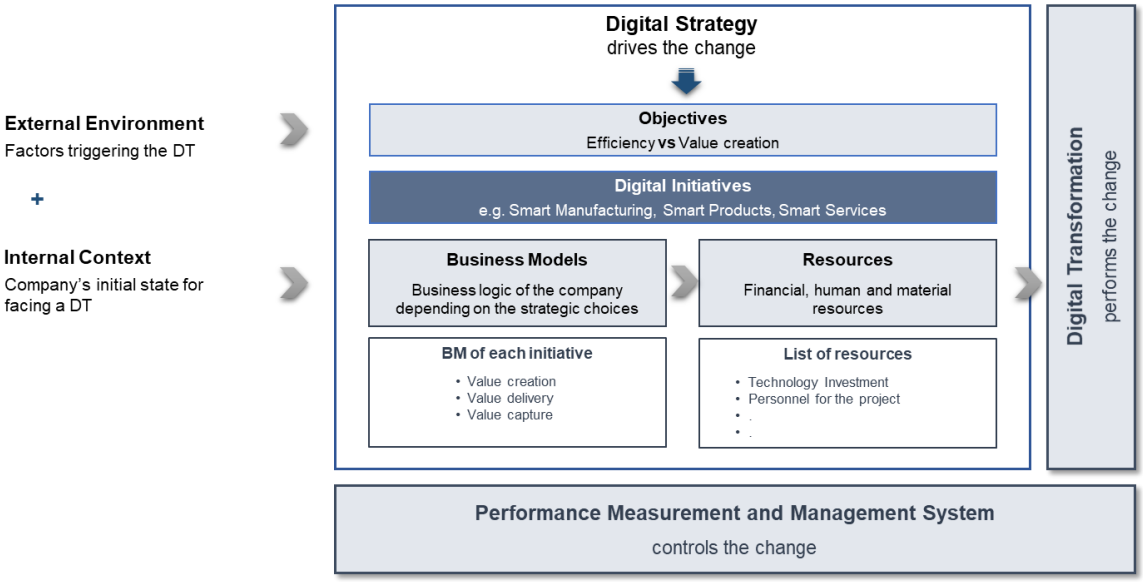


Figure 2.13 Components of the Digital Strategy element of the CDTF (author's own creation).

In the next sections, a brief description of each sub-element of the digital strategy element is presented.

2.2.4.1 Objectives

The objectives are associated, in their more basic expression, with the decrease of costs or the increase of revenues. In the digital context, the objectives to decrease costs are more associated with the use of technology to target efficiency, mostly through the automation of processes. On the other hand, the increase in revenues looks for the creation of value through new products and services that integrate technology to introduce or enhance their intelligence. As the DT is a capability-driven change as it is economic-driven, the objectives will also need to be defined in terms of the capabilities required by the digital company based on the evolution of its business dimensions (see Section 2.1.2.1).

2.2.4.2 Digital initiatives

The defined business objectives then guide the definition of the digital initiatives or projects that introduce the use of digital technologies to the company. Three types of digital initiatives are identified in this proposal: the digitalization of processes (e.g., smart manufacturing, smart supply chain), the digitization of products (smart products), or the creation of services based on data (smart services). These categories are compatible with specific initiatives like the ones that exist in the industrial context derived from the German-born Industrie 4.0 Platform.

2.2.4.3 Business models

Once defined, every initiative will require a corresponding business model that will guide the capitalization of the technology value. A business model is commonly defined as the business logic of a company (Osterwalder et al., 2005). Therefore, depending on the strategic choices, new business models could change the value creation, value delivery, and value capture activities of

the company. Specifically, the digital initiatives and the type of business objectives they are intended to achieve will determine the type of business model required. These business models can be the same traditional ones of selling physical products or new and innovative ones like platforms that transform products into services (see Figure 2.14).

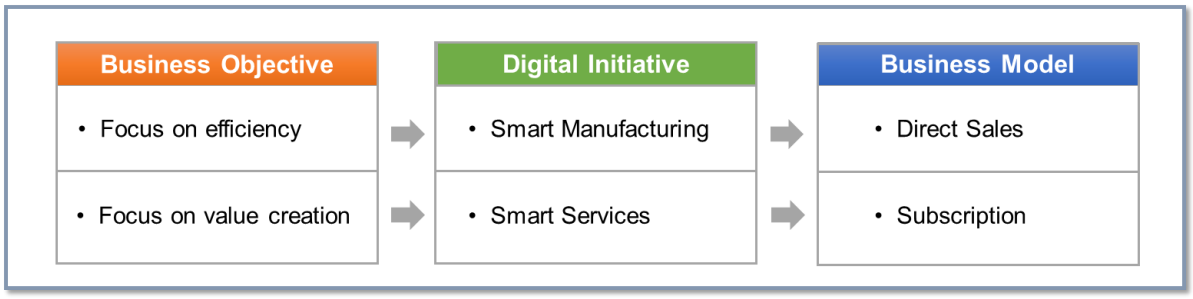


Figure 2.14 Examples inside the components of the Digital Strategy element of the CDTF (author's own creation).

Going towards the objectives of value creation, companies are starting to innovate in new business models to commercialize new products and services and even explore new markets. Regardless of the scenario, the company must document the business models of each initiative as they will guide the design of the changes needed in the business dimensions to support the implementation of the initiatives.

2.2.4.4 Resources

As business models define the company's value creation, delivery, and capture activities that will guide the implementation of the digital initiatives, the different types of resources required (financial, human, and material) must be defined and assigned accordingly. The assignment must be made considering the companies' requirements to achieve the business objectives. The importance of the analysis of the company's internal context is key to determining the objectives according to the company's possibilities, so it has the necessary resources to accomplish them.

2.2.5 The digital transformation

The digital initiatives defined by the strategy will be the target of the DT that should guide how the company should reorganize to support the associated introduction of digital technology. The role of the DT element is to perform the change inside the company. The DT will detail the changes required in each business dimension to implement the digital initiatives. In this proposal, the process to achieve the DT and digital maturity is not static as its design will be particular to each company's conditions in its current context and the business dimensions involved.

The business dimensions proposed in this framework are:

- digital technology,
- business process,
- organizational structure,
- competencies,
- organizational culture.

The design of the changes in each business dimension will depend on the objectives fixed by the digital strategy. Figure 2.15 shows in detail the composition of this element.

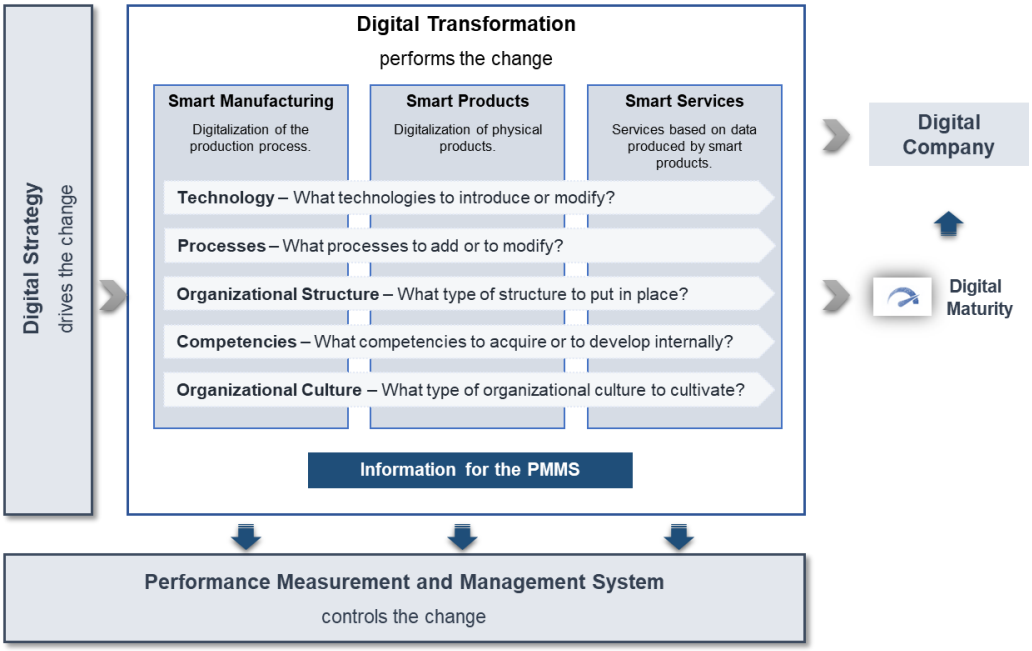


Figure 2.15 Components of the Digital Transformation element of the CDTF (author's own creation).

The DT element receives from the digital strategy the directions to follow in order to achieve the DT and, if needed, updates to steer in a different direction. The DT has constant communication with the PMMS element to deliver the information to produce the KPIs. In the next sections, a brief description of the business dimensions will be presented. They will be described in full detail in Chapter 3, along with the factors proposed for each of them and an explanation of their interactions.

2.2.5.1 Technology dimension

In this proposal, the dimension of technology comprises the digital technologies on which the DT relies, but also the technological framework of the company that will support the new technologies. The selection of digital technologies (e.g., artificial intelligence, cloud computing, and robotics) involves having a clear view of the company's capabilities required to implement the digital initiatives, as the chosen technologies must be the enablers of those capabilities.

2.2.5.2 Process dimension

The processes of the company, considered one of the supports of the realization of a strategy along with the organizational structure (Miles et al., 1978), will adapt to the changes brought by the technology introduction. In this dimension, following the technology introduction, it is expected that the business processes change as a result of the automation of tasks and the replacement of others with higher-value activities. Additionally, as functions such as innovation and collaboration are becoming more relevant and even critical to cope with the new digital environment, new processes and practices will also need to be created to formalize them and systematically perform them.

2.2.5.3 Organizational structure dimension

Just as the business processes, this dimension should be designed to support the company strategy. The organizational structure and the employees' competencies within will also be redefined according to the changes in the business process. Therefore, it should follow its definition in coordination with the changes in business processes and the other dimensions. In order to support the implementation of the digital initiatives, the structure will adapt to enhance current roles, create new ones and possibly reduce the staff of others. Furthermore, the changes will go beyond the evident ones to those aiming to boost innovation, collaboration, and the agility needed to face competition efficiently, like the creation of new roles in charge of those functions.

2.2.5.4 Competencies dimension

The changes in the digital environment call for a different set of competencies to deal with the complexity of digital technologies. However, even though most competencies required during a DT will be linked to technology management, a new kind of company in the digital era will demand a set of soft skills that help to deal with an environment of constant change in which innovation and collaboration will have a key role. Companies will need to carefully plan the evolution of both sets of skills to keep evolving and taking advantage of new opportunities. Competencies planning should also consider the decision to develop them internally or acquire them in the market depending on the type of competency and its use inside the company.

2.2.5.5 Organizational culture dimension

Culture is central to change, and when facing a transformation, leaders should be prepared to foster a culture that supports the DT as it can become the key ingredient to success. Culture, therefore, should be carefully and proactively designed and implemented to that objective. In line with the other dimensions, as the DT unfolds, the culture of a company should evolve towards a type of culture characterized as innovative, collaborative, agile, and open to change.

2.2.5.6 Business dimensions' interactions

The business dimensions are all interconnected and considering the main premises of the STS theory (see Section 2.1.2.2), for them to achieve the desired performance, their changes need to be designed in a coordinated manner. During a DT, main changes can be triggered either by the introduction of technology or by the redesign of a process that will be followed by the modification of the rest of the dimensions to support that first change (see Figure 2.16).

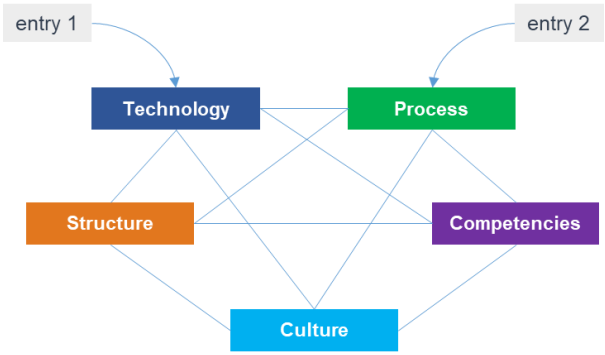


Figure 2.16 Interactions between the business dimensions (author's own creation).

The changes in the business dimension must also consider the following elements:

- the digital initiatives defined (short-term objective),
- the type of digital company the company ambitions to become (long-term objective),
- the initial state of the same dimensions (required to define the gap vs. the objectives),
- the business models to implement (that have all the details of how the value will be created),
- the resources available for the DT (that define the limits on the extent of the changes that are possible).

Finally, changes in all dimensions during the DT, as proposed by the CDTF, go beyond the ones required by the initiatives' implementation or the technological perspective. Recently, it is recognized that innovation, collaboration, and agility are becoming trademarks of the digital context and, therefore, should be acknowledged and included in the changes considered.

The details of the business dimensions proposed, as well as their interactions and the factors that constitute them, are presented in Chapter 3.

2.2.6 The Performance Measurement and Management System (PMMS)

The DT takes time and is highly complex and dynamic; therefore, it should be managed appropriately to ensure the achievement of its objectives. The importance of using relevant performance measures to achieve sustainable success has been long recognized (Kaplan and Norton, 1993). In these turbulent times, the scenario is no different but more pressing to make use of performance as the tool to lead the achievement of the objectives set by the strategy (Gamache et al., 2019). The current context, however, has affected the conceptualization of performance indicators (PI). Constituted by an objective, a measurement, and a criterion, PIs have evolved towards a "complex, systemic and multi-criteria model" (Berrah et al., 2018; Berrah et al., 2020). Consequently, performance measurement in the digital context must be adapted to the new challenges to reflect the volatility of the business environment and the type and volume of data to consider (Nudurupati et al., 2016).

In this proposal, the DT is controlled and managed by using a performance measurement and management system (PMMS). A PMMS not only analyzes and assesses performance (measurement) but also involves the actions to control the performance (management) to ensure the achievement of the company objectives (Shah, 2012). In consequence, the link between the PMMS and the digital strategy is key.

In the CDTF, the PMMS element has the role of controlling the DT through the measurement of the relevant Key Performance Indicators (KPIs), but also of managing it in a way that success is ensured with the appropriate actions. In consequence, a PMMS should provide the information needed to support the opportune decision-making during the DT. The sub-elements of the PMMS are references, assessments, and KPIs. References are seen from two perspectives. First, they will provide the strategy with appropriate DMFs (e.g., Maturity Models) that can serve as a standard for defining the objectives of the DT. Additionally, when the objectives are set, they will become the reference for the KPIs that will measure the evolution of the DT. Assessments are tools that will provide the measurement of the digital readiness and maturity of the company regarding its DT. KPIs will integrate the objectives defined by the strategy (reference) and the results of the assessments to monitor the success of the DT.

As the other main elements of this proposal (i.e., digital strategy and digital transformation elements), the PMMS element should be designed based on the characteristics of the company (see Figure 2.17).

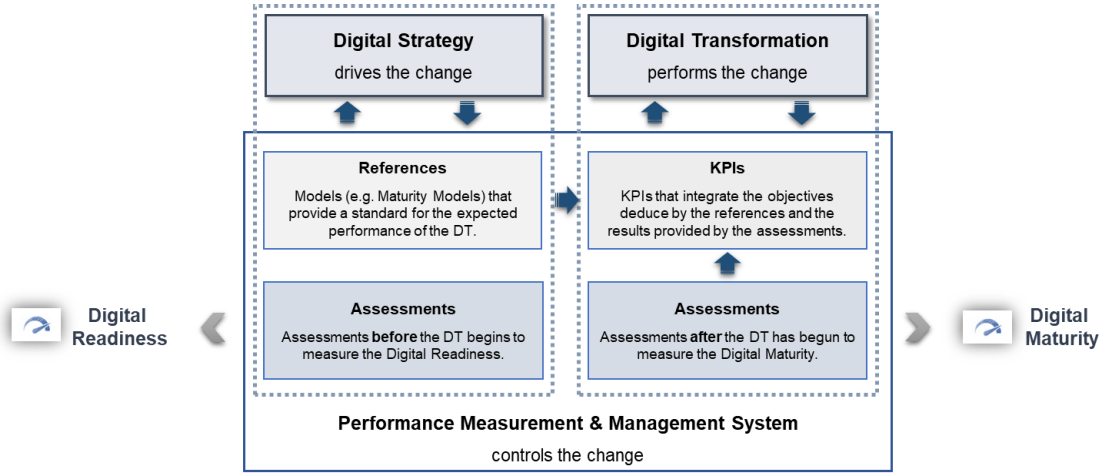


Figure 2.17 Components of the PMMS element of the CDTF (author's own creation).

This proposal goes further to suggest the implementation of a system to measure and manage the DT success achievement instead of a simpler scheme of performance measurement with stand-alone KPIs. The system is in place before the DT starts to assess the as-is situation through the digital readiness indicator and after to confirm the digital maturity has been achieved.

The components of the proposed PMMS are the following:

- references,
- assessments,
- Key Performance Indicators (KPIs).

This structure presents an attempt to decomplexify the notions of performance and performance measurement and management for a better understanding of their role in a DT effort. Nevertheless, performance measurement and management and PMMSs are a complex subject that must be explored further. Especially important is to go beyond the design of the PMMSs and explore the implications of their implementation and integration of information systems, a critical requirement for its success (Ravelomanantsoa et al., 2019). In the next sections, a brief description of each sub-element of the PMMS element is presented.

2.2.6.1 References

The references in this proposal, in one sense, are represented by all the DMFs available to provide directions on different subjects regarding the DT (see Chapter 1, Section 1.2). These references should be available also to provide information that helps to define the levels of the factors for each type of milestone or objective, short and long-term alike. Though it can feel more natural to think about frames of reference regarding technology, in the digital context, there is an incremental development in frameworks regarding the other dimensions, such as culture and competencies. In the other sense, once the digital strategy has considered such references provided by literature, it will provide the ultimate reference, the definition of the objectives that will be integrated by the KPIs.

2.2.6.2 Assessments

Assessments are tools mostly in the form of questionnaires or indices that, through the answers of some sets of questions, allow defining a position or status regarding a subject matter (see Chapter 1, Section 1.1.4.4). They can be conducted by the company itself (self-assessments), or they can be applied by a third party. The last scenario takes place when the company has the support of a consulting firm (e.g., McKinsey, Boston Consulting Group) in its DT project. These types of service providers have specific assessments to diagnose the state of a company before or during a DT.

The assessments in this proposal serve two purposes. First, they are used to determine the digital readiness of the company that will provide important information for the digital strategy definition. With this input, the digital strategy considers the level of willingness and preparedness of the company required to assure the success of the digital initiatives. The second purpose of the assessment is to provide a tool to measure the level of digital maturity during the DT. The assessment of digital maturity must be coordinated to evaluate short-term and long-term objectives. Short-term objectives refer to either the completion of digital initiatives or any other intermediate milestone. Long-term objectives, on the other hand, are related to the achievement of the digital company status.

2.2.6.3 Key Performance Indicators (KPIs)

The proposal regarding the KPIs goes beyond measures of industrial performance, as it is required to follow up on the evolution of the business dimensions towards a DT. Indeed, some business dimensions, especially on the social side, such as culture or competencies, demand a different approach to measure their evolution. Measuring the know-how, soft skills or even the adequacy of certain organizational structures for the scenario requires a paradigm change, but it is considered in this framework a necessary condition for achieving success. Considering that the changes in the business dimensions will define the transformation of the company, their measurement is key to attaining success. KPIs will integrate the references provided by the digital strategy (objectives) and the results of the assessments to provide a measure of the advancement of the DT. If appropriate, the results they provide will be a strong foundation of action plans to control the trajectory to the success of the DT.

2.2.7 The digital maturity indicator

In Chapter 1, a definition of digital maturity is positioned to be used in this work. According to this definition, digital maturity is seen as a *"state of advancement or development of the DT in a company"* (Cambridge English Dictionary, n.d.). In the design of the CDTF, the role of digital

maturity is to determine if the target of the DT has been achieved, a target whose achievement is monitored all along the DT with the help of the PMMS. This measurement is carried out with the assessments, a sub-element of the PMMS element. Figure 2.18 shows the detail of the vision of the digital maturity element and its interactions with other elements.

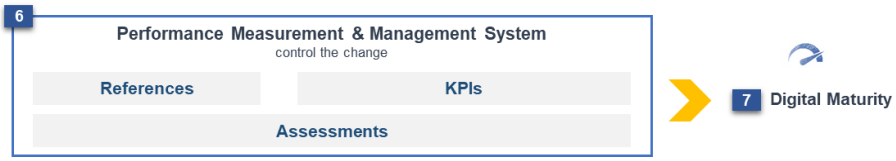


Figure 2.18 Digital Maturity (author's own creation).

In this proposal, the concept of digital maturity as a target has a short-term dynamic nature but also a long-term generic objective. Its short-term dynamic side is associated with an assessment of the development of the digital initiatives that are included in a company's DT. At the same time, a long-term objective must be fixed to follow up on the evolution of the capabilities of the company that ensure it is preparing for an environment of constant change. In this way, the company achieves the so-called transformation state (see Figure 2.19).

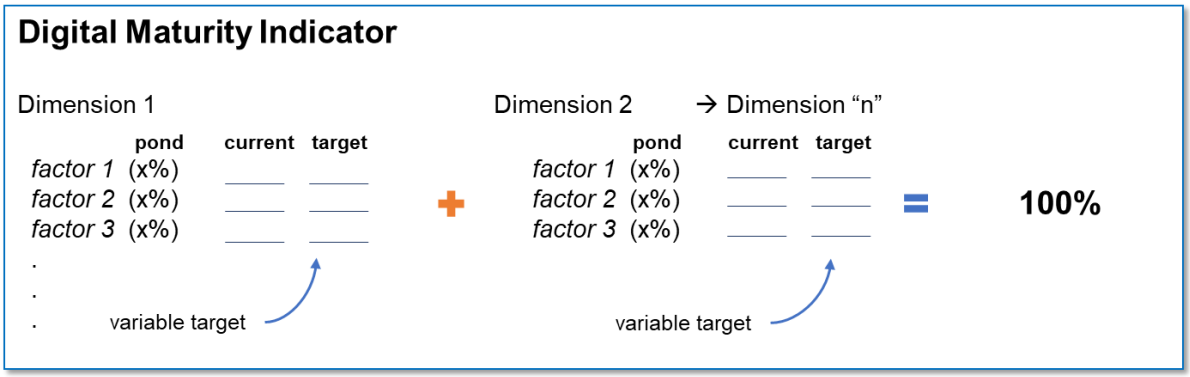


Figure 2.19 Conceptualization of the calculation of the digital maturity indicator (author's own creation).

To define the digital maturity targeted, the process starts with the objectives defined by the digital strategy. Based on those objectives and the changes required by the associated digital initiatives, the aspects to measure are defined, and their objectives are set. For the long-term target of digital maturity, another characterization of the changes required for building the capabilities of the new digital company should be made.

The measurement of digital maturity must consider all the relevant factors of each business dimension (see Chapter 3). As the target values of each factor depend on the objectives of each company, the mature state for each dimension might be different. The milestones of digital maturity, otherwise called maturity levels, in this logic are defined by an aggregation of a specific expected level of each factor inside the business dimensions involved. Therefore, maturity is achieved by a combined effort of the company that delivers real value and, in consequence, shows a real advancement in its digital maturity (joint optimization principle of the STS theory). The digital maturity is constantly monitored by the PMMS element through the measure of the state of the

business dimensions before, during and after completing the DT to validate the success of the efforts.

2.2.8 The digital company

The ultimate goal of a DT in this proposal is to become a digital company. The definition of the DT concept characterizes the DT as a capability-building change. Consequently, a digital company will have built the required capabilities to compete in the digital context according to the selected strategy and the type of opportunities it decides to pursue (see Figure 2.20).

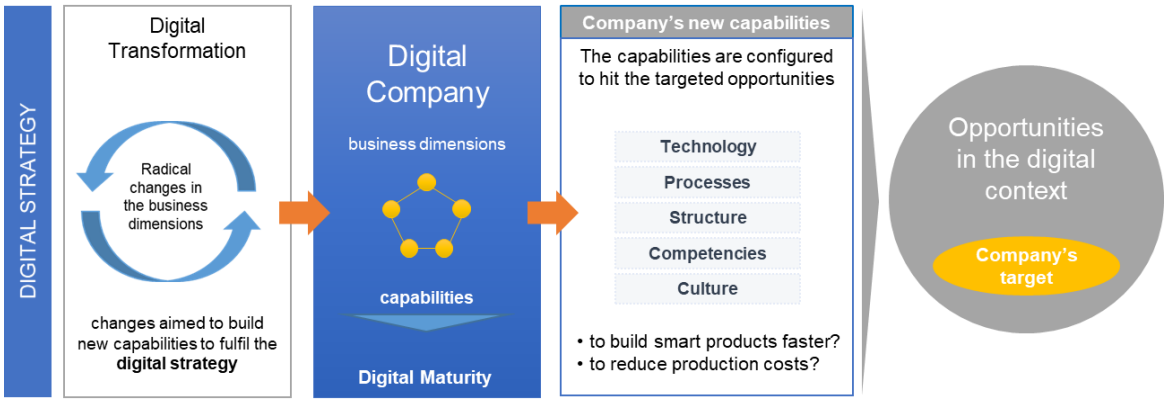


Figure 2.20 The capabilities of a digital company (author's own creation).

Achieving the status of a digital company is particular to every company, depending on how it wants to compete in the digital context. Companies that decide, for example, to compete with a value creation strategy will build capabilities that allow them to build smart products faster. Beyond the digital technologies needed, the strategy could also include designing an innovation process, developing new competencies in new disciplines like mechatronics, or fostering cultural traits in employees that incentive creativity. Some of those capabilities may differ from those that need to be developed by companies whose focus is on improving performance.

The final configuration of the capabilities should be clearly defined in the digital strategy of the DT, but the trajectory to the final state will benefit from completing a set of digital initiatives as a part of the trajectory towards a transformation, but that is not all. The company will need to build all the necessary capabilities in all dimensions to be ready to profit from the type of digital opportunities it is interested in pursuing. In following this trajectory, a company will evolve from facing highly technical projects that it is not prepared to handle to a company that is prepared for managing technology implementation smoothly.

In this parallel evolution, the company is building its "digital" status incrementally with each digital initiative, not only with the capabilities associated with technology that are critical. Developing specific factors, especially inside their "social" business dimensions (i.e., structure, competencies, and culture), will switch its perspective on how to approach the business environment. Innovation, creativity, and experimentation coupled with a more flexible organizational structure and a culture that thrives in continuous change environments are part of this vision that understands "digital" as more than technology.

This conception directly affects the definition of the digital maturity that a company must achieve and, therefore, the factors of each dimension that will be considered in such measurement. It

equally affects the definition of digital readiness. The magnitude of the gap between where a company is now and how it conceptualizes itself as a digital company should define the minimum level required from each of the relevant variables of this indicator so it can be called “ready” to start a DT.

After reviewing all the relevant arguments, it is possible to conclude that the digital company that this proposal envisions is a company that has built the necessary capabilities to profit fully from digital technologies. That means not only integrating them efficiently and effectively but also starting to see them as an integral part of every solution used to address problems or opportunities.

2.2.9 The DT process

Having reviewed all the elements of the CDTF, it is possible to deduce a high-level process that can guide the planning of a DT. In Figure 2.21, the DT process proposed is presented.



Figure 2.21 DT Process proposed based on the main elements of the CDTF (author’s own creation).

The DT process is constituted of five steps that cover all the elements proposed in the CDTF and their roles. First, before beginning a DT effort, an analysis of the context, internal and external, should be performed. The result should feed the strategy definition, represented by step number two. After the digital strategy has been defined, the direction of the DT is set, the transformation of the company starts. In parallel, the performance is managed until the highest level of digital maturity has been achieved. The validation of the status of the digital company is then performed to ensure the success of the DT.

2.2.10 Conclusions

The CDTF design was introduced in this section as a theoretical answer to the questions of this research work by considering the following propositions:

- establishing the digital company as the objective of a DT that is focused on capability-building;
- defining a high-level process of the DT that can guide the application of the CDTF;
- recognizing that the trajectory towards a DT is constituted of the digital initiatives strategically defined according to the company’s needs;
- identifying DT’s main elements and assigning them specific roles during the transformation;
- proposing a theory-based set of the specific business dimensions involved in the transformation;
- distinguishing the factors of the company’s context, internal and external, that are believed to have an important effect on DT success.

The CDTFs’ main propositions aim to provide a frame of reference with a holistic view of the DT. By doing so, the design addresses the limitations presented by current digital models and

frameworks (DMFs). Additionally, the use of theory made it possible to reposition what it means for a company to be transformed to allow this work to propose a new vision with a stronger foundation.

2.3 Chapter's conclusion and summary

The need for a new vision of a Digital Transformation (DT) that clarifies the understanding of the DT leads this work to the proposal of the Conceptual Digital Transformation Framework (CDTF). In the CDTF, DT is a process driven by a clear digital strategy and controlled and managed by a Performance Measurement and Management System (PMMS) to ensure its success. The conception of the CDTF puts particular emphasis on defining not only the internal elements but also the effect of the company's context on the transformation process. Relevant factors in the external environment and the conditions of the internal context of the company are recognized.

Having identified the main elements of the DT with the help of the selected theories and models, mainly related to the Socio-Technical Systems (STS) theory, the proposal focuses particularly on the business dimensions inside the company that are involved in the DT. The definition of the set of business dimensions with a theoretical foundation distinguishes itself from previous works that have used other less formal methods that provide an incomplete view of the changes required inside the company. The relevance of the business dimensions is their key role in defining the digital maturity of the company, which at the same time will define the success of the DT and determine the status of a "digital company."

In the next chapter, a deeper understanding of the business dimensions involved in the DT is presented, along with their interactions. This detailed view into the logic of the DT will clarify how the CDTF will allow proposing a way to take advantage and use the framework to guide a DT effort.

Chapter 3: Business dimensions' transformation

The review of literature on the different Digital Models and Frameworks (DMFs) that intend to guide the Digital Transformation (DT) revealed several limitations related to the implications of the change within the company. In the proposed Conceptual Digital Transformation Framework (CDTF), this part is represented by the element labeled "Digital Transformation." The Digital Transformation element includes all the changes that are executed during a DT in different company aspects that are better known as business dimensions. As the changes inside the business dimensions are critical to attaining success in a DT, deeper detail is needed to complete an answer to the main question of this research.

In this chapter, the focus is, therefore, on the set of business dimensions proposed and the relevant factors that constitute each of them. Details of the content of each dimension are presented, as well as the type of changes that are important to consider when designing its evolution towards a DT. Following the Socio-Technical Systems (STS) principles, the interactions between them, as well as the effect of the internal context on them, are also discussed, as they must be considered during the design of the change to optimize the result of the DT.

This chapter is structured as follows. Section 3.1 introduces the business dimensions and the logic of their change, as well as the theoretical foundation of the proposal of their factors. Section 3.2 details the changes that the business dimensions go through during a DT and a proposal of the relevant components that are included in each of them. Section 3.3 explains the interactions between the dimensions and with other elements of the CDTF. Section 3.4 presents the conclusion and a summary of the chapter.

3.1 The core of the digital transformation

The definition of a set of the business dimensions involved in a change of the nature of a Digital Transformation (DT) is at the core of the proposal of this work, along with the characterization of the evolution of their components during this type of change. The reason behind its importance lies in the fact that the business dimensions' evolution is what transforms a company. It is believed that success and maturity can be achieved with the adequate management of the changes inside each of the business dimensions involved.

3.1.1 The logic of business dimensions' change

In designing the Conceptual Digital Transformation Framework (CDTF), specifically the digital transformation element, it was crucial to understand the logic of the changes inside the company during the DT. The interest in the evolution of each business dimension was driven by the need to identify the relevant components inside them that contribute to DT's success.

3.1.1.1 The scope of the business dimensions' change

The nature of each business dimension is different, and in consequence, the factors that change inside them vary from one to the other. In figure 3.1, an understanding of the scope of the changes in each dimension during a DT is presented.

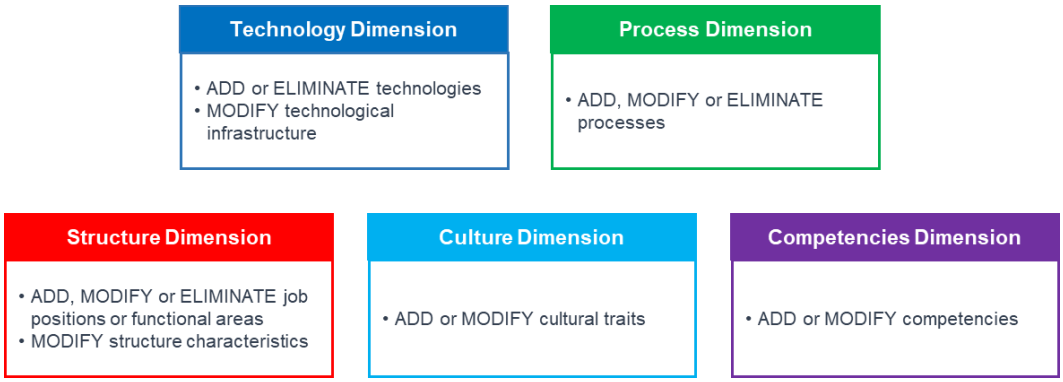


Figure 3.1 Scope of the changes in business dimensions during a DT (author's own creation).

In section 3.2, further details are added about the changes in each dimension. These first two sections intend to ease the understanding of the logic of the changes that are included in this proposal. To complete this brief introduction to the scope of changes in each dimension in the next section, the type of changes will also be classified.

3.1.1.2 The type of changes in the business dimensions

In this proposal, the DT inside the company is divided into two types of changes, the changes required in the business dimensions for managing the digital initiatives (see Figure 3.2, #1 on the left) and the changes required in the business dimensions for realizing the digital initiatives (see Figure 3.2, #2 on the right).

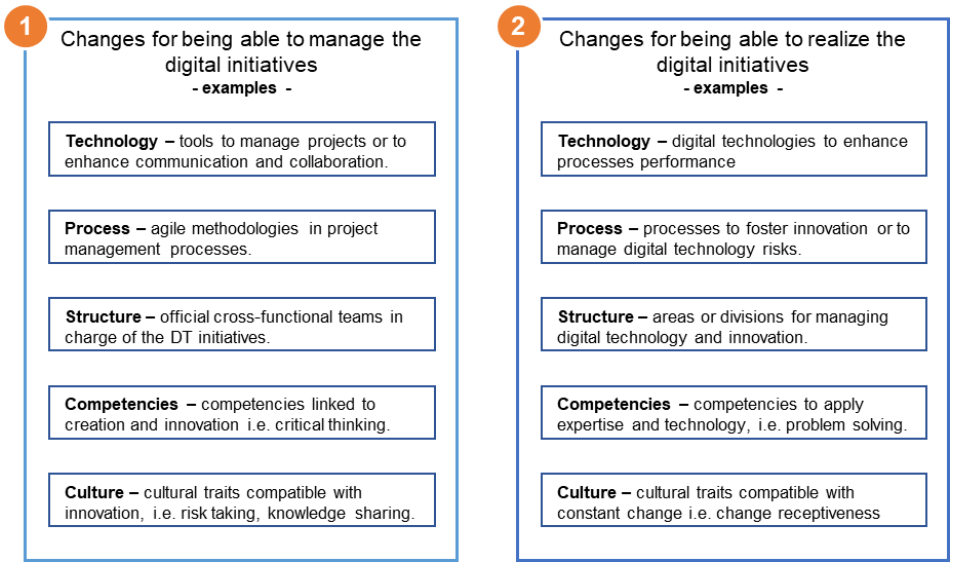


Figure 3.2 Type of changes in the business dimensions according to their function (author's own creation).

Both types of changes are also relevant in the long term to build the capabilities of the digital company. Especially the changes to manage the digital initiatives, as the digital company should be able to be flexible and agile enough to better integrate new digital technologies. But also, the

capabilities built in the different dimensions for a particular initiative during the DT can be well useful for future projects.

In this sense, and as discussed in Chapter 2, for achieving a DT, there should be two development plans in parallel. The first one, in the short term, concerns the different initiatives that will compose the trajectory toward the DT. The other one with a long-term vision that will increasingly build the rest of the capabilities required by the digital company (see Figure 3.3).

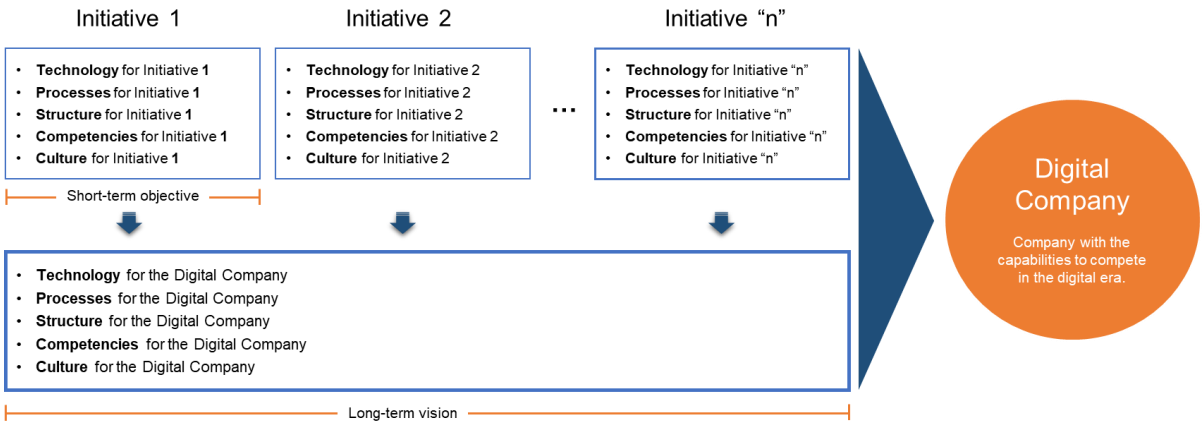


Figure 3.3 Type of changes in the business dimensions according to their time span (author's own creation).

Naturally, in implementing each digital initiative, technology introduction will become easier for the company as, consequently, it will be building valuable capabilities in all dimensions. In this proposal, however, the objective is that the capabilities building is intentionally planned according to the type of digital company the company envisions to be (see Chapter 2, Section 2.2.8).

Finally, each of these plans, for the short (digital initiatives) and the long-term (digital company) is composed of a set of changes in each dimension derived from the digital context requirements and another group of more generic changes that concern any exercise of organizational change of the transformational type (see Figure 3.4).

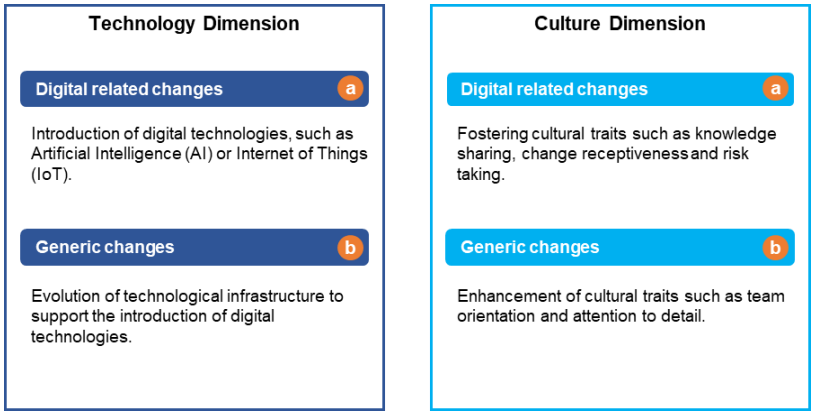


Figure 3.4 Type of changes in the business dimensions according to their nature, 2 dimensions as an example (author's own creation).

While the digital-related changes obey the need to face the challenges of the digital context, such as the constant and fast technological change and increasing competitive pressure, generic changes are required to support or facilitate those changes. Organizational change studies traditionally focus on the so-called “generic changes.” This work, however, emphasizes the need to understand that the new digital context requires considering additional factors in each dimension to succeed under the new conditions.

These new conditions that are imposed by the digital context are mainly a consequence of the fast development of technology, which brings complexity and uncertainty to the business environment. For example, in such a scenario, companies need to start considering the introduction of new technologies on a more frequent basis than before. They may also need to reconfigure their organizational culture, so employees get more comfortable taking risks or sharing knowledge, among others. New conditions force a state of constant change for which companies need to be prepared.

The three perspectives presented to understand the dynamics of the change inside of each of the business dimensions involved have the objective of contributing to building a holistic vision of the DT. It is also useful in specifying the reasons why this type of organizational change is different from the others of previous technological revolutions. Detailing the components that change in each of the business dimensions proposed in this work contributes to identifying what are the critical success factors in a DT and how they vary in different scenarios. Being aware that each initiative will require these factors in different measures adds to the subtleties to be considered in a change of these proportions.

3.1.2 The business dimensions’ documentation

The proposal of the evolution of the business dimensions during a DT is centered on the specific changes each dimension experiences. Even though this scope excludes any other external factor, the documentation of the state of each dimension will also be explored as it is considered critical for the agility of the implementation of changes. Agility becomes a key factor in scenarios of constant change, such as the digital context. Documentation of the state of the dimensions helps to accelerate the analysis of their current situation when a change is needed and to determine the gaps to fill to arrive at the desired state.

In this chapter specifically, an example of a tool used to document the state of each dimension will be introduced to illustrate the importance of the documentation of the state of the dimensions.

3.1.3 Theoretical foundation of the proposal

In Chapter 2, a detailed procedure for building the CDTF was presented, along with the relevant theories and models that support its main propositions. However, to present a proposal of the relevant factors of each dimension for succeeding in a DT, new literature was explored. The details of the factors of each dimension that are presented in this chapter come from the analysis of specific literature on each dimension related either to its conceptualization or to the effects the digital context has on them.

In this sense, Table 3.1 presents a summary of the main sources of the concepts and frameworks used to assemble the proposal of the factors of each dimension. In addition, to help in explaining the propositions of this work, these elements will be used during the validation stage of the CDTF to be presented in Chapter 4.

Table 3.1 Main frameworks used for defining the factors of each business dimension.

Business Dimension	Concept or Framework	Author
Technology	Technologies associated with smart manufacturing.	Mittal et al., 2019
	Industry 4.0 Technologies.	Frank et al., 2019
	Production and product Industry 4.0 guiding principles.	Anderl and Fleischer, 2016
Process	Cross Industry Process Classification Framework® (PCF)	APQC (American Productivity & Quality Center), 2018
Organizational structure	Elements of an organizational structure	Robbins and Judge, 2007
Competencies	Industrie 4.0 Competency Model	Prifti et al., 2017; Bartram, 2005
Organizational culture	Characteristics of the essence of an organization's culture	Robbins and Judge, 2017
	Cultural traits that support organizational change and innovation	Robbins and Judge, 2017

These were the main works that were the inspiration for this proposal, but many more are comprised in its final design. Details are added in the relevant sections of this chapter.

3.1.4 Conclusions

For presenting the factors of the business dimensions proposed in the CDTF, an understanding of the logic of the changes is required. In this section, this logic was introduced along with the main theoretical foundations for building the business dimensions' proposal. In the following sections, a detail of the changes expected in each of the business dimensions involved in a DT is presented. It is fundamental in this proposal to understand that the specific changes and the order in their implementation are inherent to the company's particular context and strategic intentions.

3.2 The business dimensions' transformation

Available guidance of DT efforts most often identifies the evident changes required in the business dimensions, the ones that are directly linked to the technology being introduced or the type of digitalization they are pursuing. For example, when digitalizing a process, it is clear that the process concerned must be updated or "redesigned." There is, however, a wide range of changes not so evident that are required to succeed in scenarios of change. Those types of changes become critical for achieving a DT and then thriving in a digital context. In the next sections, each dimension is presented along with its definition, components, examples of the type of changes presented during the DT, and some considerations on managing those changes.

3.2.1 Technology dimension

3.2.1.1 Introducing the technology dimension

Digital technologies and their fast evolution are at the core of their many opportunities and challenges. In this dimension, however, even if digital technologies are a key element of a

company's DT, their introduction is not the objective of a DT. The role of this dimension is to support the digital initiatives defined by the digital strategy. This role is fulfilled either by enabling the functionalities of a product or service or the digitalization of tasks or processes.

Digital technologies are defined as *"electronic tools, systems, devices and resources that generate, store or process data"* (Victoria State Government Education and Training, 2019). During a DT, their selection and implementation are two critical tasks. Official classification of digital technologies is yet to be available; therefore, in this work, three frames of reference are proposed. All three are linked to digital initiatives in the industrial sector.

The first one is a list of technologies associated with smart manufacturing (see Table 3.2). The list includes, however, many technologies that are common for other initiatives.

Table 3.2 Digital technologies linked to industrial companies (Mittal et al., 2019).

No.	Digital Technology	No.	Digital Technology
1	Intelligent	21	Modelling
2	Intelligent control	22	Geographic Information Science (GIS)
3	Energy saving/efficiency	23	Simulation
4	Cyber security	24	Forecasting
5	Holograms	25	Enterprise Resource Planning (ERP)
6	Virtual Reality (VR)	26	Radio-Frequency IDentification (RFID)
7	Augmented Reality (AR)	27	Machine learning
8	Real-time communication/data	28	Supply Chain Management (SCM)
9	Big data	29	Manufacturing Execution System (MES)
10	Cyber-physical infrastructure	30	Product Lifecycle Management (PLM)
11	CPS/CPPS	31	Smart Materials
12	IoT/IoS/IIoT	32	Interface (SCOR, DCOR, MESA, ISA 95/88)
13	Advanced manufacturing	33	CAM, CAD, CAx
14	Cloud computing/cloud manufacturing	34	Operations planning
15	3D printing/additive manufacturing	35	IT-based production management
16	Smart sensors	36	Tracking and tracing
17	Smart product/part	37	Knowledge decision making techniques
18	Data analytics/big data analytics	38	Statistical Process Control (SPC)
19	Predictive analytics		
20	Data visualization		

The second one includes a framework with a global view of different types of initiatives and the related technologies, including some relevant technological infrastructure to support them (see Figure 3.5).

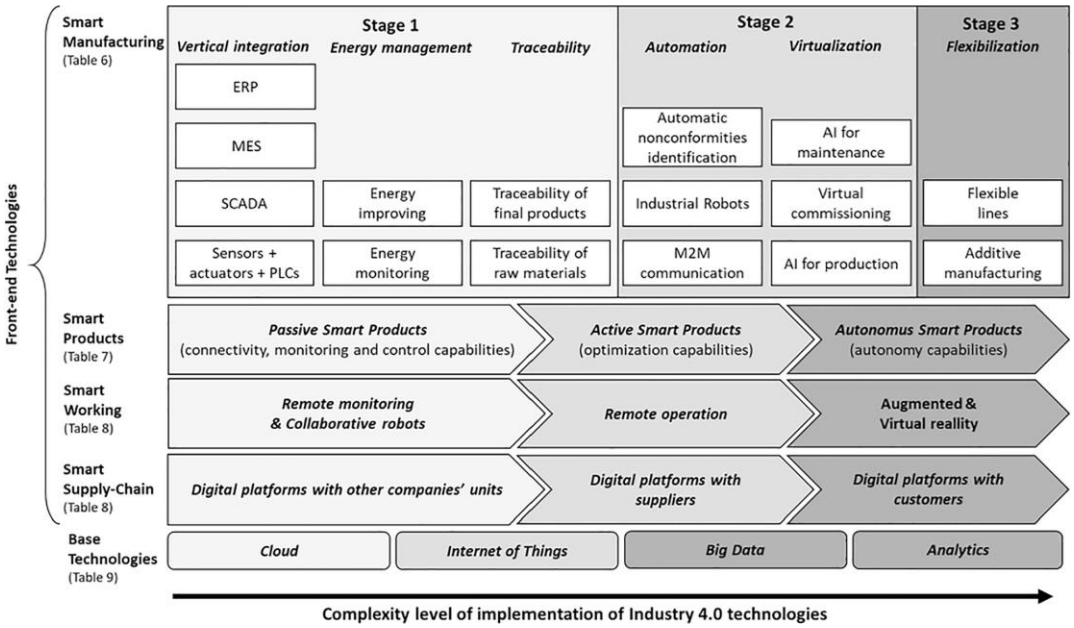


Figure 3.5 Framework of adoption patterns of Industry 4.0 (Frank et al., 2019).

Finally, the third one by Anderl and Fleischer (2016) presents a toolbox for the Industry 4.0 projects from the technological perspective.

The infrastructure on which technologies rely is the enabler or inhibiter of their potential. In consequence, this dimension is linked to both aspects of technology, not only the technologies that are being introduced to the company but also the technological infrastructure that will support them. As technology continues its relentless evolution with the exponential growth in processing power, communication bandwidth, and storage capacity, more digital technologies will be expected in the coming years. A robust and flexible technological infrastructure will become more critical when introducing new digital technologies.

3.2.1.2 Changes in the technology dimension

The changes in this business dimension are triggered by the need to solve a problem related to the performance efficiency or to seek an opportunity to create value for the customer through new products and services. In the new business context, this can happen in two senses. Continuously scanning new digital technologies can give life to new ideas to solve existing problems or to create new products or services, but also existing problems or the search for new product functionalities can lead to the search for new technologies.

Both courses of action are important. In the first case, it is possible to find inspiration in the many applications of the most developed and popular digital technologies in other domains to solve the company's current challenges. In the second scenario, the current challenges force companies to search for alternatives to integrate technologies that make processes more efficient or to enable new functionalities on products they already have in mind.

Each digital initiative will have an objective to accomplish, and technology will be the key enabler of that objective. For incumbent companies with legacy systems and infrastructures, changes in this dimension should include a progressive change into a new design that is flexible and robust enough to integrate new technologies easily and fast. Though each initiative will demand to

prioritize the changes that are required for its success, the design of the technological infrastructure of the digital company should be clearly defined for the long-term (see Figure 3.6).

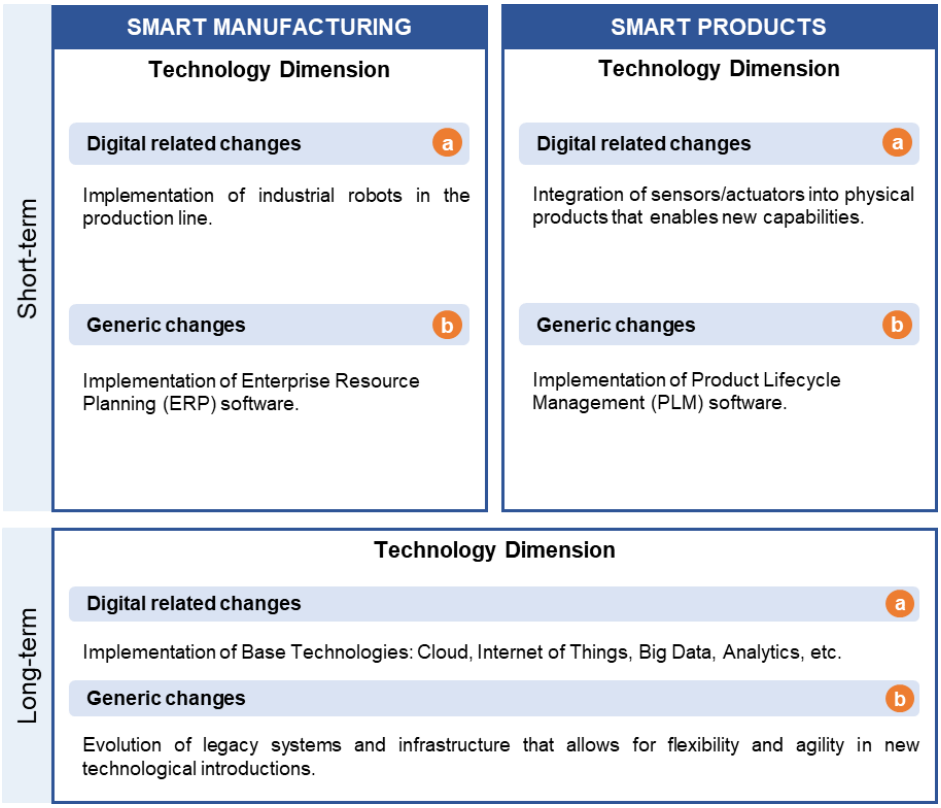


Figure 3.6 Examples of changes in the technology dimension (author's own creation).

The design of this infrastructure must consider the different initiatives that will compose the DT and the characteristics required, so the company is able to compete in the digital context. This will allow the company to be more flexible to react in facing the complexity and uncertainty of the future according to its ambitions going forward.

Technical guidance for designing and implementing digital technologies in the industrial context is abundant. There are several propositions of the technologies that are relevant for the manufacturers and assemblers alike, considering the core initiatives in the sector towards smart manufacturing and smart products. Nevertheless, it is important to emphasize that to achieve success, those changes must be paired with the evolution of legacy systems, technologies, and infrastructure to enable faster progress.

3.2.1.3 Managing the technology dimension

Once selected, the implementation of those technologies will depend on the flexibility of the infrastructure that will support them. The agility required to integrate new technologies will depend on how well documented the technological infrastructure of the company is. Therefore, complete and accurate documentation of the state of the different sets of technologies in the company is a vital element to agility in the changes of this business dimension.

This documentation can be achieved in many forms, but online or digital documentation, perhaps with specialized software, is strongly recommended. Considering the constant evolution of this dimension, a tool that allows for quick analysis of the state of the technology assets of the company may be a better choice. In any case, the requirement is a thorough documentation of technologies and infrastructure and the links between them (see Figure 3.7).

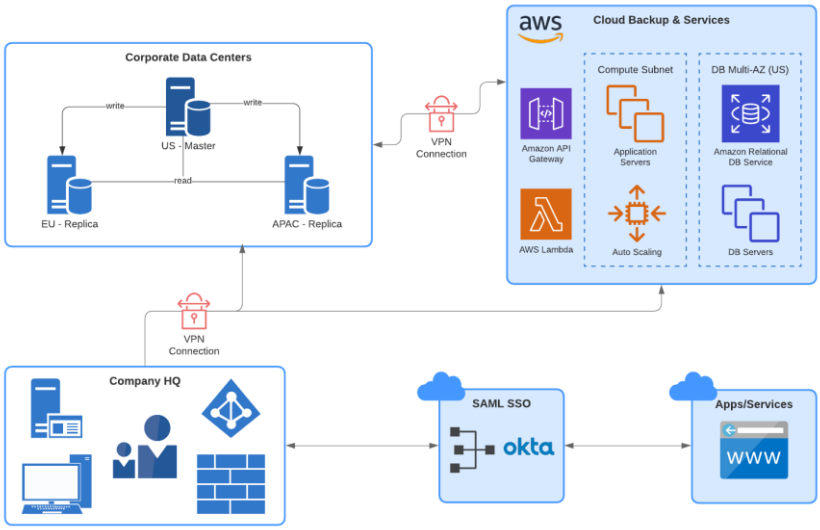


Figure 3.7 Example of the documentation of the technological infrastructure of a company.

(source: https://www.lucidchart.com/blog/digital-transformation-vs-digital-improvement).

Timely updates are required to keep an accurate status that allows the analysis and implementation of new technological solutions in an agile manner.

3.2.2 Process dimension

3.2.2.1 Introducing the process dimension

The operational model of a company is defined by its business processes. A business process is defined as *"a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer"* (Hammer and Champy, 1993). This definition helps in understanding that when a digital initiative aims to radically change the value creation activities of a company, it will certainly disrupt this operational model and require an adaptation of different business processes.

To understand the operational model of a company, first, it is necessary to understand the classification of its business processes. A popular classification by von Rosing et al. (2014) identifies three types of business processes: operational processes, supporting processes, and management processes (see Figure 3.8).

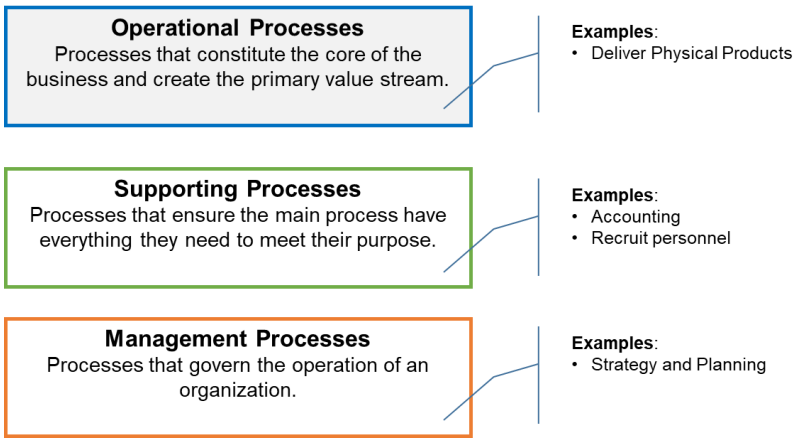


Figure 3.8 Types of Business Process and Examples (adapted from von Rosing et al., 2014).

By using this classification, a company can identify the different business processes that compose its operation. The classification of the company's business processes, and their objective, are useful to understand the logic of the operational model and show a quick way to identify how a change can affect its functioning. If, for example, a company is introducing robots to its production line, changes in the relevant processes will be in its operational processes. If, on the other hand, the company is introducing digital technologies to speed its personnel recruitment, the process to redesign will be found in the supporting category.

3.2.2.2 Changes in the process dimension

As one of the supports of the realization of the digital strategy along with the organizational structure, business processes must be adapted first to the needs of the digital initiatives but considering always in their design the features that will support the operation of the digital company. According to the characteristics of each digital initiative, the process dimension will require the modification of existing processes, the creation of new ones or the elimination of the obsolete ones (see Figure 3.9).

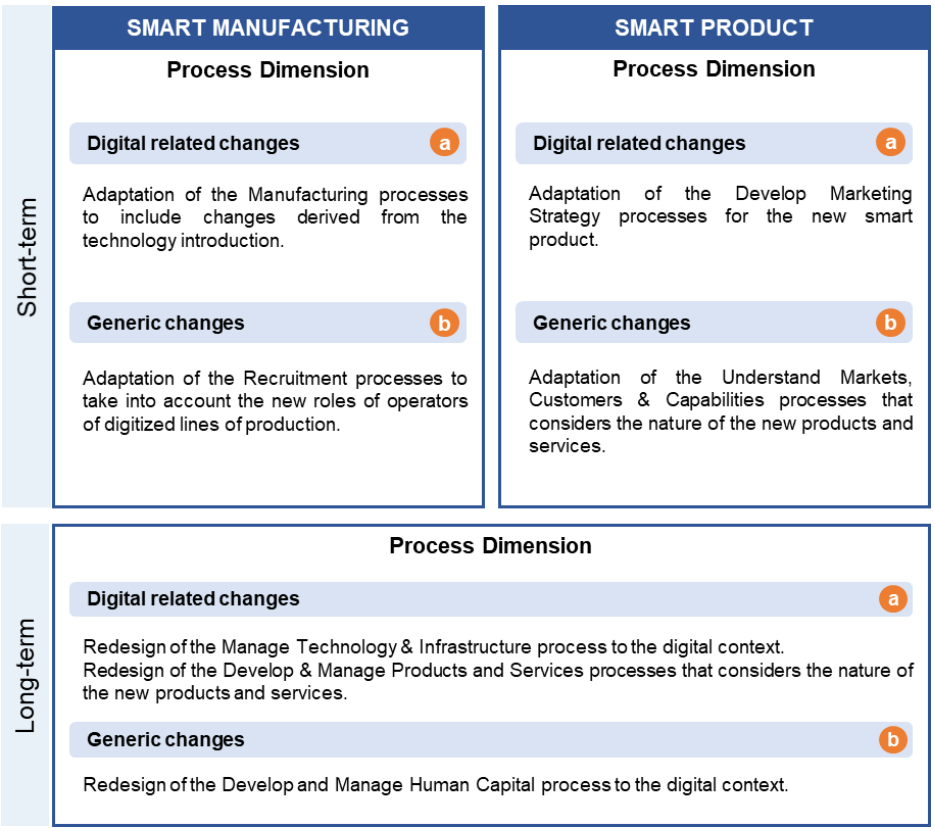


Figure 3.9 Examples of changes in the process dimension (author's own creation).

All these changes must consider one of the principles of the creation of a business process, an end-to-end design that enhances collaboration and focuses on delivering value to customers, internal or external.

3.2.2.3 Managing the process dimension

The objective of the formalization of processes is the standardization of tasks to achieve efficiency. The documentation of the business processes is commonly made in what is called a Process Map, in which the different types of processes of the company must be identified and fully documented in various levels of detail (see Figure 3.10).

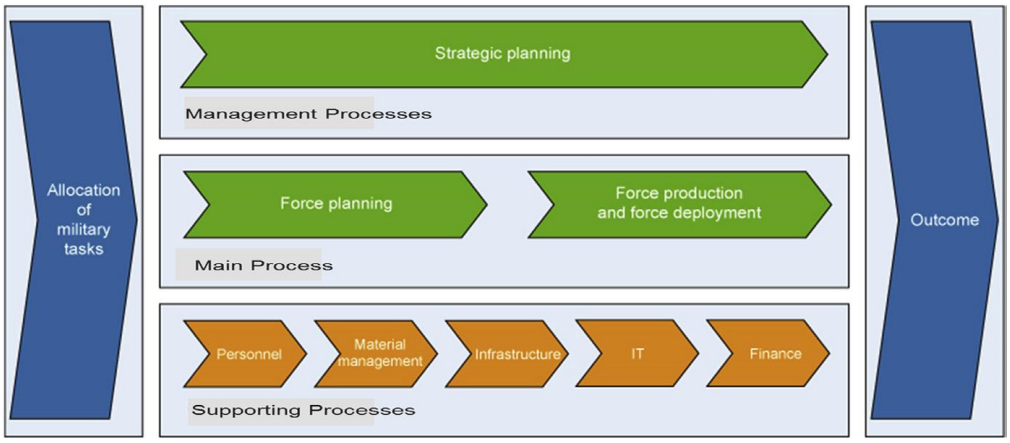


Figure 3.10 Example of the high-level view of the Process Map of a company (von Rosing et al., 2014).

A well-documented and up-to-date Process Map allows companies not only to manage their operations and to quickly identify the impact of the initiatives but is also the basis to measure its benefits on performance. Several methodologies to implement changes in the business processes such as Business Process Management (BPM) and Business Process Redesign (BPR), identify it as a critical requirement.

In certain cases, and depending on the markets companies serve or the type of products they commercialize, companies are compelled to certify their processes' documentation. In those cases, the documentation must follow strict rules of standards, such as those from the International Organization for Standardization (ISO). Required or not, the documentation of the processes is key to the agility of the company in the face of changes.

There are, however, many process standards proposed by academic and practice institutions that present lists or maps of the processes, with various levels of detail, that a company could use to design its operational model. These process standards, also known as Business Process Frameworks, are also produced for specific sectors or industries, which allows for considering the specificities of the processes of such types of companies (see Figure 3.11). See Appendix 3.1 for a complete list of the processes included in the APQC's Business Process Framework.

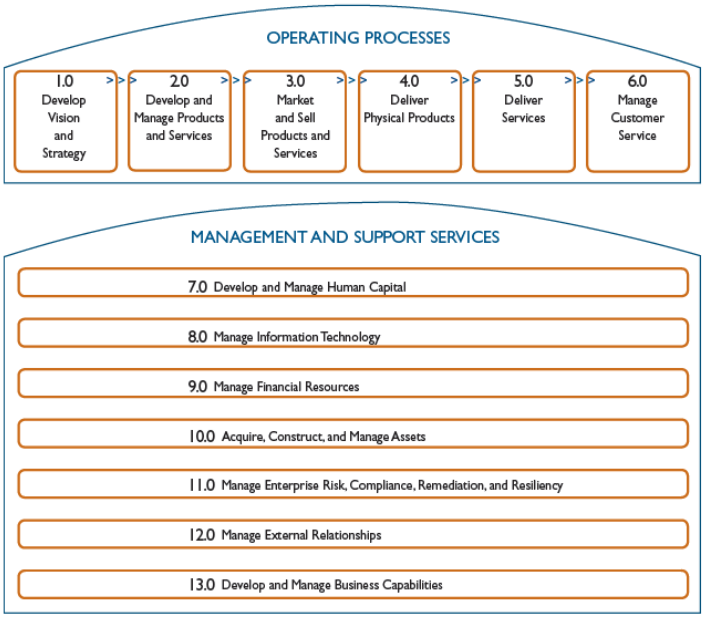


Figure 3.11 Business Processes Framework (Cross Industry Process Classification Framework® (PCF) by the APQC).

The importance of this business dimension is reflected in the many resources and tools available for its management that can be useful for a company in guiding its evolution during a DT.

3.2.3 Organizational structure dimension

3.2.3.1 Introducing the organizational structure dimension

The way in which a company is structured is linked to its agility to respond to the changes required to adapt to new conditions. The new conditions defined by the company's digital strategy will require not only adequate business processes but also an organizational structure that supports the desired performance of such processes.

An organizational structure defines *"how job tasks are formally divided, grouped, and coordinated"* (Robbins and Judge, 2017). The characterization of the structure of a company considers several factors. These factors not only define how work is organized and controlled but also define the degree of flexibility of the organization and how well and fast it adapts to changes (see Table 3.3).

Table 3.3 Attributes that characterize an organizational structure (adapted from Robbins and Judge, 2017).

Characteristic	Brief description
Structure Formalization	The degree to which the organizational structure is manifested in an organizational chart.
Work specialization	The degree to which tasks in an organization are subdivided into separate jobs.
Departmentalization	The basis by which jobs in an organization are grouped together.
Chain of command	The unbroken line of authority that extends from the top of the organization to the lowest echelon and clarifies who reports to whom.

Characteristic	Brief description
Span of control	The number of subordinates a manager can efficiently and effectively direct.
Decision Making System	The degree to which decision making is concentrated at a single or multiple points in an organization.
Rules and Regulations	The degree to which jobs within an organization are standardized and there are rules and regulations to direct employees and managers.
Boundary spanning	When individuals form relationships outside their formally assigned groups.

The structure supports the achievement of the organizational goals, the right configuration allows collaboration, fast decision making and knowledge sharing. Therefore, a configuration of the structure that suits the needs of the different stages of the DT could be critical for success.

3.2.3.2 Changes in the organizational structure dimension

The company's structure will adapt in two ways during a DT. The first one involves its characterization which is the definition of different attributes of the company, such as its decision-making system or the specialization of work (see Table 3.3). The second one is its structural composition, the definition of functional areas, the number of levels of management and the definition of roles and responsibilities. The combination of both will have a strong influence on the way and speed with which the company will respond to the different initiatives comprised in its DT.

In consequence, a company must adapt its characteristics and structure to the needs of the different stages of the DT by enhancing or modifying the scope of the roles of current positions, creating new ones and possibly reducing the staff of others or even eliminating them and shaping its characteristics accordingly (see Figure 3.12).

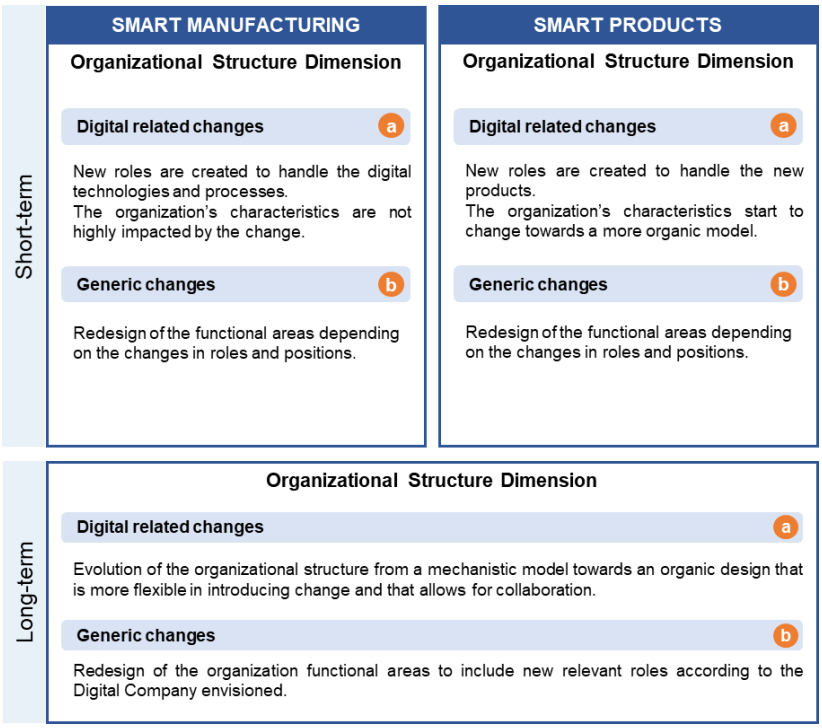


Figure 3.12 Examples of changes in the organizational structure dimension (author's own creation).

It has been a long time since the related literature (e.g. Robbins and Judge, 2017) has anticipated a change from a mechanistic structure, highly fragmented, centralized, and formal, to a more organic model in which companies are flatter, less formal and above all more adapt to the demands of the new digital context (see Figure 3.13).

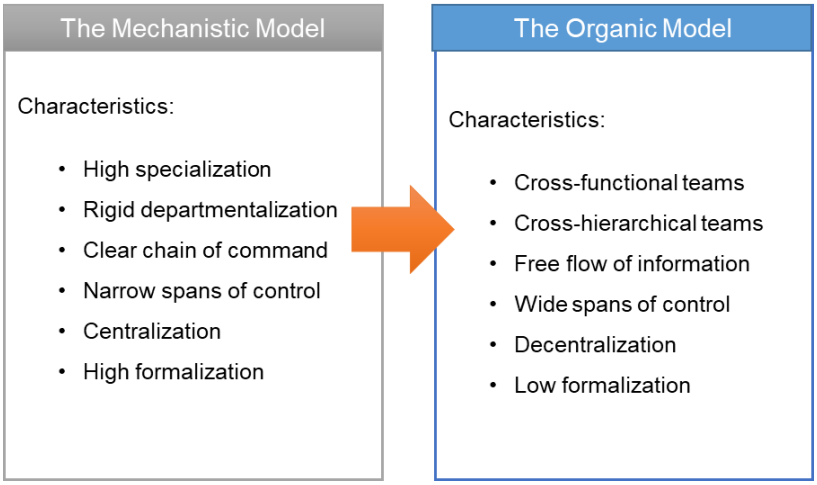


Figure 3.13 Differences between the Mechanistic and Organic Models in organizational structures (adapted from Robbins and Judge, 2017).

Considering the need for organizational agility required by the digital context, this proposal sees the organizational structure of the digital company closer to that described by the organic model.

3.2.3.3 Managing the organizational structure dimension

The organizational structure has been traditionally documented in an organizational chart. This practice is common in almost every company (see Figure 3.14). A careful design of a planned evolution of the structure considering the short and long-term objectives of the company's DT, as well as timely updates of the organizational chart, are paramount to the realization of the digital strategy.

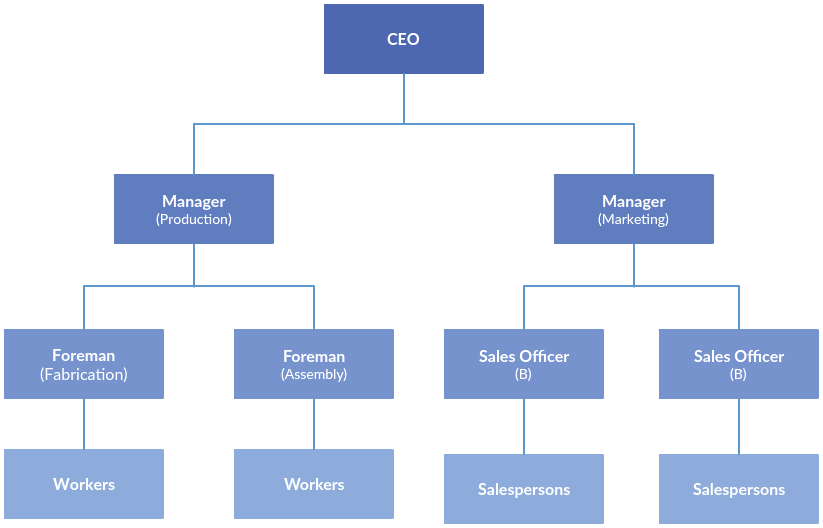


Figure 3.14 Example of an organizational structure.

(source: https://creately.com/diagram/example/gsy3ayzi8/organizational-chart-for-transport-company)

The design of the structure implicitly defines its characteristics. For example, multiple levels of authority equal narrow spans of control which results in less freedom for employees. It is important that the design, therefore, contemplates the key features of the digital company envisioned. The management of the evolution of this dimension during the DT should combine in a coordinated way the changes in the structure and the evolution of its characteristics towards a more organic layout, as mentioned before.

3.2.4 Competencies dimension

3.2.4.1 Introducing the competencies dimension

Technology is certainly offering powerful capabilities to increase the company's agility to respond to the demands of the market. Nevertheless, the "people" component in a Socio-Technical System (STS) continues to be critical for the speed of this response. In this proposal, employee competencies along with organizational culture are the main dimensions of the social side when considering a company as an STS.

According to the literature review performed in this work (see Chapter 1, Section 1.2.4), 9 out 10 of the available proposals take into consideration the competencies' dimension as a requirement

of the company's DT. The approach of those who do include them, however, focuses on the technical competencies that accompany the introduction of digital technologies (see Figure 3.15).

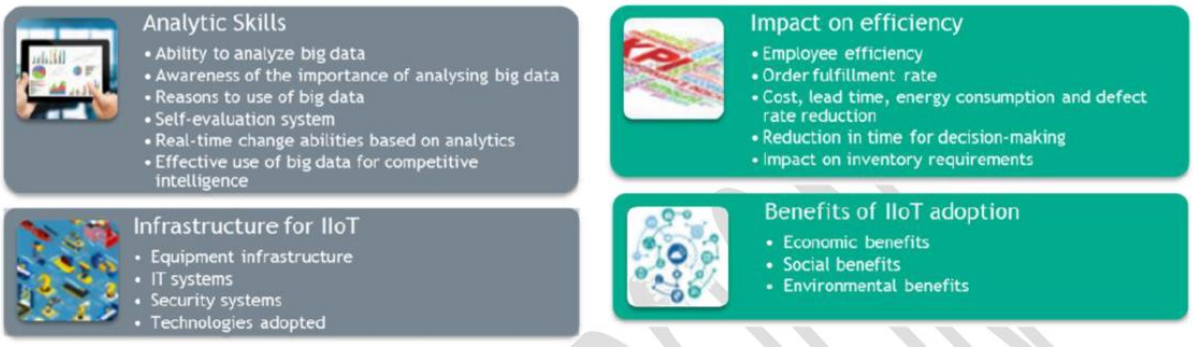


Figure 3.15 Example of the representation of the competencies dimension in current proposals (Scremin et al., 2018).

As it is observed in the example, research literature regarding the competencies required in the digital context focuses on "digital" skills, not the entire range of competencies needed. Even when they are used as synonyms, the difference between skills and competencies here is also important. While skills are *"a special ability to do something"* (Cambridge English Dictionary, n.d.), competency is "*the ability, encompassing knowledge, skills, and attitudes of an individual to perform adequately in a job*" (Rosas, 2006). Then, it is the competencies that combine many skills and translate them into how well a set of skills, combined with knowledge, behaviors, and attitudes, are applied successfully.

Understanding that competencies are a broader concept than skills, this work focuses on the employee competencies as a more direct contributor to a company's DT. In literature, there are many general competencies frameworks proposed. More recent literature, however, focuses on identifying the competencies required to be performant in the new digital context (see Table 3.4). See Appendix 3.2 for a complete list of the competencies included in the presented proposal.

Table 3.4 Categories of competencies related to the digital context (Prifti et al., 2017).

Groups (Big Eight)	Competency categories
Leading & Deciding	Deciding and Initiating Action
	Leading and Supervising
Supporting and Cooperating	Working with People
	Adhering to Principles and Values
Interacting and Presenting	Relating and Networking
	Persuading and Influencing
	Presenting and Communicating Information
Analyzing and Interpreting	Writing and Reporting
	Applying Expertise and Technology
	Analyzing
Creating and Conceptualizing	Learning and Researching
	Creating and Innovating
	Formulating Strategies and Concepts
Organizing and Executing	Planning and Organizing

Groups (Big Eight)	Competency categories
	Delivering Results and Meeting Customer Expectations
	Following Instructions and Procedures
Adapting and Coping	Adapting and Responding to Change
	Persuading and Influencing
Enterprising and Performing	Achieving Personal Work Goals and Objectives
	Entrepreneurial and Commercial Thinking

In the next section, the proposal of changes in the competencies dimensions is laid out by taking an approach that answers to the immediate needs of the digital initiatives and, at the same time, builds the competencies needed by the digital company envisioned.

3.2.4.2 Changes in the competencies dimension

Each of the digital initiatives requires a distinct set of competencies from the employees involved, not only for their design and implementation, but also for their operation once they are implemented. Moreover, in the long term, to achieve a digital company status, all employees (human capital) must be aware of the digital context and acquire a unique set of competencies to be able to operate in the new digital environment. In the proposal of this work, the short-term planning of the initiatives should contribute to the long-term vision of the company and the role they want to play in the digital context (see Figure 3.16).

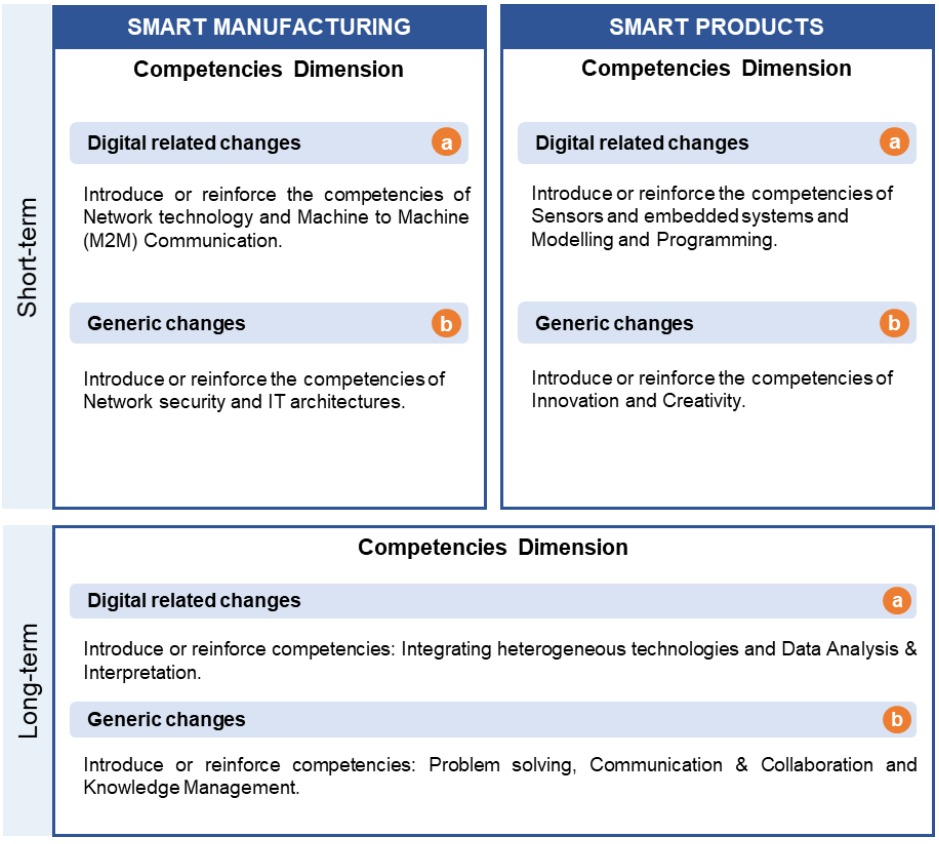


Figure 3.16 Examples of changes in the competencies dimension (author's own creation).

The more an initiative advances to the side of value creation, the more competencies such as innovation and creativity are required. Identifying current and future needs according to the digital strategy for a DT will allow the company to prepare the requirements for training or recruitment to ensure the achievement of the objectives.

3.2.4.3 Managing the competencies dimension

A complete and accurate mapping of the competencies of the company employees is a requirement for an agile response to identifying the requirements in this dimension during the different stages of a DT. The tool proposed to achieve this task is a Competency Map. A competency map allows for building the inventory of the competencies of the company's employees (see Figure 3.17).

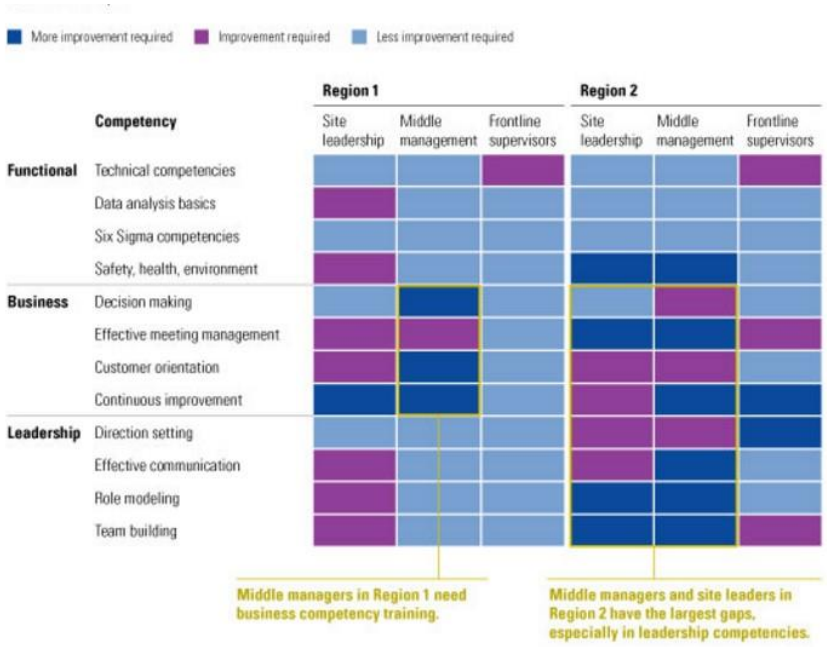


Figure 3.17 Example of a Competency Map.

(source: https://www.upsteem.com/blog/what-s-your-staff-best-at-map-their-competencies-and-find-out).

As is shown in figure 3.17, the "map" in a matrix layout presents the status (colors) of each competency (rows) for each job position (columns). A competency map can serve many functions beyond being an inventory of the employee's competencies, and it can be particularly useful for planning. In this proposal, the main objective of the map is to have an inventory of existing competencies that allows to quickly identify those needed for implementing each digital initiative and building the competencies of the digital company. This information should be complemented with an analysis of which positions, new or existing, should possess the required competencies (organizational structure dimension).

Following the identification of the competencies required for the DT and the specific level of development needed, a detailed plan should be defined and aligned with the DT's main milestones. Different tools can be used for the development of employee competencies, but training and its different modalities seem the most widely used.

3.2.5 Organizational culture dimension

3.2.5.1 Introducing the organizational culture dimension

The new digital environment presents new challenges to companies, and consequently, they must adapt their collective behavior represented in their culture to succeed under the new conditions. Organizational culture is commonly defined as *"the pattern of shared beliefs and values that give members of an institution meaning and provide them with the rules for behavior in their organization"* (Davis, 1984).

In this proposal, organizational culture is seen as a powerful support for introducing change in a company. In this dimension, two types of traits are identified, the generic cultural traits that shape a company's culture and a selection of specific cultural traits that are associated in the literature with scenarios of constant change and innovation such as the one presented by the digital context.

The generic traits of an organizational culture focus on the classical characteristics measured in companies that consider the importance of teamwork, competitiveness, and, more recently, contemporaneous subjects such as innovation (see Table 3.5).

Table 3.5 Cultural traits that shape organizational culture (Robbins and Judge, 2017).

Cultural trait	Brief description
Innovation	The degree to which employees are encouraged to be innovative.
Risk-Taking	The degree to which employees are encouraged to take risks.
Attention to detail	The degree to which employees are expected to exhibit precision, analysis, and attention to detail.
Outcome orientation	The degree to which management focuses on results or outcomes rather than on the techniques and processes used to achieve them.
People orientation	The degree to which management decisions take into consideration the effect of outcomes on people within the organization.
Team orientation	The degree to which work activities are organized around teams rather than individuals.
Aggressiveness	The degree to which people are aggressive and competitive rather than easy-going.
Stability	The degree to which organizational activities emphasize maintaining the status quo in contrast to growth.

The characteristics of the digital context, such as the fast-evolving technological landscape, demand that companies cultivate a type of culture that embraces change as a constant. In this type of culture, new traits become relevant and defy previous conceptions. An example of this is seeing mistakes as a learning opportunity, something that previously was severely penalized and now enables experimentation in a safe environment that fosters creativity and innovation (see Table 3.6).

Table 3.6 Cultural traits associated with the digital context (adapted from Robbins and Judge, 2017).

Cultural Trait	Brief description
Change receptiveness	The degree to which employees are encouraged not only to embrace constant change but to shape it.
Communication & collaboration	The degree to which employees are encouraged to communicate and collaborate.
Trust in Processes & Information Systems	The degree to which employees trust the company's processes and information systems.
Experimentation with new technology & processes	The degree to which employees are encouraged to experiment with new technology and learn new ways of operating.
Learning from mistakes	The degree to which employees are expected to recognize the value of mistakes as a learning opportunity.
Continuous learning	The degree to which employees are encouraged to keep learning throughout their lives.
Knowledge sharing	The degree to which employees are encouraged to share their knowledge and the communication between the people who possess the knowledge and the people seeking it.
Agility embracement	The degree to which employees understand the importance of agility.
Data-based learning and decision-making	The degree to which employees use information and base their learning and decision-making on actual data instead of their gut feeling.
Leadership style	The degree to which the company leadership adopt a more flexible approach to decision-making and gives people more leeway towards faster decisions.

The combination of the configuration of both sets of traits will constitute in the long-term the organizational culture of the digital company.

3.2.5.2 Changes in the organizational culture dimension

Regarding the generic cultural traits, different levels of display of each of those traits must be defined in each of the stages of the DT. In the short term, the nature of the initiatives and the degree of change required will demand a different configuration. For example, cultural traits such as “innovation” may be more important for initiatives of smart products and services than for those focused on smart manufacturing. This evolution should be designed with the final configuration in mind that will correspond to the long-term objective depending on the digital strategy.

The type of change that a DT represents and the challenges inherent to the digital context has opened a new research path to explore the traits of the organizational culture that are compatible with this context. As the company’s culture serves as a support of the transformation efforts, certain characteristics such as the willingness to experiment and to embrace risk by learning from mistakes become an asset in the new circumstances (see Figure 3.18).

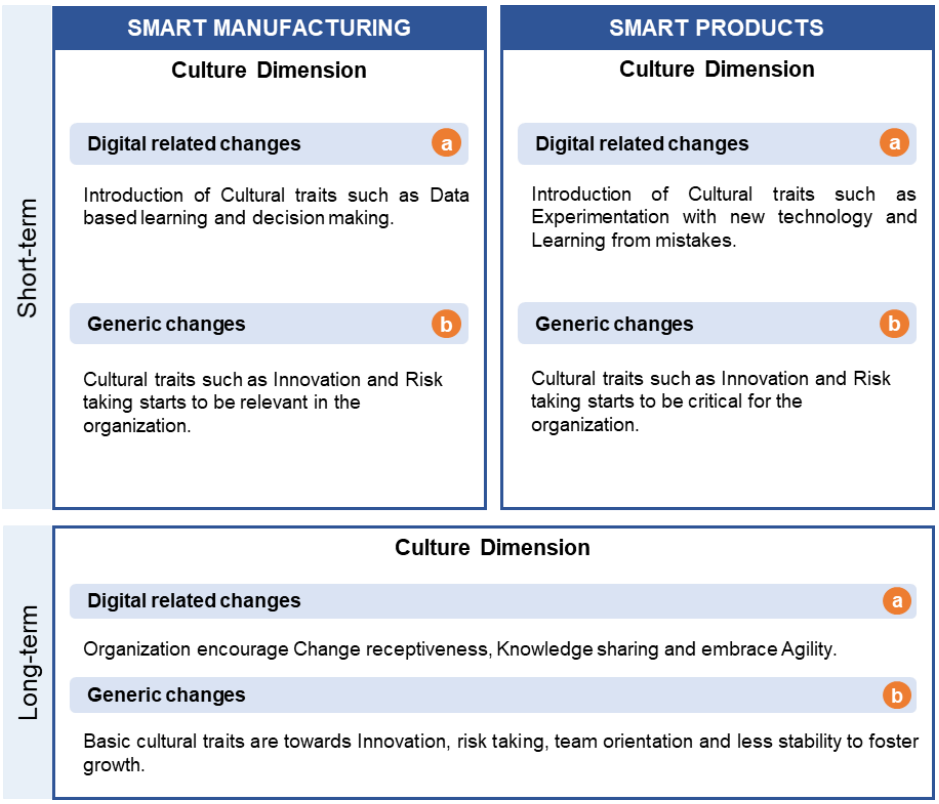


Figure 3.18 Examples of changes in the organizational culture dimension (author's own creation).

The vision of the digital company that each company ambitions to become should involve a precise definition of the traits of the culture that will better support the long-term vision and should align every short-term design to that objective.

3.2.5.3 Managing the organizational culture dimension

The documentation of the organizational culture traditionally presents the set of beliefs and values of a company and the expected behaviors. More recently, there are proposals of tools to help with the documentation and communication of the culture to the company's personnel. A culture deck is a popular example of that. Culture decks are documents that present the company's culture concisely (see Figure 3.19).

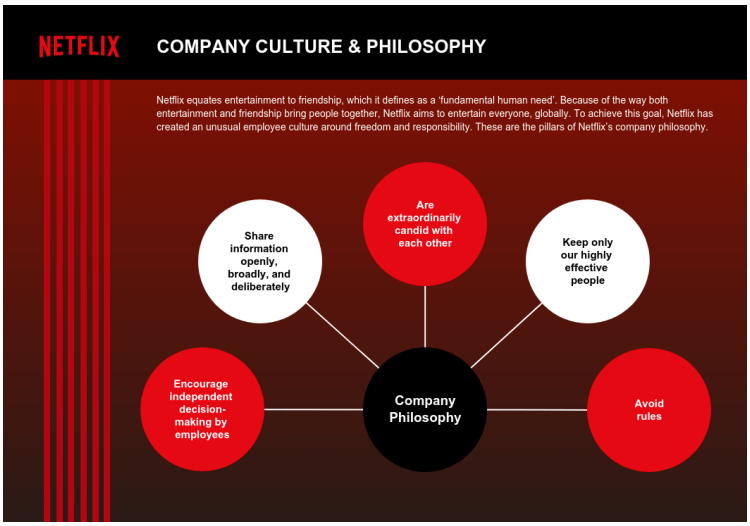


Figure 3.19 Example of a company's Culture Deck.

(source: https://venngage.com/blog/netflix-culture/).

Designing the organizational culture, documenting it, and properly communicating it to the company's employees is a critical step in making culture the cornerstone of a DT's success.

3.3 Business dimensions' interactions

The interactions between all the business dimensions are present in every implementation of changes during the transformation. Their shape and intensity, however, should vary according to the type of initiative pursued and the gap between the initial and target state of the affected factors in each dimension. In this section, an explanation of the interactions is presented as an example of the dynamic expected during a DT. Additionally, it is relevant to recognize the kind of effect the company's internal context has over each business dimensions to consider it when planning the changes inside the company during the DT. This detail is also presented in this section.

3.3.1 Interactions between business dimensions

In Chapter 2, the interactions between dimensions were briefly explained (see Chapter 2, Section 2.2.5.6). In this section, the type of expected interactions is described. Before presenting those interactions, it is convenient to elaborate on the reasons for their importance. The notion of the interactions between what here is labeled as business dimensions is part of the principles of the STS theory and a key building block of this proposal. In the STS theory, a (business) organization is considered as a system in which these variables (business dimensions) interact to produce an optimal result (Trist and Bamforth, 1951).

The principle considers that variables are highly interdependent and that a change in one will result in changes in others to compensate or reject the impact of the one initiating the change (Leavitt, 1964). Change, of course, can be triggered by any dimension, but during a DT, two possibilities can be distinguished. The first one evidently belongs to technology; the introduction of digital technologies is the trigger of changes in all dimensions. The second possibility originates when a process is redesigned. In such a case, technology will act as an enabler of a new design. In this context, it is fair to say that the degree to which these connections are considered and well-managed during the evolution of the business dimensions will contribute to the success of the

company's DT. Figure 3.20 presents a global view of the interdependencies between the business dimensions.

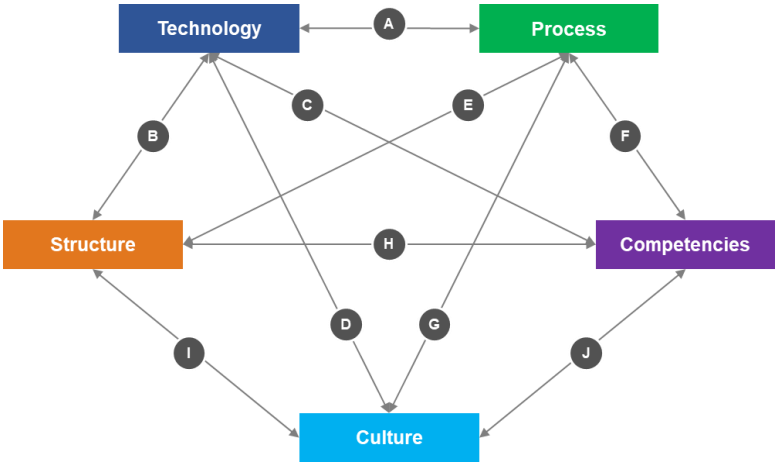


Figure 3.20 Interactions between the business dimensions (author's own creation).

A letter has been assigned to identify each of them.

Each of these interactions is briefly discussed in the following sections.

3.3.1.1 Interaction (A): Technology ←→ Process

(→) Technology is normally seen as the enabler of business processes; however, this is often not the case in the digital context, and technology takes precedent shaping the processes to their capacities.

(←) On the reverse, the appropriate business processes must be created to manage the development and evolution of new digital technologies and its implementation.

3.3.1.2 Interaction (B): Technology ←→ Organizational structure

(→) The structure of the company must adapt to reflect the increasing relevance of technology management by creating the roles and structures required.

(←) In the other sense, technology, specifically the technological framework, will have to support the evolution of the organizational structure towards a more organic configuration.

3.3.1.3 Interaction (C): Technology ←→ Competencies

(→) Every technology introduction should involve an analysis of the competencies required for the employees that are going to interact with them in the associated business processes. The need for new technical competencies to manage the new digital technologies is not restricted to the staff that is in charge of implementing and operating them. The company's awareness of digital technologies should comprise all its employees.

(←) On the other hand, competencies' fast evolution to fulfil the digital requirements will demand the technology provide a more efficient way to keep track of the needs in this aspect.

3.3.1.4 Interaction (D): Technology ←→ Organizational culture

(→) The radically different nature of digital technologies requires an organizational culture that is prepared to deal with significant changes. The continuous evolution of technology will also demand a culture open to constant change and innovation.

(←) As the organizational culture changes to be more innovative, employees will need the technology to support communication, collaboration, and innovation in an efficient and practical way. Knowledge sharing and a way to transform the data into useful insight will also be additional challenges for technology regarding the requirements of the new organizational culture.

3.3.1.5 Interaction (E): Process ←→ Organizational structure

(→) Technology in a DT leads to a new operational model in companies. Consequently, the organizational structure as a support of the processes of the new operational model must also adapt to the changes brought by the digital technologies.

(←) The business processes in charge of designing the organizational structure and implementing the changes in the roles and positions that are evolving should also be modified to cope with constant change.

3.3.1.6 Interaction (F): Process ←→ Competencies

(→) The business processes of the new operational model of the company will demand new competencies for the tasks that are added or modified.

(←) As competencies start evolving faster, continuously, and in a multidisciplinary way, processes will have to adapt to manage the human capital to support their development.

3.3.1.7 Interaction (G): Process ←→ Organizational culture

(→) To implement the changes in the business process, it will be required that the organizational culture is designed to thrive in change scenarios.

(←) The type of culture that will support all the changes in the company will require at the same time that there are processes in place that are congruent with the desired cultural traits.

3.3.1.8 Interaction (H): Organizational structure ←→ Competencies

(→) The new roles added to the organizational structure, as well as those that are being updated, will require to associate them with the necessary competencies.

(←) As competencies start evolving faster, continuously, and in a multidisciplinary way, the structure should contemplate a functional area to develop the human capital with the speed and efficiency required.

3.3.1.9 Interaction (I): Organizational structure ←→ Organizational culture

(→) The evolution of the organizational structure during the initiatives and towards the organic model of the digital company will require a supporting culture that is comfortable with constant change.

(←) The evolution of the cultural traits of the company will also require that the organizational structure is coherently changing to reflect the same values the culture is embracing (i.e., flexibility, adaptability).

3.3.1.10 Interaction (J): Competencies ←→ Organizational culture

(→) The evolution of the competencies of the company's employees, necessary to perform better in the digital context, will require an organizational culture that is supportive of this change.

(←) An organizational culture with traits suitable for the digital context will require the development of the associated competencies by the company's employees. A culture that embraces innovation, for example, will require a certain level of this competency in the relevant human resources, if not throughout the company.

3.3.1.11 Conclusions

The intention of the brief discussion of the possible interactions between the business dimensions in the context of a DT is to bring awareness of the interdependencies that exist between them. The proactive design of the changes in each dimension, considering the possible interactions, is a key aspect of the proposal of this work. Based on the theoretical background of the CDTF, changes in the dimensions must be designed in coordination, looking for their "joint optimization" to achieve the desired performance.

3.3.2 Effect of the company's internal context over the dimensions' change

In Chapter 2, a second consideration of STS theory was also introduced, the view of an organization as an open system (see Section 2.1.2.3). This principle of the STS theory indicates that an organization is affected by its environment. Specifically, the company's internal context can be an asset or a liability for the business dimensions change during a DT effort, depending on its initial state (Nightingale and Rhodes, 2015). To this effect, in Chapter 2, a set of factors of the internal context was proposed to investigate their effect on the development of the DT (see Section 2.2.2). The premise is that the state of some features of a company (internal context factors), such as the level of available resources, must be considered when designing the changes in each of the business dimensions; otherwise, they may affect the development of the transformation.

Previous works related to this thesis have found preliminary evidence of such effect by using an Impact Level (IL) indicator (Liborio Zapata et al., 2020, 2021). Even though there is still much work to do on this subject, the relationship between the state of the internal context is a consideration of the design of the changes in the dimensions. This work considers the evaluation of the internal context state from two perspectives. First, the digital readiness indicator, presented in Chapter 2 (see Section 2.2.3), gives a general sense of the state of the internal context. In this section, the

second perspective is presented in a matrix that shows the characteristics of the company's context that may affect, positively or negatively, each of the business dimensions (see Table 3.7).

Table 3.7 Effect of the characteristics of the internal context over the business dimensions involved in a DT.

The "●" indicates a possible effect of the characteristic over the specific business dimension.

ID	Characteristic/Dimension	Technology	Processes	Structure	Competencies	Culture
IC01	Access to resources for transformation and innovation	●	●	●	●	●
IC02	Adoption of new technologies	●			●	●
IC03	Investment in R&D	●	●			
IC04	Product Customization Capability	●			●	
IC05	Consideration of processes and standards	●	●			
IC06	Leadership engagement	●	●	●	●	●
IC07	Flexibility of organizational culture	●	●	●	●	●
IC08	Strategy definition		●			
IC09	Decision-making		●			
IC10	Organizational Structure formality	●	●	●		
IC11	Organizational Structure agility	●		●		
IC12	Human Resources engagement				●	
IC13	Exposure to human resources development (inside the industry)				●	
IC14	Exposure to human resources development (outside the industry)				●	
IC15	Industry knowledge and experience		●		●	
IC16	Alliances with universities	●	●			
IC17	Alliances with research institutions	●	●			
IC18	Performance of key activities		●			
IC19	Dependence on the collaborative network		●			
IC20	Customer relationship	●	●			
IC21	Supplier relationship	●	●			

According to this information, the state of the "Access to resources for transformation and innovation" (IC01), for example, will affect the changes in all dimensions. Considering that this work proposes to provide a holistic view of the DT, it is essential to emphasize the consideration of all the relevant factors to ensure the success of the DT. The information in Table 3.7 can be of service when designing the changes in the business dimensions, as it indicates the potential problem areas when a factor of the company's internal context is not favorable to its DT.

3.4 Chapter's conclusion and summary

In the proposal of the Conceptual Digital Transformation Framework (CDTF), the key to the company's Digital Transformation (DT) lies in the changes in five business dimensions: technology, business processes, organizational structure, competencies, and organizational culture. In this chapter, the different types of changes that should be considered in each dimension are discussed. Main propositions considered a double evolution of the dimensions to target both the short-term objectives (digital initiatives) and long-term objectives (digital company). The scope of the changes should include not only those that are linked to the digital technologies but those that support them. In managing those changes, documentation of the state of each dimension plays a critical role in the agility with which the necessary changes are identified. Following the theoretical foundations of this work, changes in the business dimensions should be considered as a part of an ecosystem of interdependent factors. Each of the business dimensions' design should consider the impact of its evolution on the other dimensions for a joint optimization that results in the desired performance. Finally, the design of the changes in the business dimensions is not complete without considering the effect of the state of the different factors of the company's internal context can have on them.

Chapter 4: DT in the French mechatronic industrial context

In the last two chapters, through the Conceptual Digital Transformation Framework (CDTF), a new understanding of the DT was presented with two aims. First, to introduce a holistic vision of the phenomenon that identifies its main elements and their role in the transformation (see Chapter 2), and secondly, to identify the specific aspects of the company (business dimensions) that are involved in such a change (see Chapter 3). This vision, however, is entirely theoretical and agnostic to particularities of specific contexts; therefore, its viability in real case scenarios was still to determine.

Consequently, the aim of this chapter is to validate the applicability of the CDTF. The proposed vision is compared to the path of transformation that industrial companies choose to follow to identify possible differences, their reasons, and their consequences. Additionally, in this analysis, the factors in the companies' context that influence those paths of transformation are also identified. The case study research method is used to achieve both objectives that aim to answer the research questions of this work.

The sample of companies in this multiple case study is composed of seven French industrial companies. Though all of them were documented and analyzed for practical reasons, this chapter presents only one case study to illustrate the development of a DT in an industrial context and compare it with the CDTF's main propositions. Similarly, in the analysis part, within-case and cross-case analyses were performed, but only the findings of the transversal analysis (cross-case analysis) are presented in search of conciseness. The complete information on all cases is available in the appendix section.

This chapter is structured as follows. Section 4.1 explains the research method selected and the research design. Section 4.2 focuses on describing the development of the DT of one of the seven French industrial companies included in this study's sample selected as the pilot case. The case study described is rich in insight as it has successfully advanced in its journey towards a DT. Section 4.3 presents the findings of the cross-case analysis performed on the companies of the whole sample. Section 4.4 discusses the main findings of the empirical research. Section 4.5 presents the conclusion and a summary of the chapter.

4.1 Case Study Research method

This section presents the research design for the validation of the applicability of the CDTF's main propositions and the identification of contextual factors that impact the path of the DT through the use of the case study research method.

4.1.1 Research design

As the aim of this work is to provide a frame of reference that provides a holistic view of the DT phenomenon, one that is relatively new, the nature of this research project is exploratory (Voss et al., 2002). In line with its exploratory nature, a case study research method is applied to address the research questions of this work (Voss et al., 2002).

A case study is seen as *"a history of a past or current phenomenon, drawn from multiple sources of evidence"* (Leonard-Barton, 1990). As empirical inquiries, case studies are useful to investigate complex phenomena in real-life contexts (Yin, 2018) and allow researchers to understand them better by building plausible explanations or by discovering causal relationships (Benbasat et al.,

1987; Bluhm et al., 2011). This design considered the use of the case research method in two phases. The first one defined a single case study as a pilot case that refined the procedure and tools of the data collection stage, and the second one used a multiple case study to validate the applicability of the main propositions of the CDTF (see Chapter 2 Fig. 2.7).

4.1.2 DT in the mechatronic industrial context

This research is focused on the industrial sector, a business sector with a key role in the new digital era as not only the users but the producers of the new technology that is revolutionizing the way of operating and doing business (Khurana et al., 2018). The digitalization of industrial companies in Europe is seen as a way to boost the economic growth of the region by enabling companies to compete efficiently in globalized markets (Holz, 2017). Many programs at the regional and country level are developed to boost digitalization. However, manufacturers and assemblers are especially challenged by the prospect of a DT (Khurana et al., 2018).

In France, the situation is not different, and industrial companies are feeling the constant pressure to digitalize. Especially those in challenging contexts such as Small and Medium Enterprises (SMEs) competing in Business to Business (B2B) markets as suppliers of the big assemblers or the ones in high technology markets like the aeronautics or automotive sectors. The situation is no different for Medium-Sized (MSE) and Large Enterprises (LE) competing on a global scale as they face pressure from more digitalized leaders in the market.

DT in the industrial context is often represented through several staple initiatives. These initiatives include the implementation of a smart manufacturing facility and a smart supply chain, the creation of smart products, or the sales of services based on data collected through its sensors (see Figure 4.1).

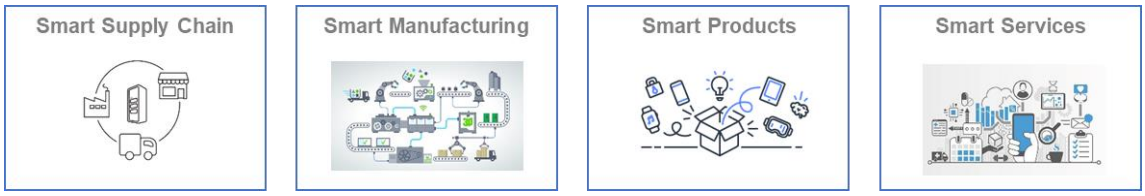


Figure 4.1 Digital initiatives associated with the DT of the companies in the industrial sector (author's own creation).

The trajectory composed of these initiatives is often the archetype of the DT of industrial companies such as those in the mechanical sector. The evolution of the industrial sector towards the digitalization of the production processes is also widely known as Industry 4.0 (see Chapter 1, Section 1.1.5.1). Even though it is a common term in literature and is often used as a synonym for DT, it will not be used in this work. The reason is that its strong focus on technology does not reflect the extent of the transformation of the industrial companies chosen for this work.

More recently, the creation of smart products has taken a more significant role in the DTs of the companies in the sector (Lichtblau et al., 2015). Especially the companies in the mechanical engineering branch are looking for a way to evolve their conventional products into smart ones that can provide more value to their customers. In this sense, mechatronics as a discipline is seen as the medium to guide the basic integration of the required elements towards achieving the desired functionality of smart products (Tomiyama et al., 2019).

The DT of the companies in the sector has the benefit of the available information on the types of trajectories and digital initiatives that can help in drawing their transformation paths. Additionally, the multidisciplinary nature of mechatronics provides them with the set of competencies and knowledge that are basic to start the conception, development, and production of smart products. These key elements make this specific context an interesting one to focus this research work on.

4.1.3 Research controls

In the two previous sections, the research design presented the case study research method to explore the DT of French companies in industrial settings. However, to maintain a minimum of standard conditions, a set of controls were established.

With this objective, the following research controls were applied to filter the companies to include in this study:

1. the company or business unit must be established in France;
2. the company must belong to the industrial sector, either as a manufacturer or an assembler;
3. the company must be engaged in the elaboration of mechanical and/or electrical products.
4. the company must participate in a Business-to-Business market (B2B);
5. the point of departure of every case should be the same, an established industrial company, manufacturing or assembling mechanical and/or electrical products;
6. the company must have achieved a degree of digitization of one or more of its products or services or a degree of digitalization on one or more of its manufacturing or assembling processes.

These controls allowed considering the context while minimizing, in some measure, other contextual conditions regarding the particularities of other industries.

4.1.4 Case selection strategy

The aim of the case selection strategy was first to find a single case in the French manufactory industry that could be analyzed as the pilot of a more extensive study on the subject (Yin, 2018). The intention was to find a case that could be classified as unique, in which the object of study is so rare that it is worth documenting it (Yin, 2018). The context of such cases is so different that it is especially useful for putting the conceptual framework to the test. Though the circumstances of such cases are very particular, it is expected that the study of the choices made in their DT can show some insight to test in a different environment (Miles and Huberman, 1994). In this research, the insight was used to refine the data collection tools before their use in the multiple case study.

As a second step, a more extensive sample was defined. Seven companies (six additional companies joined the pilot case) also in the industrial sector in a variety of scenarios constituted the study's sample. A particular emphasis was put on having different company sizes, but, at the same time, they all shared the same background, sector, industry, and type of products. The details of the case selection strategy are presented in Table 4.1.

Table 4.1 Case selection strategy.

Concept	Definition
Unit of analysis	Firm.
Time frame of cases	Retrospective (research the past).
Number of cases	Single (one case as a pilot) and Multiple cases (six additional companies).
Sampling	Theoretical sampling.
Replication logic	Literal replication (companies with the same scenario) and Theoretical replication (companies representing each scenario).
Sequence of conducting case studies	Simultaneous.

The six new required cases needed were identified with the help of the French Mechatronics Association ARTEMA (https://www.artema-france.org/), whose members expressed their interest in participating, given the relevance of the subject for the group. The companies were selected between those that fulfilled the conditions of the research controls and the case selection strategy. A contact (or more when required) with an executive-level position was defined for each company, given the strategic nature of the subject. All the cases were selected by using theoretical sampling, one that allows the selection of the cases that are more suitable to offer theoretical insight (Eisenhardt and Graebner, 2007).

Table 4.2 presents the main characteristics of the sample for this study. The order in which the companies are presented is based on their turnover. A pseudonym has been assigned to each, as they have asked to remain anonymous.

Table 4.2 Characteristics of the companies in the research's sample.

Characteristic	Company SME 1	Company SME 2	Company SME 3	Company MSE 1	Company MSE 2	Company MSE 3	Company LE
Company type	Family-owned business	Family-owned business	Family-owned business	Family-owned business	Family-owned business	Family-owned business	Corporate
Country Headquarters	France	France	France	France	France	Germany	Japan
Established in (year)	1959	1986	1995	1936	1985	1959	1916
Turnover	~**8**M€	~**12**M€	~**20**M€	~**55**M€	~**380**M€	~**450**M€	~**1010**M€
Staff	~120	~135	~120	~500	~2500	~2300	~5250
Size	Small and Medium Enterprise	Small and Medium Enterprise	Small and Medium Enterprise	Medium-Sized Enterprise	Medium-Sized Enterprise	Medium-Sized Enterprise	Large Enterprise
Business sector	Manufacture of precision mechanical parts	Manufacture of machinery and equipment	Manufacture of metal products	Manufacture of electric motors, generators and transformers	Manufacture of machinery and equipment	Manufacture of electric motors, generators and transformers	Manufacture of gears and mechanical transmission components

Company size was defined according to the parameters established by the law on the modernization of the economy in France based on turnover and staff size (Insee, n.d.).

4.1.5 Data collection

The data for this research was collected from primary and secondary sources (Kothari, 2004). Semi-structured interviews and observations are the main primary sources, while videos, websites, magazines, and presentations represent some of the secondary sources. With the use of semi-

structured interviews, the intention was to keep the consistency of the topics (Corbin and Strauss, 2015), while the use of several methods of data collection allowed triangulation to be achieved, leading thus to an increase in the validity of the data collected (Voss et al., 2002). The triangulation of sources also allowed the process to be free of any bias, since only one researcher was involved in this project, in charge of executing the entire data collection process.

The data collection activities were divided into two stages:

1st. **pilot case study data collection.** The first stage was aimed at collecting the data of the pilot case study to be used later to refine the data collection tools for the rest of the companies in the sample;
2nd. **multiple case study data collection.** The second one was executed to collect the data of the six companies that constitute the multiple case study and to complete the information missing from the pilot case study.

In the next sections, a summary of the activities that were comprised in both stages is presented.

4.1.5.1 The 1st stage of the data collection: a pilot case study

As a first step in the data collection process, a search was performed to gather information through secondary sources regarding the pilot company (Company SME3) in general and the identified events of its DT particularly. Multiple news articles about the company and videos of presentations or interviews with the Chief Executive Officer (CEO) were especially relevant. The exercise aimed to have a general understanding of the context of the company and the digitalization initiatives included in its DT before the collection of the primary data started. Afterward, in-depth semi-structured interviews were held with the company's personnel and one of its technical advisors using an interview guide designed to cover the concepts proposed in the CDTF (see Appendix 4.1).

This structure allowed the interviewer to explore the main topics related to the proposed understanding of the DT. A total of three one-hour interviews with the CEO were held by telephone at three different moments, comprised between the months of July and August of 2020. After identifying the personnel involved in the DT, three additional two-hour interviews were held in person with the personnel in charge of the departments of Operations, Innovation, and Human Resources.

These interviews took place in the corporate offices of the company in October 2020 and were followed by a visit to the plant that is located on the same premises. Just before that, in September 2020, a one-hour interview was also held with one of the external technical advisors that collaborated with the company in the conception phase of their first smart product. The interview was in person and took place in the office of the interviewee. All the interviews, in this case, were held in English. A detailed list of the interviews with the leader, the company executives involved in the DT process, and one of the company's external technical advisors, respectively, is presented in Table 4.3.

Table 4.3 Detail of the semi-structured interviews of Company SME3, the pilot case.

No	Position in the company	Area / External company	Tenure in the company	Duration
1	President and CEO	Direction	14 years	3 hours
2	Director of Innovation	Innovation	5 months	2 hours
3	Director of Operations	Operations	9 years	2 hours

No	Position in the company	Area / External company	Tenure in the company	Duration
4	Director of Human Resources	Human Resources	2 years	2 hours
5	Technical advisor	Technical Centre for Mechanical Industries (CETIM)	25 years	2 hours

After completing the first stage of the data collection activities, the following adjustments in the data collection strategy were performed:

- translation of the interview guide into a questionnaire with the details of a full range of topics that covered the scope of a DT according to the proposed CDTF;
- definition of additional surveys to measure the evolution of specific concepts before and after the beginning of their DT using 5-point Likert scales.

To complete the information of the pilot case study, additional sessions were scheduled with the company's personnel in parallel to the 2nd stage to homologate the data collected from all seven cases.

4.1.5.2 The 2nd stage of the data collection: multiple case study

Once the data collection strategy and tools were improved with the insight obtained from the first stage, the data collection of the six additional companies in the study's sample began. The kick-off of the activities was formalized in one of the official meetings of the members of ARTEMA, in which a plan of the activities was presented. A high-level view of the activities of the plan can be seen in Figure 4.2.

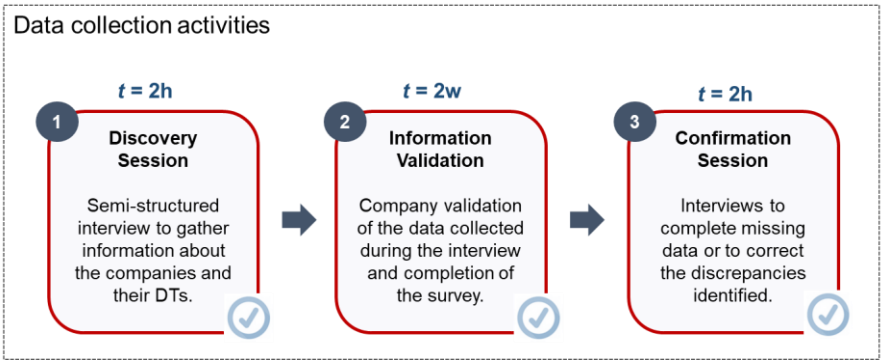


Figure 4.2 Data collection procedure for the multiple case study.

Before starting the data collection activities with the companies in the sample, a search was performed to gather information through secondary sources, as it was performed with the pilot case study. News articles and videos of presentations about the companies and their digital initiatives were collected. This time a database of the main information of all the cases was built in Excel, and news articles and videos were transcribed and uploaded to the Computer-Assisted Qualitative Data Analysis Software (CAQDAS) NVIVO for further analysis.

The data collection activities with the sample started with the discovery session in which a semi-structured interview of 2 hours was held with a company executive. During this session, the

interviews were conducted guided by the DT questionnaire (see Appendix 4.2). During the same session a document with the general information gathered about the company's profile and context was validated (see Appendix 4.3). All the interviews were held in French via videoconference and recorded for their subsequent transcription and uploading to the NVIVO software.

Following the first interview, an additional document was prepared with all the data collected regarding the company's DT (see Appendix 4.4). This document, along with an additional survey to fill out by the company, was sent a few days after the interview. The survey aimed to quantitatively measure the characteristics of the main elements proposed by the CDTF before and after beginning the DT by using 5-point Likert scales (see Appendix 4.5). Along with the instructions to fill out the survey, each company was also asked to validate the document with the data collected related to their DTs and to make the corrections they felt were appropriate to avoid misinterpretations.

After each company sent the document validated and the survey filled out, a second interview was scheduled. Before the second meeting, the survey answers were validated with other sources to adjust them in terms of coherence. During the confirmation session, the information missing was completed, and the discrepancies were solved.

4.1.5.3 The pandemics and the aerospace crisis

The data collection stage was originally planned to take place in early 2020. Two major events, however, delayed the kick-off of the activities. First, in March 2020, France went into a strict nationwide lockdown to face a pandemic situation caused by the virus COVID-19. As a consequence, the French aviation sector fell into what is labeled as the worst crisis in its history. Considering that almost all the companies in the study's sample participate in the aerospace industry as suppliers of plane assemblers, among others, the planning was delayed. Companies had to adapt to new conditions imposed by the lockdown and change their strategies to face the crisis and continue their operations. Consequently, during that period, there was no availability for the interviews. When activities started, arrangements had to be made to the original plans of in-person interviews as the lockdowns continued intermittently throughout the year. Finally, all activities were completed with success, even in the middle of these unusual circumstances.

4.1.6 Data analysis

The data analysis stage was focused on understanding the process of DT through the analysis of the transformation journey of the companies in the study's sample. Therefore, by grounding this analysis on the CDTF main propositions supported by theory, the overall analytic strategy relies on the theoretical propositions of this work (Yin, 2018). The data analysis process was performed by combining two strategies proposed by Yin (2018), *"relying on theoretical propositions"* and *"developing a case description"* to validate the applicability of the CDTF in each case and to organize the findings according to the elements proposed. The technique used for the analysis was *Pattern Matching* to compare the findings of the companies' DT with the DT illustrated in the CDTF (Yin, 2018). The data analysis stage was also performed with the NVIVO software.

4.1.6.1 Formatting and coding

First, all the secondary data sources were coded using the main elements of the CDTF as the first set of codes to start to make sense of the data by identifying the main themes (Creswell and Poth,

2018). Afterward, the survey data was formatted and graphed to facilitate their analysis. In the second phase, the interviews with the companies' executives were transcribed and then sub-sequentially coded with the same scheme. This sequence allowed for an early identification of additional topics to explore in the rest of the interviews. Finally, in the last phase, the rest of the interviews were transcribed and coded. The approach used to code all the collected data was *Directed Content Analysis,* as the study started with a theory that guided the initial set of codes (Hsieh and Shannon, 2005). This approach, combined with the pattern matching technique, allows for a contrast between the empirically-based pattern of the findings with the predicted one based on the theory (Yin, 2018).

Once the data collected was formatted, the process was performed in three main stages following the data analysis strategies and techniques selected. First, all the data collected through the interviews and the follow-up surveys were used to build an individual case of each company. The second and third stages were focused on performing a within-case analysis of each case that was later analyzed transversally through the cross-case analysis. The details of all three stages is presented next.

4.1.6.2 The 1st stage of the data analysis: Individual case study descriptions

All the data collected during the interviews and the follow-up surveys was summarized and processed to prepare a case study of the DT of each company. Here, all the secondary sources and quantitative surveys were triangulated with the data from the interviews to ensure the internal consistency and reliability of the case studies (Jick, 1979). The structure of the cases followed the structure of the elements of the CDTF. The case studies of the seven companies in the study's sample are available in Appendix 4.6. A brief extract of key information from the pilot case study is also presented in the next section (see Section 4.2) as an introduction to the cross-case analysis. The case study descriptions were used to perform the within-case, and cross-case analyses explained in the following sections.

4.1.6.3 The 2nd stage of the data analysis: Within-case Analysis

The first analysis centered on the DT experienced by each company individually. The objective of this approach of the analysis is to become familiar with each case as a unit before the analysis across cases (Eisenhardt, 1989). This analysis used the case study descriptions and the data coded by themes to propose an answer to each of the research sub-questions. The answers were compared with the theoretical answer proposed by the CDTF, and the possible causes for the differences were drafted. The assumption was that building an answer to the research sub-questions will build up an answer to the main research question of this thesis. The individual within-case analysis for each company in this study's sample is available in Appendix 4.7.

4.1.6.4 The 3rd stage of the data analysis: Cross-case Analysis

Once the within-case analysis of all cases was finished, in this last stage, the seven cases were analyzed transversally by each of the research sub-questions. The same procedure of the within-case analysis was applied, but each section emphasized exploring the patterns between the cases.

To produce a report of the results of the analysis that is at the same time complete and easy to read, a three-part structure is followed in the next sections. First, an extract of the pilot case study is presented to give a global view of a DT of a company in an industrial setting that is rich in

information (see Section 4.2). The second part presents the findings of the cross-case analysis of the seven companies and confronts them with the CDTF and the literature (see Section 4.3). Finally, the third part discusses an answer to the research question based on the previous information (see Section 4.4).

4.2 Pilot case study: Company SME3

Company SME3's first digitalization efforts (smart factory) gathered much attention for excelling in its effort under the challenging conditions of being a small company with limited resources. The uniqueness of the case was the reason for its selection as a pilot case. Manufacturing SMEs represent 99% of the manufacturers in France (Khurana et al., 2018). Therefore, their DT is important to achieving the economic growth of the sector. In the following sections, a global view of its DT is presented.

4.2.1 Case background

Company SME3, a French SME that manufactures products for engine manufacturers in the aerospace, automobile, railway, and nuclear industries, was established in the 90s. The company, since its beginnings, has based its strategy on the value of innovation. This focus has been the source of several patented products that have given them an edge over the competition. It was in 2006 that the current CEO (Chief Executive Officer) took over the leadership of the company in an unplanned succession. Around that period, the company, a design studio of only three employees, one patented product, and around €1M in profits, took a sudden turn in its strategy under the new leadership.

The CEO became the new owner in 2009 and developed a more aggressive strategy for the internationalization of the company. From that moment on, and relying on the company's participation in the French government's digitalization programs, Company SME3 formally established its strategic axis, in which its DT was positioned with a key role. After building its own production plant on the outskirts of Paris in 2013, the company became a manufacturer, enabling it to control its production process to meet its growing demand and accelerate the commercialization of new products and services. This change also facilitated the expansion of its product portfolio, composed mainly of mechanical pieces (e.g., fasteners) used as components of engines conceived for the aeronautic and automotive industries. The company now has an additional plant in Poland and a commercial office in the United States of America to handle its internationalization. An overview of the company's main information is shown in Table 4.4.

Table 4.4 Overview of the general information of Company SME3.

Attribute	Information (data from 2019)
Industrial Sector	Industrial mechanics
Staff	~120 employees
Turnover	~22M€
Exports	~85% of the turnover
R&D Investments	~20% of the turnover
Size	Small and Medium Enterprise (SME)
Company locations	The corporate office and main production site are located in France, a 2nd production site in Poland, and an international sales office in the United States.

Attribute	Information (data from 2019)
Product offerings	Fasteners and locks for engines (core business).
Markets	Aerospace and automotive industries mainly.

4.2.2 Company's context

The company's context is constituted by the external environment surrounding the company (see Chapter 2, Section 2.2.1) and the internal context or the situation of the company (see Chapter 2, Section 2.2.2).

4.2.2.1 External environment

The continued efforts of the company to innovate include the regular practice of the CEO and his management team of scanning the external environment for potential opportunities. Consisting mainly of their participation in fairs and industrial events, nationally and internationally, the practice also serves to identify threats to its current position. As a result, they appear very knowledgeable about the configuration of the business environment that surrounds the company (see Table 4.5).

Table 4.5 External environment factors and potential triggers of the DT of Company SME3.

ID	External Factor	Triggers of the Digital Transformation
EC01	**Technology**	The high-speed development of digital technologies and the opportunities it represents.
EC02	**Economy**	The value of the digitalization of the industrial companies for countries' economic growth.
EC03	**Market**	New competition is based on a digital economy and customers that demand smart and connected products/solutions.
EC04	**Politics**	Government programs promoting the digitalization of industrial companies.
EC05	**Regulation**	Strong regulations and standards governing the aeronautics and automotive sectors.
EC06	**Resource**	No factors identified.
EC07	**Environment**	No factors identified.

In the CEO's evaluation of all the relevant factors in the external environment the ones that trigger the digital initiatives were those related to politics and the market. The company's management team knew their big customers in the aeronautics and automotive industries were demanding more digital solutions and took advantage of the support of the government to start the first digital initiative.

4.2.2.2 Internal context

The state of the internal context before the beginning of the DT is summarized with a digital readiness of 2.14 based on a 5pt Likert scale (see Section 2.2.3). Figure 4.3 shows several factors that were on default before starting the DT and that soon had to evolve.

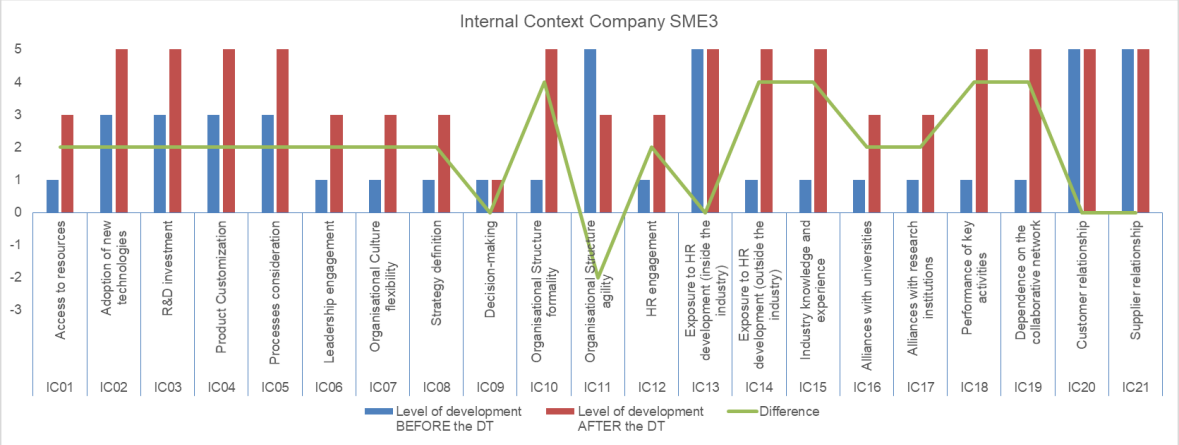


Figure 4.3 State of the factors in the internal context of Company SME3 before and after beginning its DT.

4.2.3 Digital strategy

The business strategy focused on innovation was formally defined when its CEO participated in a 2-year accelerator program in 2017 aimed at helping SMEs to grow and digitalize. This program, managed by Bpifrance, the French Public Investment Bank, was based on 3 pillars: consulting advice to set the business priorities, a training program on specific issues, and companies' networking. Understanding the level of complexity of a DT for companies of this size, the main principle of the program was for them to make progress step by step, according to the companies' challenges that could be addressed with the use of technology.

As a result of the participation in the program, the company's new business strategy established three main axes: innovation, product diversification, and international business. Even though concepts such as transformation or Industry 4.0 are in their vocabulary, there is no association with the conceptualization of a DT that is focused on capability building. The focus is on technology application to realize individual projects; a DT is not identified as an objective for the company or its strategy. Instead, the company sees digital technologies as a medium to solve problems and take advantage of opportunities. Each initiative is based on this logic. The main objective of the business strategy is growth. Grow into a medium-sized enterprise (MSE). To achieve that objective and following government guidance, digital technologies and internationalization were the best options available for French SMEs.

The beginning of the company's DT can be traced back to the formalization of a well-thought-out business strategy and digital technologies as the path to realize it. It was, however, not identified a specific digital strategy. For the company, the digital component is an enabler to propose new solutions to solve problems or create new offerings for its customers.

After a very structured procedure for the definition of the main axes of the business strategy, followed a not-so-formal definition of the objectives and the initiatives to get there. The business objectives derived from the company's strategy targeted growth. Specifically, growth into a Medium-Sized Enterprise (MSE). Therefore, the focus was on the digital initiatives that contributed to that goal (see Table 4.6).

Table 4.6 Digital initiatives included in its DT and their business objectives.

1st Initiative Smart Manufacturing	2nd Initiative Smart Product	3rd Initiative Smart Service
Business objective: Lower costs in France to increase the production	**Business objective:** Increase income with a solution for a new client.	**Business objective:** Increase income with a service for a new market.
A connected manufacturing facility, that incorporates automated production processes and robots, enabling real-time data collection and remote monitoring from different smart devices. Investment in 3D printing technology to explore additive manufacturing.	A smart piece with a sealing technology that enables touchless and wireless measurement of bolt axial load to check if each fastener is accurately tightened.	A real-time machine monitoring, production tracking and manufacturing data collection system with customizable reports, to provide accurate visibility of production processes.

No roadmap was conceived, and the initiatives were started when the opportunities presented without previous planning. Like most SMEs, the company was agile enough to quickly start the initiatives once a decision from the CEO was made (see Figure 4.3, Factors IC09, IC11). The development of the initiatives is closely followed by the leader, who implicates himself in every one of them. Though the timing and nature of each initiative were essentially different, there was a specific objective defined for each of them, and their link with the strategy was always clear.

Company SME3 associates business models with new products and services that require new schemes of commercialization. Therefore, it is only the creation of the new smart service that contemplated the definition of a new business model. For that reason, no business models were formalized to specify the changes in the activities of value creation, value delivery, and value capture that provide guidance during the organizational change. Table 4.7 describes the business models of the three initiatives identified with the help of the company personnel interviewed.

Table 4.7 Business models detailed description of Company SME3.

Element / Digital Initiative	1st Initiative Smart Manufacturing	2nd Initiative Smart Products	3rd Initiative Smart Service
Change in Business Models	Traditional business model with some modifications (sale of physical products)	Traditional business model with some modifications (sale of physical products)	New Business Model (subscription service)
Value creation	Product and resources traceability More transparent management	Product innovation: touchless and wireless sealing measurement	Service innovation: data collection system
Value delivery	More flexible offers, individualized mass production, customization More production options (3D printing)	Smart product with new functionalities Co-creation with customers (product based on relevant needs)	Real-time information for decision-making A reliable, shared and easily accessible interface
Value capture	Cost optimization (increased efficiency in processes and use of resources) and new revenue streams (increased capacity to produce)	New revenue streams (new and existing markets)	New revenue streams (new model based on a subscription service)

Something similar occurred with the resource's assignment. There was not a formal method to calculate the resources required for the planning, design, and implementation of each initiative. The financial and material resources, however, are more proactively considered than the human

resources. Considering the size of the company and the involvement of the leader in the initiatives, the human resources are assigned from the same operation activities or hired on an “as needed” basis when the competencies were not available inside the company.

There was not a formal deliverable from the strategy to the stage of the execution of changes in the business dimensions. The lack of details regarding the initiatives left the DT process without guidelines to consider in the implementation of the changes. The connection between the strategy and the PMMS was also in default, as there were no parameters set for establishing the relevant KPIs for managing and controlling the initiatives towards their success.

4.2.4 Digital Initiatives

The three axes of the company’s business strategy started to guide all its actions and projects. The new strategy led to the creation of three main initiatives that started its journey toward a DT. Table 4.6 shows an overview of the three initiatives pursued by the company. In the next sections they will be briefly introduced.

4.2.4.1 Smart manufacturing initiative

Back in 2017, the company was faced with the challenge of increasing its production capacity due to the commercial success of its products. To be able to produce in France, the objective was to do so at a cost comparable to the selling price of its polish supplier. As digitalization was one of the goals of the accelerator program the CEO was participating in, the company explored the technological options to solve its need.

The Smart Manufacturing (SM) project was complex and full of technical problems as even the most expensive solutions were not easy to implement. After eight months and 30% of productivity losses, a special team of company employees was able to create a robotized machining line with an automated inspection. This initiative allowed the company to face its growing demand, especially outside of France. The new and modern facilities also represented a new level of manufacturing flexibility to customize products and produce new ones in a shorter period of time.

A year later, the company also started to invest in 3D printing to experiment with additive manufacturing. The need behind the strategy was to find an alternative to produce a very small piece that had a high cost using the traditional production method. The objective was to produce the final piece in only one step, replacing three parts with one and reducing its production cost by two. This time the company searched for expert technical support in the Technical Centre for Mechanical Industries (CETIM) to achieve its objective more effectively. The collaboration with the CETIM not only guided the technology selection but also trained a team inside the company to handle it.

Multiple experiments have been done, and the success of the first produced pieces opened the possibility to resume the in-house production of pieces that were previously outsourced. The success of this project ultimately led to the acquisition of a 3D printing machine and the financing of a Ph.D. in partnership with the CETIM and a French university. The objective of the Ph.D. thesis is to demonstrate that the technology is generalizable and that the pieces produced with this technology can be safely installed on a plane’s engine. Now, for each project, they prepare at least two production designs, one based on traditional production methods and the second with additive manufacturing using 3D printing.

4.2.4.2 Smart product initiative

The next challenge addressed by the company began with a customer need. The customer was looking to reduce the time of maintenance of a piece inside of a helicopter's engine that cannot be easily accessed. The objective was then to verify if the piece was in good condition in less time than the two days that it took to check it. Inside the company, an idea was born to eliminate the need to open the engine to perform the status check. The idea consisted of equipping the piece with a miniaturized communication system that would allow to verify its condition remotely.

To realize this idea, the company again sought the support of the CETIM, who helped ensure the integration of the electrical components in the new Smart Product (SP). Composed mostly of technicians and mechanical engineers, the competencies required for that task were not yet developed inside the company of a more mechanical tradition. The team inside the company also developed an application for the mobile readers that will be used to communicate with the piece inside the engine. For this development, they used the knowledge they gathered during the smart manufacturing project.

Two years later, the smart and connected product was ready. The product eliminated the need to disassemble the engine to validate the condition of the piece, dramatically reducing the time of the operation from 2 days to just seconds. The conception and design of a smart product in 2019 that introduced a level of intelligence on a physical piece was part of the diversification strategy of the company. This type of opportunity resulted from the close collaboration with the customer and some partners to solve the problem using an open innovation scheme that enabled faster development and engaged a potential buyer.

4.2.4.3 Smart service initiative

The development of a Smart Service (SS) also in 2019, and the first service ever created by the company, originated from an internal need that grew into a commercial concept. After the smart manufacturing project, an internal team started to build an application for the CEO through which he could manage the line of production. The interest that the project gathered in the industrial community fueled the idea of transforming the internal development into a service for other industrial managers.

The service, which involves the use of manufacturing data to help manage the production performance, is its most recent endeavor and had the vision of continuing its strategy of diversification. The challenge, this time, was more complex than the previous projects and required a higher investment. Taking into consideration the characteristics of the project and the need to realize the idea in the short term, the company decided to create a new branch, a type of start-up that worked in an agile mode.

As the new branch resembles a tech company, its structure included other types of job profiles, with sets of competencies different from those included in the core business. With this new composition, the service was developed, including plug-and-play equipment connected to the cloud (Internet of Things) and a mobile application to access the many functionalities. The project is currently in the validation stage and has several active Proofs of Concept (PoCs) in different factories in France. The company is planning its launch by 2022 with a business model based on a subscription.

4.2.5 Transformation process

In just a few years, its ongoing DT is the result of the different digital initiatives implemented so far in the company. In the analysis of the development of such initiatives, a series of characteristics were observed in the process followed to implement the changes inside the company that aimed to support those initiatives. In this section, the focus will be on the changes inside the business dimensions.

The outcomes of the digital strategy to the DT were different in each of the initiatives of the company. For the SM and SP, there was no deliverable between the strategy stage and the implementation of the change. The indication of the implementation was only the description of an idea. By the time the SS initiative was in its conception phase, major changes were implemented in the company towards a more formal approach.

The DT was divided into stages, each representing the different initiatives that constitute the DT of the company (see Figure 4.4). Inside each initiative, however, there is a process that intends to transform each aspect of the company (business dimension) that needs to be adapted to support the technology introduction.

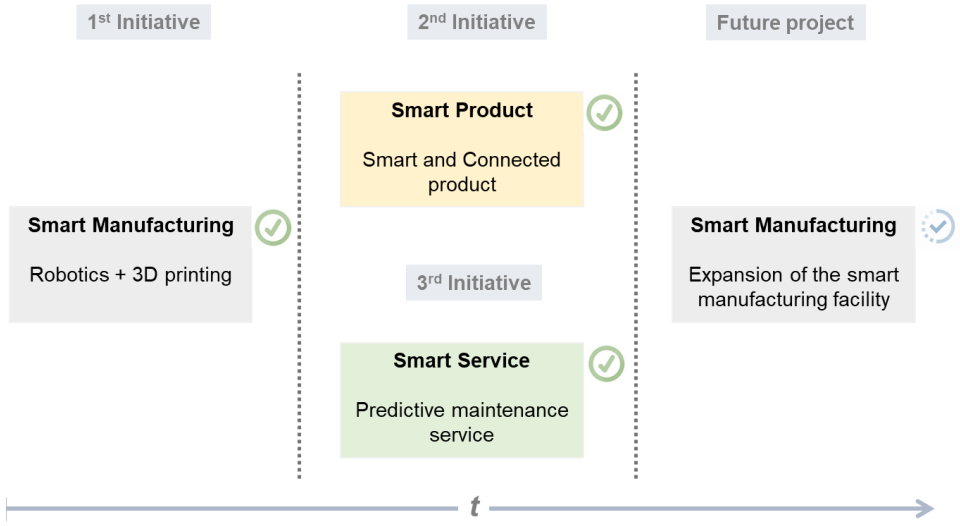


Figure 4.4 Digital initiatives of Company SME3 over time.

Being a business transformation induced by digital technologies, there is a clear focus on this aspect, as solutions are based on technological applications. Consequently, the start of the process of designing and implementing the required changes inside the company was the selection of the technologies that would enable those solutions. Based on that choice, the company identified changes in other dimensions informally and reactively.

In this dynamic, present during the implementation of solutions, only the most immediate and evident changes were identified and addressed. The ones that were not identified on time generated problems that functioned as an indication that something needed attention. In the end, most of the imperative changes in the five business dimensions proposed in the CDTF were identified and implemented, not necessarily in a formal way.

4.2.5.1 Technology dimension

Technology selection was one of the key steps of their process as it was needed to meet the requirements of the digital initiatives. Technological choices were delimitated by the available technological solutions identified in their constant scouting of the market and their efforts to increase the exchange with universities' research units and technology centers (see Table 4.8).

Table 4.8 Summary of the changes in the technology dimension triggered by each DT initiative of Company SME3.

Dimension / Digital Initiative	1st Initiative Smart Manufacturing	2nd Initiative Smart Products	3rd Initiative Smart Service
Overview	Technologies used are focused on the digitalization of the line of production.	Technologies used are focused on the digitalization of one of its mechanical products.	Technologies used are focused on the exploitation of manufacturing data to deliver a service.
Technologies	Main technologies introduced: • Artificial Intelligence (AI) for production • AI for maintenance • Sensor + actuators + PLCs • Industrial Robots • M2M communication • Additive manufacturing • Enterprise Resource Planning (ERP) • Manufacturing Execution System (MES)	Main technologies introduced: • Electronic components • Embedded Sensors • Processors • Communication System • Software This product is in the first level (of five) of intelligence "connectivity."	Main technologies introduced: • Internet of Things (IoT) • Cloud computing • Big data • Analytics • Software

The low maturity of some new digital technologies, however, came with many challenges for the company, as their results were not always predictable, and not many people knew how to handle them.

4.2.5.2 Competencies dimension

New technology introduction drove the need for specific competencies not available in an organization that had purely mechanical origins. Competencies related to electronics and information technology and other more technical competencies were the first to be integrated to handle the first digitalization initiatives. Subsequently, as the required competencies became more sophisticated, it was more difficult to develop them internally in a short period of time. It was also difficult to find them outside. The scarcity of people with the required competencies to realize their projects was a critical challenge for the company. Then, technological centers that had the resources with the required expertise, like the CETIM, filled that need and became critical for the success of the initiatives. For the company, those centers also provided them with the project management competence that gave structure to the initiatives.

Table 4.9 shows, however, that the focus of the competencies acquired was on the technical side. Other more generic competencies, such as innovation or project management, started to be introduced when they became more critical as the company started to handle more significant and complex projects.

Table 4.9 Summary of the changes in the competencies dimension triggered by each DT initiative of Company SME3.

Element / Digital Initiative	1st Initiative Smart Manufacturing	2nd Initiative Smart Products	3rd Initiative Smart Service
Overview	Competencies needed for putting in place and operating the robotized line of production.	Competencies needed for designing the new product, but also for managing the project. Later competencies for commercializing the product will be required.	Competencies needed for designing the new service and establishing a new branch of the company.
Competencies	Main competencies introduced or to be introduced (internal/external): • Robotics and AI • Network Technology • M2M communication • Predictive maintenance	Main competencies introduced or to be introduced (internal/external): • Electronics • Software engineering • Sensors and embedded systems • Data science • Innovation • Project Management • Sales and Marketing for smart products	Main competencies introduced or to be introduced (internal/external): • Electronics • Software engineering • Statistics • Data analytics • Data security • Machine learning • Innovation • Project Management • Sales and Marketing for data services

4.2.5.3 Business process dimension

The company's operational processes, standards, and policies are strongly influenced by the highly regulated markets they currently serve. Consequently, the company's formality regarding this dimension is high (see Figure 4.3, IC05), especially in the processes surrounding the product's conception and production. The changes in the company's process map after the implementation of the digital initiatives were appropriately handled. However, the combination of the company's fast growth and its DT has made them intuitively integrate several practices that helped them to manage the growing complexity of the current strategy (see Table 4.10).

Table 4.10 Summary of the changes in the business process dimension triggered by each DT initiative of Company SME3.

Element / Digital Initiative	1st Initiative Smart Manufacturing	2nd Initiative Smart Products	3rd Initiative Smart Service
Overview	Processes related to production changed due to automation, but others are recognized to change but are not documented.	Processes are expected to change as the new products go beyond the limits of the enterprise and will require new competencies.	Processes are expected to change as the new services go beyond the limits of the enterprise and will require new competencies.
Processes	Main processes changed or created formally: • Production • Quality • Maintenance	Main processes changed or created formally: • Manufacturing (change) • Product design (incorporates new disciplines e.g., mechatronics) • New product development • Innovation & co-creation	Main processes changed or created formally: • Manufacturing (change) • Product design (incorporates new disciplines e.g., data scientist) • New service development • Innovation & co-creation
		Main processes TO BE changed or created formally: • Prospection & Needs Identification • Sales and Marketing	Main processes TO BE changed or created formally: • Prospection & Needs Identification • Sales and Marketing

Element / Digital Initiative	1st Initiative Smart Manufacturing	2nd Initiative Smart Products	3rd Initiative Smart Service
		• Patent and contracts • Supplier validation to meet new requirements	• Patent and contracts • Supplier validation to meet new requirements
Practices	Informal practice of the following processes: • Technology scanning • Research management	Informal practice of the following processes: • Technology scanning • Innovation management • Research management • Knowledge Management Product conception through co-creation • Feasibility process with external expertise	Informal practice of the following processes: • Technology scanning • Innovation management • Research management • Product conception of data services • Feasibility process with external expertise

Practices such as innovation, experimentation with new solutions, and technological scanning are performed and have proved essential to the success of the initiatives. However, the lack of formal documentation has slowed their maturity and has the risk of being concentrated on one or two resources (e.g. the company's CEO). Management experiences with the first initiatives helped them to identify that these types of practices are the pillars for strategy execution, and currently, they are working on the evolution of the company's process map. These changes are linked with an important effort to redesign the organizational structure.

4.2.5.4 Organizational structure dimension

Changes in the structure were more reactive and temporal at the beginning, adding one or more resources to handle the initiatives, but eventually, the higher complexity of the projects led to a restructuring of the organization. In this dimension, the changes happened in two senses, size and configuration (see Table 4.11). The evolution of the structure in terms of size has been substantial. The company went from 3 to 120 employees to respond to company growth in the last years. However, the DT is more related to the second type of change, the reconfiguration of the structure to deal with the new challenges.

Following the implementation of the initiatives, new positions were created, and the scope of some of the existing ones was modified or even transformed. The operators of the line of production are an example of this. A relocation of human resources to positions of more added value followed. As happened with the other dimensions, these first changes were more of a reactive adaptation to what was needed at the moment. The leadership is currently working on a more formal and proactive approach to designing the organization's structure with the vision of the future in mind. In this sense, the more remarkable change is the creation of a Direction of Innovation that will handle all the activities related to the development of new products and services.

Table 4.11 Summary of the changes in the organizational structure dimension triggered by each DT initiative of Company SME3.

Element / Digital Initiative	1st Initiative Smart Manufacturing	2nd Initiative Smart Products	3rd Initiative Smart Service
Overview	In terms of size, the structure of line operators was reduced to half.	Changes in size are limited to a few new roles as the commercialization of the product has not started.	A new branch of the company called KEYPROD is created to manage the new service.

Element / Digital Initiative	1st Initiative Smart Manufacturing	2nd Initiative Smart Products	3rd Initiative Smart Service
Organizational Structure	Some roles, however, evolved to the following labels: • Machinist 4.0 • Information Technology (IT) Manager 4.0 • Cutting tool prep 4.0 • Quality Management 4.0	New roles are introduced as the company advance in its DT: • Innovations Director • Electricians (design team)	A completely new organizational structure is created for this new branch of the company. New roles are introduced as the company advance in its DT: • IT experts • Data Management experts • Marketing experts

The organizational structure design is now taking a turn to prepare the company to fulfill the objectives of the strategy and the challenges of an increasingly digital environment.

4.2.5.5 Organizational culture dimension

The organizational culture has always been a strong lever from the beginning, but it came to a halt and did not develop further. The high priority of this dimension in the management's agenda is something to note (see Table 4.12). The company's leadership early identified that culture was something to craft and cultivate to fulfill all the plans designed for the future. One of the things that helped to create an innovative and open culture was the fact that the company started with only three employees, which allowed the leader to start permeating the kind of culture he believed in early on. When growth started to happen, considerable care was placed on the recruitment and selection of human resources that had a set of beliefs and values compatible with those included in the company's culture.

Table 4.12 Summary of the changes in the organizational culture dimension triggered by each DT initiative of Company SME3.

Element / Digital Initiative	1st Initiative Smart Manufacturing	2nd Initiative Smart Products	3rd Initiative Smart Service
Overview	The culture began to be defined as the company grew.	The culture is defined as innovative.	The culture has evolved as a risk-taker toward digital initiatives.
Organizational culture	Main characteristics in the stage: • Encourage innovation and experimentation • Encourage collaboration • Recognize the value of mistakes	Main characteristics in the stage: • Encourage innovation and experimentation • Encourage collaboration • Embrace and empower change	Main characteristics in the stage: • Encourage innovation and experimentation • Encourage collaboration • Embrace and empower change • Tolerance and receptivity to risk

The company's culture is highly regarded as one of its strengths and has contributed to the fast development of its initiatives. However, in this dimension, there is a lack of formalization, and the strength of the culture relies heavily on the leader's example. No plans were identified in this dimension to formalize the documentation of the culture. In addition, most of their development was built at the beginning, but they did not continue to proactively develop it to more mature characteristics, such as regarding errors as learning opportunities. There is, therefore, a need identified by the leader to continue the evolution of culture to gain more agility.

The specific findings identified in the business dimensions indicate that there is a focus on the implementation of the changes that are the most essential, and the ones that are not immediately needed are left behind. Consequently, there is also a lack of development of variables inside the dimensions that do not have a direct impact on the changes but that can facilitate the introduction of new technologies faster and more efficiently.

4.2.6 Performance measurement and management

Regarding the performance measurement of the DT, the company relies upon its current Key Performance Indicators (KPIs) and how those metrics are affected by the initiatives' development and implementation. For example, when introducing digital technologies to the production line, attention was focused on how the process efficiency was affected by the delay in the implementation. The second (SP) and third initiative (SS) were handled by external experts that managed the initiatives as a project. Therefore, the focus shifted to following the metrics of project completion.

The CEO is concerned about how to measure innovation, as it is the main axis of the business strategy but has struggled to find the proper indicator that gives a sense of how well it is developing it. His recent appointment of a Director of Innovation is intended to formalize this function, and indeed one of the main tasks of the new executive is to restructure the organization and to formalize a way to keep track of the advancement in this area. In the vision of the CEO, however, the expected benefits of a DT go beyond the monetary ones defined by the business objectives. For the company, qualitative benefits such as the image of an innovative and modern company not only attract young talent but give certainty to new and potential customers. Nevertheless, it was not identified a plan to measure the maturity of the business dimensions towards a company that has the capabilities to innovate using technology in an agile and efficient way. As a KPI to measure maturity, it was not identified; the company does not use any type of assessment in this regard.

Instead of the use of references to guide its DT, the company rather searches for the support of advisors mainly to guide the technology selection and implementation. This support is found in technological centers such as the CETIM or in the universities. This support also helps in providing the technical competencies that the company still does not have. In the case of Company SME3, the projects with the CETIM have sometimes included technical training for the employees, as in the implementation of the 3D printing initiative.

4.2.7 Conclusions

The journey towards a DT of Company SME3 is remarkable. Three important initiatives in only five years have shaped its successful journey. The vision of the company and the changes implemented enriched the organization's capabilities for its future digital initiatives. There is evidence of an evolution in the business dimensions gained with each initiative implemented that led to a progressive DT of the company. It is because of this evolution that the development of the most recent initiative, the implementation of the smart service (SS), presented fewer challenges for the company than the digitalization of the manufacturing process (SM).

Looking to accelerate its evolution, the company is investing in restructuring the organization and becoming more formal in its approaches.

4.3 Findings: Cross-case analysis

The case study presented in the last section showed a global vision of a DT in an industrial setting. Next, in this section, the findings of a cross-case analysis are presented to show a comparison of the DT of industrial companies in a variety of scenarios. The cross-case analysis of 7 companies offers great insight into how companies with particular contexts and in different stages of their transformations handled their DT efforts. Those insights are used to answer the research sub-questions and will provide the elements to discuss an answer to the main question of this thesis.

To facilitate the reading of the analysis, this section makes use of the most relevant examples in each section. Nevertheless, the information on all the cases can be found in the appendix section (see Appendix 4.6 for the case study descriptions and Appendix 4.7 for the within-case analysis of each of the case studies).

4.3.1 What is a DT, and what is the objective that it pursues?

The practical definition of a DT is still a subject of debate or confusion. In Chapter 1, this work explored the many definitions available for the concept and based on a careful analysis; a definition was chosen. The chosen definition conceptualized DT as a capability-building process that prepares the company for the digital challenges. The industrial reality, however, shows that the companies' understanding of the DT concept and the type of objectives they assign it depends on their knowledge of the subject and of those that support them in their efforts. Their understanding of the concept is shown when defining the focus and objective of their DTs (see Table 4.13).

Table 4.13 DT focus and objectives of the companies in the study's sample.

Company	**Focus of the DT** (capability-building vs initiatives' implementation)	**Objective of the DT** (company's DT)
SME1	Digitization of products	The company's digitalization objective is to co-create high-tech digital solutions with its potential customers by developing the "mechatronicity" of its products.
SME2	Digitization of products	The current focus is on the digitalization of products and the introduction of digital tools to improve the company's performance and prepare for digital transformation.
SME3	Solving problems or taking advantage of opportunities	The objectives are focused on realizing the business strategy related to the innovation and diversification of the company.
MSE1	Digitalization of operational processes	The DT has three main objectives. First, to increase the margin and shorten delivery times by automating low-value-added tasks to deliver quickly. Secondly, to increase turnover via smart products or smart services, for example.
MSE2	Digitalization of production processes and digitization of products and services	Revenue growth and value creation through services, especially those associated with connected products, are seen as one set of objectives, as are the efficiency, productivity, and quality improvement of production processes.
MSE3	Digitalization of operational processes	The company's stated objective is twofold: to increase productivity and improve the comfort of its employees. But the aim is also to be a Lean organization allowing the delivery of the product in 5 days for each order and improving the processes permanently.
LE	Digitalization of production processes and digitization of products and services	Product: to be able to propose exploitation of the data, of the sensors which are provided to the customers and to monetize this service associated with the data. This is what is being done through the development of monitoring, to be able to provide customers with equipment control and failure prediction.

Company	Focus of the DT (capability-building vs initiatives' implementation)	Objective of the DT (company's DT)
		Processes: the digital transformation of production tools, reducing machine breakdowns by controlling processes with supervision.

From this information, it is deduced that none of the companies in the study's sample aims for a DT of the company or the development of its digital capabilities. Companies seem to have a short-term view of the DT, one that is focused on the initiatives to implement or the technologies to introduce. Furthermore, most often, those initiatives are fragmented and managed by teams that do not communicate. Company MSE2, for example, has created two digital initiatives, one dedicated to digitalizing processes and another focused on creating smart products and services. During the interviews, they declared having realized they need to communicate as they share many subjects that need to be handled together.

In this situation, it is only logical that the objective of the DT targets either the success of the initiatives or the business and performance indicators. In the information presented in Table 4.13, it is identified that companies search for efficiency in processes performance or new revenues through new products and services.

As a consequence of this short-term and disconnected vision of the DT, companies do not achieve their transformation. Without a planned evolution of its capabilities, Company SME3 started each of its initiatives with only the residual capabilities gathered in the previous one. After three successful but problematic and inefficient initiatives, it is understood that to pursue technology as key support of its strategy, the company needs to change to do it properly.

A DT understood as a long-term target should pursue precisely that: a new state of the company that allows integrating technology in an agile and efficient manner. Considering that the companies in the study's sample are targeting the creation of smart products and services on a continuous basis, this type of DT seems more suitable for that goal.

4.3.2 What are DT's main elements and their role during a DT?

Identifying the main elements of the DT and positioning them in their right role is one of the main propositions of the CDTF and one of the main limitations of the current literature. In the previous analysis of the DT process, it is possible to identify the three main elements: strategy, process, and performance measurement and management. In this section, further analysis is made by using the elements and sub-elements defined in the CDTF to validate the state of its presence and the role they played during the DT of the companies in the study's sample.

4.3.2.1 Digital strategy element

The Digital Strategy element is critical in driving the DT of the companies, according to the CDTF's main propositions. Table 4.14 presents the state of compliance of this element and its sub-elements for each company in the study's sample.

Table 4.14 Compliance of the digital strategy element and sub-elements by companies in the study's sample.

Element / Sub-element	SME1	SME2	SME3	MSE1	MSE2	MSE3	LE
Digital Strategy	Not specifically	Not specifically	Not specifically	Yes	Yes	Yes	Yes
Business Objectives	Yes, general	Yes, general	Yes, specific	Yes, specific	Yes, general	Yes, specific	Yes, specific for SM and general for SP, SS
Initiatives	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Roadmaps	No	Yes	No	Yes	Yes, one for each initiative	No	Yes, one for each initiative
Business Models	No	No, Concept associated with new commercial models	No, Concept associated with new commercial models	No, Concept associated with new commercial models	No, Concept associated with new commercial models	No, Concept associated with new commercial models	No, Concept associated with new commercial models
Resources	Self-financing with projects and current teams	Yes	Yes, but partially	Yes, but partially	Yes, but partially	Self-financing, reinvestment of profits	Yes, but partially

As discussed in the previous section, not all companies have a specific digital strategy, though all consider a strategic direction of their digital initiatives. In line with this finding, business objectives also are divided between business-based or project achievement. Both are far from targeting a real transformation of the company.

In terms of more specific plans that support the digital strategy, four of the seven companies studied declare to have a roadmap of their initiatives. However, sometimes those roadmaps are on construction even when the initiatives are well underway (Company MSE2). The reason behind this lag is that the companies find it difficult to detail 5-year plans in a situation that they consider to be full of uncertainty. Technology evolves too fast and for them identifying processes to digitalize has a lower level of difficulty than planning the products and services for the future. They reflect on how to forecast the future and how to anticipate the customer's needs.

Another issue identified concerning the roadmaps is the fragmented view of the initiatives, as the smart manufacturing initiatives are managed separately from the smart products projects. Consequently, the planning and implementation of initiatives appear to be disconnected which prevents the realization of synergies.

The formal description of business models is also missing in all projects. Though most of the initiatives in the sample target some level of smart products, no new business models are envisioned in the short term. New business models are more associated with services when the value capture activities significantly change because of a new way of commercializing them (e.g., subscription models). Nevertheless, there is no mention of business model innovation. They are mostly thinking of following the trends of business models of competitors that are leading the digitalization of the sector.

Resource planning in the companies studied is strongly focused on financial resources. Consequently, human and material resources are not properly anticipated, and in general, resources are rarely considered sufficient to meet the demands of the DT effort. On the one side, there is the complexity of determining the magnitude of a change for which there is no previous reference. For example, when human resources are estimated, they are often limited to the ones

carrying out the project. Therefore, it is complicated when the implementation of digital initiatives requires the participation of personnel from operational areas. On the other side, it is identified that the necessary resources are not assigned if the leader is not convinced of the strategic need of a DT, even in cases in which DT efforts are official. Financial resources are also insufficient to envision real transformation and sometimes rely on a scheme in which the individual results of the digital initiatives must generate the resources to continue the projects. Projects also end up relying on the willingness of human resources to participate in the DT initiatives.

Nevertheless, in Figure 4.5, it can be observed that the perception of companies of the situation is different. They consider that they mostly have access to the necessary resources for the DT (see Figure 4.5, IC01) and that their leaders are well engaged in the company's need to transform (see Figure 4.5, IC06). In fact, generally, both factors of the internal context showed an improvement after the DT began. Going further in the interviews, it was identified that sometimes the DT is seen as an experiment by the leaders, and therefore, there is not a complete commitment to what it implies. Other times the engagement was real, and the money was available, but simply companies have a hard time identifying all the implications of resources of this type of project.

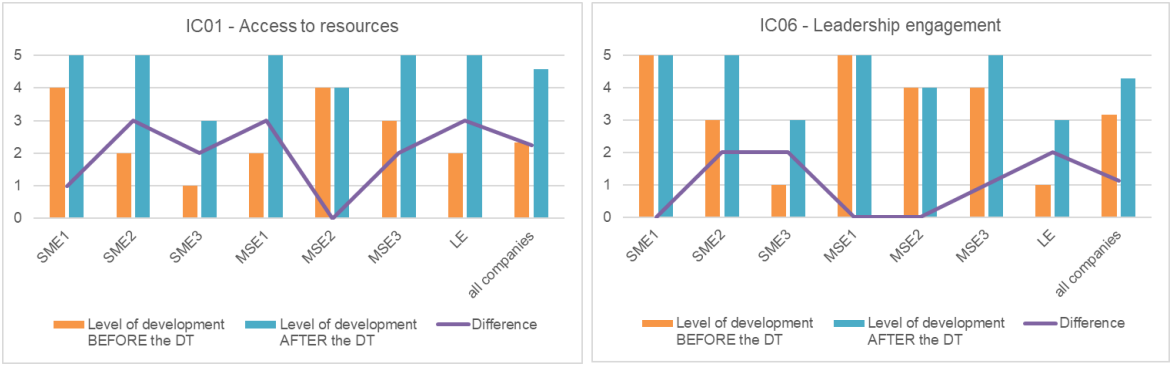


Figure 4.5 Detail of the state of factors IC01 and IC06 in the internal context of companies in the study's sample.

According to these findings, the role of the strategy of driving the DT is not completely fulfilled according to the analysis of the case studies. Even when a strategy is present, the lack of full development of all the sub-elements leaves the DT inside the company without the guidelines to follow to implement the necessary changes.

4.3.2.2 Digital transformation element

In the CDTF proposed, the Digital Transformation (DT) element is critical in performing the changes inside the company that in the short-term will realize the digital initiatives and the DT of the company in the long-term. Table 4.15 presents the state of compliance of this element and its sub-elements for each company in the study's sample.

Table 4.15 Compliance with the digital transformation element and sub-elements by companies in the study's sample.

Element/ Dimension	SME1	SME2	SME3	MSE1	MSE2	MSE3	LE
Digital Transformation	No, but a Business process	No, but a Business process	No, but a Project	No, but a Business Process	No, but a Business process	No, but a continuous improveme	Yes, a specific process for

	oriented approach	oriented approach	Management approach	Reengineering (BPR) approach	oriented approach	nt and BP oriented approach	Research and Innovation
Technology	Yes	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes	Yes, partially
Business Processes	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially
Organizational structure	Yes, partially	Yes	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially
Competencies	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially
Organizational culture	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially

The DT is guided in every case by a method or a specific process. However, the method or process used is not ensuring the coverage of the impacts in all dimensions, that in most cases, are modified in an incomplete and reactive way. Further details of these shortcomings in the business dimensions' changes are shared in Section 4.3.4. of this chapter.

In consequence, the role of the DT element of performing the change inside the organization is also not fulfilled. The main reason identified is that the DT does not receive two critical deliverables from the strategy: the business models and the appropriate resources to realize them.

4.3.2.3 PMMS element

The Performance Measurement and Management System (PMMS) element is critical in controlling the DT of the companies according to the CDTF proposed. Table 4.16 presents the state of compliance of this element and its sub-elements for each company in the study's sample.

Table 4.16 Compliance with the PMSS element and sub-elements by companies in the study's sample.

Element/Sub-element	SME1	SME2	SME3	MSE1	MSE2	MSE3	LE
PMMS	None	None	None	None	None	None	None
References	Associations, industrial fairs and customers	Associations and customers and sales teams	SMEs Acceleration Program, Associations and customers	Top consulting firms and technology integrators	Benchmarking, Associations and customers	Universities and Research & Technology Institutions	None
KPIs	Business KPIs	Commercial success (Products), company image and customer needs satisfaction	Business KPIs	Process performance	Number of Digital opportunities, Proofs of concept and Projects and company image	Process performance	Commercial success (Products) and Process performance
Assessments	Not defined or used	Not defined or used	Not defined or used	Not defined or used	Not defined or used	Not defined or used	Not defined or used

Formal PMMSs to follow up on the DT efforts are non-existent in the companies in the study's sample. Some companies acknowledge the need to measure some related topics, such as

innovation, but declare the complexity of finding the right KPI to do it. Other types of indicators used to measure what they label as DT performance are:

- the number of new patents to measure innovation related to technology,
- the number of digital opportunities identified (and their contribution to the company's success),
- the perception of the company as a digital or transformed company and its attractiveness.

In this scenario, as there are no specific KPIs defined for digital maturity, there are no assessments to validate it. Nevertheless, companies use interesting resources to guide their choices and actions like, for example, relying on other companies' support. In this sense, the participation in industry associations is a popular option. Surprisingly, existing references in the literature are not used to guide their DT efforts.

More professional guidance is provided by consulting firms or through the assistance on specific topics from specialized companies or universities and research institutions. Those methods, however, are mostly only accessible to companies with the available resources. The French government offers support in this regard, especially via the universities and other institutions. However, although the relationship with universities and research institutes is developing in most companies, it is not systematic yet, like some other practices, which leaves room for improvement.

As a result, the function of control is achieved through project management, more associated with the tasks to accomplish, not with the companies' capability building. Managing the DT's success in these terms only means finishing the projects (digital initiatives).

4.3.3 What are the business dimensions involved in a DT and their interactions?

Considering the CDTF propositions, the identification of the business dimensions involved in a DT, and the proper design of their evolution, recognizing the interactions between them, is relevant to success. In the next section, an exploration of the changes considered in each dimension proposed on the CDTF is performed, as well as an analysis of their interactions and how companies handled them.

4.3.3.1 Business dimensions involved in a DT

The individual analysis of the case studies resulted in a homogeneous view of the changes implemented inside the companies. They all have a partial consideration of the changes required in each of the business dimensions as a result of the initiatives' implementation (see Figure 4.17).

Table 4.17 Coverage of the changes in the business dimensions during a DT.

Business Dimension	SME1	SME2	SME3	MSE1	MSE2	MSE3	LE
Technology	Yes	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes	Yes, partially
Business Processes	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially
Organizational Structure	Yes, partially	Yes	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially
Competencies	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially

Business Dimension	SME1	SME2	SME3	MSE1	MSE2	MSE3	LE
Organizational Culture	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially	Yes, partially

In the next sections, a detail of the findings in each business dimension is presented.

Technology dimension

Technology's importance is understood by all companies as it is the foundation of the DT. Additionally, the complexity of choosing the right technological solution makes it the center of the decisions surrounding the DT. That is why the changes inside the companies started with this dimension in almost all the initiatives of the companies in the sample.

Of a total of 40 different digital technologies proposed to the companies in the study, almost all are used or considered to be used in the future by at least one of the companies surveyed. The analysis shows that there is a lot of exploration of new technologies by the companies, even though only safe bets are implemented (see Figure 4.6).

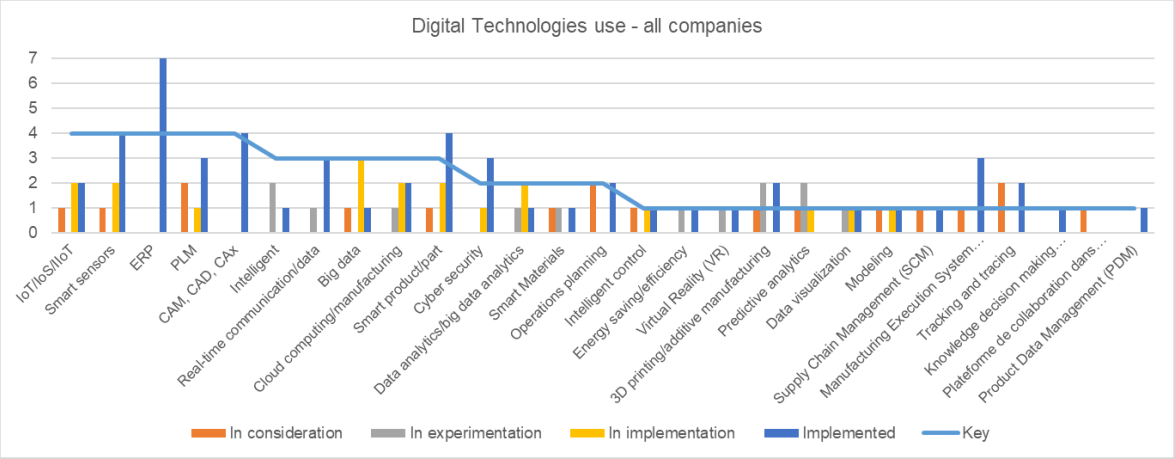


Figure 4.6 Consideration of technologies by the companies in the study's sample.

It was also discovered that companies associate some technologies with specific initiatives, but others are well understood to have applications for all the digital initiatives known in the industrial sector (see Figure 4.7). Core technologies such as the Internet of Things (IoT), Big Data, and Cloud Computing, while in the plans of the companies pursuing smart services, are recognized to imply a major challenge.

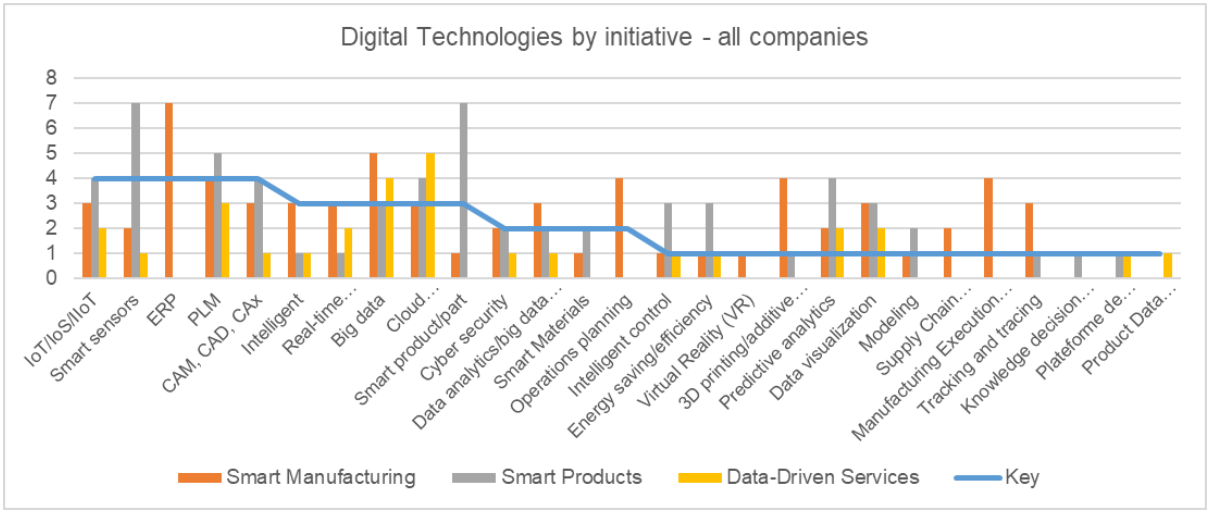


Figure 4.7 Technologies used in the digital initiatives by the companies in the study's sample.

In the technology dimension, however, there is not much awareness from companies on the need to validate the state of the technological infrastructure to see how well it supports future technology introductions. This situation is aggravated by the fact that only 4 of the companies have their technological architecture documented. Only Company MSE2 is aware of the situation of its legacy infrastructure as the teams in charge of developing smart services are realizing the challenge it will represent for the implementation of required technologies (e.g., big data, cloud computing).

Business process dimension

Process compliance derived from the need to have standards certifications such as ISO is a common trait of the sample (see Figure 4.8). The market requirements, specifically because of the type of customers they serve, are at the origin of this characteristic feature. Company SME2, having entered the medical market recently with a smart product, was the one that experienced the biggest growth in this aspect that was not previously considered.

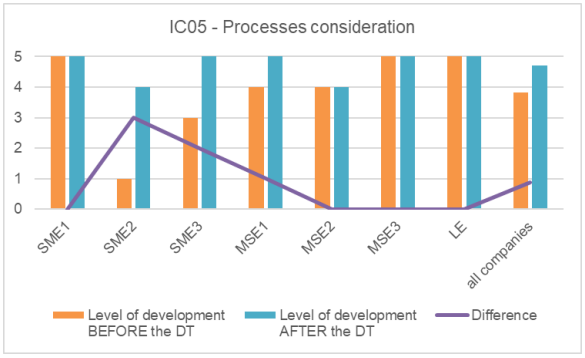


Figure 4.8 Detail of the state of factor IC05 in the internal context of companies in the study's sample.

In a deeper analysis of this dimension, however, the same issues found in Company SME3 are present in the whole sample. In most cases, process documentation is limited to the requirements of the standards certifications. Additionally, though they may seem compliant when certified, some

companies view all these requirements as a major barrier to agility, especially in new product developments.

In this scenario, the changes that are performed in this dimension during a DT are limited to the processes that seem evident to be modified and those immediately related. For example, in initiatives related to the digitalization of processes, such as the smart manufacturing initiatives, the production processes are formally updated. The same happens with the product development processes concerning the smart products initiatives.

The development of new smart products and services is another highlight of the findings in this dimension, as it involves new and unknown elements for companies. In addition to updating their production processes, the digitalization of products requires the upgrading of their associated processes: design, production, and marketing. Especially marketing a new type of product, a smart product, to new or existing markets is recognized as a very pressing challenge for companies in the sample. They find it particularly hard to know how to develop the infrastructure, the processes, and the personnel, to sell features that go beyond the company's current capabilities.

These findings show how the companies in the study's sample are gradually starting to see the whole scope of the implications of the different initiatives. Nevertheless, in all these cases, key practices such as technology scanning or innovation, among others, are carried out but are not documented, which makes it difficult to standardize them. There is also a risk associated with the fact that those practices are also performed by specific resources in which all the know-how of the company is contained.

Considering that companies do not cover even the required changes in this dimension for the full implementation of the digital initiatives, it is not surprising that they do not implement more long-term changes. In consequence, the processes that support the capability-building that contributes to the vision of a digital company are not considered.

Organizational structure dimension

All the companies in the sample have introduced changes in their organizational structure as the result of their DT efforts. Three types of changes were identified:

1. creation of special positions to manage the digital initiatives;
2. creation of positions to operate the digitalized processes, products, or services;
3. general restructuring of the organization for coping with the new reality of constant change.

In the first case, there is no consistency in the type of changes implemented. Company MSE2, for example, formed two independent teams to take charge of the two digital initiatives they had in progress. Company LE created positions for business developers dedicated to the SP & SS initiatives. Changes were observed in each case, regardless of the type of digitalization pursued. However, the type of change echoes the importance of the DT for the company, revealing a lack of full commitment that affects the transformation, as the resources allocated are reported insufficient to realize the plans.

Changes in the organizational structure for operating the digitalized processes, products, or services were aimed to support changes in the process and competencies dimensions. As a result, they suffered from the same problems found in other business dimensions. In the process dimension for example, functional areas directly affected by the implementation were the first to be considered, while other changes were delayed until the impact was evident. This was the case in commercial areas for which companies are still trying to figure out their evolution. In this case, they do not envision the same sales force specialized in mechanical products to sell smart solutions.

Regarding the integration of new competencies into the companies when they are not acquired as a service, there is no consensus on whether to add them to existing positions or to create new ones.

The last type of change in the organizational structure design is derived from a more high-level and long-term vision. In this sense, Company MSE3 redesign the structure to become a flat organization of not more than three hierarchical levels to privilege employee participation. But this is an isolated case. Even when some of the companies have created new branches to operate smart services (Company SME3) or to manage the SP or SS initiatives (Companies SME1 and SME2), redesign efforts directed towards a more organic structure were not identified. All the contrary, SME3 is losing agility as its organizational structure is growing to become more complex (see Figure 4.3, factor IC11).

Figure 4.9 shows the different configurations of the organizational structures of three companies in the sample. Considering that a more organic layout is close to a level five in all factors, there are underdeveloped areas that could be at the origin of companies' rigidity to handle change. This configuration, along with the type of changes made in these dimensions by the companies, show that the evolution of this dimension is handled in a reactive and uncoordinated manner.

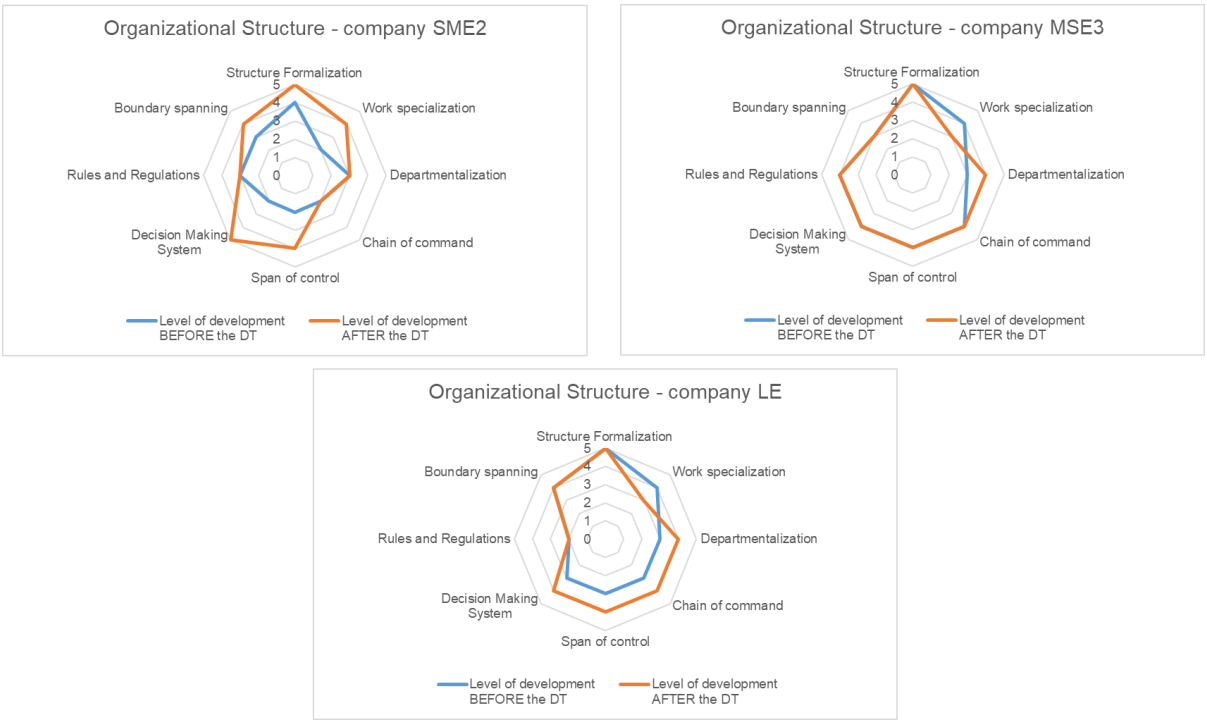


Figure 4.9 Comparison of the characterization of the organizational structure of 3 companies in the study's sample.

Especially in this dimension, the configuration of the structure of the companies made them slow as they did not promote collaboration, knowledge sharing, and ultimately innovation. It was revealed during the interviews that this was an important subject, and some companies like Company SME2 have started to make changes. For others, like Company LE, changes are more difficult given its size.

This situation was also identified through the related factors of the organization's internal context (see Figure 4.10): the organizational structure formality and agility give an idea of how the company is constituted and how that can later represent a problem for the DT efforts. Company SME3 is an

example of that. Its growth is changing the configuration of its organizational structure and the company is dangerously falling into the traps of bigger companies that become so complex that they lose their agility.

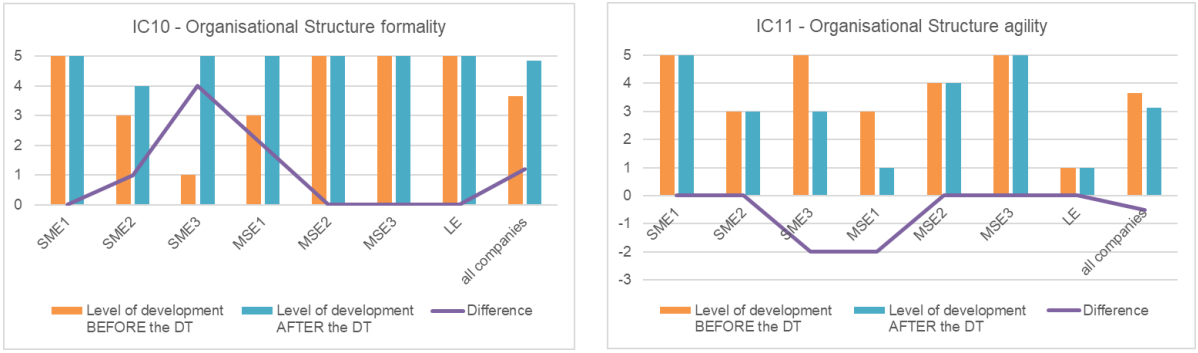


Figure 4.10 Detail of the state of factors IC10 and IC11 in the internal context of companies in the study's sample.

Competencies dimension

Regarding the competencies dimension, it was found that there is a mix of technical and human skills when defining the essential elements of a DT. The strongest growth in competencies, however, has been in the technical ones (see Figure 4.11).

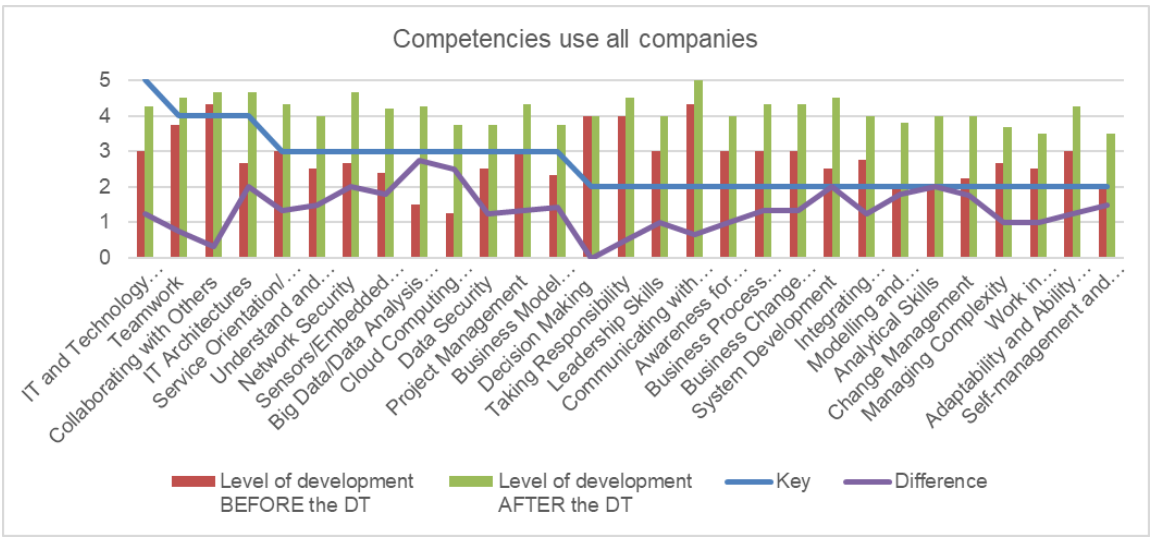


Figure 4.11 Competencies developed in the companies in the study's sample, before and after the beginning of their DT.

This discovery evidences the link between the technology and competencies dimension. However, as happens with the other dimensions, this is limited to the most immediate needs. The capacity of reaction at the last-minute regarding competencies is riskier than with the other dimensions. Competencies related to digital technologies are not easily available and can take time to develop or even acquire them in the market along with new resources. According to companies' experience, the choice to develop the competencies internally or to search for services outside it is becoming a decision of high relevance. Such services are costly as they are in high demand. Developing

them internally is also a challenge, and when hired, a person with technical characteristics far from those of the technical areas in the company often finds him/herself alone and with the risk of losing their expertise.

Beyond the technical competencies, the lack of other competencies such as “Project Management” (Company SME3), “Understand and coordinate workflows” (Company MSE1), or “Analytic skills” (Company SME3) are starting to become an issue as more complex initiatives are implemented.

These two events are making companies realize the need to plan the competencies that will be needed in the near future. Those more advanced in their DT efforts, like Company SME3, are already starting to make changes. The documentation of a competency map is not envisioned but for some, like Company SME1, it is an element that seems to become key in handling constant change.

Organizational culture dimension

Companies in the sample generally have a description of their organizational culture well documented. However, in this regard, some of them acknowledge that there is a gap between what is documented or conceptualized and the organizational reality. In this research, we only identified a company whose cultural traits are present in its actions and decisions (Company MSE3).

History, structure, and formality related to their size can be very restraining when trying to implement change. In Large Enterprises (LE), especially when speaking of organizational culture, imposition of rules (Company LE) rather than the use of rewards more practiced in smaller companies (Company SME3) are considered an “easy” way to get the projects going.

According to the study findings, the organizational culture is not proactively modeled to accept constant change. It is identified, however, that companies understand how, from the general traits that shape a culture, innovation is becoming increasingly important. Similarly, the traits more associated with the digital era are widely recognized by the companies in the study’s sample (see Figure 4.12).

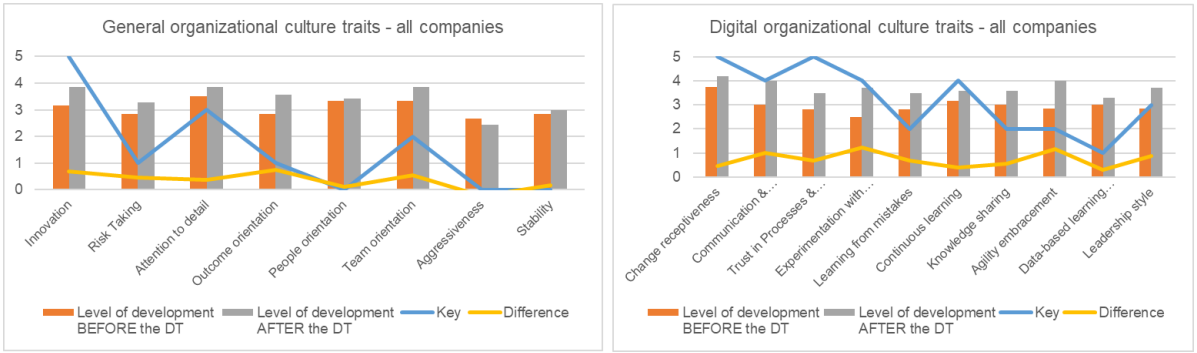


Figure 4.12 Comparison of the development of the general and cultural traits of the companies in the study’s sample.

In addition, there are certain characteristics, such as "learning from mistakes," that are not fully embraced to enable a culture of constant experimentation and innovation without fear of mistakes. The evolution of this dimension is necessary, but it is the one that leaders consider the least urgent to change, despite the fact that the literature assigns it the highest importance in relation to the success of organizational change.

After reviewing the findings in all dimensions, it can be concluded that proactive changes inside the company are those related to technology and its immediate impact on other dimensions. Other changes are performed in a reactive way when the impact of technology implementation appears as a problem in the other business dimensions. The situation described is somehow different for the dimension of organizational culture. It is revealed that in the case of culture, its nature is different from the other dimensions. Culture acts as a facilitator of change. The characteristic cultural traits of the organization can support or hinder the DT efforts. However, in those cases, as often happens with organizational change efforts, changes are imposed on the employees, or they are convinced of their benefits. In a scenario of constant change, not looking to evolve into a more open and collaborative culture could be risky as it is the lack of consideration of the whole implications of a DT inside the company.

4.3.3.2 Business dimensions' contribution to the success of a DT

Going further in the analysis, companies were also asked about the perceived contribution of each business dimension to DT success. When assigning a degree of contribution to each dimension, companies' individual perceptions varied according to the type of initiative pursued (see Figure 4.13, left side). This variation is also present when different companies assigned the importance of the same type of initiative, like Smart Manufacturing (see Figure 4.13, right side).

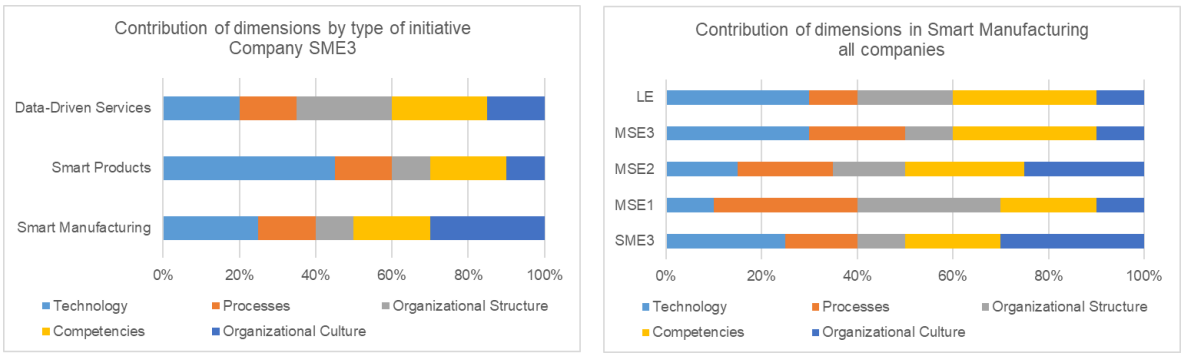


Figure 4.13 Comparison of the business dimensions' contribution in three different types of initiatives for a company and of the same initiative (Smart Manufacturing) for all the companies.

During the interviews, it was noticed that a company associates high degrees of contribution either to dimensions that were critical to the success of the initiative or to those that represented major problems during implementation. The combined contribution of technology and competencies is also interesting to discover. However, a stronger presence of culture was only identified in the companies that regard it as the key to their success (Company SME3 and MSE2).

4.3.3.3 Business dimensions' interactions during a DT

The lack of awareness of the companies regarding the business dimensions involved in a DT also affects the visibility and planning of their interactions proactively. The interactions between dimensions are considered partially. There are a couple that are classically paired: Technology and Process (e.g., Smart Manufacturing) and Technology and Competencies and Organizational Structure (general).

The first identified interaction, Technology, and Process, originated from initiatives that target the digitalization of processes. Those processes are often redesigned to consider technological introduction. If the processes involved are formally documented, they are updated. Their documentation is also used to train the employees who perform the tasks in the process. An example is Company MSE3's effort to redesign their processes for their digitalization.

The second one is basic when the technology is introduced, and personnel from the company need to operate it. An example of this situation is the Company SME3 introduction of 3D printing technology in the additive manufacturing initiative. Several employees on its staff had to be trained to manage the new equipment.

The configuration and intensity of dimensions' interactions depend on the state of the business dimensions in the companies and the type of initiative pursued. The interactions, however, are always there. Even if they have not been acknowledged and designed, they appear in some way or another, making them an important shortcoming of DT management for the companies.

4.3.4 What is the process that it follows and its trajectory towards a successful DT?

The DT process is at the core of the problem of the level of understanding of a DT. How to digitally transform is one question companies ask themselves frequently. This work proposes the following in this regard. First, a high-level process derived from the CDTF is shown in Figure 4.14 (see also Chapter 2, Section 2.2.9).

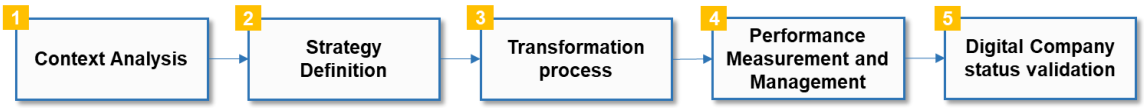


Figure 4.14 DT Process proposed based on the main elements of the CDTF.

Additionally, the proposal considers that the trajectory toward a DT is constituted by the initiatives each company decides to implement and, therefore, is specific to companies' particular situations.

Having the background of companies' conception of the DT, the process of implementation of the digital initiatives is the one analyzed. In this section, the process they followed is confronted with the proposal of this work.

4.3.4.1 The DT process

The purpose of confronting this process with the case studies is to identify how well they fit reality and the origin of any difference. Table 4.18 shows a global view of the compliance of companies in the study's sample of the proposed DT process.

Table 4.18 Compliance with the DT Process by companies in the study's sample.

Stage / Company	1 - Context Analysis	2 - Strategy definition	3 – Transformation process	4 - Performance Measurement and Management	5 - Digital Company status validation
SME1	External - Yes informal Internal - Not performed	Business Strategy, not digital	Superficial, Incomplete and reactive	Partial, based on projects performance	Not performed
SME2	External - Yes informal Internal - Not performed	Business Strategy, not digital	Superficial, Incomplete and reactive	Partial, based on projects performance	Not performed
SME3	External - Yes informal Internal - Not performed	Business Strategy, not digital	Superficial, Incomplete and reactive	Partial, based on business performance	Not performed
MSE1	External - Yes Internal - Not performed	Digital Strategy	Superficial, Incomplete and reactive	Partial, based on business performance	Not performed
MSE2	External - Yes Internal - Not performed	Digital Strategy, but separated from Business Strategy	Superficial, Incomplete and reactive	Partial, based on business performance	Not performed
MSE3	External - Yes Internal - Not performed	Digital Strategy	Superficial, Incomplete and reactive	Partial, based on business performance	Not performed
LE	External - Yes Internal - Not performed	Digital Strategy, but separated from Business Strategy	Superficial, Incomplete and reactive	Partial, based on projects performance	Not performed

Next, each stage is analyzed in more detail.

Stage 1 - Context Analysis

This work distinguishes the external and the internal context as the particularities of their analysis are different (see Chapter 2). First, in the analysis of the external environment, it is identified that smaller companies rely on the leader instinct while bigger companies make more use of formal information sources to do it. Indeed, SMEs do not have a formal practice for monitoring and evaluating the external business environment. In Figure 4.15, two of the factors of the internal context that shows the style of strategy definition and decision making may be at the origin of these findings.

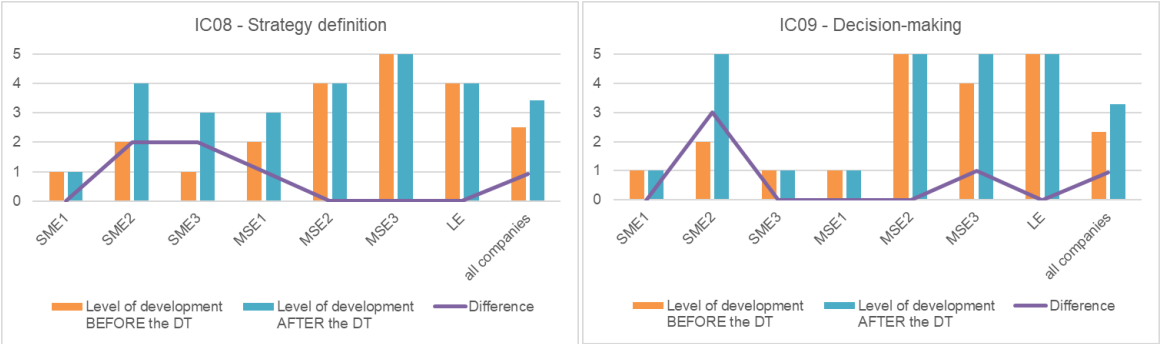


Figure 4.15 Styles of strategy definition and decision-making of the companies in the study's sample.

Nevertheless, all companies in the study's sample are regulars at the industrial fairs and commercial events that allow them to be informed of the current developments and trends in the sector. They are also members of associations such as ARTEMA, which help them build links not only for commercial purposes but also to create support networks. In Figure 4.16, the procedure identified to analyze the external environment is displayed.

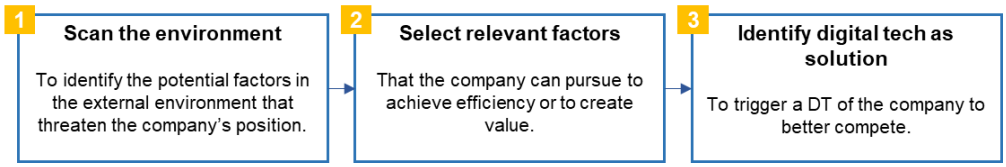


Figure 4.16 Process of analysis of the external environment of the companies in the study's sample.

The external factors identified depend entirely on how well the leaders analyze the environment that surrounds the company. This becomes evident when comparing companies in the sample that share the same conditions in the external environment. As an example, France's program to reactivate the industrial sector focuses on providing guidance and financing resources to support the digitalization of SMEs (political factor). However, only one of them acknowledges that those programs exist.

Company SME2, for example, states that it does not identify relevant factors in its external environment, either as opportunities or threats to the company's position. Currently, the company does not feel the urgency to move quickly towards its DT but strives to develop its products as digitally as possible. The feeling is that its context is not yet ready for the radical change that digitalization can bring.

There is also a difference between the external factors identified and those that are behind the decision to start a DT. When companies acknowledge the factors, they decide which and how they will act upon them. Factors associated with regulations or imminent market threats are the ones to seem more powerful to be acknowledged and trigger more immediate actions in companies. While the opportunities missed are not seen as pressing to start action, especially when their implications are not well understood. The pattern that is often observed is that the leader's management competencies, ambitions, and available resources are what define the choices they make when confronted with the options the environment presents.

The situation is widely different regarding the analysis of the internal context. In the proposal of this work, a digital readiness indicator based on the internal context factors is defined to have a

measure of how well prepared and willing a company is to start a DT. However, in practice, neither a formal nor an informal analysis of the internal conditions of the company was identified in any case. Surprisingly, the analysis of the information collected about the conditions of the factors in the internal context before and after beginning the DT revealed changes that can evidence its importance (see Figure 4.17).

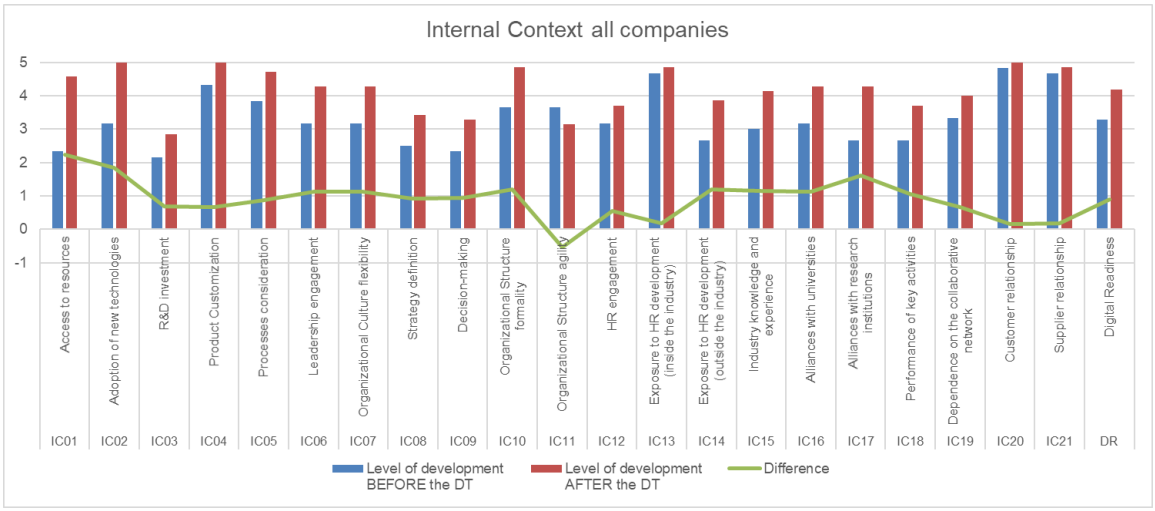


Figure 4.17 State of the factors in the internal context of the companies in the study's sample before and after beginning their DT.

Naturally, the findings evidenced growth in the resources dedicated to the transformation (IC01) and their capacity to adopt new technologies (IC02). It was also interesting to observe that the companies started to build or reinforce their links with universities (IC16) and research institutions (IC17). Some of them funded doctoral theses or hired young doctors (PhDs). Others also search for the support of institutions such as the CETIM or research laboratories to find support in searching for solutions for their initiatives.

The digital readiness of the companies before and after the beginning of the DT shows that all companies but one had an evolution of their internal context. Several changes were also identified in the interviews: getting more funds, developing human resources, and making links with institutions. The digital readiness of the companies revolved around the 4-point level, even with outstanding changes in companies SME2 and SME3 (see Figure 4.18).

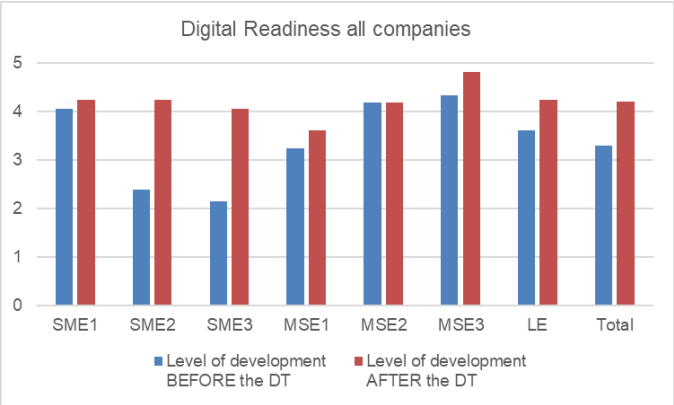


Figure 4.18 Digital readiness of all companies in the study's sample before and after beginning their DT.

Results also show that there are internal factors that seem to exert a much stronger influence on the level of readiness of the companies. Factors like Leadership engagement (IC06) and culture flexibility (IC07) are an example of this (see Figure 4.17). Both are components of the willingness factor of the digital readiness indicator that intends to show how willing the company is to start a DT (see Chapter 2). It is interesting to notice that precisely the willingness factor is the one that has the highest growth after the beginning of the DT (see Figure 4.19).

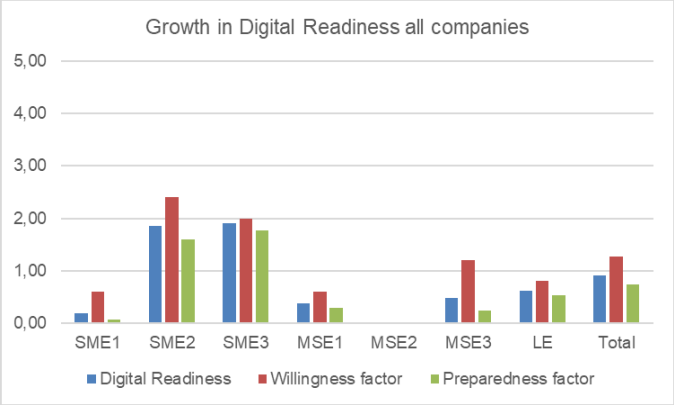


Figure 4.19 Changes in digital readiness and its factors of all companies in the study's sample.

This result also suggests that the factors of the digital readiness indicator, the willingness, and preparedness factors may have different weights to show a real measure of digital readiness. For this work, the measurement did not consider any ponderation.

It is also important to note that the companies share some common characteristics, such as a strong relationship with customers (IC20) and suppliers (IC21), a high level of competence in product customization (IC04), and the development of their human resources (HR) (IC13). This does not come as a surprise as they serve the business-to-business (B2B) markets and may also be an indication of typologies associated with family-owned businesses or industrial companies in B2B business.

In the end, that intuitiveness that is perhaps used instead of an analysis of the internal context inhibits the companies from preparing themselves for an exercise of this magnitude.

Stage 2 - Digital strategy definition

In the CDTF, the digital strategy is central to giving direction to the DT efforts. The findings indicate a distinction regarding the definition of a specific digital strategy between SMEs and MSEs or LEs (see Table 4.18). While the SMEs do not have a digital strategy per se, the others have either a digital strategy or the digital strategy that is a part of the overall business strategy.

Companies like Company SME3 have a general strategy in which digital technologies are seen as enablers for realizing the business strategy. In this case, the digital initiatives target the business objectives of the general strategy. On the other hand, companies like Company MSE1 defined a specific digitalization strategy that looks to achieve efficiency by reducing the products' delivery time by using digital technologies. In both cases, there are business objectives related to the digital initiatives defined in the strategy, sometimes not in detail, but they represent at least the general intention of the initiatives.

The types of business objectives that lead to the definition of a digital strategy are mostly based on efficiency. The hope is to justify a bigger investment in new technology that allows them to pursue the creation of new smart products and services. Probably, this lack of full confidence in technology is an indication of the reason companies do not focus their objectives on building the appropriate capabilities in the company, certainly a more ambitious and long-term target. As a result, digital strategies or business strategies with digital projects both have mostly short-term objectives that inhibit a true transformation of the company.

Stage 3 - Transformation process

The transformation process proposed by the CDTF is composed of all the changes required inside the company's business dimensions to support the defined digital initiatives. In the analysis, it was found that the process followed by the companies in the sample to implement the digital initiatives varies completely from one to the other.

At a high level, it is identified that some companies make use of organizational change methods to implement them, such as Business Process Management (BPM). It was also identified the use of lean tools when following continuous improvement approaches in the implementation or project management processes. Furthermore, the process followed with each initiative may vary if the initiatives are managed by different teams and the company does not follow a particular method (Company MSE2).

The findings also point out two different triggers of the transformation process inside the company. Most companies, like Company SME3, start the process with the technology selection and implementation. Others, more focused on efficiency targets, such as Company MSE1, first identify the process that will be digitalized and then search for the technological solution to achieve it.

Overall, the analysis showed that the pattern is the same: the focus is on the immediate and more evident changes leading to partial implementations. The consequences in the short term materialize in the form of problems that require immediate attention. In the long term, they inhibit the true transformation of the company.

Stage 4 - Performance measurement and management

Performance Measurement and Management Systems (PMMS) are key elements in the CDTF proposal to control the DT efforts. The fact that there is not an acknowledgment of DT as a capability-building change in the companies of the sample and the objectives are not aligned with

that definition severely affects the PMMS element in practice. In this sense, there is no real measure of the DT's performance identified in the case studies.

Performance measurement, when executed, relies on the same traditional Key Performance Indicators (KPIs) and how the DT initiatives impact them. Those KPIs measure the process or the business results (revenues or cost), but not the ones associated with the digital maturity of the company.

The lack of an aggregate indicator capable of measuring the evolution of the DT or the maturity of the company in terms of its digital capabilities is still unexplored by the companies. Companies then have the same recurrent errors or drawbacks over and over again with each digital initiative implemented. Digital initiatives are mostly seen as experimental projects in most companies. Therefore, the consequences of not having metrics are not seen as critical by the companies and sometimes are not even identified.

Stage 5 - Digital Company's status validation

Having a vision of the type of digital company a company desires to become to deal with the digital era according to its ambition in the new business environment is the ultimate goal of a DT defined in the CDTF. However, it was not found in the companies in the study's sample a formal objective towards a DT that get them to achieve the status of a digital company according to the definitions of this work. Findings point out the evolution of some of their capabilities with each initiative that they have implemented, but there is not a long-term objective that coordinates those efforts towards a long-term objective in an efficient manner.

Only Company SME3 gets close by having the vision to restructure its company to be able to innovate faster and continuously. In this vision, the company will adopt the configuration of a start-up, with innovation and agility as its core to take the most advantage of cutting-edge technology. The vision is close to what is theoretically proposed in this thesis, but it lacks the consideration of all the proposed elements needed to fulfill it in a comprehensive and efficient manner. As this company is the most advanced in the DT journey, it has revealed how this need to establish this long-term objective gives a true sense of direction to a final and more competitive state for a company.

4.3.4.2 The trajectory of the DT

In the CDTF, companies define their digital initiatives according to the business objectives they need to accomplish. In this sense, the efforts of the companies in the study's sample are concentrated on the digitalization of production processes (Smart Manufacturing) and products (Smart Products) (see Figure 4.20). Surprisingly, even when they all belong to the industrial sector, some do not choose to start a Smart Manufacturing project, the main initiative promoted for companies that belong to that sector.

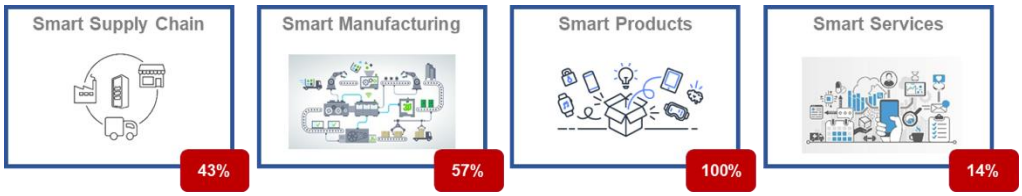


Figure 4.20 Proportion of the companies in the sample by type of digital initiative.

Assemblers specifically were not searching for the digitalization of their production process as their levels of production were not high, and they have not identified technology that could have advantages over their more manual processes (see Table 4.19).

Table 4.19 Overview of the digital initiatives of the companies in the study's sample.

Activity	Type of company	Smart Supply Chain	Smart Manufacturing	Smart Products	Smart Services
SME1	Manufacturer	No	No	**Yes**	No
SME2	Assembler	No	No	**Yes**	No
SME3	Manufacturer	No	**Yes**	**Yes**	**Yes**
MSE1	Assembler	No	No	**Yes**	No
MSE2	Manufacturer	**Yes**	**Yes**	**Yes**	*In progress*
MSE3	Manufacturer	**Yes**	**Yes**	**Yes**	*In progress*
LE	Manufacturer	**Yes**	**Yes**	**Yes**	*In progress*

According to the case studies, companies SME2 and MSE1, for example, declared that they had analyzed options concluding that there were no benefits in digitalizing their production processes. They have chosen, however, to add layers of intelligence to their products.

The development of smart products is identified as the real key target in the digital initiatives of industrial companies in the sample. There are two reasons identified. Some companies perceive more business value in developing the intelligence of their products. Others, that target the creation of smart services, see them as a way to capture the data needed (see Figure 4.21).

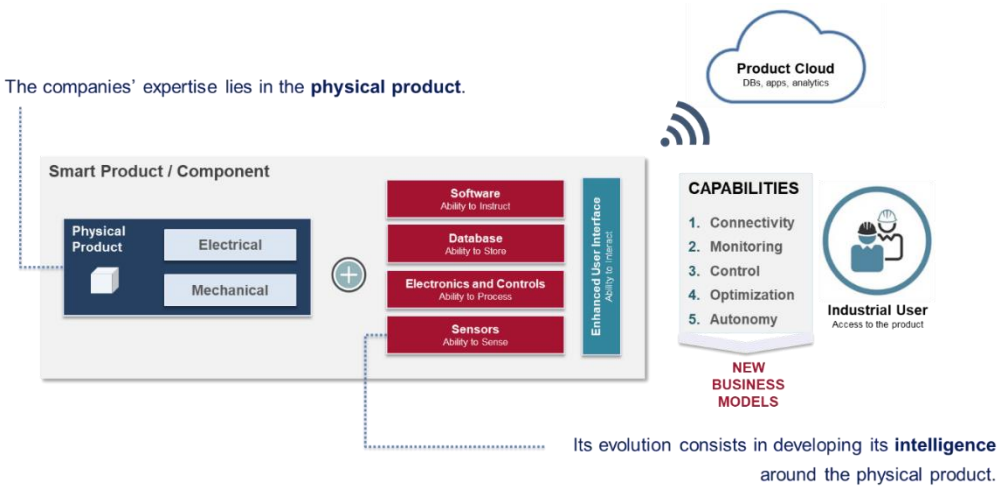


Figure 4.21 Evolution of current products towards smart products of the companies in the study's sample (author's own creation).

Some of the companies, however (companies SME1 and MSE1), have developed very advanced functionalities on their products but have yet to profit from those advantages for different reasons. One reason is that they struggle in a market that still searches for basic mechanical pieces and it is not "educated" to understand the digital offerings, a possible gap in the strategy defined.

Another interesting finding identified that even though two companies are following the patterns in the literature of initiatives suited to industrial companies, the detail of the trajectory of each company is different. Figure 4.22 shows the differences between companies MSE3 and L3 in the configuration of their initiatives. Those differences, rooted in the companies' strategic choices, evidenced that the complexity of technological solutions does not determine the order of their implementation.

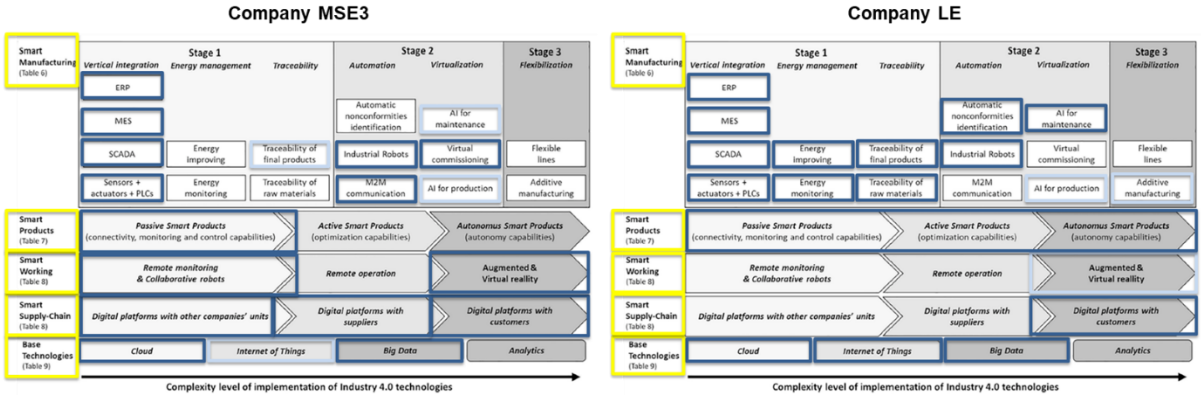


Figure 4.22 Comparison of patterns of development of smart products of the companies in the study's sample. Technologies "implemented" are framed in dark blue and "to be implemented" in light blue (adapted from Frank et al., 2019).

Each company has different objectives, and they chose the initiatives in terms of their possibility to help them face the challenges of the business environment. The initiatives, however, are sometimes defined over time without a real long-term objective, especially at the beginning of the DT, like in the case of Company SME3.

4.3.5 How does a company's context influence the development of a DT?

In this work, the influence of the company's context over the DT efforts is divided into two parts. First, the analysis centers on the external environment and how different factors of the business environment were read and analyzed by the companies' leaders and the actions that they triggered. Next, from the internal perspective, how companies' characteristic features of their particular context affect the choices they made regarding the DT and the way they handled the initiatives and the DT process.

4.3.5.1 The influence of the external environment

The analysis of the external environment made by each of the companies shows similarities as expected with companies in the same sector serving similar markets (see Appendix 4.6). It is observed, however, that the triggers of the DT are different for each company. The triggers of the so-called DT of the companies are different in each case. Those triggers are related to how the companies want to compete, and consequently, that choice also influenced the type of digital initiatives that the companies decided to implement.

4.3.5.2 The influence of the internal context

As it has been presented through the findings of the cross-case analysis, factors that constitute the internal context have a specific influence over the DT. The way leaders make decisions, prepare the employees of the company and create support networks, among others, shape the DT.

During the analysis, some common characteristics of the sample imply that there could be particular typologies belonging to family-owned businesses or SMEs, among others. For example, a family-owned business typology might point out an engaged leader that invests and cares for the culture of the company and its employees. Those typologies may be relevant to identifying potential advantages or risks during a DT.

The influence of internal context does not seem to be a determinant of success, as it was revealed that when leadership has strong motivations and sponsorship is clear, companies like Company SME3 can overcome their defaults.

In summary, regarding the influence of context, both external e internal, it is evident that it is there, but it can be shaped to achieve DT success if it is formally analyzed, and the proper actions are implemented.

4.3.6 Conclusions

The presentation of the pilot case study gives a complete view of an insightful case of a DT. Contrasting this view with a wide variety of cases in the same industry, but with very specific contexts and natures of DTs, allows to identify findings that deepen the understanding of the phenomenon.

The general conclusion of the analysis highlights the fact that there is not a long-term vision of the DT based on capabilities building. This main finding leads to a whole range of consequences that includes the partial and uncoordinated implementation of digital initiatives that do not prepare the company to compete better in the digital era.

4.4 Discussion

In the last section, the findings of this exploratory research work provide an empirical view of how a DT is implemented in real life. By performing seven case studies of companies in the industrial context, findings were drawn through within-case and cross-case analyses guided by the structure of the CDTF. In this section, a discussion of those findings follows to answer the main research question of this work.

4.4.1 Research problem and questions

Before starting the discussion of the main findings, it is important to remember that this thesis investigates the DT phenomenon and the whole scope of its implications for a company. Given the relevance of the topic for economic growth, this work addresses the problem of a lack of appropriate guidance for companies searching to digitally transform.

The identified research problem led to the definition of the following main question:

What does it imply for a company to digitally transform?

All along the previous sections of this chapter, a series of seven case studies were analyzed within and across cases following the design of the CDTF. The objective of this analysis was to confront the theoretical propositions versus the realities of the DT in practice to validate the contribution of this work. In the following sections, the main findings are summarized and an answer to the research questions is crafted according to the discoveries.

4.4.2 Key findings

Overall, the findings of this study revealed the profound misunderstanding that exists in practice regarding the DT phenomenon and the consequences it brings to their transformation efforts. Those that are completed do so under conditions that are not optimal nor efficient. This discovery is not surprising considering that traditionally, companies have issues in managing organizational change successfully. The special characteristics of the digital era discussed in Chapter 2, undoubtedly add a layer of complexity to an already challenging business transformation.

A summary of the key findings of this analysis follows:

- the DT efforts are primarily focused on short-term objectives, mainly the introduction of a technological solution;
- the DT process followed does not include all the required changes to fully support the digital initiatives;
- the trajectory of the DT is made up of the digital initiatives specific to the needs of each company and their strategic intents;
- all the main DT elements are identified but fail to fulfill their role as their components are partially considered;
- the business dimensions show a partial evolution with a short-term vision and a lack of coordination that inhibit the development of the necessary capabilities of the company;
- the company's context only becomes visible during the DT as negative effects of a lack of proactive planning.

4.4.3 Findings interpretation

After positioning an answer for the sub-questions of this research, it is possible to address the main question:

What does it imply for a company to digitally transform?

A DT for a company implies the following:

- a long-term objective centered on the company and the transformation of its capabilities;
- a digital company defined by the vision of its ambitions in that regard;
- constant monitoring of its external environment and the identification of relevant factors that challenge the company's position and how technology can help to solve them;
- a careful analysis of its internal context to evaluate the conditions in which it will face the chosen challenges;
- a strategy that is designed proactively to drive the transformation and that ensures the guidelines and resources to realize it;
- a transformation process that considers a systematic analysis of the relevant changes to implement in the business dimensions involved in a coordinated and efficient manner;
- a planned evolution of the five business dimensions proposed that goes beyond the impacts derived by the initiatives, but that supports future implementations;
- a performance measurement and management system that follows up on the success of building the necessary capabilities of the transformed company.

The theoretical answer proposed in the CDTF targets an ultimate goal of really transforming a company into an entity capable of integrating the digital point of view in all decisional and strategic aspects, given that this possibility represents a strong advantage in the current business context.

This vision is hardly present in the companies in which there is so much confusion that it is hard to understand the whole picture. A real DT in practice is hardly an objective. The focus is on the immediate introduction of technology. As a result, the evolution of the company to acquire the capabilities needed to handle technology introduction comes as a consequence of many challenging initiatives, not as planned efforts.

The same approach is seen in literature in which the implementation of projects (Industry 4.0, smart manufacturing) is the focus instead of building the bases to compete in the current challenging conditions. In the end, short-term objectives do not prepare for the future, and a DT must have an aim for the future.

4.4.4 Conclusions

The main findings of the multiple case study showed how the long-term capability-building and holistic view of the transformation proposed in the Conceptual Digital Transformation Framework (CDTF) is a contribution not only to literature but to practice. Companies' view of the Digital Transformation (DT) as only a series of sometimes disconnected initiatives to introduce technology is short from the real scope of a DT. After identifying in the cross-case analysis patterns and links in the sample's efforts toward a DT, several lessons are identified. The general findings point out a lack of understanding of the phenomenon.

Beyond the current relevance of the term, DT is not just another fad in the business world. A DT is a concept that signifies the relevance of the nature of the technological change that we are currently experiencing. A change that is constant and for which companies must be prepared. This preparation right now is not guided or performed. The literature and practice view of the DT

phenomenon is short-sighted and partial. Errors and inefficiencies plague the process followed to achieve a DT, consequence of a lack of comprehensive planning.

Key elements in the DT process like strategy and PMMS do not fulfill their respective role of driving and managing the transformation as they lack the full execution of all its sub-elements by managers. The DT efforts suffer the consequences of the lack of planning elements that, combined with the partial view of the business dimensions involved in the change, result in flawed implementations.

Furthermore, in a DT, there are no magic formulas for everyone. The findings of this study show that the company's context, external and internal, has a clear influence on all strategic decisions and the progress of the transformation, as well as on the trajectory of its initiatives. This discovery then characterizes the DT as a dynamic process that is therefore unsuited for displaying in the more static and predetermined fashion of tools like maturity models.

4.5 Chapter's conclusion and summary

In this chapter, the validation of the CDTF has been performed to confront the theoretical answer that the conceptual framework represents and the real case scenario of seven industrial companies. While other propositions in research present a linear and static view of the DT process and offer only an internal and partial perspective of the process, this research work proposes a holistic view that integrates outside factors that affect its success. By using the CDTF's more comprehensive view of the phenomenon to guide the analysis, better insight into the process is gathered to identify the nature of its dynamics to manage it successfully.

Through the cross-case analysis of a multiple case study of seven industrial companies, the main propositions of the CDTF are confronted with practice. The origin of several gaps between the theoretical vision of the framework and the real case scenarios points out several inefficiencies during the implementation of the digital initiatives. These findings, however, allowed the validation of the soundness of the proposal of this work. In this sense, a long-term vision of a company with the necessary capabilities to manage the type of technological era and a holistic process to achieve it is not only a contribution to the literature but to practice.

General conclusion and perspectives

Conclusion

Understanding Digital Transformation (DT) in its concept and application can represent for companies an important avenue for taking advantage of the opportunities the digital technologies offer for achieving efficiency or creating new value for customers. Companies all over the world and from all industries and sectors face, however, the complexity of an extensive change of multidisciplinary nature and guidance is required.

Current proposals in the literature, though numerous, evidence that there is still so much to understand about the DT. This work, therefore, addressed this lack of understanding through the main research question:

- *what does it imply for a company to digitally transform?*

The relevance of answering such a question lies in the fact that companies' DT is paramount not only for their competitiveness but also for countries' economic growth. The aim of this work was, therefore, to provide a frame of reference for a DT that helps in understanding all its implications for a company in a holistic manner. To be able to reach such an objective, the strategy that this research followed was to produce a theoretical answer to the research question by building a Conceptual Digital Transformation Framework (CDTF). This theoretical answer was later confronted with real case scenarios of the French mechatronic industrial sector.

To build this theoretical answer, this work went to the origins of the concept of (business) transformation to define a proper conceptualization of the DT. With this foundation, producing a holistic view with a formal approach required an analysis of theories and models of the organizational change domain. This analysis found that the properties of the Socio-Technical Systems (STS) theory were appropriate to address the limitations of current models. The view of the organization as an open system, the main principle of this theory, combined with the content of organizational change models of socio-technical inspiration, served as the basis for building a holistic view of the DT. Moreover, it allowed positioning the role of the company's context, internal and external, in a DT to explore its effects on its success.

The validation of the CDTF with a multiple case study of seven French industrial companies revealed a short-sighted vision of the DT and an incomplete identification of its implications, mirroring the findings of the Digital Models and Frameworks (DMFs) in literature. The confrontation of the seven case studies versus the main propositions of the CDTF, however, revealed the consequences companies suffered because of the gaps between both scenarios, validating the proposal of this work.

Summary of the contributions

As this research work concerns the development of a Conceptual Digital Transformation Framework (CDTF), the main original contributions to knowledge of this thesis lie in the CDTF's content, the process that derives from it and their ability to holistically represent the DT. Those contributions are complemented by the insights provided by the industrial case studies used in the CDTFs validation. More details on the specific contributions follow.

The Conceptual Digital Transformation Framework (CDTF)

The holistic property of the CDTF is the keystone of this proposal. The CDTF allows having a comprehensive view of its main elements as a whole, as a set of interrelated elements that have a role in the achievement of an objective: a company's DT. Based on the principles of the Socio-Technical Systems (STS) theory, this proposal recognizes the key role of a digital strategy and performance measurement and management as additional elements that drive and control the DT and acknowledges the influence of the company's context in the DT process.

A DT terminology

The lack of common terminology in the DT domain represents a barrier to understanding the meaning of the concepts surrounding it. Positioning DT's related terms to provide a DT terminology was, in the first place, a necessity of this research. Nevertheless, this effort can certainly be of use to other researchers and practitioners. It can also be used as a point of departure to formalize a common terminology that benefits future research on the subject.

A conceptualization of the Digital Company

The positioning of a definition of the DT concept as a capability-building organizational change enabled the proposal of a conceptualization of the "Digital Company". In this proposal, the definition of the digital company is inherent to each company's needs and ambitions, according to how they decide to compete in the new environment. As the ultimate objective of the DT, the digital company must be defined in terms of the capabilities required in the different business dimensions to achieve the defined objectives of the transformation. The shift from a dynamic of constantly facing the challenge of technology introduction to preparing for it can lead to an efficient DT journey in which each digital initiative is contributing to this global objective.

DT's business dimensions and their factors

The business dimensions are the company aspects that need to change in order to achieve the objectives of the DT. The capabilities of the digital company are built inside them, and therefore they transform the company. Current DMFs present an inconsistent view of the business dimensions with a predominantly technology focus and a lack of theoretical foundation. This work goes beyond the technology focus and, based on the STS theory, identifies five business dimensions involved in the process of transformation: technology, processes, structure, competencies, and culture. The contribution related to the business dimensions goes beyond their identification to also recognize their interactions. Aware of the importance of the business dimensions, this work gets deeper into their constitution to propose several factors that can be relevant to a DT based on related research. A typology of the type of changes expected is also suggested based on the double evolution of the digital company during the DT. In the scheme proposed, the companies must consider planning the development of their capabilities using the digital initiatives that constitute the trajectory towards a DT and complete them with the ones required by the digital company.

Measurement of the company's digital readiness and digital maturity

The positioning of both the concept of readiness and maturity led this work also to consider the conceptualization of its measuring. Therefore, in this work, a specific measurement for digital readiness is proposed, one that addresses its particularities, different from those of the digital maturity. In consequence, for measuring digital readiness, the factors of the internal context are considered. In the case of maturity, it was critical to link it with the real transformation inside the company, hence its formulation is based on the factors that constitute the business dimensions. Both proposals are based on qualitative measurement; therefore, further development is needed.

A DT process

Derived from the CDTF and its elements, a high-level process of the DT is proposed in this work to make emphasis on each element's role during the DT process. The process allows identifying the main actions required to cover all the elements' contributions to the DT. Though the details and operationalization of the process are to be complete in future research, the high-level view can be used as a checklist of the planning of a DT.

Insights on the effect of the context on industrial companies' DT

The case studies on the industrial context allowed this research to collect preliminary insights into the effect of different elements of the context on the changes in the business dimensions. The effect of factors such as the availability of resources was not a surprise. However, some other interesting links were revealed as those of the benefits of alliances with research institutions and universities. Additionally, it evidenced that some factors such as "leadership engagement" can potentially have more weight on that effect and reveal the need to explore the ponderations of the factors in the measurement of digital readiness.

Insights on the trajectory of industrial companies' DT

Another critical insight drawn from the case studies is related to the trajectory of the DT of industrial companies. Contrary to the many generalizations in the literature that define a generic path of the DT for industrial companies, in the case studies, companies' trajectory towards a DT is shaped by their strategy and how technology will help to achieve the strategic objectives. For example, some manufacturers will skip the smart manufacturing project if the product (e.g., artisanal) or levels of production (e.g., low levels) do not require the technology to optimize it. These types of subtleties are not considered in the more generic models in current literature.

A frame of reference for academy and practice

Academics can make use of the main propositions of this work in two ways. First, this work is to be discussed and challenged by the academic community to either improve it or disprove it. It can also be used as a reference to prepare new and improved proposals for DMFs. Additionally, companies can take advantage of the framework (and the process that accompanies it) by using it as a reference for a comprehensive view of a DT when preparing their DT efforts.

Finally, it is important to highlight that the general contribution of this framework is in its quality of being holistic: defining every part with a clear role to achieve a common objective. Additional

developments were directed to areas that are believed to be paramount for success and needed to be developed further in accordance with the CDTF's main propositions.

Research limitations

As can be expected of any research, this work also has some limitations that can potentially have an impact on results. Here are the most significant, along with the measures that were taken to try to mitigate their effects on this research.

Resources available for the research

Thesis work, by definition, will have only one researcher involved and limited time and financial resources. This situation has two potential consequences, the bias of the researcher and the methods considered to carry on the research work. The potential bias of the single research was minimized either with experts' validation or with different sources for the information (triangulation). Regarding the other limited resources, the research design was adapted to meet these constraints of the thesis with methods that were adapted to the given conditions.

Limited information available regarding the DMFs

Considering that most of the DMFs are proposed through papers in conferences or journals, the information regarding the methodology to develop and validate them is limited. In consequence, conclusions regarding the different parameters or characteristics were always drawn selectively, only considering those DMFs with the available information.

Restricted company sources for the data collection of case studies

Strategic resources of the companies were selected for the interviews, mostly the owners or the person responsible for the DT efforts inside the company. Nevertheless, in four of the seven companies, only one person participated in the interviews, which can lead to bias in the responses. In the research design, a triangulation of sources was integrated to mitigate the effects of this situation.

Canceled visits to the companies' sites due to the pandemic

An unexpected setback during the development of this research work was the COVID-19 pandemic that took the entire country (France) from full confinements to several periods of strict rules for avoiding contagions for two years. This situation eliminated the possibility of replicating the initial research design that contemplated visits to the physical sites, just as they were performed for the pilot case. The design was adapted to fit the new conditions, and triangulation with secondary sources was key in the new design.

Validation of the framework limited to the industrial sector

The validation of the CDTF in the industrial sector was always an important target of this research for many reasons, one being its importance for the digital context. The particularity of their

conditions and the well-defined type of digital initiatives also allowed this work to simplify the design of the study. It is clear, however, that there is work to be done in this regard. In the following section, perspectives of future research are further discussed.

Perspectives of future research

Since the early days of this research work, it was clear that the choice of developing a holistic view of the DT would mean that the depth of the work will need to be developed selectively due to the limitations of the time frame of a thesis. Therefore, the outlook for research possibilities to improve this work and advance it further is vast. The possibilities can be divided into three main categories:

- validation of the CDTF with different research methods;
- validation of the CDTF with companies of different sectors;
- full development and operationalization of the CDTF.

Even though further validation of the CDTF is a necessary requirement for advancing in consolidating a status of frame of reference, it is the full development of all its components that must be prioritized. In this sense, to expand on the findings of this work, the following research subjects are proposed.

First, the development of the CDTF, now only detailed for the business dimensions and context, should expand to the other elements of the framework. Strategy and its sub-elements, for example, can be explored in more depth, particularly concerning the business models and digital initiatives. There is an important quantity of literature that can be used to develop this part following the principles of the CDTF, notably on business model innovation or on the details of the digital initiatives. But perhaps the most under-researched and under-used element in practice is the Performance Measurement and Management System (PMMS), and more attention should go to that element. Critical to follow-up on the implementation of the DT, research about the related subjects is scarce, especially about the relevant Key Performance Indicators (KPIs) for the DT scenario. Following the CDTF propositions, finding the right KPIs will definitely depend on the development of the rest of the variables of the framework. From there, more adequate and complete assessments should follow based on the KPIs proposed.

For the elements that were developed the most in this thesis, further development is also needed to fully operationalize their factors. Regarding the business dimensions' proposed factors, additional validation can identify the most relevant ones and determine the effect and intensity of their interdependencies with other dimensions' factors. The knowledge of the relationship of the business dimensions with the internal context can also be explored with the further development of the Impact Level factor by building a quantitative model. A similar approach can be followed concerning the digital readiness and digital maturity indicators, now also proposed with qualitative measurements. Ponderations are yet to be explored for the factors of the company's internal context that are proposed to calculate the digital readiness indicator and the factors of the business dimensions that define digital maturity.

Full development and operationalization of the CDTF can also enable the possibility to study and identify patterns for the different specific types of conditions that can be modeled and automated to become an interactive guide of the company's DT efforts. For example, patterns of the level of development of the factors inside dimensions with each type of initiative or patterns of successful trajectories of DT for specific types of companies. Additionally, patterns of the configuration of the internal context of specific types of companies, such as family-owned businesses or Small and Medium Enterprises (SMEs), can also be identified along with their levels of success. All the research that can provide information that can be useful to manage the DT towards successful

scenarios or to show how to fix scenarios that are not favorable can also be clues for future research.

Finally, one of the aims of this research work is for the CDTF to serve as a frame of reference for future Digital Models and Frameworks (DMFs), therefore one interesting perspective for future research should be to build a new digital model based on the CDTF main propositions.

Résumé long en français

Introduction : La transformation digitale comme impératif stratégique

L'amélioration exponentielle et la disponibilité généralisée des technologies digitales démocratisent leur utilisation et accélèrent l'innovation, offrant aux entreprises de formidables opportunités d'efficacité et de croissance. Préparer l'entreprise à une introduction réussie des technologies numériques implique toutefois un degré important de changement organisationnel.

Pour reconnaître les particularités de ce type de changement, une transformation guidée par la technologie est nécessaire pour que les entreprises réussissent. Cette transformation de l'entreprise induite par l'adoption des technologies digitales est largement connue sous le nom de Transformation Digitale (TD). Cette notion fait référence aux changements que les entreprises doivent mettre en œuvre pour saisir avec succès les opportunités technologiques (voir figure 1).

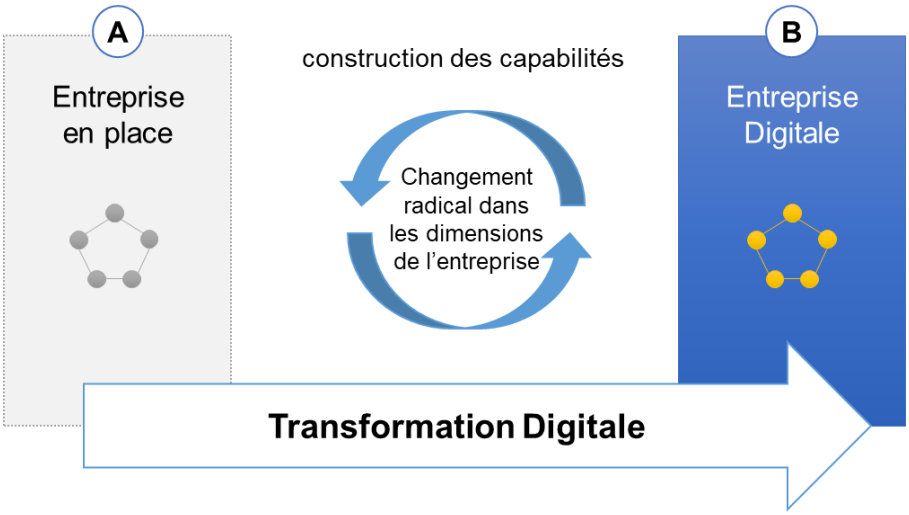


Figure 1 Représentation du phénomène de la transformation digitale (création de l'auteur).

Plus précisément, elle peut être définie comme suit :

« La TD est la transformation profonde et accélérée des activités, des processus, des compétences et des modèles d'entreprise afin de tirer pleinement parti des changements et des opportunités apportées par les technologies digitales et de leur effet sur l'ensemble de la société, d'une manière stratégique et hiérarchisée. » (Demirkan et al., 2016).

La voie de la transformation n'est cependant pas toujours claire, car les TD sont très contextuelles et la portée de leurs implications est grande. En effet, tirer parti de l'introduction de la technologie, que ce soit en optimisant les opérations et les processus ou en améliorant les produits et les services, nécessite des changements allant au-delà des aspects techniques. Les processus et les compétences, entre autres dimensions de l'entreprise, doivent également être adaptés. La gestion de ce type de changement exige une analyse minutieuse de la connaissance du point de départ d'une organisation afin de d'évaluer l'écart par rapport à l'objectif.

Dans ce contexte, les entreprises ont besoin de directives spécifiques, car le choix de la bonne voie à suivre dans le cadre d'une démarche de TD est primordial pour la réussite. La nécessité de guider les entreprises dans leur TD semble évidente aussi bien pour les chercheurs que comme

pour les praticiens. Il apparaît cependant que les solutions disponibles sont souvent en décalage avec certaines des exigences des entreprises en la matière.

Ce problème ainsi identifié met en évidence qu'il n'est pas possible de trouver dans la littérature actuelle ***les éléments de pilotage suffisants aux entreprises pour qu'elles peuvent réussir leur TD***. Suite à ce constat, ce travail répond à l'ambition d'élargir le cadre d'analyse pour intégrer les connaissances supplémentaires de ce phénomène afin de proposer une représentation enrichie. Avec cette perspective, cette recherche vise à développer pratiquement un cadre conceptuel de la transformation digitale (Conceptual Digital Transformation Framework, CDTF). L'objectif du CDTF est de servir de cadre de référence pour tenir compte de l'ensemble des implications d'une TD pour une entreprise en répondant à la question fondamentale suivante :

- *Qu'est-ce que cela implique pour une entreprise de se transformer digitalement ?*

Contribuer à la réponse à cette question fondamentale implique de répondre également aux questions de recherche suivantes :

1. *Qu'est-ce qu'une TD et quel est l'objectif qu'elle poursuit ?*
2. *Quels sont ses principaux éléments et leur rôle lors d'une TD ?*
3. *Quelles sont les dimensions business impliquées dans une TD et leurs interactions ?*
4. *Quel est le processus qu'elle suit et sa trajectoire vers une TD réussie ?*
5. *Comment le contexte d'une entreprise influence-t-il le développement d'une TD ?*

La réponse à ces questions de recherche permettra de dresser un meilleur tableau de la complexité d'une TD. En outre, une caractérisation plus précise du phénomène de la TD et l'identification de ses composantes et de sa dynamique contribueront à la constitution d'une base plus solide pour des recherches ultérieures.

Un plan de recherche en trois étapes a été conçu pour répondre aux questions fondamentales relative à la TD énoncées dans ce travail (voir figure 2).

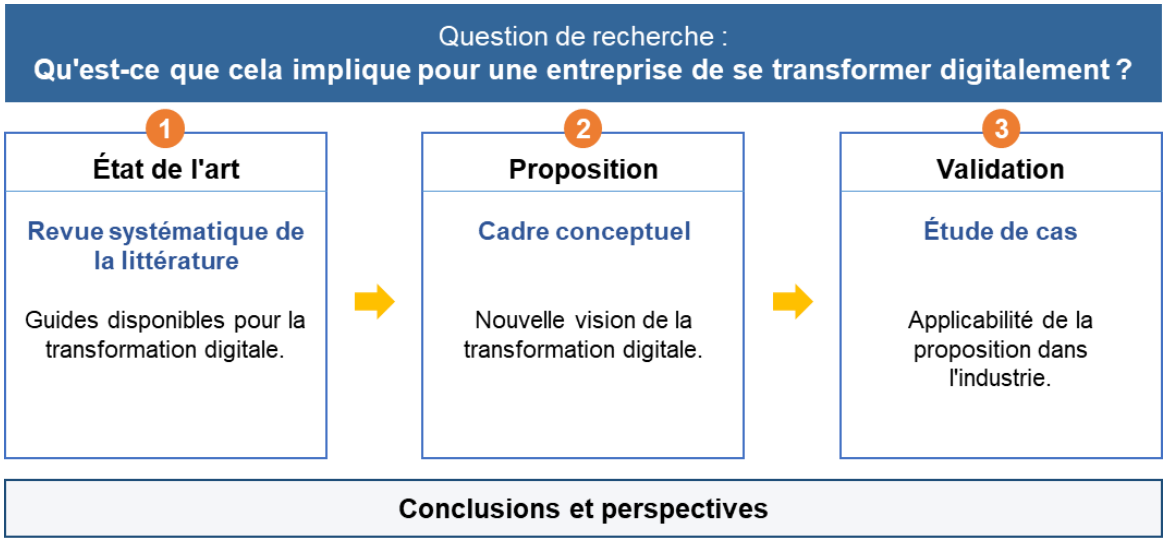


Figure 2 Grandes étapes du plan de recherche.

Les objectifs de ces étapes sont les suivants :

1. examiner l'état actuel de la littérature par le biais d'une analyse systématique de la littérature (Systematic Literature Review, SLR) afin d'identifier les modèles et les cadres qui fournissent des directives en matière de TD et de déterminer leurs limites principales,
2. proposer une vision holistique du phénomène de la TD en construisant un cadre conceptuel de ses principaux éléments sur la base d'un fondement théorique,
3. valider l'applicabilité des principales propositions du cadre conceptuel en réalisant des études de cas d'entreprises françaises appartenant au secteur industriel de la mécatronique.

État de l'art : Revue des solutions guidant la TD

Terminologie de la TD

Comprendre la complexité du panorama technologique actuel est un défi qui est amplifié par l'absence d'une terminologie commune liée aux termes de l'univers digital. L'importance de positionner les définitions des principaux concepts entourant la transformation digitale (TD) est cruciale pour assurer la clarté de ce travail et éviter toute superposition entre les notions qui créerait des confusions.

Après une recherche préliminaire dans la littérature relative à la notion de TD, un premier bilan de l'ensemble des connaissances sur le sujet a permis de définir les catégories suivantes de concepts qui aident à mieux comprendre la terminologie de la TD.

1. Le *type de changement digital* : digitisation, digitalisation, transformation digitale.
2. Le *type d'initiatives digitales* : le déploiement de la fabrication intelligente, la conception de produits intelligents ou connectés et la mise en place de services basés sur l'exploitation massive de données.
3. Le *type d'outils digitaux* : les modèles de maturité, les cadres et les feuille de route.
4. Le *type d'indicateurs digitaux* : le niveau de maturité digitale et le niveau de préparation digitale.
5. Le *type de programmes digitaux* : l'industrie 4.0 (Allemagne), l'usine du future (France), la fabricca del futuro (Italie).

Chaque concept a été spécifié au moyen d'une définition volontairement réduite strictement à l'essentiel de façon à éviter le plus possible les superpositions avec les autres concepts du même ensemble. L'annexe 1.1 présente une vue consolidée du glossaire complet de ces termes.

L'établissement d'une terminologie de la TD pour ce travail est également fondamental pour comprendre les utilisations des différentes notions et pour identifier les termes à utiliser dans la revue systématique de la littérature (Systematic Literature Review - SLR) conduite pour réaliser l'état de l'art. Sachant que dans la littérature de recherche, la plupart des termes pour nommer les propositions pour guider la TD des entreprises ne sont pas standards, la discussion sur l'utilisation des différentes notions a permis de construire une combinaison de termes qui permettra une recherche plus ciblée et efficace.

Revue des modèles et cadres numériques actuels

La revue de la littérature porte sur l'identification et l'analyse des modèles et cadres digitaux (Digital Models and Frameworks, DMF) disponibles et proposés pour guider les entreprises dans leurs

efforts de transformation digitale (TD). L'objectif est de déterminer leur pertinence pour représenter pleinement les implications d'une TD pour une entreprise. Cette revue de littérature s'inscrivant dans le contexte digital implique cependant de nombreux défis. La littérature sur le sujet et les termes qui s'y rapportent sont nombreux. Cette richesse, qui témoigne de la pertinence actuelle du sujet, présente certains défis lorsqu'elle est combinée à sa nouveauté. Comme nous l'avons vu précédemment, les définitions officielles du terme et de la terminologie connexe ne sont pas encore disponibles dans la littérature académique, ce qui a un impact sur l'utilisation des différentes notions et leur analyse. Des stratégies de recherche qui tiennent compte de la nature multidisciplinaire du sujet sont également nécessaires, étant donné la critique des vues limitées des travaux disponibles dans la littérature. Cette situation implique d'effectuer une recherche plus large qui couvre de nombreuses perspectives et différents niveaux de détail afin de fournir une vision complète de l'état de l'art.

Dans la recherche d'une base solide pour construire une proposition, ce travail repose sur une revue systématique de la littérature (Systematic Literature Review, SLR) comme méthode. La qualité des SLR repose sur la transparence de la méthode utilisée pour l'exploration de la littérature, de son analyse et des procédures de rapport (Booth, 2016). Pour atteindre la qualité requise, cette section a été construite en suivant les principales directives de la déclaration PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) (Page et al., 2021).

Pour répondre à la première exigence d'une recherche systématique, à savoir sa couverture, une combinaison de bases de données multidisciplinaires et spécifiques à un domaine a été sélectionnée. Les bases de données utilisées à cette fin étaient Scopus, Web of Science (WoS), IEEE Xplore, EBSCO et Science Direct (SD). Compte tenu de la nature du sujet et du domaine d'application (secteur industriel), ces bases de données ont été considérées comme les plus adéquates car elles comptent une quantité importante de documents de recherche de qualité (Scopus, WoS, SD) ou sont réputées dans les domaines de l'ingénierie (IEEE) ou du management (EBSCO). Voir l'annexe 1.2 pour les détails intégraux de la stratégie de recherche.

La recherche a donc été effectuée en utilisant la combinaison de termes suivante :

("smart" OR "digital" OR "Industry 4.0" OR "digitalization") AND ("maturity model" OR "index" OR "framework" OR "roadmap" OR "assessment")

La recherche a été effectuée en octobre 2021 et mise à jour en décembre 2021, compte tenu de la croissance exponentielle de la littérature sur le sujet. Les résultats ont été récupérés uniquement en anglais et la période considérée pour la recherche s'étend de 2010 à 2022 (2022 pour inclure les preprints), car le sujet est très sensible au facteur temps en raison de l'évolution rapide de la technologie (voir la figure 3).

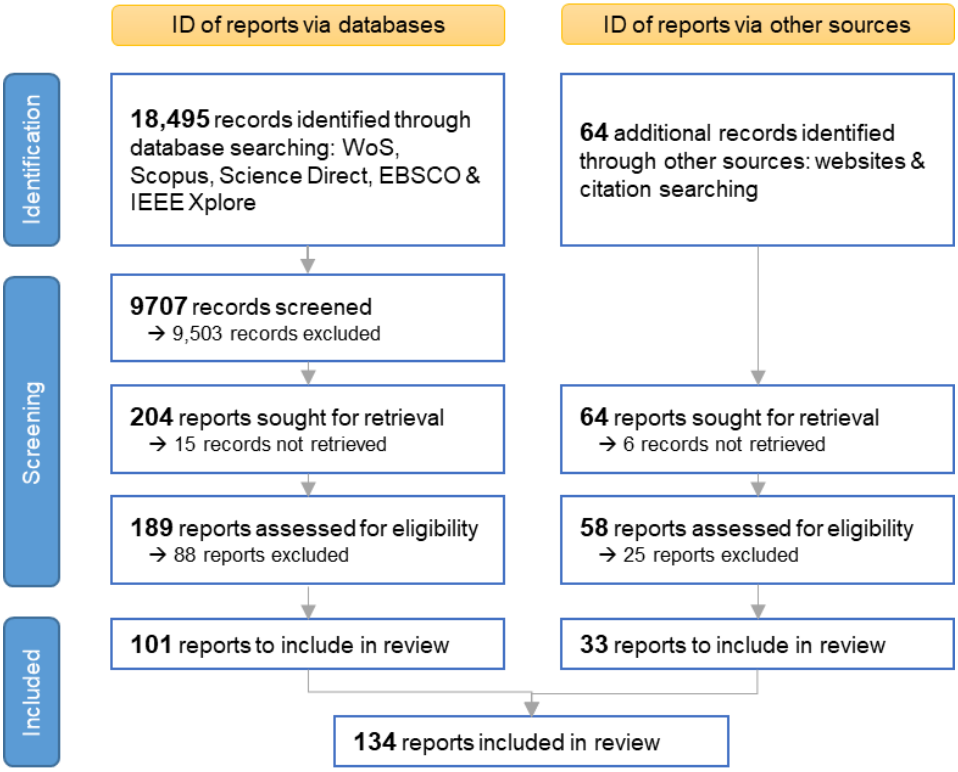


Figure 3 Procédure PRISMA pour SLR (version adaptée de Page et al., 2021).

La SLR des DMF actuels a permis de trouver 101 travaux répondant aux critères définis. Néanmoins, comme il est généralement connu que les recherches électroniques présentent des lacunes et qu'il est toujours possible de passer à côté de certains travaux importants, 33 DMF supplémentaires ont également été localisés par le biais de sites web ou de recherches de sources dans les listes de références des articles pertinents, une méthode communément appelée « snowballing » (Hiebl, 2021). Ces articles supplémentaires, qui complètent ceux trouvés dans les bases de données académiques, proviennent de la communauté des praticiens qui a également produit des travaux fortement référencés par des articles de recherche pertinents, d'où leur inclusion. Au total, 134 DMF ont été identifiés dans la littérature pour guider les entreprises dans leur TD (voir l'annexe 1.3). La figure 4 présente les DMF par année de publication.

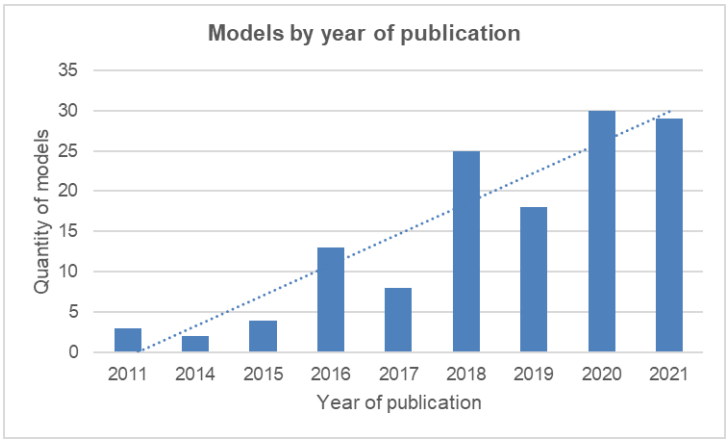


Figure 4 DMF par année de publication.

Le nombre de DMF disponibles dans la littérature s'accroit de façon exponentielle, dont 45% d'entre eux ont été publiés entre 2020 et 2021. Constitués de 82% des travaux de recherche, on trouve donc également des travaux phares issus de la pratique depuis les années 2010 (voir section 1.2.2.3). Le type de publications choisi pour présenter les DMF va des conférences aux articles de journaux dans la recherche, à l'utilisation de « white papers » (rapports) privilégié par les praticiens. Alors qu'on constate une nette prédominance de la contribution allemande, le reste des travaux provient néanmoins de pays du monde entier, ce qui atteste de la pertinence globale du sujet. Cette situation montre également à quel point les efforts de recherche sur le sujet sont dispersés.

Les méthodes utilisées pour élaborer les DMF sont variées, et répondent à des objectifs différents. Leur évaluation est faite ici en considérant leur représentation du phénomène qui peut servir de guide pour la TD des entreprises. A cet égard, bien que les modèles de maturité (Maturity Models, MM) et les cadres représentent 71% des DMF, les MM sont ceux qui sont en mesure de fournir plus d'informations sur la trajectoire vers une TD (ou une initiative digitale) que les cadres (voir section 1.2.3.1).

La situation devient plus critique en ce qui concerne la méthode de génération du contenu. Les résultats ont montré que la plupart des DMF s'appuient principalement sur des revues de la littérature pour définir leur contenu. Lorsque ces analyses s'appuient sur la littérature existante, en particulier sur des DMF précédents, pour élaborer leur contenu, il existe un risque certain d'hériter des mêmes problèmes que ceux de la source. Seuls des cas isolés s'appuient sur la théorie pour construire le contenu. Il est également intéressant de noter que le niveau de rigueur des méthodes utilisées pour valider le contenu des DMF, comme les entretiens avec des experts, peut affecter la qualité de leur contribution.

L'objectif des DMF tourne généralement autour des initiatives digitales. Étant donné que la plupart d'entre eux visent le secteur manufacturier, l'industrie 4.0 est un objectif populaire. Seule une fraction des modèles cible une TD, mais la manière dont ils caractérisent ses objectifs est un élément d'information qui n'est pas toujours disponible en raison du manque de détails concernant les DMF (voir section 1.2.4.1). Compte tenu de l'importance accordée à l'industrie 4.0 et à la fabrication intelligente, un nombre important de DMF ont été conçues pour aider les entreprises manufacturières dans leurs efforts de digitalisation de leurs processus de production. D'autres DMF orientent également leurs efforts vers le soutien aux petites et moyennes entreprises (PME) ou, plus précisément, aux PME manufacturières, car elles sont considérées comme un groupe particulièrement vulnérable à la perspective d'une TD en raison du manque de ressources (voir la section 1.2.4.2).

La capacité des DMF à représenter une TD pour ces groupes est toutefois sérieusement limitée par les outils qui ont été choisis. Seuls les MM et les feuilles de route s'approchent de la représentation de la TD sous forme d'une série d'étapes (MM) ou de phases (feuilles de route) à suivre. Cependant, cette représentation est statique et manque de flexibilité pour s'adapter au contexte des entreprises. L'évaluation de la couverture de l'étendue des implications de la TD couverte par les DMF est difficile. Les aspects considérés relativement aux entreprises sont nombreux, mais il n'y a pas d'accord sur ceux sélectionnés pour chaque DMF ni de justification solide de la raison de leur choix. Les critères détaillés pour un même aspect peuvent également être différents d'un DMF à l'autre, ce qui témoigne de l'absence de consensus sur les facteurs qui jouent un rôle sur la réussite de la TD (voir figure 5).

Criteria / DMFs Name	Strategy	Business Model	Investment	Customer	Partners	Products	Services	Process	Governance	Culture	Leadership	Employee Competencies	Organizational Structure	Technology	Performance Measurement
Industry 4.0 Maturity Model (Schumacher et al., 2016)	•		•	•	•	•		•	•	•	•	•		•	
Industrie 4.0 Maturity Index (Schuh et al., 2017)										•			•	•	
Smart Factory Maturity Model (Sjödin et al., 2018)								•				•		•	
Digital Readiness Level 4.0 (Pirola et al., 2020)	•			•	•			•				•		•	
Company Compass 2.0 (Nick et al., 2020)	•					•	•	•		•		•		•	
DT Capability Maturity Model (Gökalp and Martinez, 2021)	•							•		•		•	•	•	

Figure 5 Critères pour mesurer la maturité de l'entreprise vers une transformation digitale.

L'analyse des DMF met en évidence que leur adaptabilité au contexte des entreprises est limitée non seulement par la nature statique des outils qu'ils utilisent pour représenter la TD mais aussi par le manque de considération de l'effet du contexte sur la TD des entreprises. Le manque apparent de la perception du rôle des facteurs du contexte des entreprises dans le développement d'une TD réussie amène une grave carence des DMF proposés. Même lorsqu'ils visent des groupes spécifiques, les MM actuels, par exemple, sont des représentations statiques qui n'offrent aucun degré de personnalisation.

Des études antérieures liées à cette thèse ont exploré l'effet des traits caractéristiques des entreprises sur leurs efforts de TD (Liborio Zapata et al., 2021), mais il reste encore beaucoup à faire en la matière. Le besoin est reconnu, car les DMF ciblent des groupes spécifiques avec leurs propositions, mais une combinaison de mauvais choix méthodologiques et le faible niveau de conscience des implications de la TD lors de leur construction ne permettent pas de garantir le succès à l'issue du processus de transformation entamé.

Limitations des DMF

Sur la base des résultats identifiés lors de la SLR et des particularités et des exigences liées au scénario de la TD, il est possible d'identifier les déficits des travaux actuels dans la littérature. Cette vision globale de la situation permet de développer une meilleure compréhension de la cause profonde du problème dans la perspective de recherche d'une solution. En examinant la littérature pertinente, on constate que le contenu des DMF montre que leur vision est incomplète et superficielle.

Les limites des DMF pour guider la TD des entreprises et représenter fidèlement le phénomène sont les suivantes :

- l'objectif des DMF est déconnecté de la nature de long terme de la TD,
- les DMF offrent une vision inconsistante et incomplète de la TD,
- les DMF présentent une caractérisation générique de la TD.

Après avoir effectué cette revue critique des DMF disponibles dans la littérature, il est possible de déterminer un manque global de représentation de l'ensemble des implications de la TD par leurs auteurs. L'origine des limitations qui ont conduit à cette évaluation générale semble provenir non

seulement des outils utilisés pour développer et présenter les DMF mais surtout des méthodes utilisées pour créer leur contenu qui manquent de fondement théorique.

Comme l'objectif de ce travail est focalisé sur la création d'un cadre de référence pour l'ensemble des implications de la TD, la limitation des DMF concernant les outils utilisés ne sera pas abordée dans ce travail. L'accent sera mis sur la présentation d'une vision de la TD qui soit complète et cohérente avec une base théorique.

Proposition : Une nouvelle vision holistique de la TD d'une entreprise

Ayant constaté l'absence d'une approche formelle basée sur la théorie et une vision holistique, ce travail établit d'abord une fondation plus solide du CDTF en construisant sa base théorique. Dans ce contexte, il semble tout à fait approprié d'aborder la tâche de construire une vision holistique du phénomène de la TD en utilisant un cadre conceptuel, car les cadres conceptuels sont le « résultat final du regroupement d'un certain nombre de concepts connexes pour donner une compréhension plus large du phénomène d'intérêt » (Imenda, 2014). Les TD, comme la plupart des phénomènes sociaux, est complexe et nécessite une approche multidisciplinaire pour une meilleure compréhension qui peut être réalisée avec la construction d'un cadre conceptuel (Jabareen, 2009). Comme le cadre conceptuel proposé est construit sur des éléments conceptuels issus de la théorie, une revue de la littérature n'a pas été la source exclusive de ce dernier.

En fait, la contribution de ce travail repose précisément là sur la présentation d'une définition qui s'appuie sur la théorie existante du changement organisationnel. Cette approche permettra de construire une vue d'entreprise large et structurée de ce type de changement et de positionner d'autres éléments critiques impliqués dans une TD. Un cadre conceptuel qui reconnaît tous les éléments d'une TD apporte une base solide pour guider les initiatives digitales et éventuellement la création de meilleurs modèles et cadres digitaux (Digital Models and Frameworks, DMF). En outre, l'utilisation d'un cadre conceptuel sert un double objectif puisque sa conception guide également la phase de validation de ce travail de recherche. La représentation de la vision globale de la TD s'est également avérée utile dans les phases de sélection des cas et de collecte des données en clarifiant les informations à collecter pour valider la proposition.

Ainsi, le point de départ de la recherche d'une ou de plusieurs théories qui constituent la base de cette proposition est constitué par les limites des DMF actuels disponibles dans la littérature.

Tout d'abord, pour répondre à la déconnexion de l'objectif des DMF avec la conceptualisation d'une TD, ce travail se réoriente vers le concept de « business transformation » pour caractériser ce type de changement. Depuis les années 90, la transformation de l'entreprise est un sujet récurrent dans la théorie des organisations et est particulièrement liée au changement organisationnel. Muzyka et al. (1995) ont présenté l'une des premières tentatives de définition lorsqu'ils ont introduit la transformation de l'entreprise comme un *« changement fondamental dans la logique organisationnelle, qui a entraîné ou a été causé par un changement fondamental dans les comportements. »*

De nombreux auteurs se sont accordés sur la complexité de ce type de changement, notamment sur le fait qu'il implique des *« changements interdépendants à l'échelle du système »* (Prahalad et Oosterveld, 1999), et ont insisté sur la nécessité d'identifier clairement les éléments impliqués pour les gérer efficacement (Mintzberg et Westley, 1992). En ce sens, la définition la plus pertinente de cette époque en rapport avec ce travail est peut-être le type de changement qui représente une transformation pour réussir. Une transformation ne consiste pas seulement à mettre en œuvre un changement pour passer d'un point A à un point B, mais à « mettre en place une organisation

durable à long terme » (Muzyka et al., 1995). L'objectif d'une transformation est donc axé sur les capacités, tout comme il est axé sur les aspects économiques (Riasanow et al., 2017).

Ensuite, pour tenter de résoudre un problème clé de la représentation actuelle d'une TD, une analyse des théories sur le changement organisationnel est effectuée pour définir les éléments impliqués dans un tel changement. L'examen critique des DMF de l'état de l'art a montré que la représentation de la TD qu'ils fournissent est inconsistante et incomplète. Ces limites des DMF actuelles ont conduit à déterminer qu'une vision holistique qui présente toutes les implications d'une TD pour une entreprise est nécessaire. Les exigences de cette nouvelle vision, selon les résultats de la revue de la littérature, sont les suivantes :

- les éléments qui sont impliqués dans le processus de transformation et leur rôle,
- les dimensions de l'entreprise impliquées dans la transformation de l'entreprise, et leurs interactions,
- la définition d'un processus de haut niveau de transformation d'une entreprise.

Pour construire une vision holistique de la TD fondée sur la théorie, il faut d'abord identifier les éléments à différents niveaux qui devraient être pris en compte dans une TD. En partant de l'hypothèse qu'une TD est un changement organisationnel, la voie la plus évidente est de chercher une théorie appropriée dans le riche corpus de littérature dans ce domaine. La littérature sur le domaine du changement organisationnel est abondante et varie profondément selon les différentes perspectives. Plusieurs auteurs ont passé en revue les théories et les recherches sur le changement organisationnel. Notamment, Armenakis et Bedeian (1999) et, plus récemment, Burke (2017) font un compte rendu des théories et des recherches axées sur ce domaine. Ces deux analyses présentent un intérêt particulier pour ce travail car elles se concentrent sur ce qu'Armenakis et Bedeian appellent les « facteurs de contenu » qui sont fixés pour prédire la performance du changement.

Une analyse sélective du contenu d'une théorie et de deux modèles a été effectuée, en considérant que leur contenu est pertinent dans le cadre de ce travail. La sélection est composée des ouvrages suivants :

- la théorie des systèmes socio-techniques de Trist et Bamforth (1951),
- le modèle de performance et de changement organisationnel de Burke et Litwin (1992),
- le modèle de l'impératif de transformation de Vollmann (1996).

Ces ouvrages représentent les principales sources théoriques retenues pour déterminer les concepts ou éléments qui composeront finalement le cadre conceptuel. L'analyse a porté sur trois thèmes à prendre en compte :

1. la nature d'une TD et l'objectif qu'il poursuit,
2. les éléments d'une vision holistique de la TD,
3. l'effet du contexte de l'entreprise sur une TD.

De l'analyse du premier thème, on peut déduire que la nature transformative de la TD donne naissance à une toute nouvelle version de l'entreprise préparée pour le contexte digital, donc une « entreprise digitale ». L'évolution vers une entreprise digitale nécessite des indicateurs qui visent à sécuriser la TD en mesurant son état de préparation et sa maturité.

L'analyse du troisième thème peut également fournir les concepts nécessaires à la prise en compte de cette proposition d'une manière très directe. L'effet du contexte sur une TD est à examiner du point de vue interne et externe. Les approches socio-techniques se distinguent par la caractérisation des organisations comme des systèmes ouverts (Emery, 1959) qui interagissent avec l'environnement qui les entoure. Nightingale et Rhodes (2015) ont élargi cette compréhension

dans leur concept de « paysage d'entreprise » qui comprend non seulement l'environnement externe mais aussi le paysage ou le contexte interne de l'organisation.

Les premier et troisième thèmes identifient donc le groupe de éléments suivants :

- entreprise digitale (digital company), préparation digitale (digital readiness), et maturité digitale (digital maturity) et
- environnement externe (external environment) et contexte interne (internal context).

Pour compléter la liste des concepts, le deuxième thème, les éléments de la vision holistique de la TD, est analysé plus en détail. Les trois ouvrages examinés ont fourni différentes perspectives des éléments qui sont impliqués dans un changement organisationnel. Afin de construire une vision holistique, ces perspectives seront ensuite confrontées afin d'identifier où elles coïncident et où elles diffèrent.

Dans le tableau 1, les éléments des trois points de vue offert par la théorie et les deux modèles de changement organisationnel retenus dans cette étude sont également confrontés aux éléments considérés par les DMF actuels analysés dans la revue de la littérature (voir chapitre 1, section 1.2). Les éléments similaires sont affichés sur la même ligne, un « - » symbolise l'absence d'un élément similaire pour une théorie ou un modèle donné.

Table 1 Éléments considérés par trois théories et modèles de changement organisationnel et ceux proposés par les DMF disponibles dans la littérature.

No	**Socio-Technical Systems Theory** (Trist and Bamforth, 1951; Nightingale and Rhodes, 2015)	**Model of Organizational Performance and Change** (Burke and Litwin, 1992)	**The Transformation Imperative Model** (Vollmann, 1996)	**DT elements proposed by current DMFs in the literature**
1	External Environment	External Environment	-	-
2	Internal Context	-	-	-
3	-	Mission and Strategy	Strategic intent	Strategy
4	-	-	Strategic responses	Products and Services
5	-	-	-	Business Model
6	-	-	Resources	Investment
7	-	Leadership	-	Leadership
8	-	Organizational Culture	Culture	Culture
9	Structure	Structure	Configuration (organization design)	Organizational Structure
10	Task	Systems (policies and procedures)	Processes	Process
11	-	-	Information	-
12	-	Management Practices	Coordination	Governance
13	People	-	People	-
14	-	Tasks and individual skills	Competencies	Competencies
15	-	-	Learning capacity	-
16	-	Individual and Organizational Performance	Outputs	Performance Measurement
17	Technology	-	Technology	Technology
18	-	-	-	Customer and Partners
19	-	-	Challenges	-

No	**Socio-Technical Systems Theory** (Trist and Bamforth, 1951; Nightingale and Rhodes, 2015)	**Model of Organizational Performance and Change** (Burke and Litwin, 1992)	**The Transformation Imperative Model** (Vollmann, 1996)	**DT elements proposed by current DMFs in the literature**
20	-	Individual needs and values	-	-
21	-	Work Unit Climate	-	-
22	-	Motivation	-	-

Des éléments importants ressortent de l'analyse des travaux sélectionnés comme fondements théoriques du cadre conceptuel. Ces éléments complètent ceux déjà identifiés et définissent la liste finale suivante :

- environnement externe (external environment) et contexte interne (internal context)
- entreprise digitale (digital company)
- préparation digitale (digital readiness), et maturité digitale (digital maturity)
- stratégie (« digital » strategy), ressources (resources), modèles commerciaux (business models), initiatives digitales (digital initiatives : products, services),
- technologie (technology), processus (processes), compétences (competencies), structure organisationnelle (organizational structure), et culture (culture),
- gestion de la performance (performance management).

Les éléments identifiés ont fourni les éléments nécessaires à la construction d'un cadre conceptuel qui a élargi la compréhension actuelle de la TD, en mettant l'accent sur les composantes qui sont omises dans les propositions de solutions actuelles (DMF). Une exploration plus approfondie de la littérature sur chaque élément individuel a permis à ce travail de construire une nouvelle version de la TD qui offre une vision plus équilibrée et complète du phénomène. La figure 6 présente le cadre conceptuel de la transformation digitale (CDTF).

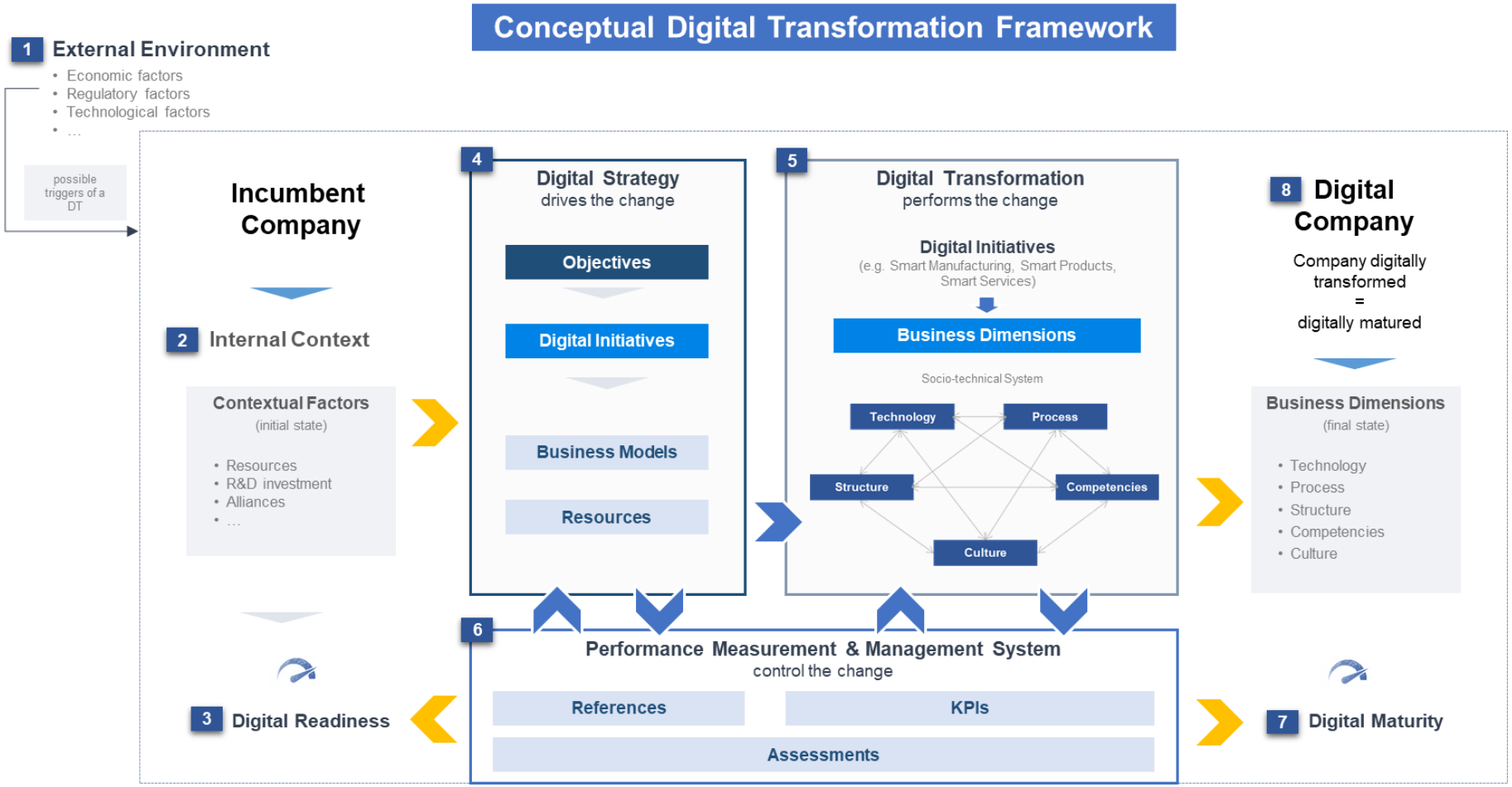


Figure 6 Cadre Conceptuel de Transformation Digitale (Conceptual Digital Transformation Framework, CDTF).

Les principaux concepts de la TD sont numérotés. Le « ... » indique que les facteurs ne sont qu'un échantillon de la liste complète.

Le CDTF est une vue d'ensemble de tous les éléments qui doivent être pris en compte lors d'une TD et des interactions entre eux. Les éléments qui composent le CDTF fonctionnent ensemble pour montrer une proposition de la façon dont une TD devrait fonctionner pour tirer pleinement parti de ses opportunités.

Le CDTF commence par la saisie du contexte de l'entreprise. Les facteurs de l'environnement externe (nº **1**) peuvent accroître l'urgence d'une TD. Le contexte interne (nº **2**) de l'entreprise établit les conditions d'un tel changement. Les deux ont un effet sur la stratégie digitale (nº **4**) qui doit être élaborée. Par conséquent, pour qu'une stratégie soit efficace, elle doit les prendre en compte lors de la définition des objectifs de l'entreprise. Ces objectifs sont le point de départ pour déterminer les initiatives digitales à poursuivre. Les modèles commerciaux doivent être définis et les ressources nécessaires doivent être attribuées au projet en conséquence.

Les sous-éléments de la stratégie digitale donnent une orientation au cœur de la transformation digitale. L'élément de transformation digitale (nº **5**) effectue la transformation en mettant en œuvre des changements au sein de l'entreprise, en particulier dans les dimensions impliquées. La conception de ces changements tient compte des interactions entre ces dimensions. De cette façon, les changements produisent la performance ou le résultat souhaité pour la TD.

Un système de gestion et de mesure de la performance (Performance Measurement and Management System, PMMS) permet de superviser cet effort, depuis le début de la phase de planification jusqu'à la réalisation de la TD (maturité digitale). Un PMMS (nº **6**) détermine d'abord le niveau de préparation digitale de l'entreprise (nº **3**) pour lancer une TD. Il fournit ensuite un retour d'information à la stratégie digitale, afin que la planification stratégique tienne compte de son état actuel et des références pour établir les objectifs. Ensuite, il mesure les progrès de l'entreprise vers la réalisation des objectifs grâce à l'indicateur du niveau de maturité digitale (nº **7**). La maturité digitale représente dans ce schéma non seulement la réalisation des objectifs de digitalisation mais aussi le statut d'une entreprise digitale (nº **8**), une entreprise mieux préparée pour faire face aux défis du contexte digital qui se caractérise comme d'un environnement de changements constants.

Les dimensions de l'entreprise impliquées dans une TD

Dans la proposition du Cadre Conceptuel de Transformation Digitale (Conceptual Digital Transformation Framework, CDTF), la clé de la Transformation Digitale (TD) de l'entreprise réside dans les changements de cinq dimensions : la technologie, les processus, la structure organisationnelle, les compétences et la culture organisationnelle (voir figure 7).

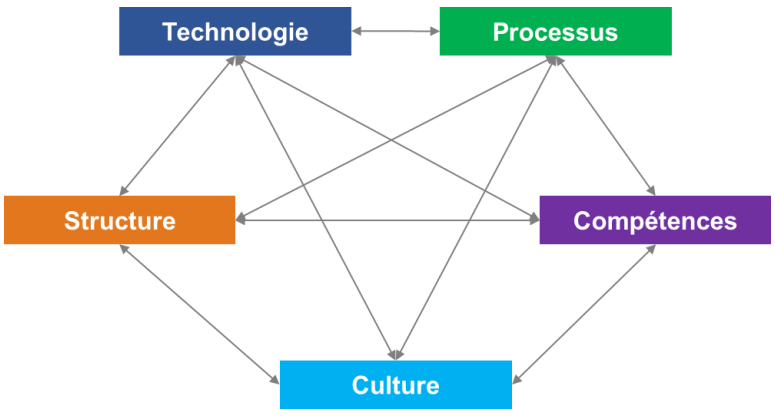


Figure 7 Dimensions de l'entreprise et leurs interactions (création de l'auteur).

La définition d'un ensemble de dimensions impliquées dans un changement de la nature d'une TD est au cœur de la proposition de ce travail, ainsi que la caractérisation de leurs interactions et de l'évolution de leurs composantes au cours de ce type de changement. La raison de son importance réside dans le fait que l'évolution de ces dimensions est ce qui transforme une entreprise. On pense que le succès et la maturité peuvent être atteints avec une gestion adéquate des changements à l'intérieur de chacune des dimensions de l'entreprise.

Lors de la conception du CDTF, et plus particulièrement de l'élément transformation digital, il est crucial de comprendre la logique des changements au sein de l'entreprise au cours de la TD. L'intérêt pour l'évolution de chaque dimension de l'entreprise est motivé par la nécessité d'identifier les composantes pertinentes en leur sein qui contribuent au succès de la TD.

La nature de chaque dimension de l'entreprise est différente, et par conséquent, les facteurs qui changent en leur sein varient de l'un à l'autre. La figure 8 présente une compréhension de l'étendue des changements au cours d'une TD dans chaque dimension.

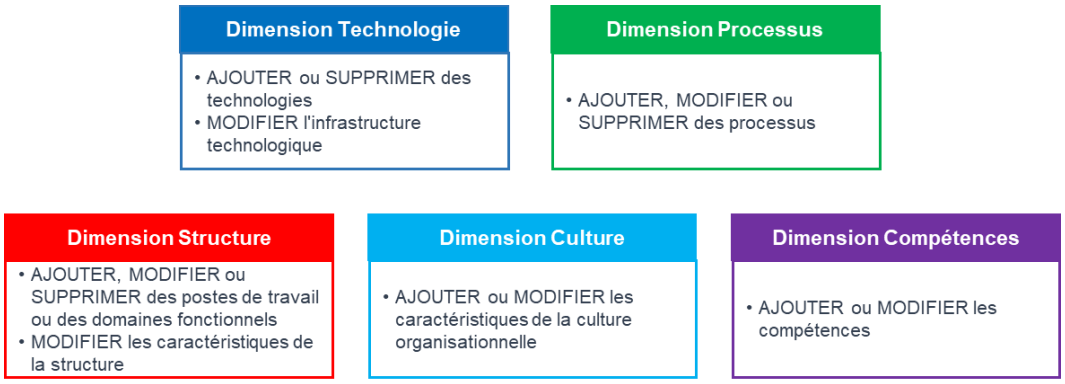


Figure 8 Étendue des changements dans les dimensions de l'entreprise pendant une TD (création de l'auteur).

Dans cette proposition, la TD au sein de l'entreprise est divisée en deux types de changements, les changements requis dans les dimensions de l'entreprise pour gérer les initiatives digitales (voir figure 9, #1 à gauche) et les changements requis dans les dimensions de l'entreprise pour réaliser les initiatives digitales (voir figure 9, #2 à droite).

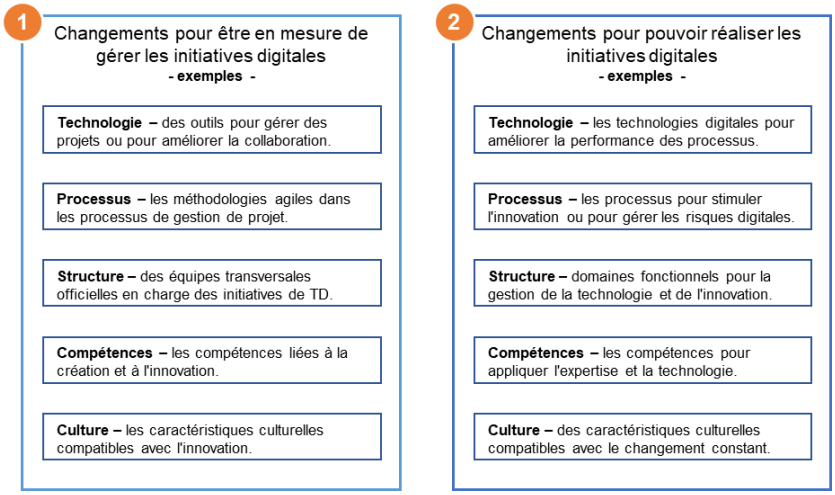


Figure 9 Type de changements dans les dimensions de l'entreprise en fonction de leur utilisation (création de l'auteur).

Ces deux types de changement sont également pertinents à long terme pour renforcer les capacités de l'entreprise digitale. En particulier les changements pour gérer les initiatives digitales, car l'entreprise digitale doit être capable d'être suffisamment flexible et agile pour mieux intégrer les nouvelles technologies digitales. Mais aussi, les capacités construites dans les différentes dimensions pour une initiative particulière pendant la TD peuvent être très utiles pour les projets futurs.

En ce sens, pour parvenir à une TD, il devrait y avoir deux plans de développement en parallèle. Le premier, à court terme, concerne les différentes initiatives qui composeront la trajectoire vers la TD. L'autre, avec une vision à long terme, permet de développer le reste des capacités requises par l'entreprise digitale (voir figure 10).

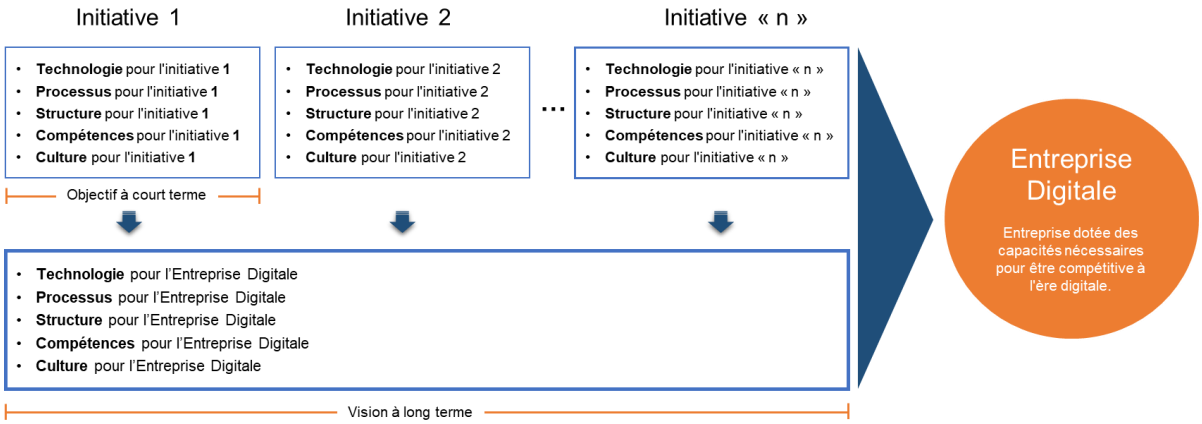


Figure 10 Types de changements dans les dimensions de l'entreprise en fonction de leur durée (création de l'auteur).

Naturellement, en mettant en œuvre chaque initiative digitale, l'introduction de la technologie devient plus facile pour l'entreprise car, par conséquent, elle contribue au développement des capacités cruciales pour toutes les dimensions. Dans cette proposition, cependant, l'objectif est que le renforcement des capacités soit intentionnellement planifié en fonction du type d'entreprise digitale que l'entreprise envisage de devenir (voir chapitre 2, section 2.2.8).

Enfin, chacun de ces plans, à court (initiatives digitales) et à long termes (entreprise digitale) est composé dans chaque dimension d'un ensemble de changements dérivés des exigences du contexte digital et d'un autre groupe de changements plus génériques qui concernent tout exercice de changement organisationnel de type transformationnel (voir figure 11).

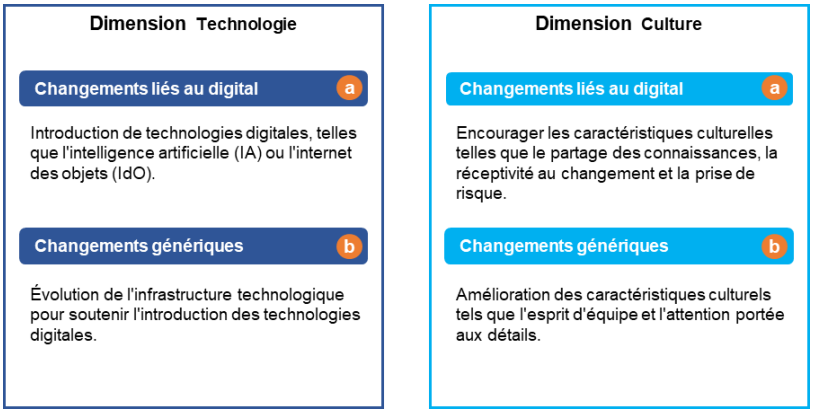


Figure 11 Types de changements dans les dimensions de l'entreprise en fonction de leur nature, 2 dimensions à titre d'exemple (création de l'auteur).

Alors que les changements liés au digital répondent à la nécessité de faire face aux défis du contexte digital, tels que l'évolution technologique constante et rapide et la pression concurrentielle croissante, les changements génériques sont nécessaires pour soutenir ou faciliter ces changements. Les études sur le changement organisationnel se concentrent traditionnellement sur les « changements génériques ». Ce travail, cependant, souligne la nécessité de comprendre que le nouveau contexte digital exige de considérer des facteurs supplémentaires dans chaque dimension pour réussir dans ces nouvelles conditions.

Ces nouvelles conditions imposées par le contexte digital sont principalement une conséquence du développement rapide de la technologie, qui apporte complexité et incertitude à l'environnement des entreprises. Par exemple, dans un tel scénario, les entreprises doivent commencer à envisager l'introduction de nouvelles technologies de manière plus fréquente qu'auparavant. Elles peuvent également être amenées à reconsidérer leur culture organisationnelle, afin que les employés soient plus à l'aise pour prendre des risques ou partager leurs connaissances, entre autres. Les nouvelles conditions imposent un état de changement constant auquel les entreprises doivent être préparées.

Les trois perspectives présentées pour comprendre la dynamique du changement à l'intérieur de chacune des dimensions concernées ont pour objectif de contribuer à la construction d'une vision holistique de la TD. Elles sont également utiles pour préciser les raisons pour lesquelles ce type de changement organisationnel est différent des autres révolutions technologiques précédentes. Détailler les composantes qui changent dans chacune des dimensions de l'entreprise proposées dans ce travail contribue à identifier quels sont les facteurs critiques de succès (critical sucess factors) dans une TD et comment ils varient dans différents scénarios. Être conscient que chaque initiative nécessitera les composants identifiés dans des mesures différentes ajoute aux subtilités à prendre en compte dans un changement de ces proportions.

La proposition de l'évolution des dimensions de l'entreprise pendant une TD est centrée sur les changements spécifiques que chaque dimension subit. Même si ce champ d'application exclut tout autre facteur externe, la documentation de l'état de chaque dimension doit également être prise en compte car elle est considérée comme critique pour l'agilité de la mise en œuvre des changements. L'agilité devient un facteur clé dans les scénarios de changement constant, tels que le contexte digital. La documentation de l'état des dimensions permet d'accélérer l'analyse de leur situation actuelle lorsqu'un changement est nécessaire et de déterminer les lacunes à combler pour atteindre l'état souhaité.

Validation : Analyse du contexte industriel mécatronique français

A travers le Cadre Conceptuel de Transformation Digitale (Conceptual Digital Transformation Framework, CDTF), ce travail permet de dégager une nouvelle compréhension de la TD avec deux objectifs. Premièrement, introduire une vision holistique du phénomène qui identifie ses principaux éléments et leur rôle dans la transformation (voir chapitre 2), et deuxièmement, identifier les aspects spécifiques de l'entreprise (dimensions de l'entreprise) qui sont impliqués dans un tel changement (voir chapitre 3). Cette vision, cependant, est entièrement théorique et agnostique aux particularités des contextes spécifiques ; par conséquent, sa viabilité dans des scénarios de cas réels restait à déterminer.

Dans ce contexte, l'objectif de l'étape suivante était de valider l'applicabilité du CDTF. La vision holistique proposée est comparée au chemin de transformation que les entreprises industrielles choisissent de suivre pour identifier les différences possibles, leurs raisons et leurs conséquences. De plus, dans cette analyse, les facteurs du contexte des entreprises qui influencent ces voies de transformation ont également été identifiés.

L'objectif de ce travail étant de fournir un cadre de référence offrant une vision holistique du phénomène de la TD, un phénomène relativement nouveau, la nature de ce projet de recherche est exploratoire (Voss et al., 2002). Conformément à sa nature exploratoire, une méthode de recherche par étude de cas est utilisée pour répondre aux questions de recherche de ce travail (Voss et al., 2002).

Une étude de cas est considérée comme « une histoire d'un phénomène passé ou actuel, tirée de multiples sources de preuves » (Leonard-Barton, 1990). En tant qu'enquêtes empiriques, les études de cas sont utiles pour étudier des phénomènes complexes dans des contextes réels (Yin, 2018) et permettent aux chercheurs de mieux les comprendre en construisant des explications plausibles ou en découvrant des relations causales (Benbasat et al., 1987 ; Bluhm et al., 2011). Ce design a envisagé l'utilisation de la méthode de recherche par cas en deux phases. La première a défini une étude de cas unique comme un cas pilote qui a affiné la procédure et les outils de l'étape de collecte des données, et la seconde a utilisé une étude de cas multiples pour valider l'applicabilité des principales propositions du CDTF (voir chapitre 2 Fig. 2.3).

Cette recherche est axée sur le secteur industriel, un secteur d'activité qui joue un rôle clé dans la nouvelle ère digitale, car il n'est pas seulement l'utilisateur mais aussi le producteur de la nouvelle technologie qui révolutionne la façon de fonctionner et de faire des affaires (Khurana et al., 2018). La digitalisation des entreprises industrielles en Europe est considérée comme un moyen de stimuler la croissance économique de la région afin de rivaliser efficacement sur les marchés globalisés (Holz, 2017). De nombreux programmes au niveau régional et national sont développés pour stimuler la digitalisation. Cependant, les fabricants et les assembleurs sont particulièrement mis au défi par la perspective d'une TD (Khurana et al., 2018). En France, la situation n'est pas différente et les entreprises industrielles ressentent une pression constante pour se digitaliser.

Dans le contexte industriel, la TD est souvent représentée par plusieurs initiatives de base. Ces initiatives comprennent la mise en place d'une usine de fabrication intelligente et d'une chaîne d'approvisionnement intelligente, la création de produits intelligents ou la vente de services basés sur les données collectées par ses capteurs. Une trajectoire composée de ces initiatives dans un ordre ou un autre est souvent l'archétype de la TD des entreprises industrielles telles que celles du secteur mécanique.

Plus récemment, la création de produits intelligents a pris une place plus importante dans les TD des entreprises du secteur (Lichtblau et al., 2015). En particulier, les entreprises de la branche du génie mécanique cherchent un moyen de faire évoluer leurs produits conventionnels vers des produits intelligents qui peuvent apporter plus de valeur à leurs clients. Dans ce sens, la mécatronique en tant que discipline est considérée comme le moyen de guider l'intégration de base des éléments requis vers la réalisation de la fonctionnalité souhaitée des produits intelligents (Tomiyama et al., 2019).

La TD des entreprises du secteur industriel bénéficie des informations disponibles sur les types de trajectoires et d'initiatives digitales qui peuvent aider à dessiner leurs chemins de transformation. En outre, la nature multidisciplinaire de la mécatronique leur fournit l'ensemble des compétences et des connaissances qui sont fondamentales pour commencer la conception, le développement et la production de produits intelligents. Ces éléments clés font de ce contexte spécifique un élément intéressant sur lequel concentrer ce travail de recherche. L'objectif de la stratégie de sélection des cas était d'abord de trouver un seul cas dans l'industrie manufacturière française qui pourrait être analysé comme le pilote d'une étude plus approfondie sur le sujet (Yin, 2018).

Dans un deuxième temps, un échantillon plus large a été défini. Six entreprises, également dans le secteur industriel et impliquées dans une variété de scénarios, ont été considérées en plus du cas pilote pour constituer l'échantillon de l'étude. L'accent est mis sur le fait que les entreprises

sont de tailles différentes, mais qu'elles ont en commun les mêmes antécédents, le même secteur, la même industrie et le même type de produits.

La table 2 présente les principales caractéristiques de l'échantillon de cette étude. Les entreprises sont présentées selon l'ordre croissant de leur chiffre d'affaires. Un pseudonyme a été attribué à chacune d'entre elles, car elles ont demandé à rester anonymes.

Table 2 Caractéristiques des entreprises de l'échantillon de la recherche.

Caractéristique	SME 1	SME 2	SME 3	MSE 1	MSE 2	MSE 3	LE 1
Type d'entreprise	Familial	Familial	Familial	Familial	Familial	Familial	Groupe
Origine	France	France	France	France	France	Allemagne	Japon
Ancienneté (ans)	1959	1986	1995	1936	1985	1959	1916
Chiffre d'affaires	~**8**M€	~**12**M€	~**20**M€	~**55**M€	~**380**M€	~**450**M€	~**1010**M€
Collaborateurs	~120	~135	~120	~500	~2500	~2300	~5250
Taille	Petite et Moyenne Entreprise	Petite et Moyenne Entreprise	Petite et Moyenne Entreprise	Entreprise de Taille Intermédiaire	Entreprise de Taille Intermédiaire	Entreprise de Taille Intermédiaire	Grande Entreprise
Secteur d'activité	Fabrication de pièces mécaniques de précision	Fabrication de machines et équipements	Fabrication de produits métalliques	Fabrication de moteurs, génératrices et transformateurs électriques	Fabrication de machines et équipements	Fabrication de moteurs, génératrices et transformateurs électriques	Fabrication d'engrenages et d'organes mécaniques de transmission

Les activités de collecte de données ont été divisées en deux étapes.

1er. **Collecte des données d'étude du cas pilote**. La première étape vise à collecter les données du cas pilote qui sont utilisées pour affiner les outils de collecte de données pour le reste des entreprises de l'échantillon.
2e. **Collecte de données d'études de cas multiples**. La seconde étape a été conduite pour collecter les données des six entreprises qui constituent l'étude de cas multiples et pour compléter les informations manquantes de l'étude du cas pilote.

L'étape d'analyse des données vise la compréhension du processus de TD à travers l'analyse du parcours de transformation des entreprises de l'échantillon de l'étude. Par conséquent, en fondant cette analyse sur les propositions principales du CDTF soutenues par la théorie, la stratégie analytique globale s'appuie sur les propositions théoriques de ce travail (Yin, 2018). Le processus d'analyse des données a été réalisé en combinant deux stratégies proposées par Yin (2018), « s'appuyer sur les propositions théoriques » et « élaborer une description de cas », afin de valider l'applicabilité du CDTF dans chaque cas et d'organiser les résultats selon les éléments proposés. La technique utilisée pour l'analyse a été le « Pattern Matching » pour comparer les résultats de la TD des entreprises avec la TD illustrée dans le CDTF (Yin, 2018). Cette analyse des données a été réalisée avec le logiciel NVIVO.

Ensuite, les activités d'analyse des données ont été divisées en trois étapes.

1er. **Description des cas individuelles**. La première étape vise à créer une description individuelle de la TD de chaque entreprise incluse dans l'échantillon de l'étude.
2e. **Analyse des cas individuels**. La seconde consiste en une analyse des réponses aux questions de recherche de chaque entreprise incluse dans l'échantillon de l'étude.
3e. **Analyse transversale des cas**. La troisième et dernière étape consiste en une analyse transversale des réponses à chaque question par toutes les entreprises incluses dans l'échantillon de l'étude afin de trouver les similitudes et les différences et leurs origines.

L'entreprise SME3, sélectionnée comme cas pilote de ce travail, a été présentée comme un exemple de l'analyse de cas individuel. Le parcours de l'entreprise SME3 lors de sa TD est remarquable. Trois initiatives importantes en seulement cinq ans ont complété son parcours réussi jusqu'ici. La vision de l'entreprise et les changements mis en œuvre ont enrichi les capacités de l'organisation pour entreprendre ses futures initiatives digitales. Il existe des preuves d'une évolution dans les dimensions de l'entreprise acquise avec chaque initiative mise en œuvre qui a conduit à une TD progressive de l'organisation. C'est grâce à cette évolution que le développement de l'initiative la plus récente, la mise en œuvre du service intelligent, a présenté moins de défis pour l'entreprise que la digitalisation du processus de fabrication (fabrication intelligente). Cherchant à accélérer son évolution, l'entreprise investit actuellement dans la restructuration de l'organisation et dans la formalisation de ses processus de transformation.

La présentation de l'étude du cas pilote donne une vue complète et révélatrice d'un cas de TD. La comparaison de cette vue avec une grande variété de cas dans la même industrie, mais avec des contextes et des natures de TD très spécifiques, a permis d'identifier des résultats qui approfondissent la compréhension du phénomène.

La conclusion générale de l'analyse transversale souligne le fait qu'il n'existe pas de vision à long terme de la TD basée sur le renforcement des capacités. Cette constatation principale entraîne toute une série de conséquences, notamment la mise en œuvre partielle et non coordonnée d'initiatives digitales qui ne préparent pas l'entreprise à être plus compétitive à l'ère digitale.

Dans l'ensemble, les résultats de cette étude de cas multiples ont révélé la profonde incompréhension qui existe dans la pratique concernant le phénomène de la TD et les conséquences qu'il entraîne sur leurs efforts de transformation. Ceux qui sont menés à bien le sont dans des conditions qui ne sont ni optimales ni efficaces. Cette découverte n'est pas surprenante si l'on considère que, traditionnellement, les entreprises ont des difficultés à gérer avec succès les changements organisationnels. Les caractéristiques particulières de l'ère digitale abordées au chapitre 2 ajoutent sans aucun doute une couche de complexité à une transformation d'entreprise déjà difficile.

Un résumé des principales conclusions de cette analyse transversale des cas suit :

- les efforts de TD sont principalement axés sur des objectifs à court terme, notamment l'introduction d'une solution technologique,
- le processus de TD suivi n'inclut pas tous les changements nécessaires pour soutenir pleinement les initiatives digitales,
- une trajectoire de TD est constituée d'initiatives digitales spécifiques répondant aux besoins de chaque entreprise et à leurs intentions stratégiques,
- tous les principaux éléments de la TD sont identifiés mais ne remplissent pas leur rôle car leurs composants sont partiellement pris en compte,
- les dimensions de l'entreprise évoluent partiellement avec une vision à court terme et un manque de coordination qui empêchent le développement des capacités nécessaires de l'entreprise,
- le contexte de l'entreprise n'est intégré qu'au cours de la TD en raison d'un manque de planification et pour rattraper des effets négatifs de cette carence.

Après l'analyse des multiples études de cas incluses dans cette recherche, il est possible de répondre à la question principale :

Qu'est-ce que cela implique pour une entreprise de se transformer digitalement ?

Une TD pour une entreprise implique ce qui suit :

- un objectif à long terme centré sur l'entreprise et la transformation de ses capacités,
- une entreprise digitale définie par la vision de ses ambitions en la matière,
- une surveillance constante de son environnement externe et l'identification des facteurs pertinents qui remettent en cause la position de l'entreprise et la manière dont la technologie peut contribuer à les résoudre,
- une analyse minutieuse de son contexte interne pour évaluer les conditions dans lesquelles elle fera face aux défis choisis,
- une stratégie conçue de manière proactive pour conduire la transformation et qui garantit les orientations et les ressources nécessaires à sa réalisation,
- un processus de transformation qui prévoit une analyse systématique des changements pertinents à mettre en œuvre dans les dimensions de l'entreprise concernées de manière coordonnée et efficace,
- une évolution planifiée des cinq dimensions de l'entreprise proposées qui va au-delà des impacts dérivés des initiatives, mais qui soutient les mises en œuvre futures et
- un PMMS qui assure le suivi de la réussite de la mise en place des capacités nécessaires à l'entreprise transformée.

La réponse théorique proposée dans le CDTF vise l'objectif ultime de transformer réellement une entreprise en une entité capable d'intégrer le point de vue digital dans tous les aspects décisionnels et stratégiques, étant donné que cette possibilité représente un fort avantage dans le contexte commercial actuel.

Cette vision est à peine présente dans les entreprises où règne une confusion telle qu'il est difficile de comprendre l'ensemble de la situation. De surcroit, une véritable TD dans la pratique n'est que rarement l'objectif. L'accent est en effet souvent mis sur l'introduction immédiate de la technologie. En conséquence, l'évolution de l'entreprise vers l'acquisition des capacités nécessaires pour gérer l'introduction de la technologie est la conséquence de nombreuses initiatives difficiles, et pas d'efforts planifiés.

Les mêmes limitations sont constatées dans la littérature où l'accent est plutôt mis sur la mise en œuvre de projets (industrie 4.0, fabrication intelligente) plutôt que sur la mise en place des bases nécessaires pour être compétitif dans les conditions difficiles actuelles. En fin de compte, les objectifs à court terme ne préparent pas l'avenir, et une TD doit avoir un objectif à long terme pour réussir.

Conclusion générale

Les principaux résultats de l'étude de cas multiples ont montré comment le renforcement des capacités à long terme et la vision holistique de la transformation proposés dans le cadre conceptuel de la transformation digitale (Conceptual Digital Transformation Framework, CDTF) constituent une contribution non seulement à la littérature mais aussi à la pratique. La vision des entreprises de la transformation digitale (TD) comme étant seulement une série d'initiatives parfois déconnectées pour introduire la technologie est loin de la portée réelle d'une TD. Après avoir identifié dans l'analyse de cas croisés des modèles et des liens dans les efforts de l'échantillon vers une TD, plusieurs leçons sont retenues. Les résultats généraux mettent en évidence un manque de compréhension du phénomène.

Au-delà de la pertinence actuelle du terme, la TD n'est pas seulement une mode du monde des affaires. Une TD est un concept qui relève de la nature du changement technologique qui nous affecte tous. Ce changement s’inscrit dans la durée et les entreprises doivent s’y préparer. À l'heure

actuelle, cette préparation n'est pas envisagée d'autant qu'il n'existe pas de guide pour la définir. La vision de la littérature et de la pratique du phénomène TD est de courte portée et partielle. Des erreurs et des inefficacités affecte le processus de mise en œuvre de la TD, conséquence d'un manque de planification globale.

Les éléments clés du processus de TD, tels que la stratégie et le système de mesure et gestion de la performance (Performance Measurement and Management System, PMMS), ne remplissent pas leur rôle respectif de conduite et de gestion de la transformation, car il manque l'exécution complète de tous ses sous-éléments. Les efforts de TD subissent les conséquences du manque d'éléments de planification qui, combinés à la vision partielle des dimensions de l'entreprise impliquées dans le changement, aboutissent à des mises en œuvre imparfaites.

De plus, dans une TD, il n'y a pas de formule magique pour tout le monde. Les résultats de cette étude montrent que le contexte de l'entreprise, externe et interne, a une influence évidente sur toutes les décisions stratégiques et l'avancement de la transformation, ainsi que sur la trajectoire de ses initiatives. Cette découverte caractérise ensuite la TD comme un processus dynamique qui ne se prête donc pas à une visualisation sur le mode plus statique et prédéterminé d'outils comme les modèles de maturité.

Contributions à la recherche

Comme ce travail de recherche concerne le développement d'un Cadre Conceptuel de Transformation Digitale (CDTF), les principales contributions originales à la connaissance de cette thèse résident dans le contenu du CDTF, le processus qui en résulte et leur capacité à représenter la DT de manière holistique. Ces contributions sont complétées par les éclairages fournis par les études de cas industrielles utilisées dans la validation des CDTF. Les contributions spécifiques sont détaillées ci-dessous.

Le cadre conceptuel de la Transformation Digitale (CDTF)

La propriété holistique du CDTF est la pièce centrale de cette proposition. Le CDTF permet d'avoir une vue globale de ses principaux éléments comme un tout, comme un ensemble d'éléments interdépendants qui jouent un rôle dans la réalisation d'un objectif : la TD d'une entreprise. Basée sur les principes de la théorie des systèmes socio-techniques (STS), cette proposition reconnaît le rôle clé d'une stratégie digitale et de la mesure et de la gestion de la performance en tant qu'éléments supplémentaires qui conduisent et contrôlent la TD et reconnaît l'influence du contexte de l'entreprise dans le processus de TD.

Une terminologie de la TD

L'absence de terminologie commune dans le domaine de la TD représente un obstacle à la compréhension de la signification des concepts qui l'entourent. Positionner les termes liés à la TD pour fournir une terminologie était, en premier lieu, une nécessité de cette recherche. Néanmoins, cet effort peut certainement être utile à d'autres chercheurs et praticiens. Il peut également servir de point de départ à la formalisation d'une terminologie commune qui profitera aux recherches futures sur le sujet.

Une conceptualisation de l'entreprise digitale

Le positionnement d'une définition du concept TD comme un changement organisationnel de développement des capacités a permis de proposer une conceptualisation de l'entreprise digitale. Dans cette proposition, la définition de l'entreprise digitale est inhérente aux besoins et aux ambitions de chaque entreprise, en fonction de la manière dont elle décide d'être compétitive dans le nouvel environnement. En tant qu'objectif ultime de la TD, l'entreprise digitale doit être définie en termes de capacités requises dans les différentes dimensions de l'entreprise pour atteindre les objectifs définis de la transformation. Le passage d'une dynamique consistant à relever constamment le défi de l'introduction de la technologie à une dynamique consistant à s'y préparer peut conduire à un parcours de TD efficace dans lequel chaque initiative digitale contribue à un objectif global.

Les dimensions commerciales de la TD et leurs composantes

Les dimensions de l'entreprise sont les aspects qu'elle doit changer pour atteindre les objectifs de la TD. Les capacités de l'entreprise digitale sont construites en leur sein et transforment donc l'entreprise. Les DMF actuels présentent une vision incohérente des dimensions de l'entreprise, avec un accent prédominant sur la technologie et un manque de fondement théorique. Ce travail va au-delà de la technologie et, sur la base de la théorie STS, identifie cinq dimensions de l'entreprise impliquées dans le processus de transformation : la technologie, les processus, la structure, les compétences et la culture. La contribution liée aux dimensions de l'entreprise va au-delà de leur identification pour reconnaître également leurs interactions. Conscient de l'importance des dimensions de l'entreprise, ce travail va plus loin dans leur constitution pour proposer un certain nombre de composantes peuvent être pertinents pour une TD sur la base de recherches connexes. Une typologie du type de changements attendus est également suggérée sur la base de la double évolution de l'entreprise digitale pendant la TD. Dans le schéma proposé, les entreprises doivent envisager de planifier le développement de leurs capacités en utilisant les initiatives digitales qui constituent la trajectoire vers une TD et les compléter par celles requises par l'entreprise digitale.

Mesure de la préparation digitale et de la maturité digitale de l'entreprise

Le positionnement du concept de préparation et de maturité a conduit ce travail à envisager également la conceptualisation de sa mesure. Par conséquent, dans ce travail, une mesure spécifique pour la préparation digitale est proposée, une mesure qui aborde ses particularités, différentes de celles de la maturité digitale. En conséquence, pour mesurer la préparation digitale, les facteurs du contexte interne sont pris en compte. Dans le cas de la maturité, il était essentiel de la relier à la transformation réelle au sein de l'entreprise, d'où sa formulation basée sur les composantes qui constituent les dimensions de l'entreprise. Les deux propositions sont basées sur une mesure qualitative ; il est donc nécessaire de les développer davantage.

Un processus de TD

Dérivé du CTDF et de ses éléments, un processus de haut niveau de la TD est proposé dans ce travail pour mettre l'accent sur le rôle de chaque élément pendant le processus de transformation. Le processus permet d'identifier les principales actions requises pour couvrir toutes les contributions des éléments à la TD. Bien que les détails et l'opérationnalisation du processus

doivent être complétés dans des recherches futures, la vue de haut niveau peut être utilisée comme une liste de contrôle de la planification d'une TD.

Réflexions sur l'effet du contexte sur les TD des entreprises industrielles

Les études de cas sur le contexte industriel ont permis à cette recherche de recueillir des informations préliminaires sur l'effet des différents éléments du contexte sur les changements dans les dimensions de l'entreprise. L'effet de facteurs tels que la disponibilité des ressources n'a pas été une surprise. Cependant, d'autres liens intéressants ont été révélés comme ceux des avantages des alliances avec les institutions de recherche et les universités. En outre, il a été démontré que certains facteurs tels que "l'engagement des dirigeants" peuvent potentiellement avoir plus de poids sur cet effet, ce qui révèle la nécessité d'explorer les pondérations des facteurs dans la mesure de la préparation digitale.

Réflexions sur la trajectoire de la TD des entreprises industrielles

Un autre élément critique tiré des études de cas est lié à la trajectoire de la TD des entreprises industrielles. Contrairement aux nombreuses généralisations de la littérature qui définissent une trajectoire générique de la TD pour les entreprises industrielles, dans les études de cas, la trajectoire des entreprises vers une TD est déterminée par leur stratégie et la façon dont la technologie aidera à atteindre leurs objectifs stratégiques. Par exemple, certains fabricants sauteront le projet de fabrication intelligente si le produit (p. ex., artisanal) ou les niveaux de production (p. ex., faibles) ne nécessitent pas la technologie pour l'optimiser. Ces types de subtilités ne sont pas pris en compte dans les modèles plus génériques de la littérature actuelle.

Un cadre de référence pour la recherche et la pratique

Les chercheurs peuvent utiliser les principales propositions de ce travail de deux manières. Tout d'abord, ce travail doit être discuté et contesté par la communauté universitaire afin de l'améliorer ou de le réfuter. Il peut également être utilisé comme référence pour préparer des propositions nouvelles et améliorées pour les DMF. En outre, les entreprises peuvent tirer parti du cadre (et du processus qui l'accompagne) en l'utilisant comme référence pour une vue d'ensemble d'une TD lors de la préparation de leurs efforts de transformation.

Enfin, il est important de souligner que la contribution générale de ce cadre réside dans sa qualité d'être holistique : définir chaque partie avec un rôle clair pour atteindre un objectif commun. Les développements supplémentaires ont été orientés vers les domaines considérés comme primordiaux pour le succès et devant être développés davantage conformément aux propositions principales du CDTF.

Perspectives de recherches ultérieures

Dès les premiers jours de ce travail de recherche, il était clair que le choix de développer une vue holistique de la TD signifierait que la profondeur du travail devait être développée de manière sélective en raison des contraintes de temps d'une thèse. Par conséquent, les perspectives de recherche pour améliorer ce travail et le faire avancer sont vastes. Ces possibilités peuvent être divisées en trois catégories principales :

- la validation du CDTF avec différentes méthodes de recherche,

- la validation du CDTF auprès d'entreprises de différents secteurs et
- le développement et l'opérationnalisation intégrale du CDTF.

La poursuite de la validation du CDTF est certes une condition nécessaire pour avancer dans la consolidation d'un statut de cadre de référence, mais c'est le développement complet de toutes ses composantes qui doit être priorisé. En ce sens, pour approfondir les conclusions de ce travail, les sujets de recherche suivants sont proposés.

Tout d'abord, l'élaboration du CDTF, qui n'est actuellement détaillée que pour les dimensions de l'entreprise et le contexte, devrait s'étendre aux autres éléments du cadre. La stratégie et ses sous-éléments, par exemple, peuvent être approfondis, notamment en ce qui concerne les modèles commerciaux et les initiatives digitales. Il existe une quantité importante de littérature qui peut être utilisée pour développer cette partie en suivant les principes du CDTF, notamment sur l'innovation des modèles commerciaux ou sur les détails des initiatives digitales. Mais l'élément le moins étudié et le moins utilisé dans la pratique est sans doute le système de mesure et de gestion de la performance (PMMS), auquel il faudrait accorder plus d'attention. En ce qui concerne le suivi de la mise en œuvre de la TD, les recherches sur les sujets connexes sont rares, en particulier sur les indicateurs clés de performance (Key Performance Indicator, KPI) pertinents pour le scénario de la TD. Conformément aux propositions du CDTF, trouver les bons KPI dépendra certainement du développement des autres variables du cadre. A partir de là, des évaluations plus adéquates et plus complètes devraient suivre sur la base des KPI proposés.

Pour les éléments qui ont été les plus développés dans cette thèse, des développements supplémentaires sont également nécessaires pour rendre leurs facteurs pleinement opérationnels. En ce qui concerne les composants proposés pour les dimensions de l'entreprise, une validation supplémentaire peut identifier les plus pertinents et déterminer l'effet et l'intensité de leurs interdépendances avec les composants des autres dimensions. La connaissance de la relation entre les dimensions d'entreprise et le contexte interne peut également être explorée en développant davantage le facteur « niveau d'impact » par la construction d'un modèle quantitatif. Une approche similaire peut être suivie concernant les indicateurs de préparation digitale et de maturité digitale, actuellement également proposés avec des mesures qualitatives. Il reste encore à explorer les facteurs du contexte interne de l'entreprise qui sont proposés pour calculer l'indicateur de préparation digitale et les composants des dimensions de l'entreprise qui définissent la maturité digitale.

Le développement et l'opérationnalisation complets du CDTF peuvent également permettre d'étudier et d'identifier des patterns pour les différents types de conditions spécifiques qui peuvent être modélisés et automatisés pour devenir un guide interactif des efforts de TD de l'entreprise. Par exemple, des tendances du niveau de développement des facteurs à l'intérieur des dimensions avec chaque type d'initiative ou des tendances des trajectoires réussies de TD pour des types spécifiques d'entreprises. En outre, les tendances de la configuration du contexte interne de certains types d'entreprises, comme les entreprises familiales ou les petites et moyennes entreprises (PME), peuvent également être identifiées ainsi que leurs niveaux de réussite. Toutes les recherches qui peuvent fournir des informations utiles pour mener la TD de façon positive ou pour montrer comment corriger des scénarios qui ne sont pas favorables peuvent aussi être des pistes à explorer dans le futur.

Pour finir, l'un des objectifs de ce travail de recherche est que le CDTF serve de cadre de référence pour les futurs modèles et cadres digitaux (Digital Models and Frameworks, DMF). Par conséquent, une perspective intéressante pour les recherches futures devrait être de construire un nouveau modèle digital fondé sur les propositions principales du CDTF.

References

Abdallah, Y. O., Shehab, E., & Al-Ashaab, A. (2021). Towards managing digital transformation in manufacturing industry: Theoretical framework. *Advances in Transdisciplinary Engineering*, *15*, 21–26. https://doi.org/10.3233/ATDE210006

Abernathy, W. J., & Utterback, J. M. (1978). Patterns of Industrial Innovation. *Technology Review*, *80*, 40–47.

Agca, O., Gibson, J., Godsell, J., Ignatius, J., Wyn Davies, C., & Xu, O. (2017). An Industry 4 readiness assessment tool. *International Institute for Product and Service Innovation*, 1–19. www.warwick.ac.uk/scip1

Aguiar, T., Gomes, S. B., Da Cunha, P. R., & Da Silva, M. M. (2019). Digital transformation capability maturity model framework. *Proceedings - 2019 IEEE 23rd International Enterprise Distributed Object Computing Conference, EDOC 2019*, 51–57. https://doi.org/10.1109/EDOC.2019.00016

Akdil, K. Y., Ustundag, A., & Cevikcan, E. (2018). *Maturity and Readiness Model for Industry 4.0 Strategy*. Springer, Cham. https://doi.org/10.1007/978-3-319-57870-5_4

AlFedaghi, H. S. (2019). Kipic readiness framework for industry 4.0. *Society of Petroleum Engineers - SPE Kuwait Oil and Gas Show and Conference 2019, KOGS 2019*. https://doi.org/10.2118/198039-ms

Allen-Bradley. (2014). The Connected Enterprise Maturity Model. *Industria Conectada 4.0*, 1–12. http://www.rockwellautomation.com/rockwellautomation/innovation/connected-enterprise/maturity-model.page?

Almamalik, L. (2020). *The Development of the Maturity Model to Assess the Smart Indonesia Manufacturing Companies 4.0 Readiness*. *March*, 0–5. https://doi.org/10.2991/aebmr.k.200305.026

Amaral, A., & Peças, P. (2021). A framework for assessing manufacturing smes industry 4.0 maturity. *Applied Sciences (Switzerland)*, *11*(13). https://doi.org/10.3390/app11136127

Ambra Cala, A. L., Boschi, F., Tavola, G., & Taisch, M. (2018). Migration towards digital manufacturing automation - An assessment approach. *Proceedings - 2018 IEEE Industrial Cyber-Physical Systems, ICPS 2018*, 714–719. https://doi.org/10.1109/ICPHYS.2018.8390795

Anderl, R., & Fleischer, J. (2016). Guideline Industrie 4.0. *VDMA Verlag*, 32. industrie40.vdma.org

APQC. (2018). APQC Process Classification Framework (PCF) - Cross Industry - Excel Version 7.2.1. *Apqc*, *September*, 33. http://www.apqc.org/knowledge-base/documents/apqc-process-classification-framework-pcf-cross-industry-excel-version-520

Arbaiza, C. E. S. (2018). Critical variables for success in the technology adoption process in the framework of digital transformation. *ACM International Conference Proceeding Series*, 109–113. https://doi.org/10.1145/3277139.3277163

Armenakis, A. A., & Bedeian, A. G. (1999). Organizational Change: A Review of Theory and Research in the 1990s. *Journal of Management*, *25*(3), 293–315. https://doi.org/10.1177/014920639902500303

Asdecker, B., & Felch, V. (2018). Development of an Industry 4.0 maturity model for the delivery process in supply chains. *Journal of Modelling in Management*, *13*(4), 840–883. https://doi.org/10.1108/JM2-03-2018-0042

Assessment Definition - The Glossary of Education Reform. (n.d.). Retrieved June 17, 2022, from https://www.edglossary.org/assessment/

Azevedo, A., & Santiago, S. B. (2019). Design of an assessment industry 4.0 maturity model: An application to manufacturing company. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 208–217. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85079280890&partnerID=40&md5=84a5237e197f25986659b82ae940b9af

Azhar, M. N., Omar, M. N., & Shaiful, A. I. M. (2021). Implementation of Industry4WRD readiness assessment (RA) model for industry 4.0. *AIP Conference Proceedings*, *2339*. https://doi.org/10.1063/5.0044573

Azhari, P., Faraby, N., Rossmann, A., Steimel, B., & Wichmann, K. S. (2014). *Digital Transformation Report - eine empirische Studie*. 1–156. www.wiwo.de

Bandara, O. K. K., Tharaka, V. K., & Wickramarachchi, A. P. R. (2019). Industry 4.0 maturity assessment of the Banking Sector of Sri Lanka. *Proceedings - IEEE International Research Conference on Smart Computing and Systems Engineering, SCSE 2019*, 190–195. https://doi.org/10.23919/SCSE.2019.8842818

Barbosa, G. F., Shiki, S. B., & da Silva, I. B. (2020). R&D roadmap for process robotization driven to the digital transformation of the industry 4.0. *Concurrent Engineering Research and Applications*, *28*(4), 290–304. https://doi.org/10.1177/1063293X20958927

Bartram, D. (2005). The Great Eight Competencies: A Criterion-Centric Approach to Validation. *The Journal of Applied Psychology*, *90*, 1185–1203. https://doi.org/10.1037/0021-9010.90.6.1185

Bartunek, J. M., & Moch, M. K. (1987). First-Order, Second-Order, and Third-Order Change and Organization Development Interventions: A Cognitive Approach. *The Journal of Applied Behavioral Science*, *23*(4), 483–500. https://doi.org/10.1177/002188638702300404

Beaudoin, J. E. (2016). *Prendre part à la révolution manufacturière ?*

Becker, J., Knackstedt, R., & Pöppelbuß, J. (2009). Developing Maturity Models for IT Management. *Business & Information Systems Engineering*, *1*(3), 213–222. https://doi.org/10.1007/s12599-009-0044-5

Benbasat, I., Goldstein, D. K., & Mead, M. (1987). The Case Research Strategy in Studies of Information Systems. *MIS Quarterly*, *11*(3), 369–386. https://doi.org/10.2307/248684

Berghaus, S., & Back, A. (2016). Stages in Digital Business Transformation: Results of an Empirical Maturity Study. *Mediterranean Conference on Information Systems (MCIS)*, *Paper 22*, 1–17. http://aisel.aisnet.org/mcis2016%0Ahttp://aisel.aisnet.org/mcis2016

Berman, S., & Bell, R. (2011). Digital transformation course. *IBM Institute for Business Value Strategy*, 1–17. https://www.ibm.com/downloads/cas/KWRV8QK6

Berrah, L., Clivillé, V., & Foulloy, L. (2018). *Objectifs et performances industriels*. ISTE Editions. https://hal.archives-ouvertes.fr/hal-01825322

Berrah, L., Clivillé, V., Verjus, H., & Gandia, R. (2020). IMPACT D'UNE EXPRESSION DE PERFORMANCE ELEMENTAIRE SUR L'EXPRESSION DE PERFORMANCE AGREGEE : UNE APPROCHE PAR L'INTEGRALE DE CHOQUET. *MOSIM 2020 (13ème Conférence Francophone de Modélisation, Optimisation et Simulation)*. https://hal.archives-ouvertes.fr/hal-02960911

Bibby, L., & Dehe, B. (2018). Defining and assessing industry 4.0 maturity levels – case of the defense sector. *Production Planning \& Control*, *29*(12), 1030–1043. https://doi.org/10.1080/09537287.2018.1503355

Bishop, R. H. (2008). The mechatronics handbook. In *The Mechatronics Handbook* (2e ed.). CRC Press. https://doi.org/10.5860/choice.40-0318

Bloomberg, J. (2018). *Digitization, Digitalization, And Digital Transformation: Confuse Them At Your Peril*. https://www.forbes.com/sites/jasonbloomberg/2018/04/29/digitization-digitalization-and-digital-transformation-confuse-them-at-your-peril/

Bluhm, D. J., Harman, W., Lee, T. W., & Mitchell, T. R. (2011). Qualitative Research in Management: A Decade of Progress. *Journal of Management Studies*, *48*(8), 1866–1891. https://doi.org/https://doi.org/10.1111/j.1467-6486.2010.00972.x

Booth, A. (2016). Searching for qualitative research for inclusion in systematic reviews: A structured methodological review. *Systematic Reviews*, *5*. https://doi.org/10.1186/s13643-016-0249-x

Borštnar, M. K., & Pucihar, A. (2021). Multi-attribute assessment of digital maturity of SMEs. *Electronics (Switzerland)*, *10*(8). https://doi.org/10.3390/electronics10080885

Bostrom, R. P., & Heinen, J. S. (1977a). MIS Problems and Failures: A Socio-Technical Perspective. Part I: The Causes. *MIS Quarterly*, *1*(3), 17–32. https://doi.org/10.2307/248710

Bostrom, R. P., & Heinen, J. S. (1977b). MIS Problems and Failures: A Socio-Technical Perspective, Part II: The Application of Socio-Technical Theory. *MIS Quarterly*, *1*(4), 11–28. https://doi.org/10.2307/249019

Botha, A. (2018). Rapidly arriving futures: Future readiness for industry 4.0. *South African Journal of Industrial Engineering*, *29*. https://doi.org/10.7166/29-3-2056

Brozzi, R., D'Amico, R. D., Pasetti Monizza, G., Marcher, C., Riedl, M., & Matt, D. (2018). Design of self-assessment tools to measure industry 4.0 readiness. A methodological approach for craftsmanship SMEs. *IFIP Advances in Information and Communication Technology*, *540*, 566–578. https://doi.org/10.1007/978-3-030-01614-2_52

Burke, W. W. (2017). *Organization Change: Theory and Practice* (5th ed.). SAGE Publications.

Burke, W. W., & Litwin, G. H. (1992). A causal model of organizational performance and change. *Journal of Management*, *18*(3), 523–545.

business noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/business?q=business

Bustinza, O. F., Gomes, E., Vendrell-Herrero, F., & Tarba, S. Y. (2018). An organizational change framework for digital servitization: Evidence from the Veneto region. *Strategic Change*, *27*(2), 111–119. https://doi.org/10.1002/jsc.2186

Butt, J. (2020). A conceptual framework to support digital transformation in manufacturing using an integrated business process management approach. *Designs*, *4*(3), 1–39. https://doi.org/10.3390/designs4030017

Caiado, R. G. G., Scavarda, L. F., Gavião, L. O., Ivson, P., Nascimento, D. L. de M., & Garza-Reyes, J. A. (2021). A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management. *International Journal of Production Economics*, *231*. https://doi.org/10.1016/j.ijpe.2020.107883

Calabrese, A., Levialdi Ghiron, N., & Tiburzi, L. (2021). 'Evolutions' and 'revolutions' in manufacturers' implementation of industry 4.0: a literature review, a multiple case study, and a conceptual framework. *Production Planning and Control*, *32*(3), 213–227. https://doi.org/10.1080/09537287.2020.1719715

Candelon, F., Bürkner, H.-P., Grebe, M., Charme di Carlo, R., & De Bondt, M. (2020). As the COVID-19 Crisis Reveals, Europe Urgently Needs to Digitize Its Industry | BCG. *Boston Consulting Group*. https://www.bcg.com/en-nor/publications/2020/covid-crisis-reveals-europe-urgently-needs-industry-digitization

Canetta, L., Barni, A., & Montini, E. (2018). Development of a Digitalization Maturity Model for the Manufacturing Sector. *2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings*, 1–7. https://doi.org/10.1109/ICE.2018.8436292

Chandler Jr., A. D. (1962). Strategy and structure: chapters in the history of the industrial enterprise. In *Strategy and structure: chapters in the history of the industrial enterprise.* M.I.T. Press.

Chaopaisarn, P., & Woschank, M. (2021). Maturity Model Assessment of SMART Logistics for SMEs. *Chiang Mai University Journal of Natural Sciences*, *20*(2), 1–8. https://doi.org/10.12982/CMUJNS.2021.025

Chen, H., Chiang, R. H. L., & Storey, V. C. (2012). Business Intelligence and Analytics: From Big Data to Big Impact. *MIS Quarterly*, *36*(4), 1165–1188. https://doi.org/10.2307/41703503

Chonsawat, N., & Sopadang, A. (2021). Smart SMEs 4.0 Maturity Model to Evaluate the Readiness of SMEs Implementing Industry 4.0. *Chiang Mai University Journal of Natural Sciences*, *20*(2), 1–13. https://doi.org/10.12982/CMUJNS.2021.027

Cimini, C., Pinto, R., & Cavalieri, S. (2017). The business transformation towards smart manufacturing: a literature overview about reference models and research agenda. *IFAC-PapersOnLine*, *50*(1), 14952–14957. https://doi.org/10.1016/j.ifacol.2017.08.2548

Çınar, Z. M., Zeeshan, Q., & Korhan, O. (2021). A framework for industry 4.0 readiness and maturity of smart manufacturing enterprises: A case study. *Sustainability (Switzerland)*, *13*(12). https://doi.org/10.3390/su13126659

Colli, M., Berger, U., Bockholt, M., Madsen, O., Møller, C., & Wæhrens, B. V. (2019). A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era. *Annual Reviews in Control*, *48*(xxxx), 165–177. https://doi.org/10.1016/j.arcontrol.2019.06.001

company noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/company?q=company

concept noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/concept?q=concept

context noun - Definition, pictures, pronunciation and usage notes | Oxford Learner's Dictionary of Academic English at OxfordLearnersDictionaries.com. (n.d.). Retrieved July 8, 2022, from https://www.oxfordlearnersdictionaries.com/definition/academic/context

Corbin, J., & Strauss, A. (2015). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (4e ed.). Sage publications.

Cortés Serrano, D., Chavarría-Barrientos, D., Ortega, A., Falcón, B., Mitre, L., Correa, R., Moreno, J., Funes, R., & Molina Gutiérrez, A. (2018). A Framework to Support Industry 4.0: Chemical Company Case Study. In CamarinhaMatos, LM and Afsarmanesh, H and Rezgui, Y (Ed.), *IFIP Advances in Information and Communication Technology* (Vol. 534, pp. 387–395). https://doi.org/10.1007/978-3-319-99127-6_33

Cotrino, A., Sebastián, M. A., & González-Gaya, C. (2020). Industry 4.0 roadmap: Implementation for small and medium-sized enterprises. *Applied Sciences (Switzerland)*, *10*(23), 1–17. https://doi.org/10.3390/app10238566

Creswell, J. W., & Poth, C. N. (2018). *Qualitative Inquiry and Research Design Choosing among Five Approaches* (4th Editio). SAGE Publications.

Crispeels, P., & Misljencevic, D. (2020). Heavy industry's digital transformation: Vision, diagnostic, and roadmap. *McKinsey Insights*, N.PAG-N.PAG. https://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=144766452&lang=fr&site=ehost-live

Daim, T. U., & Oliver, T. (2008). Implementing technology roadmap process in the energy services sector: A case study of a government agency. *Technological Forecasting and Social Change*, *75*(5), 687–720. https://doi.org/10.1016/j.techfore.2007.04.006

Davenport, T. H. (2013). Analytics 3.0. *Harvard Business Review*, *91*(12), 64–72.

Davis, S. M. (1984). Managing Corporate Culture, Ballinger. In *Cambridge: MA*. Ballinger Publishing Company.

de Bruin, T., Rosemann, M., Freeze, R., & Kulkarni, U. (2005). Understanding the main phases of developing a maturity assessment model. *ACIS 2005 Proceedings - 16th Australasian Conference on Information Systems*, *December*.

De Carolis, A., Macchi, M., Negri, E., & Terzi, S. (2017). A maturity model for assessing the digital readiness of manufacturing companies. *IFIP Advances in Information and Communication Technology*, *513*, 13–20. https://doi.org/10.1007/978-3-319-66923-6_2

De Carolis, A., Macchi, M., Negri, E., & Terzi, S. (2018). Guiding manufacturing companies towards digitalization a methodology for supporting manufacturing companies in defining their digitalization roadmap. In JardimGoncalves, R and Mendonca, JP and Pallot, M and Zarli, A and Martins, J and Marques, M (Ed.), *2017 International Conference on Engineering, Technology and Innovation: Engineering, Technology and Innovation Management Beyond 2020: New Challenges, New Approaches, ICE/ITMC 2017 - Proceedings* (Vols. 2018-Janua, pp. 487–495). https://doi.org/10.1109/ICE.2017.8279925

Deepu, S. T., & Ravi, V. (2021). A conceptual framework for supply chain digitalization using integrated systems model approach and DIKW hierarchy. *Intelligent Systems with Applications*, *10–11*. https://doi.org/10.1016/j.iswa.2021.200048

Définition - Catégorie d'entreprise | Insee. (n.d.). Retrieved June 17, 2022, from https://www.insee.fr/fr/metadonnees/definition/c1057

Definition of Digitalization - IT Glossary | Gartner. (n.d.). Retrieved July 17, 2022, from https://www.gartner.com/en/information-technology/glossary/digitalization

Deloitte. (2018). Digital Maturity Model. *Deloitte*, *February*, 9–12. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Technology-Media-Telecommunications/deloitte-digital-maturity-model.pdf

Demirkan, H., Spohrer, J. C., & Welser, J. J. (2016). Digital Innovation and Strategic Transformation. *IT Professional*, *18*(6), 14–18. https://doi.org/10.1109/MITP.2016.115

Devi K, S., Paranitharan, K. P., & Agniveesh A, I. (2021). Interpretive framework by analysing the enablers for implementation of Industry 4.0: an ISM approach. *Total Quality Management and Business Excellence*, *32*(13–14), 1494–1514. https://doi.org/10.1080/14783363.2020.1735933

digital adjective - Definition, pictures, pronunciation and usage notes | Oxford Learner's Dictionary of Academic English at OxfordLearnersDictionaries.com. (n.d.). Retrieved July 8, 2022, from https://www.oxfordlearnersdictionaries.com/definition/academic/digital

Digital Improvement vs. Digital Transformation | Lucidchart Blog. (n.d.). Retrieved July 18, 2022, from https://www.lucidchart.com/blog/digital-transformation-vs-digital-improvement

dimension noun - Definition, pictures, pronunciation and usage notes | Oxford Learner's Dictionary of Academic English at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/academic/dimension

Dossou, P. E. (2019). Development of a new framework for implementing industry 4.0 in companies. *Procedia Manufacturing*, *38*(2019), 573–580. https://doi.org/10.1016/j.promfg.2020.01.072

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *The Academy of Management Review*, *14*(4), 532–550. https://doi.org/10.2307/258557

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, *50*(1), 25–32. https://doi.org/10.5465/AMJ.2007.24160888

element noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/element?q=element

Emery, F. (1959). Characteristics of socio-technical systems. In *The Social Engagement of Social Science, a Tavistock Anthology, Volume 2* (pp. 157–186).

Exner, K., Balder, J., & Stark, R. (2018). A PSS maturity self-assessment tool. *Procedia CIRP*, *73*, 86–90. https://doi.org/10.1016/j.procir.2018.04.013

factor_1 noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved July 17, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/factor_1?q=factor

Felch, V., Asdecker, B., & Sucky, E. (2019). Maturity models in the age of industry 4.0 - Do the available models correspond to the needs of business practice? *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2019-Janua*, 5165–5174. https://doi.org/10.24251/hicss.2019.620

FIRM | meaning in the Cambridge English Dictionary. (n.d.). Retrieved June 30, 2022, from https://dictionary.cambridge.org/dictionary/english/firm

FRAMEWORK | meaning in the Cambridge English Dictionary. (n.d.). Retrieved June 17, 2022, from https://dictionary.cambridge.org/dictionary/english/framework

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15–26. https://doi.org/https://doi.org/10.1016/j.ijpe.2019.01.004

Gajdzik, B., Grabowska, S., & Saniuk, S. (2021). A theoretical framework for industry 4.0 and its implementation with selected practical schedules. *Energies*, *14*(4). https://doi.org/10.3390/en14040940

Gamache, S., Abdul-Nour, G., & Baril, C. (2019). Development of a digital performance assessment model for Quebec manufacturing SMEs. *Procedia Manufacturing*, *38*(2019), 1085–1094. https://doi.org/10.1016/j.promfg.2020.01.196

Ganzarain, J., & Errasti, N. (2016). Three stage maturity model in SME's towards industry 4.0. *Journal of Industrial Engineering and Management*, *9*(5), 1119–1128. https://doi.org/10.3926/jiem.2073

Garcia, M. L., & Bray, O. H. (1997). Fundamentals of Technology Roadmapping. In *Distribution* (Vol. 4205, Issue April). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.31.1385&rep=rep1&type=pdf

Gard, J.-C., Shah, A., Dreischmeier, R., & Niddam, M. (2016). a Roadmap for Winning As Insurance Goes Digital. *FICCI Studies {&} Surveys*, *January*, 53–59. http://search.ebscohost.com/login.aspx?direct=true%7B&%7Ddb=bth%7B&%7DAN=112817841%7B&%7Dsite=ehost-live

Gartner. (n.d.). *5 Stages Of Logistics Maturity*. Retrieved July 17, 2022, from https://www.gartner.com/smarterwithgartner/5-stages-of-logistics-maturity

Geissbauer, R., Lübben, E., Schrauf, S., & Pillsbury, S. (2018). Global Digital Operations Study 2018 - Digital Champions. In *PwC*. http://www.pwc.com/m1/en/about-us.html

Geissbauer, R., Vedso, J., & Schrauf, S. (2016). Industry 4.0: Building the digital enterprise. *2016 Global Industry 4.0 Survey*, 1–39. www.pwc.com/industry40

Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*, *29*(6), 910–936. https://doi.org/10.1108/JMTM-02-2018-0057

Gill, M., & VanBoskirk, S. (2016). The Digital Maturity Model 4.0. *Forrester*, 0–17.

Glogovac, M., Ruso, J., & Maricic, M. (2020). ISO 9004 maturity model for quality in industry 4.0. *Total Quality Management and Business Excellence*. https://doi.org/10.1080/14783363.2020.1865793

Gökalp, E., & Martinez, V. (2021). Digital transformation capability maturity model enabling the assessment of industrial manufacturers. *Computers in Industry*, *132*. https://doi.org/10.1016/j.compind.2021.103522

Gökalp, E., Şener, U., & Eren, P. E. (2017). Development of an assessment model for industry 4.0: Industry 4.0-MM. In Mas, A and Mesquida, A and O'Connor, RV and Rout, T and Dorling, A (Ed.), *Communications in Computer and Information Science* (Vol. 770, Issue November, pp. 128–142). https://doi.org/10.1007/978-3-319-67383-7_10

Gollhardt, T., Halsbenning, S., Hermann, A., Karsakova, A., & Becker, J. (2020). Development of a Digital Transformation Maturity Model for IT Companies. *Proceedings - 2020 IEEE 22nd Conference on Business Informatics, CBI 2020*, *1*, 94–103. https://doi.org/10.1109/CBI49978.2020.00018

Goumeh, F., & Barforoush, A. A. (2021). A Digital Maturity Model for digital banking revolution for Iranian banks. *26th International Computer Conference, Computer Society of Iran, CSICC 2021*. https://doi.org/10.1109/CSICC52343.2021.9420566

Govindasamy, A., & Arularasan, A. (2021). Readiness and Maturity Assessment Model to Measure the Industry 4.0 Ecosystem. *Lecture Notes in Electrical Engineering*, *355*, 57–67. https://doi.org/10.1007/978-981-16-1244-2_5

Gracel, J. (2017). The concept of Industry 4.0 related manufacturing technology maturity model (ManuTech Maturity Model , MTMM). *Decision Making in Manufacturing and Services*, *12*(1), 17–31.

Grant, C., & Osanloo, A. (2014). Understanding, selecting, and integrating a theoretical framework in dissertation research: Developing a "blueprint" for your 'house.' *Administrative Issues Journal*, *4*. https://doi.org/10.5929/2014.4.2.9

Greif, H., Kühnis, N., & Warnking, P. (2016). Digital transformation: How mature are Swiss SMEs? *Pwc*, 28. https://www.pwc.ch/en/publications/2016/pwc_digital_transform_how_mature_are_swiss_smes_survey_16_en.pdf

Häberer, S., Lau, L., & Behrendt, F. (2017). *Development of an Industrie 4.0 Maturity Index for Small and Medium-Sized Enterprises*.

Hajoary, P. K., & Akhilesh, K. B. (2021). Conceptual Framework to Assess the Maturity and Readiness Towards Industry 4.0. *Lecture Notes in Mechanical Engineering*, 13–23. https://doi.org/10.1007/978-981-15-5689-0_2

Hammer, M., & Champy, J. (1993). *Reengineering the Corporation: A Manifesto for Business Revolution*. HarperBusiness.

Hiebl, M. R. W. (2021). Sample Selection in Systematic Literature Reviews of Management Research. *Organizational Research Methods*, 1–33. https://doi.org/10.1177/1094428120986851

holism noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved July 16, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/holism?q=holism

holistic adjective - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/holistic?q=holistic

Holz, M. (2017). *European SME-Action Programme Imprint Publisher Federal Ministry for Economic Affairs on behalf of the SME Envoys Network Coordination and final editing Federal Ministry for Economic Affairs and Energy*.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, *15*(9), 1277–1288. https://doi.org/10.1177/1049732305276687

Imenda, S. (2014). Is There a Conceptual Difference between Theoretical and Conceptual Frameworks? *Journal of Social Sciences*, *38*(2), 185–195. https://doi.org/10.1080/09718923.2014.11893249

Imran, F., Shahzad, K., Butt, A., & Kantola, J. (2021). Digital Transformation of Industrial Organizations: Toward an Integrated Framework. *Journal of Change Management*, *21*(4), 451–479. https://doi.org/10.1080/14697017.2021.1929406

index_1 noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 17, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/index_1?q=index

Issa, A., Hatiboglu, B., Bildstein, A., & Bauernhansl, T. (2018). Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment. *Procedia CIRP*, *72*, 973–978. https://doi.org/10.1016/j.procir.2018.03.151

Jabareen, Y. (2009). Building a Conceptual Framework: Philosophy, Definitions, and Procedure. *International Journal of Qualitative Methods*, *8*(4), 49–62. https://doi.org/10.1177/160940690900800406

Jick, T. D. (1979). Mixing Qualitative and Quantitative Methods: Triangulation in Action. *Administrative Science Quarterly*, *24*(4), 602–611. https://doi.org/10.2307/2392366

Jodlbauer, H., & Schagerl, M. (2016). Maturity model Industry 4.0 - A process model for the identification of Industry 4.0 potentials | Reifegradmodell Industrie 4.0 - Ein Vorgehensmodell zur Identifikation von Industrie 4.0 Potentialen. *Lecture Notes in Informatics (LNI), Proceedings - Series of the Gesellschaft Fur Informatik (GI)*, *P-259*, 1473–1487. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028647671&partnerID=40&md5=fd97f06d3af9049f21668c603291af4d

Jung, K., Kulvatunyou, B., Choi, S., & Brundage, M. P. (2016). An overview of a smart manufacturing system readiness assessment. *IFIP Advances in Information and Communication Technology*, *488*, 705–712. https://doi.org/10.1007/978-3-319-51133-7_83

Kagermann, H., Wahlster, W., & Helbig, J. (2013). Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative INDUSTRIE 4.0. *Final Report of the Industrie 4.0 Working Group*, *April*, 1–84.

Kaiser, C., Stocker, A., Viscusi, G., Fellmann, M., & Richter, A. (2021). Conceptualising value creation in data-driven services: The case of vehicle data. *International Journal of Information Management*, *59*, 102335. https://doi.org/10.1016/J.IJINFOMGT.2021.102335

Kane, G. C., Palmer, D., Phillips, A. N., Kiron, D., & Buckley, N. (2016). Aligning the Organization for Its Digital Future. *MITSloan Management Review*, *58180*, 1–29. https://sloanreview.mit.edu/projects/aligning-for-digital-future/

Kaplan, R., & Norton, D. P. (1993). Putting the balanced scorecard to work. *Harvard Business Review*, *71*, 134–142.

Kellner, T., Necas, M., Kanak, M., Kyncl, M., & Kyncl, J. (2020). Assessment of Readiness for Industry 4.0 Implementation in Ceramic Industry. *Manufacturing Technology*, *20*(6), 763–770. https://doi.org/10.21062/MFT.2020.110

Khurana, A., Al-Olama, B., Shaban, M., & Wijeratne, D. (2018). The Future of Manufacturing - France. *Global Manufacturing & Industrialisation Summit*.

Klötzer, C., & Pflaum, A. (2017). Toward the development of a maturity model for digitalization within the manufacturing industry's supply chain. In Bui, TX and Sprague, R (Ed.), *Proceedings of the Annual Hawaii International Conference on System Sciences* (Vols. 2017-Janua, pp. 4210–4219). https://doi.org/10.24251/hicss.2017.509

Ko, M., Kim, C., Lee, S., & Cho, Y. (2020). An assessment of smart factories in Korea: An exploratory empirical investigation. *Applied Sciences (Switzerland)*, *10*(21), 1–15. https://doi.org/10.3390/app10217486

Kolla, S., Minufekr, M., & Plapper, P. (2019). Deriving essential components of lean and industry 4.0 assessment model for manufacturing SMEs. *Procedia CIRP*, *81*, 753–758. https://doi.org/10.1016/j.procir.2019.03.189

Konopik, J., Jahn, C., Schuster, T., Hoßbach, N., & Pflaum, A. (2022). Mastering the digital transformation through organizational capabilities: A conceptual framework. *Digital Business*, *2*(2), 100019. https://doi.org/10.1016/j.digbus.2021.100019

Kothari, C. R. (2004). *Research Methodology: Methods and Techniques*. New Age International (P) Limited.

Kozina, M. (2019). Framework for assessing the company's maturity of digital business transformation. In Beker, V and Lackovic, A and Pavelin, G (Ed.), *Economic and Social Development: Book of Proceedings* (pp. 80–87).

KPMG. (2016). *Digital Readiness Assessment*. *April*, 1-2.

Kupriyanova, M. V., Evdokimova, E. N., Solovyova, I. P., & Simikova, I. P. (2020). Methods of developing digital maturity models for manufacturing companies. *E3S Web of Conferences*, *224*. https://doi.org/10.1051/e3sconf/202022402034

Lakmali, E., Vidanagamachchi, K., & Nanayakkara, J. (2020). Industry 4.0 readiness assessment for apparel industry: A study in the Sri Lankan context. *Proceedings - International Research Conference on Smart Computing and Systems Engineering, SCSE 2020*, 174–181. https://doi.org/10.1109/SCSE49731.2020.9313026

Leavitt, H. J. (1964). Applied Organizational Change in Industry: Structural, Technological and Humanistic Approaches. *Handbook of Organizations*, 1144–1170.

Lee, J., Jun, S., Chang, T. W., & Park, J. (2017). A smartness assessment framework for smart factories using analytic network process. *Sustainability (Switzerland)*, *9*(5), 1–15. https://doi.org/10.3390/su9050794

Legner, C., Eymann, T., Hess, T., Matt, C., Böhmann, T., Drews, P., Mädche, A., Urbach, N., & Ahlemann, F. (2017). Digitalization: Opportunity and Challenge for the Business and Information Systems Engineering Community. *Business and Information Systems Engineering*, *59*(4), 301–308. https://doi.org/10.1007/s12599-017-0484-2

Leineweber, S., Wienbruch, T., Lins, D., Kreimeier, D., & Kuhlenkötter, B. (2018). Concept for an evolutionary maturity based Industrie 4.0 migration model. *Procedia CIRP*, *72*, 404–409.

Leonard-Barton, D. (1990). A Dual Methodology for Case Studies: Synergistic Use of a Longitudinal Single Site with Replicated Multiple Sites. *Organization Science*, *1*(3), 248–266. https://doi.org/10.1287/orsc.1.3.248

Lezina, T., Stoianova, O., Ivanova, V., & Gadasina, L. (2019). Assessment the Company's Readiness for Digital Transformation: Clarifying the Issue. *Lecture Notes in Business Information Processing*, *358*, 3–14. https://doi.org/10.1007/978-3-030-30874-2_1

Li, J., Dou, K., Wen, S., & Li, Q. (2021). Monitoring index system for sectors' digital transformation and its application in China. *Electronics (Switzerland)*, *10*(11). https://doi.org/10.3390/electronics10111301

Liborio Zapata, M., Berrah, L., & Tabourot, L. (2020). *Towards the Definition of an Impact Level Factor of SME Features Over Digital Transformation. BT - Advances in Production Management Systems. The Path to Digital Transformation and Innovation of Production Management Systems - IFIP WG 5.7 International C* (pp. 123–130). https://doi.org/10.1007/978-3-030-57993-7_15

Liborio Zapata, M., Berrah, L., & Tabourot, L. (2021). Analyzing the Impact Level of SMEs Features Over Digital Transformation: A Case Study. *IFIP International Conference on Advances in Production Management Systems*, 40–48.

Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E., & Schröter, M. (2015). Impuls - Implications of Chinese Competitor Strategies for German Machinery Manufacturers. *Impuls-Stiftung Des VDMA*, 0–76.

Liebrecht, C., Kandler, M., Lang, M., Schaumann, S., Stricker, N., Wuest, T., & Lanza, G. (2021). Decision support for the implementation of Industry 4.0 methods: Toolbox, Assessment and Implementation Sequences for Industry 4.0. *Journal of Manufacturing Systems*, *58*, 412–430. https://doi.org/10.1016/j.jmsy.2020.12.008

Liere-Netheler, K., Vogelsang, K., Packmohr, S., & Hoppe, U. (2018). Towards a framework for digital transformation success in manufacturing. *26th European Conference on Information Systems: Beyond Digitization - Facets of Socio-Technical Change, ECIS 2018*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85061298286&partnerID=40&md5=795d10cdbcce589575ef9df658acfaaa

Lizarralde Dorronsoro, R., Jaione, G. E., Cristina, L., & Ibon, S. L. (2020). An Industry 4.0 maturity model for machine tool companies. *Technological Forecasting and Social Change*, *159*(July), 120203. https://doi.org/10.1016/j.techfore.2020.120203

Machado, C. G., Almstrom, P., Oberg, A. E., Kurdve, M., & Almashalah, S. Y. (2020). Maturity Framework Enabling Organizational Digital Readiness. *Advances in Transdisciplinary Engineering*, *13*, 649–660. https://doi.org/10.3233/ATDE200204

Maisiri, W., & van Dyk, L. (2019). Industry 4.0 readiness assessment for South African industries. *South African Journal of Industrial Engineering*, *30*(3), 134–148. https://doi.org/10.7166/30-3-2231

Majdalawieh, M. (2019). Advancing digital transformation: Integrated digital transformation framework for a successful deployment. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 439–447. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85079289770&partnerID=40&md5=3109ace87bf0b0fc84c619ac8274cd82

Matt, C., Hess, T., & Benlian, A. (2015). Digital Transformation Strategies. *Business and Information Systems Engineering*, *57*(5), 339–343. https://doi.org/10.1007/s12599-015-0401-5

MATURITY | English meaning - Cambridge Dictionary. (n.d.). Retrieved February 16, 2022, from https://dictionary.cambridge.org/dictionary/english/maturity

McKinsey & Company. (2015). Raise your digital quotient. *McKinsey Quarterly*, *3*. https://www.mckinsey.com/featured-insights/digital-disruption/raise-your-digital-quotient

Mettler, T. (2009). *A Design Science Research Perspective on Maturity Models in Information Systems*. *41*(0).

Miche, M., Schreiber, D., & Hartmann, M. (2009). *Core Services for Smart Products*.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook*. SAGE Publications.

Miles, R. E., Snow, C. C., Meyer, A. D., & Coleman, H. J. (1978). Organizational Strategy, Structure, and Process. *The Academy of Management Review*, *3*(3), 546–562. http://www.jstor.org/stable/257544

Mintzberg, H., & Westley, F. (1992). Cycles of organizational change. *Strategic Management Journal*, *13*(2 S), 39–59. https://doi.org/10.1002/smj.4250130905

Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of Manufacturing Systems*, *49*, 194–214. https://doi.org/10.1016/j.jmsy.2018.10.005

Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2019). Smart manufacturing: Characteristics, technologies and enabling factors. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 233(5), 1342–1361. https://doi.org/10.1177/0954405417736547

Mittal, S., Romero, D., & Wuest, T. (2018). Towards a smart manufacturing maturity model for SMEs (SM3E). *IFIP Advances in Information and Communication Technology*, *536*, 155–163. https://doi.org/10.1007/978-3-319-99707-0_20

Mittelstand 4.0. (n.d.). *Self check - competence center*. Retrieved July 17, 2022, from https://betrieb-machen.de/selfcheck/#liOrganization

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Altman, D., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J. A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J. J., Devereaux, P. J., Dickersin, K., Egger, M., Ernst, E., … Tugwell, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7). https://doi.org/10.1371/journal.pmed.1000097

Mokgohloa, K., Kanakana-Katumba, G., & Maladzhi, R. (2020). Development of a technology and digital transformation adoption framework of the postal industry in Southern Africa: From critical literature review to a theoretical framework. *Advances in Science, Technology and Engineering Systems*, *5*(6), 1190–1206. https://doi.org/10.25046/aj050743

Muhamad, M. Q. B., Mohamad, S. J. A. N. S., & Nor, N. M. (2021). Navigating the future of industry 4.0 in Malaysia: A proposed conceptual framework on SMEs' readiness. *International Journal of Advanced and Applied Sciences*, *8*(7), 41–49. https://doi.org/10.21833/ijaas.2021.07.006

Mühlhäuser, M. (2008). Smart Products: An Introduction. In M. Mühlhäuser, A. Ferscha, & E. Aitenbichler (Eds.), *Constructing Ambient Intelligence* (pp. 158–164). Springer Berlin Heidelberg.

Muzyka, D., De Koning, A., & Churchill, N. (1995). On transformation and adaptation: Building the entrepreneurial corporation. *European Management Journal*, *13*(4), 346–362. https://doi.org/10.1016/0263-2373(95)00029-K

Nadler, D. A., & Tushman, M. L. (1980). A congruence model for organizational assessment. *Organizational Assessment: Perspectives on the Measurement of Organizational Behavior and the Quality of Work Life*, 261–278.

National Institute of Standards and Technology. (n.d.). Retrieved July 17, 2022, from https://www.nist.gov/

Netflix Culture: How it Redefined Employee Success - Venngage. (n.d.). Retrieved July 18, 2022, from https://venngage.com/blog/netflix-culture/

Newman, M. (2017). Digital Maturity Model (DMM): A Blueprint for Digital Transformation. *TM Forum White Paper*, *May*, 1–11. https://www.tmforum.org/wp-content/uploads/2017/05/DMM-WP-2017-Web.pdf

Nick, G., Kovács, T., Ko, A., & Kádár, B. (2020). Industry 4.0 readiness in manufacturing: Company Compass 2.0, a renewed framework and solution for Industry 4.0 maturity assessment. *Procedia Manufacturing*, *54*, 39–44. https://doi.org/10.1016/j.promfg.2021.07.007

Nightingale, D. J., & Rhodes, D. H. (2015). Architecting the future enterprise. In *Architecting the future enterprise*. The MIT Press.

Nogalski, B., & Niewiadomski, P. (2020). Industry 4.0 desiderata as micro foundations in the assessment of companies' maturity-Case study. *Management and Production Engineering Review*, *11*(4), 92–103. https://doi.org/10.24425/mper.2020.136123

notion noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/notion?q=notion

Nudurupati, S. S., Tebboune, S., & Hardman, J. (2016). Contemporary performance measurement and management (PMM) in digital economies. *Production Planning \& Control*, *27*(3), 226–235. https://doi.org/10.1080/09537287.2015.1092611

Nwaiwu, F., Duduci, M., Chromjakova, F., & Otekhile, C. A. F. (2020). Industry 4.0 concepts within the czech sme manufacturing sector: An empirical assessment of critical success factors. *Business: Theory and Practice*, *21*(1), 58–70. https://doi.org/10.3846/btp.2020.10712

O'Hea, K. (2011). *Digital Capability – How to Understand, Measure, Improve and Get Value from it*. *October*, 1–8.

Organizational Chart for Transport Company | Creately. (n.d.). Retrieved July 18, 2022, from https://creately.com/diagram/example/gsy3ayzi8/organizational-chart-for-transport-company

Orji, C. I. (2019). Digital Business Transformation: Towards an Integrated Capability Framework for Digitization and Business Value Generation. *Journal of Global Business and Technology*, *15*(1), 12. https://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=138407525&lang=fr&site=ehost-live

Osterwalder, A., Pigneur, Y., & Tucci, C. L. (2005). Clarifying Business Models: Origins, Present, and Future of the Concept. *Commun. Assoc. Inf. Syst.*, *16*, 1. http://dblp.uni-trier.de/db/journals/cais/cais16.html#OsterwalderPT05

Oxford English Dictionary. (n.d.). Digitalization. In OED Online. Retrieved November 10, 2014 from http://www.oed.com/

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *The BMJ*, *372*. https://doi.org/10.1136/bmj.n71

Pan Nogueras, M. L., Perea Muñoz, L., Cosentino, J. P., & Suarez Anzorena, D. (2022). RAISE 4.0: A Readiness Assessment Instrument Aimed at Raising SMEs to Industry 4.0 Starting Levels – an Empirical Field Study. *Lecture Notes in Mechanical Engineering*, 713–720. https://doi.org/10.1007/978-3-030-90700-6_81

Peng, L., Feng, W., Chen, K., & Li, C. (2016). Smart manufacturing capability maturity model: Connotation, feature and trend. *Proceedings of the International Conference on Electronic Business (ICEB)*, 151–157. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85021700779&partnerID=40&md5=21b9f7048623babfc6711b8ae1bb6131

PERFORMANCE | meaning in the Cambridge English Dictionary. (n.d.). Retrieved July 8, 2022, from https://dictionary.cambridge.org/dictionary/english/performance

Pessl, E., Sorko, S. R., & Mayer, B. (2020). Roadmap industry 4.0 - Implementation guideline for enterprises. *26th International Association for Management of Technology Conference, IAMOT 2017*, 1728–1743. https://doi.org/10.11648/j.ijsts.20170506.14

phenomenon noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/phenomenon?q=phenomenon

Philip, G., & McKeown, I. (2004). Business transformation and organizational culture: The role of competency, IS and TQM. *European Management Journal*, *22*(6), 624–636. https://doi.org/10.1016/j.emj.2004.09.026

Pirola, F., Cimini, C., & Pinto, R. (2020). Digital readiness assessment of Italian SMEs: a case-study research. *Journal of Manufacturing Technology Management*, *31*(5), 1045–1083. https://doi.org/10.1108/JMTM-09-2018-0305

Plattform Industrie 4.0 - What is Industrie 4.0? (n.d.). Retrieved June 17, 2022, from https://www.plattform-i40.de/IP/Navigation/EN/Industrie40/WhatIsIndustrie40/what-is-industrie40.html

Pöppelbuß, J., & Röglinger, M. (2011). What makes a useful maturity model? A framework of general design principles for maturity models and its demonstration in business process management. *19th European Conference on Information Systems, ECIS 2011*.

Porter, M. E. (1980). *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. Free Press.

Porter, M. E. (1996). What is strategy? *Harvard Business Review*, 1–20.

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review*, *93*(November 2014), 4.

Prahalad, C. K., & Oosterveld, J. P. (1999). Transforming Internal Governance. *Sloan Management Review*, 31–39.

Prifti, L., Knigge, M., Kienegger, H., & Krcmar, H. (2017). *A Competency Model for "Industrie 4.0" Employees*. 46–60.

Raab, M., & Griffin-Cryan, B. (2011). Digital Transformation of the Supply Chain. *Digital Transformation of the Supply Chain*. https://doi.org/10.1142/12079

Rahamaddulla, S. R. Bin, Leman, Z., Baharudin, B. T. H. T. Bin, & Ahmad, S. A. (2021). Conceptualizing smart manufacturing readiness-maturity model for small and medium enterprise (Sme) in malaysia. *Sustainability (Switzerland)*, *13*(17). https://doi.org/10.3390/su13179793

Rauch, E., Unterhofer, M., Rojas, R. A., Gualtieri, L., Woschank, M., & Matt, D. T. (2020). A maturity level-based assessment tool to enhance the implementation of industry 4.0 in small and medium-sized enterprises. *Sustainability (Switzerland)*, *12*(9). https://doi.org/10.3390/SU12093559

Ravelomanantsoa, M. S., Ducq, Y., & Vallespir, B. (2019). A state of the art and comparison of approaches for performance measurement systems definition and design. *International Journal of Production Research*, *57*(15–16), 5026–5046. https://doi.org/10.1080/00207543.2018.1506178

READINESS | meaning in the Cambridge English Dictionary. (n.d.). Retrieved June 16, 2022, from https://dictionary.cambridge.org/dictionary/english/readiness

Riasanow, T., Soto Setzke, D., Hoberg, P., & Krcmar, H. (2017). Clarifying the Notion of Digital Transformation in IS Literature: A Comparison of Organizational Change Philosophies. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3072318

ROAD MAP | English meaning - Cambridge Dictionary. (n.d.). Retrieved February 15, 2022, from https://dictionary.cambridge.org/dictionary/english/road-map?q=roadmap

Robbins, S. P., & Judge, T. A. (2017). Organizational Behavior. Pearson.

Rosas, G. (2006). *Glossary of Key Terms on Learning and Training for Work*. ILO.

Rueckel, D., Muehlburger, M., & Koch, S. (2020). An Updated Framework of Factors Enabling Digital Transformation. *Pacific Asia Journal of the Association for Information Systems*, *12*(4), 1–26. https://doi.org/10.17705/1pais.12401

Sahu, N., Deng, H., & Molla, A. (2018). A capability based framework for customer experience focused digital transformation. *ACIS 2018 - 29th Australasian Conference on Information Systems*. https://doi.org/10.5130/acis2018.an

Samaranayake, P., Ramanathan, K., & Laosirihongthong, T. (2017). Implementing industry 4.0—A technological readiness perspective. *2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 529–533.

Sammut-Bonnici, T., & Wensley, R. (2003). Darwinism, Probability and Complexity: Market-Based Organizational Transformation and Change Explained Through the Theories of Evolution. *International Journal of Management Reviews*, *4*. https://doi.org/10.1111/1468-2370.00088

Sanchez, M. A. (2017). Framework to assess organizational readiness for digital transformation. *Dimensión Empresarial*, *15*(2), 27–40. https://doi.org/10.15665/rde.v15i2.976

Santiago da Costa, L., Pereira, L., & Akkari, A. (2018). A Proposed Framework to Identify Digital Transformation Maturity in Small Industries. *Proceedings Name*, *156*(November), 30–33. https://doi.org/10.3384/ecp1815630

Santos, R. C., & Martinho, J. L. (2020). An Industry 4.0 maturity model proposal. *Journal of Manufacturing Technology Management*, *31*(5), 1023–1043. https://doi.org/10.1108/JMTM-09-2018-0284

Sassanelli, C., Rossi, M., & Terzi, S. (2020). Evaluating the smart maturity of manufacturing companies along the product development process to set a PLM project roadmap. *International Journal of Product Lifecycle Management*, *12*(3), 210–225. https://doi.org/10.1504/IJPLM.2020.109789

Schallmo, D. R. A., & Williams, C. A. (2018). Digital Transformation Now! Guiding the Successful Digitalization of Your Business Model. In *Springer Briefs in Business* (Vol. 35, Issue 4). Springer International Publishing.

Schallmo, D., Williams, C. A., & Boardman, L. (2017). Digital transformation of business models-best practice, enablers, and roadmap. *International Journal of Innovation Management*, *21*(8), 1–17. https://doi.org/10.1142/S136391961740014X

Schmidt, R., Möhring, M., Härting, R.-C., Reichstein, C., Neumaier, P., & Jozinović, P. (2015). Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results. In W. Abramowicz (Ed.), *Business Information Systems* (pp. 16–27). Springer International Publishing.

Schneider, D., Huth, T., Vietor, T., Schumacher, P., Weckenborg, C., & Spengler, T. (2020). DEVELOPMENT of A POTENTIAL MODEL to SUPPORT the ASSESSMENT and INTRODUCTION of INDUSTRY 4.0 TECHNOLOGIES. *Proceedings of the Design Society: DESIGN Conference*, *1*, 707–716. https://doi.org/10.1017/dsd.2020.85

Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W. (2017). *Industrie 4.0 maturity index: managing the digital transformation of companies*. Herbert Utz Verlag GmbH.

Schumacher, A., Erol, S., & Sihn, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP*, *52*, 161–166. https://doi.org/10.1016/j.procir.2016.07.040

Schumacher, A., Nemeth, T., & Sihn, W. (2019). Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. *Procedia CIRP*, *79*, 409–414. https://doi.org/10.1016/j.procir.2019.02.110

Schumacher, A., Schumacher, C., & Sihn, W. (2020). Industry 4.0 Operationalization Based on an Integrated Framework of Industrial Digitalization and Automation. *Lecture Notes in Mechanical Engineering*, 301–310. https://doi.org/10.1007/978-3-030-31343-2_26

Schüritz, R., Farrell, K., Wixom, B., & Satzger, G. (2019). *Value Co-Creation in Data-Driven Services: Towards a Deeper Understanding of the Joint Sphere*.

Schüritz, R., Seebacher, S., & Dorner, R. (2017). Capturing Value from Data: Revenue Models for Data-Driven Services. *HICSS*.

Schwab, K. (2017). *The Fourth Industrial Revolution*. Crown Publishing Group.

Scremin, L., Armellini, F., Brun, A., Solar-Pelletier, L., & Beaudry, C. (2018). Towards a framework for assessing the maturity of manufacturing companies in industry 4.0 adoption. In *Analyzing the Impacts of Industry 4.0 in Modern Business Environments*. https://doi.org/10.4018/978-1-5225-3468-6.ch012

Shah, L.-A. (2012). *Value-risk based performance evaluation of industrial systems* (Issue 2012ENAM0033) [Arts et Métiers ParisTech]. https://pastel.archives-ouvertes.fr/pastel-00745792

Sheen, D. P., & Yang, Y. (2018). Assessment of Readiness for Smart Manufacturing and Innovation in Korea. *2018 IEEE Technology and Engineering Management Conference, TEMSCON 2018*. https://doi.org/10.1109/TEMSCON.2018.8488424

Shukla, M., & Shankar, R. (2021). An Extended Technology-Organization-Environment Framework to Investigate Smart Manufacturing System Implementation in Small and Medium Enterprises. *Computers & Industrial Engineering*, *163*, 107865. https://doi.org/10.1016/j.cie.2021.107865

Siedler, C., Dupont, S., Zavareh, M. T., Zeihsel, F., Ehemann, T., Sinnwell, C., Göbel, J. C., Zink, K. J., & Aurich, J. C. (2021). Maturity model for determining digitalization levels within different product lifecycle phases. *Production Engineering*, *15*(3–4), 431–450. https://doi.org/10.1007/s11740-021-01044-4

Sjödin, D. R., Parida, V., Leksell, M., & Petrovic, A. (2018). Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing Moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, p. *Research Technology Management*, *61*(5), 22–31. https://doi.org/10.1080/08956308.2018.1471277

SKILL | meaning in the Cambridge English Dictionary. (n.d.). Retrieved June 17, 2022, from https://dictionary.cambridge.org/dictionary/english/skill

Soares, N., Monteiro, P., Duarte, F. J., & Machado, R. J. (2021). Extended Maturity Model for Digital Transformation. In O. Gervasi, B. Murgante, S. Misra, C. Garau, I. Blecic, D. Taniar, B. O. Apduhan, A. M. A. C. Rocha, E. Tarantino, & C. M. Torre (Eds.), *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 12952 LNCS* (pp. 183–200). Springer. https://doi.org/10.1007/978-3-030-86973-1_13

Sternad, M., Lerher, T., & Gajsek, B. (2018). Maturity Levels for Logistics 4.0 Based on Nrw'S Industry 4.0 Maturity Model. In Dujak, D (Ed.), *Business Logistics in Modern Management* (Vol. 18, pp. 695–708).

Stoianova, O., Lezina, T., & Ivanova, V. (2020). The framework for assessing company's digital transformation readiness. *St Petersburg University Journal of Economic Studies*, *36*(2), 243–265. https://doi.org/10.21638/spbu05.2020.204

Strutynska, I., Dmytrotsa, L., Kozbur, H., & Melnyk, L. (2020). System-integrated methodological approach development to calculating the digital transformation index of businesses. *CEUR Workshop Proceedings*, *2740*, 373–379. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85096408863&partnerID=40&md5=ca9bc0adfb81b2b6affe147ff1766d85

Sufian, A. T., Abdullah, B. M., Ateeq, M., Wah, R., & Clements, D. (2019). A roadmap towards the smart factory. *Proceedings - International Conference on Developments in ESystems Engineering, DeSE*, *October-20*(8), 978–983. https://doi.org/10.1109/DeSE.2019.00182

Suleiman, Z., Dikhanbayeva, D., Shaikholla, S., & Turkyilmaz, A. (2021). Readiness Assessment of SMEs in Transitional Economies: Introduction of Industry 4.0. *ACM International Conference Proceeding Series*, 8–13. https://doi.org/10.1145/3447432.3447434

system noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved June 30, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/system?q=system

terminology noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. (n.d.). Retrieved July 8, 2022, from https://www.oxfordlearnersdictionaries.com/definition/english/terminology?q=terminology

Thiesse, F., & Köhler, M. (2008). An Analysis of Usage-Based Pricing Policies for Smart Products. *Electronic Markets*, *18*(3), 232–241. https://doi.org/10.1080/10196780802265751

Tichy, N. M. (1982). Managing change strategically: the technical, political, and cultural keys. *Organizational Dynamics*, *11*(2), 59–80. https://doi.org/10.1016/0090-2616(82)90005-5

Tilson, D., Lyytinen, K., & Sørensen, C. (2010). Digital Infrastructures: The Missing IS Research Agenda. *Information Systems Research*, *21*, 748–759. https://doi.org/10.1287/isre.1100.0318

Tomiyama, T., Lutters, E., Stark, R., & Abramovici, M. (2019). Development capabilities for smart products. *CIRP Annals*, *68*(2), 727–750. https://doi.org/10.1016/j.cirp.2019.05.010

Trautmann, L. (2021). MAP 4.0 – Proposal for a Prescriptive Maturity Model to Assess the Digitalization of Procurement. *Lecture Notes in Logistics*, 90–104. https://doi.org/10.1007/978-3-030-85843-8_6

Trist, E. L., & Bamforth, K. W. (1951). Some Social and Psychological Consequences of the Longwall Method of Coal-Getting: An Examination of the Psychological Situation and Defences of a Work Group in Relation to the Social Structure and Technological Content of the Work System. *Human Relations*, *4*(1), 3–38. https://doi.org/10.1177/001872675100400101

Tushman, M. L., & Romanelli, E. (1985). Organizational evolution: A metamorphosis model of convergence and reorientation. *Research in Organizational Behavior*.

Valdez-de-Leon, O. (2016). A Digital Maturity Model for Telecommunications Service Providers. *Technology Innovation Management Review*, *6*(8), 19–32. https://doi.org/10.22215/timreview1008

Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *Journal of Strategic Information Systems*, *28*(2), 118–144. https://doi.org/10.1016/j.jsis.2019.01.003

Victoria State Government Education and Training. (2019). Teach with digital technologies. In *State Government of Victoria, Australia* (p. 1). https://www.education.vic.gov.au/school/teachers/teachingresources/digital/Pages/teach.aspx

Vollmann, T. E. (1996). *The Transformation Imperative: Achieving Market Dominance Through Radical Change* (Vol. 30, Issue 2). Harvard Business School Press. https://doi.org/10.1016/s0024-6301(97)80024-6

von Rosing, M., Von Scheel, H., & Scheer, A. W. (2014). The Complete Business Process Handbook: Body of Knowledge from Process Modeling to BPM. In *The Complete Business Process Handbook: Body of Knowledge from Process Modeling to BPM* (Vol. 1, Issue v. 1). Elsevier Science. https://doi.org/10.1016/C2013-0-13596-9

von Solms, J., & Langerman, J. (2021). Digital technology adoption in a bank Treasury and performing a Digital Maturity Assessment. *African Journal of Science, Technology, Innovation and Development*. https://doi.org/10.1080/20421338.2020.1857519

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations and Production Management*, *22*(2), 195–219. https://doi.org/10.1108/01443570210414329

Vrchota, J., & Pech, M. (2019). Readiness of enterprises in Czech Republic to implement industry 4.0: Index of industry 4.0. *Applied Sciences (Switzerland)*, *9*(24). https://doi.org/10.3390/app9245405

Wagire, A. A., Joshi, R., Rathore, A. P. S., & Jain, R. (2021). Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice. *Production Planning and Control*, *32*(8), 603–622. https://doi.org/10.1080/09537287.2020.1744763

Webster, J., & Watson, R. T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly*, *26*(2), xiii–xxiii. http://www.jstor.org/stable/4132319

Wee, D., Kelly, R., Cattel, J., & Breunig, M. (2015). Industry 4.0 - how to navigate digitization of the manufacturing sector. *McKinsey & Company*, 1–62.

Weisbord, M. R. (1976). Organizational Diagnosis: Six Places To Look for Trouble with or Without a Theory. *Group \& Organization Studies*, *1*(4), 430–447. https://doi.org/10.1177/105960117600100405

Weiser, M. (1991). The computer for the 21st century. *Scientific American*, *256*(3), 94–104. https://doi.org/10.1145/329124.329126

Weiss, B., Freeman, P., Lee, J., & Pavel, R. (2016). *Editorial - Special Issue: Smart Manufacturing PHM*. https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=922354

Westerman, G., Calméjane, C., Bonnet, D., Ferraris, P., McAfee, A., & others. (2011). Digital Transformation: A roadmap for billion-dollar organizations. *MIT Center for Digital Business and Capgemini Consulting*, *1*, 1–68.

What's Your Staff Best At? Map Their Competencies and Find Out! | *Upsteem.com*. (n.d.). Retrieved July 18, 2022, from https://www.upsteem.com/blog/what-s-your-staff-best-at-map-their-competencies-and-find-out#.YtTBB3ZBzIU

Wu, L., Yue, X., Jin, A., & Yen, D. C. (2016). Smart supply chain management: a review and implications for future research. *The International Journal of Logistics Management*, *27*(2), 395–417. https://doi.org/10.1108/IJLM-02-2014-0035

Yin, R. (2018). Case study research and applications: Design and methods. In *Journal of Hospitality & Tourism Research* (6e ed., Vol. 53, Issue 5). SAGE Publications.

Yoo, S., Kim, Y. W., & Choi, H. (2018). An assessment framework for smart manufacturing. *International Conference on Advanced Communication Technology, ICACT*, *2018-Febru*, 553–555. https://doi.org/10.23919/ICACT.2018.8323828

Yue, L., Wang, Z., Fang, Y., & Han, Z. (2020). Implementation of smart manufacturing maturity assessment framework: A socio-technical perspective. *E3S Web of Conferences*, *179*. https://doi.org/10.1051/e3sconf/202017902023

Zaoui, F., & Souissi, N. (2020a). A framework for a strategic digital transformation. *Colloquium in Information Science and Technology, CIST*, *2020-June*, 502–508. https://doi.org/10.1109/CiSt49399.2021.9357314

Zaoui, F., & Souissi, N. (2020b). Roadmap for digital transformation: A literature review. *Procedia Computer Science*, *175*, 621–628. https://doi.org/10.1016/j.procs.2020.07.090

Zhang, Y., & Zhang, D. (2021). Research on the Construction of Traditional Enterprise Digital Evaluation Index System. *2021 IEEE 2nd International Conference on Big Data, Artificial Intelligence and Internet of Things Engineering, ICBAIE 2021*, *Icbaie*, 842–846. https://doi.org/10.1109/ICBAIE52039.2021.9389962

Appendix

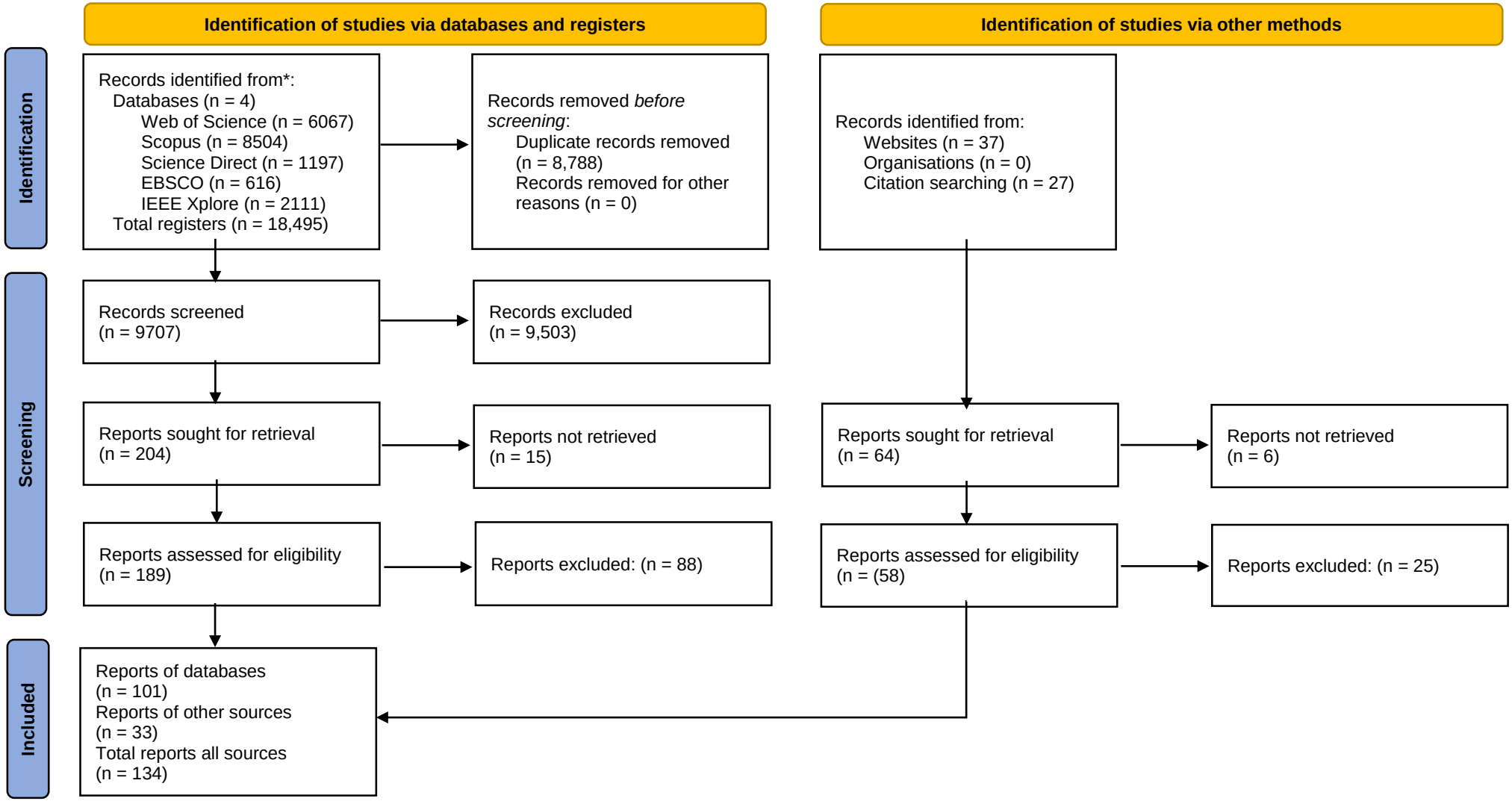
Appendix 1.1

Digital Transformation terminology

Concept	Definition	Author(s) & Year
Digitization	The technical process of converting analogue signals into a digital form, and ultimately into binary digits.	Legner et al., 2017
Digitalization	The fundamental changes made to business operations and business models based on newly acquired knowledge gained via value-added digitization initiatives.	Schalmo et al., 2018
Digital Transformation	The profound and accelerating transformation of business activities, processes, competencies, and models to fully leverage the changes and opportunities brought by digital technologies and their impact across society in a strategic and prioritized way.	Demirkan et al., 2016
Smart manufacturing	Smart Manufacturing are systems that are fully integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs.	National Institute of Standards and Technology (NIST)
Smart supply chain	Smart Supply Chain has the capability for extensive information availability, and enables superior collaboration and communication across digital platforms resulting in improved reliability, agility and effectiveness.	Raab and Griffin-Cryan, 2011
Smart products	Smart Products are complex systems that combine their physical nature composed of mechanical and electrical parts with hardware, sensors, data storage, microprocessors, software and connectivity in multiple ways.	Porter and Heppelmann, 2014
Smart services	Smart services are the use of data and analytics by a provider to support a customer's decision-making process with the intent to create value for the customer.	Schüritz et al., 2019
Digital Readiness	Willingness of a company or a state of being prepared for beginning a DT.	Adapted from the Cambridge Dictionary
Digital Maturity	State of advancement or development of the DT in a company.	Adapted from the Cambridge Dictionary
Maturity Model	A maturity model consists of a sequence of maturity levels for a class of objects (e.g., organizations, processes) that represent an anticipated, desired or typical evolution paths of these objects shaped as discrete stages in which the highest stage represents a conception of total maturity.	Becker et al., 2009
Roadmap	A roadmap is an overall plan for the deployment of new technologies, containing organizational change, that explains the main phases that need to be taken.	Daim and Oliver, 2008; Issa et al., 2018
Conceptual Framework	A conceptual framework identifies the main concepts that explain a phenomenon and the relationship between them.	Miles and Huberman, 1994
Theoretical Framework	A theoretical framework consists of the theoretical principles, constructs, concepts and tenants of a theory.	Grant & Osanloo, 2014
Assessment	An assessment refers to the wide variety of methods or tools that are used to evaluate, measure, and document the readiness or maturity progress of companies.	Adapted from the Glossary of Education Reform
Index	An index is a sign or measure of maturity that companies can be judged by.	Adapted from the Oxford Dictionary

Appendix 1.2

Systematic Literature Review search strategy



From: Page M. J., McKenzie J. E., Bossuyt P. M., Boutron I., Hoffmann T. C., Mulrow C. D., et al., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Appendix 1.3

Digital Models and Frameworks

No.	DMF's name	Author(s)	Year
1	Industry 4.0 Maturity	Akdil, K. Y., Ustundag, A., & Cevikcan, E.	2018
2	Adoption Maturity Model (AMM)	Scremin, L., Armellini, F., Brun, A., Solar-Pelletier, L., & Beaudry, C.	2018
3	IMPULS – Industrie 4.0 Readiness	Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E., & Schröter, M.	2015
4	PwC Maturity Model for manufacturing managers to assess Industry 4.0 maturity.	Geissbauer, R., Vedso, J., & Schrauf, S.	2016
5	The Connected Enterprise Maturity Model	Allen-Bradley	2014
6	Industry 4.0 Maturity Model	Schumacher, A., Erol, S. & Sihn, W.	2016
7	Smart Manufacturing System Readiness Level (SMSRL) Index	Jung, K., Kulvatunyou, B., Choi, S., & Brundage, M. P.	2016
8	Three Stages Maturity Model in SMEs towards Industry 4.0	Ganzarain, J., & Errasti, N.	2016
9	A Smartness Assessment Framework for Smart Factories	Lee, J., Jun, S., Chang, T. W., & Park, J.	2017
10	Industrie 4.0 Maturity Index	Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W.	2017
11	Future Readiness for Industry 4.0.	Botha, A.	2018
12	Digitalization Maturity Model for the manufacturing sector	Canetta, L., Barni, A., & Montini, E.	2018
13	Industry 4.0 migration model to help manufacturing production environments mature	Leineweber, S., Wienbruch, T., Lins, D., Kreimeier, D., & Kuhlenkötter, B.	2018
14	Industry 4.0 - A Technological Readiness Perspective	Samaranayake, P., Ramanathan, K., & Laosirihongthong, T.	2017
15	Maturity Model for supply chain Digitalization	Klötzer, C., & Pflaum, A.	2017
16	Digital Maturity Model (DMM)	Deloitte	2018
17	Digital Readiness Assessment (DRA)	KPMG	2016
18	Digital Quotient (DQ)	McKinsey & Company	2018
19	PwC's Industry 4.0 / Digital Operations Self-Assessment	Geissbauer, R., Lübben, E., Schrauf, S., & Pillsbury, S.	2018
20	Digital Maturity Matrix MIT & Capgemini	Westerman, G., Calméjane, C., Bonnet, D., Ferraris, P., McAfee, A., & others.	2011
21	Digital Maturity Model (DMM)	Berghaus, S., & Back, A.	2016
22	Digital Maturity Model	Azhari, P., Faraby, N., Rossmann, A., Steimel, B., & Wichmann, K. S.	2014
23	Paths to digital transformation	Berman, S., & Bell, R.	2011
24	Maturity Model PwC	Greif, H., Kühnis, N., & Warnking, P.	2016
25	Digital Capability Framework (DCF)	O'Hea, K.	2011
26	Aligning the Organization for its Digital Future	Kane, G. C., Palmer, D., Phillips, A. N., Kiron, D., & Buckley, N.	2016
27	Digital Maturity Model for Telecommunications Service Providers	Valdez-de-Leon, O.	2016
28	TM Forum's Digital Maturity Model	Newman, M.	2017
29	The Digital Maturity Model 4.0	Gill, M., & VanBoskirk, S.	2016
30	McKinsey Digital Compass	Wee, D., Kelly, R., Cattel, J., & Breunig, M.	2015
31	Supply Chain Visibility Maturity	Gartner	n.d.
32	Four levels of I4.0 capability	Beaudoin, J. E.	2016
33	Reifegradmodell Industrie 4.0	Jodlbauer, H., & Schagerl, M.	2016
34	Industrie 4.0 Maturity Index	Häberer, S., Lau, L., & Behrendt, F.	2017

No.	DMF's name	Author(s)	Year
35	Smart Manufacturing Maturity Model for SMEs (SM3E)	Mittal, S., Romero, D., & Wuest, T.	2018
36	Digital Transformation Maturity Model	Gollhardt, T., Halsbenning, S., Hermann, A., Karsakova, A., & Becker, J.	2020
37	Smart Factory Maturity Model	Sjödin, D. R., Parida, V., Leksell, M., & Petrovic, A.	2018
38	Roadmap Industry 4.0	Pessl, E., Sorko, S. R., & Mayer, B.	2020
39	ManuTech Maturity Model (ManuTech MM, MTMM)	Gracel, J.	2017
40	Industry 4.0 conceptual framework	Bibby, L., & Dehe, B.	2018
41	Industry 4 readiness assessment tool	Agca, O., Gibson, J., Godsell, J., Ignatius, J., Wyn Davies, C., & Xu, O.	2017
42	4.0 manufacturing industry readiness and maturity	Almamalik, L.	2020
43	Self-check - competence center	Mittelstand 4.0	n.d.
44	Roadmap Industrial Digitalization	Schumacher, A., Nemeth, T., & Sihn, W.	2019
45	Delivery Process Maturity Model (DPMM) 4.0.	Asdecker, B., & Felch, V.	2018
46	Model for Assessing Maturity of Industry 4.0	Bandara, O. K. K., Tharaka, V. K., & Wickramarachchi, A. P. R.	2019
47	Framework Digital Transformation Maturity in Small Industries	Santiago da Costa, L., Pereira, L., & Akkari, A.	2018
48	A PSS maturity self-assessment tool	Exner, K., Balder, J., & Stark, R.	2018
49	Extended Maturity Model for Digital Transformation	Soares, N., Monteiro, P., Duarte, F. J., & Machado, R. J.	2021
50	Digital Transformation Framework	Abdallah, Y. O., Shehab, E., & Al-Ashaab, A.	2021
51	Digital transformation capability maturity model framework	Aguiar, T., Gomes, S. B., Da Cunha, P. R., & Da Silva, M. M.	2019
52	KIPIC Readiness Framework for Industry 4.0	AlFedaghi, H. S.	2019
53	Framework for Assessing Manufacturing SMEs Industry 4.0 Maturity	Amaral, A., & Peças, P.	2021
54	Digital Manufacturing Automation - an Assessment Approach	Ambra Cala, A. L., Boschi, F., Tavola, G., & Taisch, M.	2018
55	Critical variables for success in the technology adoption process in the framework of digital transformation	Arbaiza, C. E. S.	2018
56	Assessment Industry 4.0 Maturity Model: an application to manufacturing company	Azevedo, A., & Santiago, S. B.	2019
57	Industry4WRD readiness assessment (RA) model for Industry 4.0	Azhar, M. N., Omar, M. N., & Shaiful, A. I. M.	2021
58	R&D roadmap for process robotization driven to the digital transformation of the Industry 4.0	Barbosa, G. F., Shiki, S. B., & da Silva, I. B.	2020
59	Multi-Attribute Assessment of Digital Maturity of SMEs	Borštnar, M. K., & Pucihar, A.	2021
60	Self-assessment tools to measure Industry 4.0 readiness	Brozzi, R., D'Amico, R. D., Pasetti Monizza, G., Marcher, C., Riedl, M., & Matt, D.	2018
61	An organizational change framework for digital servitization	Bustinza, O. F., Gomes, E., Vendrell-Herrero, F., & Tarba, S. Y.	2018
62	A Conceptual Framework to Support Digital Transformation in Manufacturing	Butt, J.	2020
63	A fuzzy rule-based Industry 4.0 maturity model for operations and supply chain management	Caiado, R. G. G., Scavarda, L. F., Gavião, L. O., Ivson, P., Nascimento, D. L. de M., & Garza-Reyes, J. A.	2021
64	Conceptual framework	Calabrese, A., Levialdi Ghiron, N., & Tiburzi, L. (2021)	2021

No.	DMF's name	Author(s)	Year
65	Maturity Model Assessment of SMART Logistics for SMEs	Chaopaisarn, P., & Woschank, M.	2021
66	The Smart SMEs 4.0 Maturity Model	Chonsawat, N., & Sopadang, A.	2021
67	A Framework for Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises	Çınar, Z. M., Zeeshan, Q., & Korhan, O.	2021
68	A Framework to Support Industry 4.0	Cortés Serrano, D., Chavarría-Barrientos, D., Ortega, A., Falcón, B., Mitre, L., Correa, R., Moreno, J., Funes, R., & Molina Gutiérrez, A.	2018
69	Industry 4.0 Roadmap: Implementation for Small and Medium-Sized Enterprises	Cotrino, A., Sebastián, M. A., & González-Gaya, C.	2020
70	Heavy industry's digital transformation: Vision, diagnostic, and roadmap	Crispeels, P., & Misljencevic, D.	2020
71	The Digital Readiness Assessment Maturity Model (DREAMY)	De Carolis, A., MacChi, M., Negri, E., & Terzi, S.	2018
72	Conceptual framework for supply chain digitalization	Deepu, S. T., & Ravi, V.	2021
73	Interpretive framework	Devi K, S., Paranitharan, K. P., & Agniveesh A, I.	2021
74	Framework for implementing Industry 4.0	Dossou, P. E.	2019
75	Theoretical framework for Industry 4.0	Gajdzik, B., Grabowska, S., & Saniuk, S.	2021
76	A Roadmap for Winning	Gard, J.-C., Shah, A., Dreischmeier, R., & Niddam, M.	2016
77	A strategic roadmap toward Industry 4.0.	Ghobakhloo, M.	2018
78	ISO 9004 maturity model for quality in Industry 4.0	Glogovac, M., Ruso, J., & Maricic, M.	2020
79	DX-CMM	Gökalp, E., & Martinez, V.	2021
80	Digital Maturity Model for digital banking	Goumeh, F., & Barforoush, A. A.	2021
81	Readiness and Maturity Assessment Model	Govindasamy, A., & Arularasan, A.	2021
82	Conceptual Framework to Assess the Maturity and Readiness	Hajoary, P. K., & Akhilesh, K. B.	2021
83	Integrated Framework	Imran, F., Shahzad, K., Butt, A., & Kantola, J.	2021
84	Industrie 4.0 roadmap	Issa, A., Hatiboglu, B., Bildstein, A., & Bauernhansl, T.	2018
85	Assessment of Readiness for Industry 4.0 Implementation	Kellner, T., Necas, M., Kanak, M., Kyncl, M., & Kyncl, J.	2020
86	Assessment of smart factories	Ko, M., Kim, C., Lee, S., & Cho, Y.	2020
87	Lean and Industry 4.0 assessment model for manufacturing SMEs	Kolla, S., Minufekr, M., & Plapper, P.	2019
88	Conceptual framework	Konopik, J., Jahn, C., Schuster, T., Hoßbach, N., & Pflaum, A.	2022
89	Framework for assessing the company's maturity of digital business transformation	Kozina, M.	2019
90	Methods of developing digital maturity models	Kupriyanova, M. V., Evdokimova, E. N., Solovyova, I. P., & Simikova, I. P.	2020
91	Industry 4.0 readiness assessment	Lakmali, E., Vidanagamachchi, K., & Nanayakkara, J.	2020
92	Assessment the Company's Readiness for Digital Transformation	Lezina, T., Stoianova, O., Ivanova, V., & Gadasina, L.	2019
93	Monitoring index system for sectors' digital transformation	Li, J., Dou, K., Wen, S., & Li, Q.	2021
94	Decision support for the implementation of Industry 4.0 methods	Liebrecht, C., Kandler, M., Lang, M., Schaumann, S., Stricker, N., Wuest, T., & Lanza, G.	2021

No.	DMF's name	Author(s)	Year
95	Framework for digital transformation success in manufacturing	Liere-Netheler, K., Vogelsang, K., Packmohr, S., & Hoppe, U.	2018
96	Maturity Framework Enabling Organizational Digital Readiness	Machado, C. G., Almstrom, P., Oberg, A. E., Kurdve, M., & Almashalah, S. Y.	2020
97	Industry 4.0 readiness assessment	Maisiri, W., & van Dyk, L.	2019
98	Integrated digital transformation framework	Majdalawieh, M.	2019
99	Technology and digital transformation adoption framework	Mokgohloa, K., Kanakana-Katumba, G., & Maladzhi, R.	2020
100	Conceptual framework on SMEs' readiness	Muhamad, M. Q. B., Mohamad, S. J. A. N. S., & Nor, N. M.	2021
101	Company Compass (CCMS) 2.0	Nick, G., Kovács, T., Ko, A., & Kádár, B.	2020
102	Assessment of companies' maturity	Nogalski, B., & Niewiadomski, P.	2020
103	Assessment of critical success factors	Nwaiwu, F., Duduci, M., Chromjakova, F., & Otekhile, C. A. F.	2020
104	Integrated Capability Framework for Digitization and Business Value Generation	Orji, C. I.	2019
105	RAISE 4.0: A Readiness Assessment Instrument	Pan Nogueras, M. L., Perea Muñoz, L., Cosentino, J. P., & Suarez Anzorena, D.	2022
106	SM CMM	Peng, L., Feng, W., Chen, K., & Li, C.	2016
107	Digital Readiness Level 4.0 Model (DRL 4.0)	Pirola, F., Cimini, C., & Pinto, R.	2020
108	Industry 4.0 maturity model for machine tool companies	Lizarralde Dorronsoro, R., Jaione, G. E., Cristina, L., & Ibon, S. L.	2020
109	Smart manufacturing readiness-maturity model	Rahamaddulla, S. R. Bin, Leman, Z., Baharudin, B. T. H. T. Bin, & Ahmad, S. A.	2021
110	Maturity level-based assessment tool	Rauch, E., Unterhofer, M., Rojas, R. A., Gualtieri, L., Woschank, M., & Matt, D. T.	2020
111	Framework of Factors Enabling Digital Transformation	Rueckel, D., Muehlburger, M., & Koch, S.	2020
112	Capability based framework for customer experience	Sahu, N., Deng, H., & Molla, A.	2018
113	Framework to assess organizational readiness for digital transformation	Sanchez, M. A.	2017
114	An Industry 4.0 maturity model proposal	Santos, R. C., & Martinho, J. L.	2020
115	Evaluating the smart maturity of manufacturing companies along the product development process	Sassanelli, C., Rossi, M., & Terzi, S.	2020
116	Potential Model	Schneider, D., Huth, T., Vietor, T., Schumacher, P., Weckenborg, C., & Spengler, T.	2020
117	Integrated Framework of Industrial Digitalization and Automation	Schumacher, A., Schumacher, C., & Sihn, W.	2020
118	Assessment of Readiness for Smart Manufacturing	Sheen, D. P., & Yang, Y.	2018
119	CSFs for SM system implementation	Shukla, M., & Shankar, R.	2021
120	InAsPro maturity model	Siedler, C., Dupont, S., Zavareh, M. T., Zeihsel, F., Ehemann, T., Sinnwell, C., Göbel, J. C., Zink, K. J., & Aurich, J. C.	2021
121	Maturity Levels for Logistics 4.0	Sternad, M., Lerher, T., & Gajsek, B.	2018
122	DTRA framework	Stoianova, O., Lezina, T., & Ivanova, V.	2020
123	Digital transformation index of businesses	Strutynska, I., Dmytrotsa, L., Kozbur, H., & Melnyk, L.	2020
124	A roadmap towards the smart factory	Sufian, A. T., Abdullah, B. M., Ateeq, M., Wah, R., & Clements, D.	2019
125	Readiness Assessment of SMEs in Transitional Economies	Suleiman, Z., Dikhanbayeva, D., Shaikholla, S., & Turkyilmaz, A.	2021

No.	DMF's name	Author(s)	Year
126	MAP 4.0 Maturity Model to Assess the Digitalization of Procurement	Trautmann, L.	2021
127	Digital Maturity Assessment	von Solms, J., & Langerman, J.	2021
128	VPi4 index	Vrchota, J., & Pech, M.	2019
129	Maturity model for assessing the implementation of Industry 4.0	Wagire, A. A., Joshi, R., Rathore, A. P. S., & Jain, R.	2021
130	Assessment framework for smart manufacturing	Yoo, S., Kim, Y. W., & Choi, H.	2018
131	Smart Manufacturing Maturity Assessment Framework	Yue, L., Wang, Z., Fang, Y., & Han, Z.	2020
132	A framework for a strategic digital transformation	Zaoui, F., & Souissi, N.	2020a
133	Roadmap for digital transformation	Zaoui, F., & Souissi, N.	2020b
134	Digital Evaluation Index System	Zhang, Y., & Zhang, D.	2021

Appendix 3.1

APQC’s Cross-Industry Process Model

Processes/Sub-Processes
1.0 Develop Vision and Strategy
1.1 Define the business concept and long-term vision
1.2 Develop business strategy
1.3 Execute and measure strategic initiatives
1.4 Develop and maintain business models
2.0 Develop and Manage Products and Services
2.1 Govern and manage product/service development program
2.2 Generate and define new product/service ideas
2.3 Develop products and services
3.0 Market and Sell Products and Services
3.1 Understand markets, customers, and capabilities
3.2 Develop marketing strategy
3.3 Develop and manage marketing plans
3.4 Develop sales strategy
3.5 Develop and manage sales plans
4.0 Deliver Physical Products
4.1 Plan for and align supply chain resources
4.2 Procure materials and services
4.3 Produce/Assemble/Test product
4.4 Manage logistics and warehousing
5.0 Deliver Service
5.1 Establish service delivery governance and strategies
5.2 Manage service delivery resources
5.3 Deliver service to customer
6.0 Manage Customer Service
6.1 Develop customer care/customer service strategy
6.2 Plan and manage customer service contacts
6.3 Service products after sales
6.4 Manage product recalls and regulatory audits
6.5 Evaluate customer service operations and customer satisfaction
7.0 Develop and Manage Human Capital
7.1 Develop and manage human resources planning, policies, and strategies
7.2 Recruit, source, and select employees
7.3 Manage employee on boarding, development, and training
7.4 Manage employee relations
7.5 Reward and retain employees
7.6 Redeploy and retire employees
7.7 Manage employee information and analytics
7.8 Manage employee communication
7.9 Deliver employee communications
8.0 Manage Information Technology
8.1 Develop and manage IT customer relationships
8.2 Develop and manage IT business strategy

Processes/Sub-Processes
8.3 Develop and manage IT resilience and risk
8.4 Manage information
8.5 Develop and manage services/solutions
8.6 Deploy services/solutions
8.7 Create and manage support services/solutions
9.0 Manage Financial Resources
9.1 Perform planning and management accounting
9.2 Perform revenue accounting
9.3 Perform general accounting and reporting
9.4 Manage fixed-asset project accounting
9.5 Process payroll
9.6 Process accounts payable and expense reimbursements
9.7 Manage treasury operations
9.8 Manage internal controls
9.9 Manage taxes
9.10 Manage international funds/consolidation
9.11 Perform global trade services
10.0 Acquire, Construct, and Manage Assets
10.1 Plan and acquire assets
10.2 Design and construct productive assets
10.3 Maintain productive assets
10.4 Dispose of assets
11.0 Manage Enterprise Risk, Compliance, Remediation, and Resiliency
11.1 Manage enterprise risk
11.2 Manage compliance
11.3 Manage remediation efforts
11.4 Manage business resiliency
12.0 Manage External Relationships
12.1 Build investor relationships
12.2 Manage government and industry relationships
12.3 Manage relations with board of directors
12.4 Manage legal and ethical issues
12.5 Manage public relations program
13.0 Develop and Manage Business Capabilities
13.1 Manage business processes
13.2 Manage portfolio, program, and project
13.3 Manage enterprise quality
13.4 Manage change
13.5 Develop and manage enterprise-wide knowledge management (KM) capability
13.6 Measure and benchmark
13.7 Manage environmental health and safety (EHS)
13.8 Develop, Manage, and Deliver Analytics

Appendix 3.2

Prifti's Competency Model

Big Eight	Competency Dimensions	Competencies
Leading & Deciding	Deciding and Initiating Action	Decision Making
		Taking Responsibility
	Leading and Supervising	Leadership Skills
Supporting and Cooperating	Working with People	Teamwork
		Collaborating with Others
		Communicating with People
	Adhering to Principles and Values	Respecting Ethics
		Environmental Awareness
		Awareness for Ergonomics
Interacting and Presenting	Relating and Networking	Compromising
		Creating Business Networks
		Maintaining Customer Relationships
	Persuading and Influencing	Negotiating
		Emotional Intelligence
	Presenting and Communicating Information	Presentation and Communication Ability
Analyzing and Interpreting	Writing and Reporting	Targeted/Technical Communication
		Literacy
	Applying Expertise and Technology	IT and Technology Affinity
		Economics
		Extract Business Value from Social Media
		Service Orientation/ Product Service Offerings
		Business Process Management
		Business Change Management
		Understand and Coordinate Workflows
		Network Security
		IT Architectures
		Machine Learning
		System Development
		Integrating Heterogeneous Technologies
		Mobile Technologies
		Sensors/Embedded Systems
		Network Technology /M2M Communication
		Robotics/Artificial Intelligence
		Predictive Maintenance
		Modelling and Programming
		Big Data/Data Analysis and Interpretation
		Cloud Computing /Architectures
		In-Memory DBs
		Statistics
		Data Security
	Analyzing	Problem Solving
		Optimization
		Analytical Skills
		Cognitive Ability
Creating and Conceptualizing	Learning and Researching	Life-long Learning
		Knowledge Management
	Creating and Innovating	Innovating
		Creativity
		Critical Thinking
		Change Management
	Formulating Strategies and Concepts	Business Strategy
		Abstraction Ability
		Managing Complexity
Organizing and Executing	Planning and Organizing	Project Management
		Planning and Organizing Work
		Management Ability
	Delivering Results and Meeting Customer Expectations	Customer Orientation
		Customer Relationship Management
	Following Instructions and Procedures	Legislation Awareness
		Safety Awareness
		Individual Responsibility
Adapting and Coping	Adapting and Responding to Change	Work in Interdisciplinary Environments
		Intercultural Competency
		Flexibility
		Adaptability and Ability to Change Mind-set
	Persuading and Influencing	Work-Life Balance
Enterprising and Performing	Achieving Personal Work Goals and Objectives	Self-management and -organization
	Entrepreneurial and Commercial Thinking	Business Model Understanding
		Entrepreneurship

Appendix 4.1

Interview guide – pilot case

Digital Transformation

Interview guideline

Demographics & Business Info

(This information can be collected previously and be confirmed during the interview)

- Interviewee's Name
- Position in the organization or level of responsibility
- Company's Name
- Industry / Economic sector
- Postal code
- Country's Region
- Country
- Locations and Size of workforce by location
- Annual Revenue
- Business or industry associations is your company a member
- Brief business description (History, products, customers, suppliers)

Digital Transformation Project Info

- Digital Transformation **Project Objectives**
- Digital Transformation **Business Objectives**
- **Stages** of the project and its **status** of implementation (+ reason/justification)
- Overall **priority** of your digital transformation initiatives in your organization
- Business **results** to date with digital transformation (+ source)
- Return on investment period (**ROI**) do you expect from your digital investments (+ calculation)
- Main **challenges** or inhibitors for the DT initiatives in your company (+solution)
- Main **positive** or **easy** aspects of the DT initiatives in your company
- External **support** received for the implementation of the I4.0 (+what, how, which project stage)
- General (economic, environmental, social, internal) **benefits** from the Digital Transformation (+ source)
- General **limitations** or **disadvantages** from the Digital Transformation (+ source)
- Level of "**Success**" achieved with the DT & related **Satisfaction** with the project (+reason)

Strategy

It takes strategy to set the agenda in terms of transformation objectives, focus to maintain the customer-centric (outside-in) perspective and align the organization, and investment to drive transformational change.

- Reasons that led to the DT initiative(s)
- DT strategy position inside the Business Strategy (+ explain)
- Decision-Making Process
- Extent/Scope of the Digital Transformation Initiative
- Roadmap of the DT Initiatives (+ description)
- Approach to customer-centricity in your transformation initiatives
- Level of investment allocated to digital transformation
- Sources of Projects' financing and funding and degree of difficulty to obtain them
- Use of indicators to track the implementation status of the DT strategy (+detail)
- Products comply with Digital Business Model
- Creation of new business opportunities for your company (Improved product, new markets and products, etc.)
- Development of new disruptive business models
- How the partnerships affect the degree of maturity in the digitalization of products?
- What type of partnerships are we looking for? With which kind of companies?

- Company offers products equipped with the following add-on functionalities based on information and communications technology
- Company offers Smart (Data-driven) services that are possible only through the integration of products, production, and customers
- Ability of your products to be controlled with IT, making it possible for them to communicate and interact with higher-level systems along the value chain
- Analysis of the data collected from the production phase
- Analysis of the data collected from the usage phase

Business Process

A business process is a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer.

- Processes that need to change or to be created in order to enable or support the evolution of products and services.
- Leading practices in corporate innovation are important to identify and accelerate digital transformation.
- Organizational Structure for Digital Governance

Culture

Culture is the pattern of shared beliefs and values that give members of an institution meaning and provide them with the rules for behavior in their organization.

- Type of Culture?
- Appetite for risk related to new digital initiatives.
- Recognition of the value of mistakes as an opportunity to gain a better understanding of the company's processes and uncover previously unknown cause-and-effect relationships.
- Openness to innovation and new ways of doing things.
- Openness to collaborate and willingness to share knowledge.
- Trust in the company's processes and information systems.
- Willingness to experiment with new technologies and learn new ways of operating.
- Culture (Siloed, Integrating, Integrated and innovative, measured as the % of interviewed people that said the culture is collaborative and innovative – separately – compared to competitors)
- Sets of Values and Beliefs in employees

Organizational Structure

An organizational structure defines how job tasks are formally divided, grouped, and coordinated.

- Type of Organizational Structure (mechanistic or organic)
    - Rigid hierarchical relationships vs Collaboration (both vertical and horizontal)
    - Fixed duties vs Adaptable duties
    - Many rules vs Few rules
    - Formalized communication channels vs Informal communication
    - Centralized decision authority vs Decentralized decision authority
    - Taller structures vs Flatter structures
- Creation of new organizational structures for innovation (*ambidexterity*)
- Introduction of new roles and update of job profiles to take into account new digital skills

Competences

Competencies are those characteristics- knowledge, skills, mindsets, thought patterns, and the like-that, when used either singularly or in various combinations, result in successful performance.

- Level and distribution of digital skills
- Employee training procedure for transitioning to a Digital Company
- Mechanism to assure the company retains the knowledge that is absorbed by its employees
- Mechanism to keep the skills level up to date
- Level of Talent development (Tepid interest, Investing, Committed measured as the % of interviewed people that said their company provides resources to obtain digital skills)
- Leadership (lacking skills, Learning, Sophisticated measure as the % of interviewed people that said leadership has sufficient digital skills)
- Innovation
- Collaboration
- Digital Skills

Technology

- Description of the digital technologies implemented
- Description of the decision-making process that led to the selection of these technologies
- Current use of emerging and disruptive technologies
- Maturity of the data analytics capabilities in your company
- Use of all data that are now available
- Management of cybersecurity
- Modification of your infrastructure, Equipment, Computer systems or Others required by the implementation of the new technologies

To finish…

- Looking back, do you think that your company was ready for a Digital Transformation when you did so? Why?
    - What would you have done differently?
- Would you recommend other companies to DT? Why?
    - (If yes) What would be your advice to them to succeed in the implementation of such a project?
- Do you have any suggestions to the government to be able to help companies like yours during the DT?
- Do you have anything to add, a question or a comment that you believe to be important that has not been addressed in the interview?

Appendix 4.2

Digital Transformation Questionnaire



Université Savoie Mont Blanc

Digital Transformation of Manufacturing Enterprises

Research Project



Melissa Liborio Zapata
[Date]

Digital Transformation of Manufacturing Enterprises

The laboratories SYMME and LISTIC at the Université Savoie Mont Blanc are currently carrying out a study of digital transformation initiatives in the manufacturing industry. The research involves a series of case studies of French manufacturing companies with the overall aim to develop understanding of how companies experience the journey towards Digital Transformation in their particular business and manufacturing contexts.

PLEASE NOTE that all answers will be treated with full confidentiality. All data collected in this research will remain at Université Savoie Mont Blanc and will not be disseminated in such a manner that it identifies participating companies.

The questionnaire is divided in five sections:

- **SECTION I** - Demographics and Business Info
- **SECTION II** - Enterprise Context
- **SECTION III** - Digital Transformation Initiatives
- **SECTION IV** - Digital Strategy
- **SECTION V** - Digital Transformation Process
- **SECTION VI** - Performance Measurement and Management Systems
- **SECTION VII** - Final Comments

If you wish to receive an analysis of the results and/or more information regarding this research work, please contact Melissa LIBORIO ZAPATA at the following email: melissa.liborio-zapata@univ-smb.fr

THANK YOU VERY MUCH FOR YOUR COOPERATION!

Digital Transformation of Manufacturing Companies

Interview Guideline

Digital Transformation (DT) is the profound and accelerating transformation of business activities, processes, competencies, and models to fully leverage the changes and opportunities brought by digital technologies and their impact across society in a strategic and prioritized way.

In this context, this interview will be focused on identifying patterns of digital transformation followed by different types of manufacturing companies via the digitalization of their manufacturing process, products and/or services.

SECTION I - DEMOGRAPHICS & BUSINESS INFO

The demographics and general information of the business is the data collected to build a profile for the organization.

Main Topics:

- Interviewee's Profile
- Enterprise's Profile
- Brief business description (History, products, customers, suppliers)

Section II - ENTERPRISE CONTEXT

The context of an enterprise is the combination of internal and external factors and conditions that can have an effect on an organization's approach to its products, services and investments and interested parties.

Main Topics:

- Key external factors in the ecosystem of the company, especially those accelerating its transformation.
- Key factors in the internal context of the company and their evolution during the transformation:
  - Availability of resources, adoption of new technologies, R&D investment, process & standards consideration, organization culture and leadership flexibility, alliances with universities/research institutions
- Management of the enterprise context and its effect (positive or negative) on the transformation and innovation projects

Section III - DIGITAL TRANSFORMATION INITIATIVES

The Digital Transformation projects involve the business transformation enabled by digitalization, a term that refers to enabling or improving processes (i.e., manufacturing) or product offerings by leveraging digital technologies and digitized data.

[This section will guide the rest of the interview, as the objective of the study is to identify the stages and the changes involved in the road towards the digitalization of the company's manufacturing process, its products and/or services.]

Main Topics:

- DT initiatives in which the company has invested: smart manufacturing/smart products/ smart services
- Degree of digitalization achieved in each of the DT initiatives and the roadmap to get there
- General description of each project, their time frame, status and main motivation

Section IV - STRATEGY

Strategy is the definition of a “unique and valuable position” for an enterprise. Strategy develops a link of the ends or objectives of the business actions and the means or resources to get there.

- **Key elements**: business objectives, business model, resources

Main Topics:

- DT positioning inside the Company’s Strategy
- Decision-making process regarding the initiatives and level of sponsorship of senior executives
- Extent of knowledge of the DT initiatives of the average employee
- Business objectives pursued by the DT
- Business models evolution and innovation as a result of the DT
- Resources assigned to the DT initiatives

Section V - DIGITAL TRANSFORMATION PROCESS

The digital transformation process refers to the process of change that undergoes the different dimensions of the company to take advantage of the introduction of the digital technologies to achieve a business objective.

[This section is the heart of the interview; the focus will be in identifying the changes in the main aspects of the business (business dimensions) brought by the DT and how the management of these aspects contributes to the success of the initiatives.]

- **Key elements**: technology, process, organizational structure, organizational culture, employee competencies

Main Topics:

- General description of the planning and implementation processes used for the DT initiatives and its effectivity
- Customers and suppliers’ involvement in the efforts
- Main tools or methodologies used during the implementation
- Main challenges of the implementation
- Planning and management of changes in the *business dimensions* of the company as a result of the DT initiatives:
  - Details of the new (digital) **technologies** introduced and the changes in the infrastructure of the company
  - Details of the evolution of the **process** map of the company
  - Details of the evolution of the **organizational structure** of the company
  - Details of the new **competencies** introduced in the company
  - Details of the evolution of the **organizational culture** of the company
- Tools and methodologies used in the design and implementation of the changes
- Level of the importance of the changes for the DT success and individual contribution

Section VI - PERFORMANCE MEASUREMENT & MANAGEMENT SYSTEM

A performance measurement and management system is a balanced and dynamic system that facilitates support of decision-making processes by congregating, elaborating and analyzing relevant information.

- **Key elements**: References, Assessments, KPIs

Main Topics:

- Assessments or evaluations used for establishing a degree of readiness before starting a digital transformation
- Frameworks, models or guides used for planning and/or implementing the DT initiatives
- Use of business consulting companies or experts to guide the DT initiatives
- Main KPIs used to manage and control the DT initiatives
- Evolution of the company’s KPIs as a result of the DT
- KPIs defined to identify the results obtained from the DT

Section VII - FINAL COMMENTS

Last subject to get the final impressions of the Digital Transformation experience from the enterprise.

Main Topics:

- Lessons learned regarding the DT of the company
- Critical topics related to the DT that were not addressed in the interview

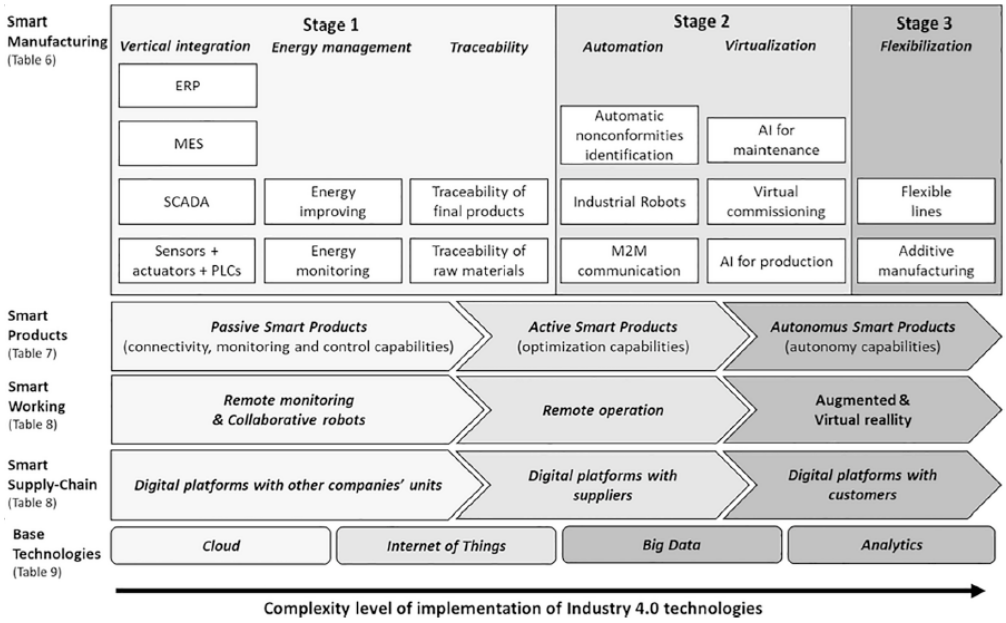
Thank you for your help!

We greatly appreciate your time and effort. Please once again note that your answers will be treated with full confidentiality. You will receive a report with the project results as soon as it is available.

Appendix

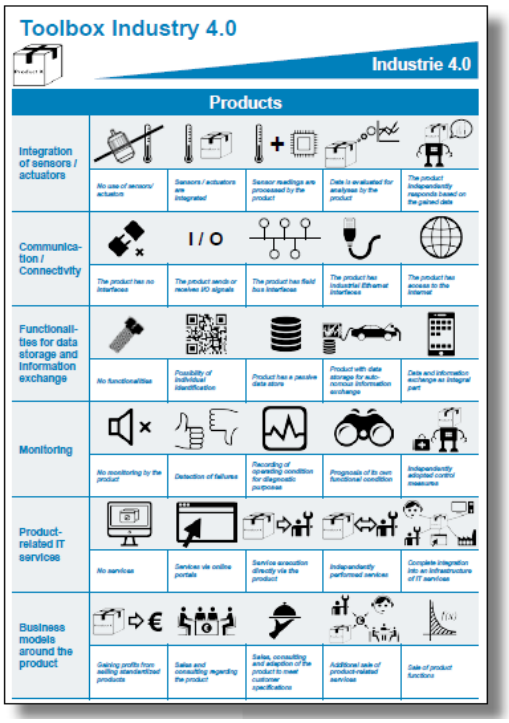
Appendix 1 – Type of DT Initiatives & their Stages

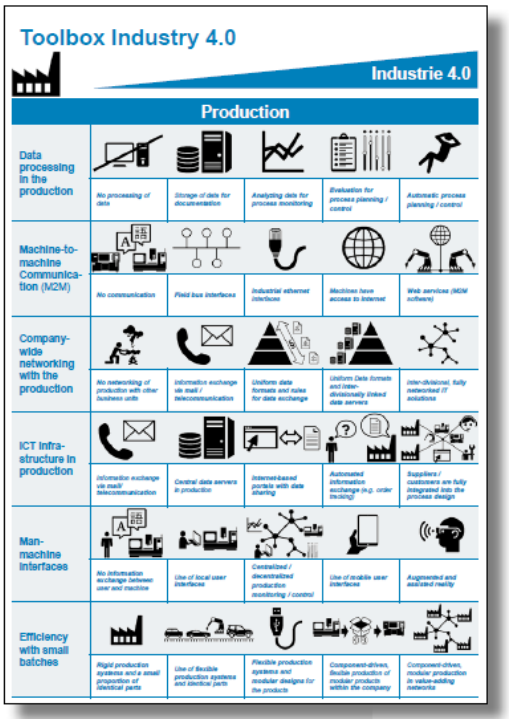
The figure proposes a classification of different initiatives for Digital Transformation and some of the technologies used by different stages of development. The chart will guide the classification of the DT initiatives in the enterprise and their current state of development.



Appendix 2 – Levels of Digitalization

Both figures show different levels of digitalization of products and the production process by a number of related criteria. These charts will help to detail the level of digitalization of the company's DT initiatives.





Appendix 3 – Technologies associated with a DT

This comprehensive list of technologies related to DT will be used to explore the analysis of this business dimension. Not only which technologies have been used in the DT initiatives of the enterprise, but also how do they keep up with technology evolution and the decision-making process of their technological choices.

Digital Technologies			
	Intelligent		Modeling
	Intelligent control		Geographic Information Science (GIS)
	Energy saving/efficiency		Simulation
	Cyber security		Forecasting
	Holograms		Enterprise Resource Planning (ERP)
	Virtual Reality (VR)		Radio-Frequency IDentification (RFID)
	Augmented Reality (AR)		Machine learning
	Real-time communication/data		Supply Chain Management (SCM)
	Big data		Manufacturing Execution System (MES)
	Cyber-physical infrastructure		Product Lifecycle Management (PLM)
	CPS/CPPS		Smart Materials
	IoT/IoS/IIoT		Interface (SCOR, DCOR, MESA, ISA 95/88)
	Advanced manufacturing		CAM, CAD, CAx
	Cloud computing/cloud manufacturing		Operations planning
	3D printing/additive manufacturing		IT-based production management
	Smart sensors		Tracking and tracing
	Smart product/part		Knowledge decision making techniques
	Data analytics/big data analytics		Statistical Process Control (SPC)
	Predictive analytics		
	Data visualization		

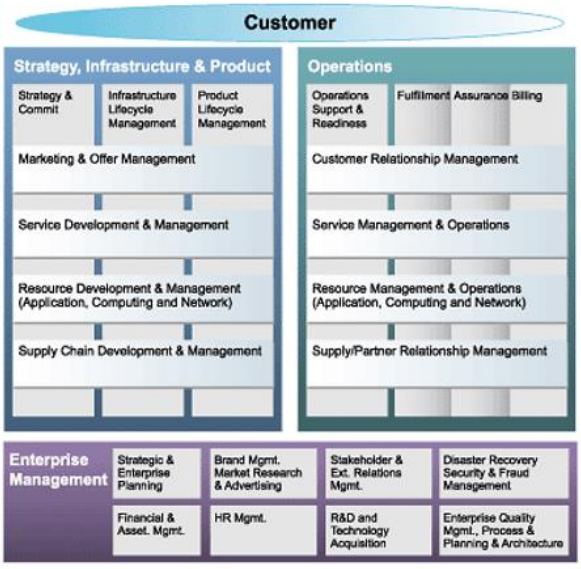
Appendix 4 – Processes

These two recognized process frameworks will guide our discovery of how the process map of the enterprise has changed with the DT initiatives. Processes added for dealing with the changes brought by the DT and also for keeping up with the constant change of the digital era.

APQC Model



eTOM Model



Appendix 5 – Organizational Structure

The list of the standard attributes of an organizational structure will guide the characterization of the enterprise organizational structure and how it had to evolve to cope with the changes brought by the DT. Additionally, changes in the structure such as new or redesigned organizational areas or positions/roles also will be explored.

Characteristic	Brief Description
Structure Formalization	The degree in which the organizational structure is manifested in organizational chart.
Work specialization	The degree to which tasks in an organization are subdivided into separate jobs.
Departmentalization	The basis by which jobs in an organization are grouped together.
Chain of command	The unbroken line of authority that extends from the top of the organization to the lowest echelon and clarifies who reports to whom.
Span of control	The number of subordinates a manager can efficiently and effectively direct.
Decision Making System	The degree to which decision making is concentrated at a single or multiple points in an organization.
Rules and Regulations	The degree to which jobs within an organization are standardized and there are rules and regulations to direct employees and managers
Boundary spanning	When individuals form relationships outside their formally assigned groups.

Appendix 6 – Competencies

This compilation of competencies associated with the digital context will be the reference to discuss the ones that has been introduced during the DT, but also the ones needed during the implementation and the ones needed for keeping up with the technological evolution.

Big Eight	Competency Dimensions	Competencies		
		Information Systems (IS)	Computer Science	Engineering
Leading & Deciding	Deciding and Initiating Action	□ Decision Making □ Taking Responsibility		
	Leading and Supervising	□ Leadership Skills		
Supporting and Cooperating	Working with People	□ Teamwork □ Collaborating with Others □ Communicating with People		
	Adhering to Principles and Values	□ Respecting Ethics □ Environmental Awareness □ Awareness for Ergonomics		
Interacting and Presenting	Relating and Networking	□ Compromising □ Creating Business Networks □ Maintaining Customer Relationships		
	Persuading and Influencing	□ Negotiating □ Emotional Intelligence		
	Presenting and Communicating Information	□ Presentation and Communication Ability		
Analyzing and Interpreting	Writing and Reporting	□ Targeted/Technical Communication □ Literacy		
	Applying Expertise and Technology	□ IT and Technology Affinity □ Economics □ Extract Business Value from Social Media		
		□ Service Orientation/ Product Service Offerings □ Business Process Management □ Business Change Management □ Understand and Coordinate Workflows	□ Network Security □ IT Architectures □ Machine Learning	
			□ System Development □ Integrating Heterogeneous Technologies □ Mobile Technologies □ Sensors/Embedded Systems □ Network Technology /M2M Communication □ Robotics/Artificial Intelligence □ Predictive Maintenance	
		□ Modelling and Programming □ Big Data/Data Analysis and Interpretation □ Cloud Computing /Architectures □ In-Memory DBs □ Statistics □ Data Security		
	Analyzing	□ Problem Solving □ Optimization □ Analytical Skills □ Cognitive Ability		
Creating and Conceptualizing	Learning and Researching	□ Life-long Learning □ Knowledge Management		
	Creating and Innovating	□ Innovating □ Creativity □ Critical Thinking □ Change Management		
	Formulating Strategies and Concepts	□ Business Strategy □ Abstraction Ability □ Managing Complexity		
Organizing and Executing	Planning and Organizing	□ Project Management □ Planning and Organizing Work □ Management Ability		
	Delivering Results and Meeting Customer Expectations	□ Customer Orientation □ Customer Relationship Management		
	Following Instructions and Procedures	□ Legislation Awareness □ Safety Awareness □ Individual Responsibility		
Adapting and Coping	Adapting and Responding to Change	□ Work in Interdisciplinary Environments □ Intercultural Competency □ Flexibility □ Adaptability and Ability to Change Mind-set		
	Persuading and Influencing	□ Work-Life Balance		
Enterprising and Performing	Achieving Personal Work Goals and Objectives	□ Self-management and -organization		
	Entrepreneurial and Commercial Thinking	□ Business Model Understanding □ Entrepreneurship		

Appendix 7 – Organizational Culture

The list of the cultural traits will guide the characterization of the enterprise organizational culture and how its characteristics or its evolution help dealing with the changes brought by the DT.

Cultural Trait	Brief Description
Innovation	The degree to which employees are encouraged to be innovative.
Risk Taking	The degree to which employees are encouraged to take risks.
Attention to detail	The degree to which employees are expected to exhibit precision, analysis, and attention to detail.
Outcome orientation	The degree to which management focuses on results or outcomes rather than on the techniques and processes used to achieve them.
People orientation	The degree to which management decisions take into consideration the effect of outcomes on people within the organization.
Team orientation	The degree to which work activities are organized around teams rather than individuals.
Aggressiveness	The degree to which people are aggressive and competitive rather than easygoing.
Stability	The degree to which organizational activities emphasize maintaining the status quo in contrast to growth.
Change receptiveness	The degree to which employees are encouraged not only to embrace constant change but to shape it.
Communication & collaboration	The degree to which employees are encourage to communicate and collaborate.
Trust in Processes & Information Systems	The degree to which employees trust the company's processes and information systems.
Experimentation with new technology & processes	The degree to which employees are encourage to experiment with new technology and learn new ways of operating
Learning from mistakes	The degree to which employees are expected to recognize the value of mistakes as a learning opportunity.
Continuous learning	The degree to which employees are encourage to keep learning throughout their lives.
Knowledge sharing	The degree to which employees are encourage to share their knowledge and the communication between the people who possess the knowledge and the people seeking it.
Agility embracement	The degree to which employees are understand the importance of agility.
Data-based learning and decision-making	The degree to which employees use information and base their learning and decision-making in actual data instead of their gut feeling.
Leadership style	The degree to which the company leadership adopt a more flexible approach to decision-making and give people more leeway towards faster decisions.

Appendix 4.3

Companies' Profile & Context document

LA TRANSFORMATION DIGITALE DES ENTREPRISES MANUFACTURIÈRES

Projet de recherche

Etude de Cas

Profil et Contexte de l'Entreprise

(Information préliminaire)

[Company Logo]

Université Savoie Mont Blanc

Melissa LIBORIO ZAPATA

Etude de Cas

Profil et Contexte de l'Entreprise

[Company Logo]

Dans le cadre de l'étude sur les initiatives de transformation digitale dans l'industrie manufacturière qui mènent actuellement les laboratoires SYMME et LISTIC de l'USMB, ce document présent information préliminaire du profil et contexte de l'entreprise **[**Name of the Company**]**.

En préparation de la réunion déjà fixée avec l'entreprise, nous proposons ce travail à l'avance dans le but de rendre le processus d'entretien plus efficace.

Le document couvre l'information concernant les sections suivantes du questionnaire proposé pour l'entretien :

- SECTION I – Profil de l'entreprise
- SECTION II - Contexte de l'entreprise

Ce document est basé sur des informations provenant d'articles ou d'interviews de membres de la société, nous le confirmerons avec vous lors de la réunion.

SECTION I – Profil de l'Entreprise

[Company Logo]

Les données et les informations générales de l'entreprise sont les données recueillies pour établir un profil de l'organisation. Dans cette première section, nous présentons l'information qui cherche à construire une vision globale de ses principales caractéristiques et des membres qui participeront à l'entretien.

Nom de l'interviewé :

- Poste dans l'organisation ou niveau de responsabilité :
- Ancienneté dans le poste :

* Information sur LinkedIn

Nom de la société :

Divisions :

Année d'établissement :

Taille :

Industrie :

Secteur d'activité :

Adresse du siège de la société :

Sites d'entreprise :

Taille de la main-d'œuvre :

Chiffre d'affaires :

Part du CA à l'export :

Investissement en R&D :

Investissement en RH :

Brève description de l'entreprise (Historique, produits, clients, fournisseurs)

Produits :

Marchés :

Clients :

Clients principaux :

Fournisseurs :

Fournisseurs principaux :

SECTION II – Contexte de l'Entreprise

[Company Logo]

Le contexte d'une entreprise est la combinaison de facteurs et de conditions internes et externes qui peuvent avoir un effet sur l'approche d'une organisation à l'égard de ses produits, services et investissements. Dans cette section, nous présentons notre interprétation de la qualification des différents éléments du contexte interne de l'entreprise sur la base des informations disponibles sur différents médias. L'intention est de faire une révision et d'affiner cette analyse lors de la rencontre avec les personnes de l'entreprise qui participeront à l'entretien.

Accès aux ressources pour la transformation et l'innovation : Bas vs Haut

« company information in the media that back the selection »

~~Article~~ : Source

Adoption de nouvelles technologies : Bas vs Haut

« company information in the media that back the selection »

~~Article~~ : Source

Investissement en R&D : Bas vs Haut ← ?

« company information in the media that back the selection »

~~Article~~ : Source

Capacité de Personnalisation des produits : Bas vs Haut ← ?

« company information in the media that back the selection »

~~Article~~ : Source

Considération des processus et des normes : Bas vs Haut

« company information in the media that back the selection »

~~Article~~ : Source

Flexibilité de la culture organisationnelle et du leadership : Bas vs Haut

« company information in the media that back the selection »

~~Article~~ : Source

Définition de la stratégie : Dicté par l'instinct de dirigeant (propriétaire) vs Basé sur des études de marché et des analyses précises

« company information in the media that back the selection »

~~Article~~ : Source

SECTION I – Profil de l'Entreprise

[Company Logo]

Les données et les informations générales de l'entreprise sont les données recueillies pour établir un profil de l'organisation. Dans cette première section, nous présentons l'information qui cherche à construire une vision globale de ses principales caractéristiques et des membres qui participeront à l'entretien.

Nom de l'interviewé :

- Poste dans l'organisation ou niveau de responsabilité :
- Ancienneté dans le poste :

* Information sur LinkedIn

Nom de la société :

Divisions :

Année d'établissement :

Taille :

Industrie :

Secteur d'activité :

Adresse du siège de la société :

Sites d'entreprise :

Taille de la main-d'œuvre :

Chiffre d'affaires :

Part du CA à l'export :

Investissement en R&D :

Investissement en RH :

Brève description de l'entreprise (Historique, produits, clients, fournisseurs)

Produits :

Marchés :

Clients :

Clients principaux :

Fournisseurs :

Fournisseurs principaux :

SECTION II – Contexte de l'Entreprise

[Company Logo]

Le contexte d'une entreprise est la combinaison de facteurs et de conditions internes et externes qui peuvent avoir un effet sur l'approche d'une organisation à l'égard de ses produits, services et investissements. Dans cette section, nous présentons notre interprétation de la qualification des différents éléments du contexte interne de l'entreprise sur la base des informations disponibles sur différents médias. L'intention est de faire une révision et d'affiner cette analyse lors de la rencontre avec les personnes de l'entreprise qui participeront à l'entretien.

Accès aux ressources pour la transformation et l'innovation : Bas vs Haut

« company information in the media that back the selection »

Article ; Source

Adoption de nouvelles technologies : Bas vs Haut

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Article ; Source

Investissement en R&D : Bas vs Haut

« company information in the media that back the selection »

Article ; Source

Capacité de Personnalisation des produits : Bas vs Haut

« company information in the media that back the selection »

Article ; Source

Considération des processus et des normes : Bas vs Haut

« company information in the media that back the selection »

Article ; Source

Flexibilité de la culture organisationnelle et du leadership : Bas vs Haut

« company information in the media that back the selection »

Article ; Source

Définition de la stratégie : Dicté par l'instinct de dirigeant (propriétaire) vs Basé sur des études de marché et des analyses précises

« company information in the media that back the selection »

Article ; Source

Prise de décision : Limitée au dirigeant vs Conseil d'administration

« company information in the media that back the selection »

Article, Source

Structure organisationnelle : Moins complexe et informelle vs Complexe et formelle

« company information in the media that back the selection »

Article, Source

Engagement des ressources humaines : Plusieurs domaines vs Domaines spécifiques

« company information in the media that back the selection »

Article, Source

Exposition au développement des ressources humaines : Haut dans l'industrie / bas en dehors de l'industrie vs Bas dans l'industrie / Haut en dehors de l'industrie

« company information in the media that back the selection »

Article, Source

Connaissances et expérience dans l'industrie : Focalisé dans un domaine spécifique vs Dispersé dans différents domaines

« company information in the media that back the selection »

Article, Source

Alliances avec les universités/institutions de recherche : Bas vs Haut

« company information in the media that back the selection »

Article, Source

Réalisation des activités clés : Dans l'entreprise vs Sous-traitance

« company information in the media that back the selection »

Article, Source

Dépendance à l'égard du réseau de collaboration : Bas vs Haut

« company information in the media that back the selection »

Article, Source

Relations clients/fournisseurs : Faible vs Forte

« company information in the media that back the selection »

Article, Source/

Appendix 4.4

Company’s DT document

LA TRANSFORMATION DIGITALE DES ENTREPRISES MANUFACTURIÈRES

Projet de recherche

Etude de Cas

Transformation Digitale de l'Entreprise

(Information collecté dans le cadre de l'interview)

[Company Logo]

Université Savoie Mont Blanc

Melissa LIBORIO ZAPATA

Etude de Cas

Transformation Digitale de l'Entreprise

[Company Logo]

Dans le cadre de l'étude sur les initiatives de transformation digitale dans l'industrie manufacturière que mènent actuellement les laboratoires SYMME et LISTIC de l'USMB, ce document présente l'information recueillie dans le cas de l'entreprise **[**Name of the Company**]**.

En préparation de la **seconde réunion** avec l'entreprise, nous proposons ce travail à l'avance dans le but de rendre le processus d'entretien plus efficace.

Le document couvre l'information concernant les sections suivantes du questionnaire proposé pour l'entretien :

- SECTION I - Profil de l'entreprise
- SECTION II - Contexte de l'entreprise
- SECTION III - Initiatives de Transformation Digitale
- SECTION IV - Stratégie Digitale
- SECTION V - Processus de Transformation Digitale
- SECTION VI - Système de Mesure et de Gestion des Performances
- SECTION VII - Commentaires Finaux

Le contenu de ce document est fondé sur des informations collectées lors des **interviews réalisées le [**date**]** et est complété par des informations provenant d'articles de presse ou du site web de l'entreprise. L'objectif est d'en faire la revue et de le compléter (si nécessaire) avant la deuxième réunion avec le personnel de l'entreprise, qui reste à fixer.

Confidentialité de la thèse :

La thèse étant un travail en cours, nous vous demandons également la confidentialité des détails du modèle présenté.

SECTION I – Profil de l'Entreprise

[Name of the Company]

Les données et les informations générales de l'entreprise sont les données recueillies pour établir un profil de l'organisation. Dans cette première section, nous présentons l'information qui cherche à construire une vision globale de ses principales caractéristiques et des membres qui participeront à l'entretien.

Nom de l'interviewé :

- Poste dans l'organisation ou niveau de responsabilité :
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* Information sur LinkedIn

Nom de la société :

Divisions :

Année d'établissement :

Taille :

Industrie :

Secteur d'activité :

Adresse du siège de la société :

Sites d'entreprise :

Taille de la main-d'œuvre :

Chiffre d'affaires :

Part du CA à l'export :

Investissement en R&D :

Investissement en RH :

Brève description de l'entreprise (Historique, produits, clients, fournisseurs)

Produits :

Marchés :

Type de Clients :

Clients principaux :

Type de Fournisseurs :

Fournisseurs principaux :

SECTION II – Contexte de l'Entreprise

[Name of the Company]

Le contexte d'une entreprise se définit par l'identification d'un ensemble de facteurs et de conditions internes et externes qui peuvent avoir un effet sur l'approche d'une organisation à l'égard de ses produits, services et investissements.

Dans cette section, vous trouverez les informations suivantes à valider ou à compléter, si nécessaire :

1. La qualification des différents éléments du **contexte externe** de l'entreprise.
2. La qualification des différents éléments du **contexte interne** de l'entreprise.

1. Contexte Externe

Les éléments de l'écosystème de l'entreprise exercent des influences et génèrent des incertitudes uniques lors d'un TD. Ces facteurs évoluent au fil du temps en réponse à un monde en mutation, et ces changements affectent l'entreprise, de manière positive ou négative.

➔ Veuillez vérifier, corriger et compléter si nécessaire dans le cadre des « Commentaires ».

Facteur Externe	Les catalyseurs de la Transformation	Commentaires de l'entreprise
Politique		
Réglementation		
Économie		
Marché		
Technologie		
Ressources		
Environnement		

2. Contexte Interne

Cette version du contexte interne inclut les informations recueillies lors du premier entretien. Cependant, après la première série d'entretiens, nous avons identifié différents scénarios qui n'étaient pas couverts par une échelle binaire, nous avons donc reformulé le tableau du contexte, disponible pour votre révision dans la feuille « Contexte » du fichier Excel « Résultats Individuels ».

MESSAGES IMPORTANTS :

- Dans la nouvelle version, vous trouverez les mêmes critères pour qualifier « AVANT » et « APRÈS » la TD avec une échelle de 5 niveaux, au lieu de l'échelle originale à 2 niveaux, pour améliorer la précision des réponses.
- Vous trouverez que le scénario « APRÈS » est déjà rempli avec les informations de l'entretien, mais il est nécessaire de valider les réponses et de les ajuster à la nouvelle échelle de 5 niveaux.

- Comme l'entreprise transforme ses produits et processus depuis longtemps, l'intérêt des scénarios « AVANT » et « APRÈS » est d'identifier les changements qui se sont produits pendant cette période.

➔ Veuillez vérifier et compléter si nécessaire dans le fichier Excel « Résultats Individuels ».

Caractéristique	→	
Accès aux ressources pour la transformation et l'innovation :	Bas	Haut
Adoption de nouvelles technologies :	Bas	Haut
Investissement en R&D :	Bas	Haut
Capacité de Personnalisation des produits :	Bas	Haut
Considération des processus et des normes :	Bas	Haut
Flexibilité de la culture organisationnelle et du leadership :	Bas	Haut
Définition de la stratégie	Dicté par l'instinct de dirigeant (propriétaire)	Basé sur des études de marché et des analyses précises
Prise de décision	Limitée au dirigeant	Conseil d'administration

Caractéristique	→	
Structure organisationnelle	Moins complexe et informelle	Complexe et formelle
Engagement des ressources humaines	Plusieurs domaines	Domaines spécifiques
Exposition au développement des ressources humaines	Haut dans l'industrie / bas en dehors de l'industrie	Bas dans l'industrie / Haut en dehors de l'industrie
Connaissances et expérience dans l'industrie	Focalisé dans un domaine spécifique	Dispersé dans différents domaines
Alliances avec les universités/institutions de recherche	Bas	Haut
Réalisation des activités clés	Dans l'entreprise	Sous-traitance
Dépendance à l'égard du réseau de collaboration	Bas	Haut
Relations clients/fournisseurs	Faible	Forte

SECTION III - Initiatives de Transformation Digitale

[Name of the Company]

Les projets de transformation digitale impliquent la transformation de l'entreprise rendue possible par la digitalisation, un terme qui fait référence à l'activation ou à l'amélioration des processus (c'est-à-dire la fabrication) ou des offres de produits en tirant parti des technologies digitales et des données numérisées.

Dans cette section, vous trouverez les informations suivantes à valider ou à compléter, si nécessaire :

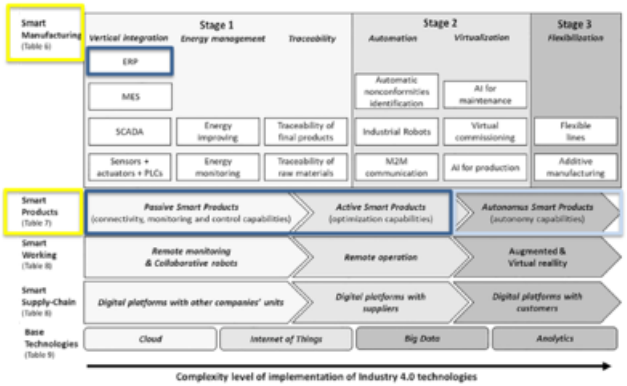
1. Initiatives de TD mises en œuvre ou prévues par l'entreprise
2. Niveaux de digitalisation dans ses initiatives "Smart Manufacturing" et "Smart Products".

1. Type d'initiatives de TD et leurs étapes

La figure propose une classification des différentes initiatives de transformation digitale et de certaines technologies utilisées à différents stades de développement. Le tableau guidera la classification des initiatives de TD dans l'entreprise et leur état de développement actuel.

L'entreprise se concentre sur son initiative de digitalisation des produits. En fait, l'entreprise a déjà géré son activité principale, qu'elle consolide actuellement, mais elle ne poursuit pas la fabrication intelligente au-delà de la mise en œuvre d'éléments tels que l'ERP, nécessaire à la traçabilité des produits, requise par les clients dans des domaines tels que le médical. Maintenant, il y a des possibilités de poursuivre la possibilité d'une usine intelligente pour moderniser ses installations de production en utilisant l'aide gouvernementale au secteur de l'aéronautique, mais il n'y a pas de plan pour le faire actuellement.

➔ Veuillez vérifier et corriger si nécessaire.



Code de couleur :
Jaune - Initiatives en cours ; Bleu foncé – technologies déployées ; Bleu clair – technologies déployées localement o en considération.

IMPORTANT : Dans cette validation, il est important de considérer que ces éléments doivent exister sous une forme automatisée. Par exemple, la "Traçabilité des produits" ne doit être marquée ici que si elle est rendue possible par le suivi de capteurs dans les produits.

[Veuillez enregistrer vos commentaires ici ou dans le texte d'une autre couleur]

2. Niveaux de digitalisation

Les figures suivantes montrent différents niveaux de digitalisation du processus de production et des produits selon un certain nombre de critères connexes. Ces graphiques permettront de détailler le niveau de digitalisation des initiatives de TD de l'entreprise. Où se situe l'entreprise en fonction de ces critères ?

La sélection suivante a été effectuée sur la base des informations recueillies lors de l'interview ou de l'information disponible sur le site de l'entreprise. Pour les cas où des niveaux différents sont atteints par des usines ou des produits différents, seul *le niveau maximum est sélectionné*.

➔ Veuillez vérifier et corriger si nécessaire.

Smart Manufacturing

Le point de départ des réflexions est la question de savoir comment les processus de production ont été optimisés et comment les coûts de production ont été réduits grâce à la digitalisation.

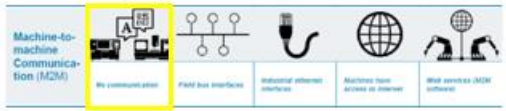
Traitement des données en production (Data processing in production)

Le traitement des données pour diverses applications est une question essentielle pour les applications de l'industrie 4.0 dans la production. Le traitement des données dans la production peut être utilisé pour une simple documentation ainsi que pour des objectifs visant la surveillance des processus, la planification et le contrôle autonomes des processus.



Communication de machine à machine (Machine-to-machine communication)

Les interfaces pour l'échange automatisé de données entre machines constituent la base de nombreuses applications de l'industrie 4.0. Les interfaces de bus de terrain ainsi que les interfaces Ethernet et web industrielles sont appliquées dans l'environnement industriel. Les interfaces web et les applications avec échange d'informations autonome (services web) offrent l'avantage d'une séparation possible des informations et de la localisation.



Mise en réseau de l'entreprise avec la production (Company-wide networking with the production)

Une amélioration de la mise en réseau entre la production et les autres niveaux de l'entreprise permet de créer des synergies et d'éviter les tâches redondantes. La mise en réseau entre la production et les autres départements facilite les solutions informatiques unifiées, les flux de travail standardisés ou les formats de fichiers utilisés de manière homogène, dont toute l'entreprise profite.



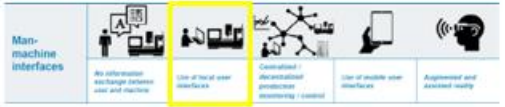
Infrastructure des technologies de l'information et des télécommunications dans la production (Infrastructure of information and telecommunication technologies in production)

L'infrastructure des technologies de l'information et des télécommunications dans la production détermine les possibilités de mise en œuvre d'applications innovantes et les améliorations potentielles des processus techniques et organisationnels. Outre l'utilisation de serveurs de données centraux, des portails de communication basés sur le web peuvent être utilisés. Les processus automatisés d'échange de données avec des partenaires externes de la chaîne de valeur ou plutôt du réseau de valeur représentent des étapes ultérieures vers une vision Industrie 4.0.



Interfaces homme-machine (Human-machine interfaces)

Compte tenu de la complexité croissante des systèmes de production, les interfaces homme-machine font l'objet d'une attention particulière. Dans la réalité industrielle, le point de départ est souvent représenté par des unités d'affichage locales qui ne disposent pas de concepts d'utilisation pratiques. De nouveaux concepts d'utilisation, tels que les tablettes mobiles ou les lunettes de données, qui fournissent de manière pratique les bonnes informations au bon endroit, sont potentiellement prometteurs pour simplifier le travail des employés et augmenter l'efficacité de la production.



Efficacité pour les petits lots (Efficiency for small batches)

La tendance à la production de biens individuels et de lots de plus en plus petits entraîne une complexité croissante des processus de production. Atteindre une plus grande efficacité avec des lots de petite taille devient donc un facteur concurrentiel décisif. À cet égard, une structure modulaire des produits concernés ou l'utilisation d'installations de production flexibles avec une coordination appropriée dans la chaîne de valeur respective peut offrir de nouveaux potentiels.



[Veuillez enregistrer vos commentaires ici ou dans le texte d'une autre couleur]

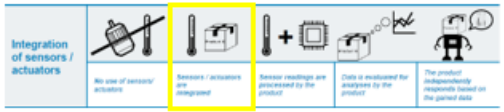
Smart Products

La question clé est la suivante : dans quelle mesure de nouveaux produits ont-ils été développés ou des produits existants ont-ils été perfectionnés grâce à la numérisation ? Comment cela a-t-il créé une valeur ajoutée pour les clients potentiels ?

Produit évalué :

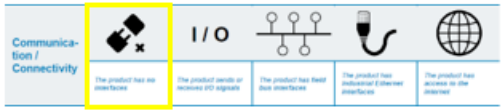
Intégration de capteurs et d'actionneurs (Integration of sensors and actuators)

L'intégration de capteurs et d'actionneurs ainsi que de capacités de calcul dans des objets physiques est une idée centrale de l'Industrie 4.0 ou des systèmes cyber-physiques. Le spectre comprend aussi bien des produits sans aucune fonction de capteur ou d'actionneur que des produits avec leur propre évaluation des données de capteur et des réponses autonomes basées sur cette évaluation.



Communication et connectivité (Communication and connectivity)

Des interfaces de communication appropriées permettent de nouvelles applications qui peuvent être physiquement découplées et qui bénéficient d'une meilleure disponibilité des données collectées. Sur la voie de la réalisation de la vision d'un réseau entièrement basé sur le web au sens de l'"Internet des objets", des étapes intermédiaires peuvent être observées dans les systèmes de bus de terrain ou d'Ethernet industriel.



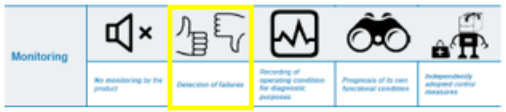
Fonctionnalités pour le stockage des données et l'échange d'informations (Functionalities for data storage and information exchange)

Les produits peuvent se différencier par des fonctions de stockage de données et d'échange d'informations conçues différemment. Le spectre comprend les simples codes-barres et les dispositifs de stockage de données réinscriptibles, ainsi que la présentation et l'échange d'informations en tant que composant intégral du produit.



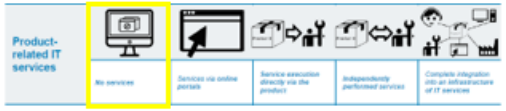
Surveillance (Monitoring)

Le vaste champ d'application de la surveillance représente un aspect essentiel de nombreuses applications de l'Industrie 4.0. Le spectre des applications possibles va de la simple détection des défaillances et du diagnostic et du pronostic de sa propre capacité opérationnelle jusqu'aux possibilités de contrôle autonome, qui pourraient éviter des dommages consécutifs coûteux en cas de défaillance.



Services informatiques liés aux produits (Product-related IT services)

Les services informatiques liés aux produits, souvent évoqués dans le contexte de l'Industrie 4.0, peuvent être physiquement découplés du produit (par exemple dans des portails en ligne pour présenter des listes de pièces détachées) ou être directement liés au produit. On peut imaginer des services de maintenance basés sur l'état ou d'assistance produit avec des fonctions de diagnostic à distance.



Modèles d'affaires autour du produit (Business models around the product)

Les technologies innovantes permettent le développement de nouveaux modèles d'affaires. Une plus grande adaptation des produits aux besoins des clients peut être soutenue par l'utilisation d'approches de l'Industrie 4.0, par exemple, en combinaison avec une production flexible. Même la vente de fonctions de produits où le produit reste la propriété du fabricant et où seule la réalisation d'une fonction est rémunérée peut-être facilitée par les technologies de l'Industrie 4.0. Un enregistrement étendu des états de fonctionnement ou le contrôle d'une maintenance basée sur l'état par le fabricant peuvent être cités comme des exemples permettant une telle vente de fonctions.



[Veuillez enregistrer vos commentaires ici ou dans le texte d'une autre couleur]

SECTION IV - Stratégie Digitale

[Name of the Company]

La stratégie est la définition d'une "position unique et de valeur" pour une entreprise. La stratégie développe un lien entre les fins ou les objectifs des actions de l'entreprise et les moyens ou les ressources pour y parvenir.

Dans cette section, vous trouverez les informations liées à la stratégie numérique de l'entreprise.

L'entreprise considère que sa transformation a commencé avec la création de la filiale Pack'Aero Mécatronique, une entité dédiée à la mécatronique de pointe.

L'entreprise fabrique des composants qui sont enrichis et rendus plus mécatroniques, mais qui sont finalement intégrés dans des machines et des équipements dans lesquels la mécatronique trouve son sens dans le digital. Par conséquent, la stratégie commerciale consiste à cibler les clients commerciaux qui créent les produits dits numériques. Dans cette position stratégique pour eux, il est vital d'aller dans cet axe-là chez les clients avec une offre adaptée et la stratégie digitale suit cette direction.

Pas encore d'informations sur l'existence d'une stratégie numérique formellement documentée et de feuilles de route pour les projets de numérisation.

➔ Veuillez vérifier et corriger si nécessaire.

Elément	Information	Commentaires de l'entreprise
Objectives de la digitalisation		
Parrainage des cadres supérieurs de l'entreprise (sponsorship of leaders)		
Feuille de route (roadmaps)		
Modèle d'affaires (business models)		
Ressources		

SECTION V - Processus de Transformation Digitale

[Name of the Company]

Le processus de transformation digitale fait référence au processus de changement qui traverse les différentes dimensions de l'entreprise pour tirer profit de l'introduction des technologies digitales afin d'atteindre un objectif commercial.

Les dimensions commerciales impliquées dans une DT sont la technologie, les processus, la structure, les compétences et la culture.

Dans cette section, vous trouverez les informations suivantes à valider ou à compléter, si nécessaire :

1. Planification et gestion des changements dans les dimensions de l'entreprise suite aux initiatives de la TD
2. Documentation de l'état des dimensions de l'entreprise impliquées dans la TD.
3. Détail des changements dans chacune des dimensions de l'entreprise impliquées dans la TD.

➔ Veuillez vérifier et corriger si nécessaire.

1. Planification et gestion des changements dans les dimensions de l'entreprise suite aux initiatives de la TD

L'entreprise mène les activités suivantes pour planifier et gérer sa TD :

- **Communication**. Aucune information n'est encore recueillie sur le niveau de connaissance du projet par les employés de l'entreprise.
- **Processus d'implémentation**. L'entreprise se concentre sur la digitalisation des produits et les initiatives mises en œuvre sont encore en cours d'implémentation. Par conséquent, il n'a pas été identifié de processus de mise en œuvre concernant les changements impliqués dans toutes les dimensions de l'entreprise. À confirmer.

2. Documentation de l'état des dimensions de l'entreprise impliquées dans la TD

Le bilan de la documentation de l'état des dimensions de l'entreprise est le suivant :

Elément	Information	Commentaires de l'entreprise
Structure		
Technologie		
Processus		
Compétences		
Culture		

3. Détail des changements dans chacune des dimensions de l'entreprise impliquées dans la TD.

Le détail de l'information de chacune des dimensions est disponible pour votre révision dans le fichier Excel « Résultats Individuels ».

MESSAGES IMPORTANTS :

- Ce fichier contient les informations détaillées concernant les dimensions de l'entreprise affectées par la TD et le contexte organisationnel.
- Dans le but de standardiser les informations de tous les cas (entreprises), une liste de valeurs pour chaque dimension (technologie, processus, etc.) est proposée, divisée en deux scénarios « avant » et « après » la TD.
- Les données sont déjà remplies dans la plupart des dimensions pour le scénario « après » avec les informations recueillies lors du premier entretien, à l'exception d'une partie des feuilles de structure et de culture.
- Il est important de lire les instructions de chaque section du document avant de commencer.

Nous nous sommes efforcés de le rendre aussi simple que possible, afin qu'il soit facile à valider et à compléter, mais faites-nous savoir si nous pouvons l'améliorer.

➔ Veuillez vérifier et compléter si nécessaire dans le fichier Excel « Résultats Individuels ».

SECTION VI - Système de Mesure et de Gestion des Performances

[Name of the Company]

Un système de mesure et de gestion des performances est un système équilibré et dynamique qui facilite les processus décisionnels en rassemblant, en élaborant et en analysant les informations pertinentes.

Dans cette section, vous trouverez les informations suivantes à valider ou à compléter, si nécessaire :

1. Ressources utilisés pour guider la TD
2. Principaux indicateurs de performance clés (KPIs) utilisés pour gérer et contrôler les initiatives de TD et pour identifier les résultats obtenus

➔ Veuillez vérifier et corriger si nécessaire.

1. Ressources utilisés pour guider la TD

L'entreprise utilise les réseaux, comme Artema ou la rencontre d'entreprises dans des salons industriels, car il y en a certains qui sont très avancés dans des sujets liés à la TD, mais qui sont dans d'autres domaines comme le domaine agricole par exemple.

L'entreprise suit également l'évolution de la chaîne de production de certains de ses principaux clients, comme GE Medical Systems, même s'il ne s'agit pas du tout des mêmes machines. C'est important pour eux de voir les grandes tendances. Les grands groupes tirent sur les modèles de l'usine du futur, par exemple, et ils ont des moyens énormes, notamment humains, pour réfléchir.

[Veuillez enregistrer vos commentaires ici ou dans le texte d'une autre couleur]

2. Principaux indicateurs de performance clés (KPIs) utilisés pour gérer et contrôler les initiatives de TD et pour identifier les résultats obtenus

Ce sujet n'a pas été abordé pendant l'interview.

L'hypothèse est que si chaque changement est effectué en vue de l'augmentation des chiffre d'affaires, ce KPI est utilisé pour déterminer le succès des initiatives. → A confirmer

D'autre part, concernant l'identification des KPIs utilisés pour gérer et contrôler les projets liés à la numérisation, les mesures spécifiques sont encore à identifier. → A compléter

[Veuillez enregistrer vos commentaires ici ou dans le texte d'une autre couleur]

SECTION VII - Commentaires Finaux

[Name of the Company]

Derniers points pour obtenir les impressions finales de l'entreprise sur l'expérience de la transformation digitale.

Dans cette section, vous trouverez des informations sur les principaux défis que l'entreprise a identifiés pour mener sa transformation digitale.

➔ Veuillez vérifier et corriger si nécessaire.

Sujet	Principaux défis	Commentaires de l'entreprise
Technologie		
Besoins de Clients		
Compétences		
La survie		
Un autre ?		

Merci de votre aide !

Nous apprécions grandement votre temps et vos efforts. Veuillez noter une fois encore que vos réponses seront traitées en toute confidentialité. Vous recevrez un rapport détaillé à la fin de l'étude.

Melissa LIBORIO ZAPATA, doctorante a l'USMB

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Appendix 4.5

Digital Transformation Survey

LA TRANSFORMATION DIGITALE DES ENTREPRISES MANUFACTURIÈRES

Projet de recherche

Etude de Cas

Transformation Digitale de l'Entreprise

(Information collecté dans le cadre de l'interview)

[Company Logo]

Université Savoie Mont Blanc

Melissa LIBORIO ZAPATA

INSTRUCTIONS

Confidentialité de la thèse :

La thèse étant un travail en cours, nous vous demandons également la confidentialité des détails du modèle présenté.

MESSAGES IMPORTANTS :

· Ce fichier contient les informations détaillées concernant les dimensions de l'entreprise affectées par la TD et le contexte organisationnel.

· Dans le but de standardiser les informations de tous les cas (entreprises), une liste de valeurs pour chaque dimension (technologie, processus, etc.) est proposée, divisée en deux scénarios « avant » et « après » la TD.

· Les données sont déjà remplies dans la plupart des dimensions pour le scénario « après » avec les informations recueillies lors du premier entretien, à l'exception d'une partie des feuilles de structure et de culture.

· Il est important de lire les instructions de chaque section du document avant de commencer. Nous nous sommes efforcés de le rendre aussi simple que possible, afin qu'il soit facile à valider et à compléter, mais faites-nous savoir si nous pouvons l'améliorer.

Contexte de l'entreprise

Le contexte d'une entreprise est la combinaison de facteurs et de conditions internes et externes qui peuvent avoir un effet sur l'approche d'une organisation à l'égard de ses produits, services et investissements.

Après la première série de ces interviews, nous avons identifié différents scénarios qui n'étaient pas couverts par l'échelle binaire du tableau de contexte, nous l'avons donc redessiné. L'intention de cette nouvelle conception est de mesurer les opinions avec un plus haut degré de nuance.

Les résultats précédents sont affichés dans la section "APRES la digitalisation", en les considérant comme l'état actuel.

**Veuillez compléter les informations de la section "AVANT la digitalisation" et vérifier les informations de la section "APRÈS la digitalisation", merci de les corriger si nécessaire.

Caractéristique	Description	Niveau de developpement AVANT de commencer la digitalisation					Niveau de developpement APRES la digitalisation				
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 1	Level 2	Level 3	Level 4	Level 5
Accès aux ressources pour la transformation et l'innovation	L'entreprise dispose-t-elle du niveau de ressources adéquat pour la transformation numérique et l'innovation ?	Insuffisant ☐	☐	☐	☐	Suffisant ☐	Insuffisant ☐	☐	☐	☐	Suffisant ☐
Adoption de nouvelles technologies	Quel est le niveau de capacité de l'entreprise à intégrer les nouvelles technologies ?	Bas ☐	☐	☐	☐	Haut ☐	Bas ☐	☐	☐	☐	Haut ☐
Investissement en R&D	Quel est le niveau des ressources investies dans les activités de R&D ?	Bas (moins de 5% de CA) ☐	☐	☐	☐	Haut (plus de 20% de CA) ☐	Bas (5% ou moins de CA) ☐	☐	☐	☐	Haut (20% ou plus de CA) ☐
Capacité de Personnalisation des produits	Quel est le niveau de compétence de l'entreprise pour développer des produits hautement personnalisés ?	Bas ☐	☐	☐	☐	Haut ☐	Bas ☐	☐	☐	☐	Haut ☐
Considération des processus et des normes	Quel est le niveau de prise en compte par l'entreprise des processus, standards et normes ?	Bas ☐	☐	☐	☐	Haut ☐	Bas ☐	☐	☐	☐	Haut ☐

...

Technologies Digitales

Digital technologies are electronic tools, systems, devices and resources that generate, store or process data.

Dans cette liste exhaustive des technologies liées à la DT, nous présentons les technologies mises en œuvre par l'entreprise ou en projet de mise en œuvre dans le cadre de leurs initiatives de digitalisation, selon les informations recueillies lors du premier interview.

**Veuillez vérifier, correger ou compléter les informations si nécessaire.

Les informations ne doivent être remplies que pour les technologies concernées par le TD.

ID	Technologies Digitales	Status dans l'entreprise	Essentiel pour la digitalisation ?	Initiative de TD (utilisée dans quelle initiative?)			Commentaires des Chercheurs	Commentaires de l'Entreprise
				Smart Manufacturing	Smart Products	Data-Driven Services		
1	Intelligent		☐	☐	☐	☐		
2	Intelligent control		☐	☐	☐	☐		
3	Energy saving/efficiency		☐	☐	☐	☐		
4	Cyber security		☐	☐	☐	☐		
5	Holograms		☐	☐	☐	☐		
6	Virtual Reality (VR)		☐	☐	☐	☐		
7	Augmented Reality (AR)		☐	☐	☐	☐		
8	Real-time communication/data		☐	☐	☐	☐		
9	Big data		☐	☐	☐	☐		
10	Cyber-physical infrastructure		☐	☐	☐	☐		

Processus

A business process is a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer.

Dans cette liste exhaustive des processus, nous présentons les processus mises en œuvre par l'entreprise ou en projet de mise en œuvre dans le cadre de leurs initiatives de digitalisation, selon les informations recueillies lors du premier interview.

L'intention de cette section est de decouvrir la manière dont la structure des processus de l'entreprise a changé avec les initiatives de la TD. Processus ajoutés ou modifiés pour faire face aux changements apportés par la TD et aussi pour suivre l'évolution constante de l'ère digitale.

**Veuillez vérifier, correger ou compléter les informations si nécessaire.

Les informations ne doivent être remplies que pour les processus concernées par le TD.

Processus/Sub-Processus	Type de changement	Essentiel pour la digitalisation ?	Initiative de TD (utilisée dans quelle initiative?)			Commentaires des Chercheurs	Commentaires de l'Entreprise
			Smart Manufacturing	Smart Products	Data-Driven Services		
1.0 Develop Vision and Strategy		☐	☐	☐	☐		
1.1 Define the business concept and long-term vision		☐	☐	☐	☐		
1.2 Develop business strategy		☐	☐	☐	☐		
1.3 Execute and measure strategic initiatives		☐	☐	☐	☐		
1.4 Develop and maintain business models		☐	☐	☐	☐		
2.0 Develop and Manage Products and Services		☐	☐	☐	☐		
2.1 Govern and manage product/service development program		☐	☐	☐	☐		
2.2 Generate and define new product/service ideas		☐	☐	☐	☐		
2.3 Develop products and services		☐	☐	☐	☐		
3.0 Market and Sell Products and Services		☐	☐	☐	☐		
3.1 Understand markets, customers, and capabilities		☐	☐	☐	☐		
3.2 Develop marketing strategy		☐	☐	☐	☐		
3.3 Develop and manage marketing plans		☐	☐	☐	☐		
3.4 Develop sales strategy		☐	☐	☐	☐		
3.5 Develop and manage sales plans		☐	☐	☐	☐		

...

Structure Organisationnelle

An organizational structure defines how job tasks are formally divided, grouped, and coordinated.

La liste des attributs standard d'une structure organisationnelle guidera la caractérisation de la structure organisationnelle de l'entreprise et la façon dont elle a dû évoluer pour faire face aux changements apportés par la TD (**Section 1**). De plus, les changements dans la structure, tels que des domaines organisationnels nouveaux ou redéfinis ou des postes/rôles, seront également étudiés (**Section 2**).

Section 1 : Characteristiques de la Structure Organisationnelle

**Veuillez compléter les informations de la section "AVANT la digitalisation" et de la section "APRÈS la digitalisation", étant donné que ce sujet n'a pas pu être exploré en détail lors du premier interview.

Caractéristique	Description brève	Essentiel pour la digitalisation ?	Niveau de developpement AVANT de commencer la digitalisation					Niveau de developpement APRES la digitalisation				
			Level 1	Level 2	Level 3	Level 4	Level 5	Level 1	Level 2	Level 3	Level 4	Level 5
Structure Organisationnelle	Manifestation de la structure organisationnelle dans un organigramme.	☐	Pas de documentation ☐	☐	☐	☐	Documentation formelle et mise à jour ☐	Pas de documentation ☐	☐	☐	☐	Documentation formelle et mise à jour ☐
Spécialisation du travail (Work Specialization or Division of Labor)	La mesure dans laquelle les tâches d'une organisation sont subdivisées en emplois individuels.	☐	Haute spécialisation ☐	☐	☐	☐	Équipes multidisciplinaires ☐	Haute spécialisation ☐	☐	☐	☐	Équipes multidisciplinaires ☐
Départementalisation (Departmentalization)	Base sur laquelle sont regroupés les postes de travail d'une organisation.	☐	Départementalisation rigide ☐	☐	☐	☐	Équipes interhiérarchiques ☐	Départementalisation rigide ☐	☐	☐	☐	Équipes interhiérarchiques ☐
Chaîne de commandement (Chain of Command)	La ligne d'autorité ininterrompue qui s'étend du sommet de l'organisation à l'échelon le plus bas et qui clarifie qui rend compte à qui.	☐	Chaîne de commandement claire ☐	☐	☐	☐	La libre circulation de l'information ☐	Chaîne de commandement claire ☐	☐	☐	☐	La libre circulation de l'information ☐
Étendue du contrôle (Span of Control)	Le nombre de subordonnés qu'un supérieur peut diriger de manière efficace et efficiente.	☐	Des champs d'action étroits ☐	☐	☐	☐	De champs d'action étendus ☐	Des champs d'action étroits ☐	☐	☐	☐	De champs d'action étendus ☐
Système de prise de décision (Decision-Making)	Le degré de concentration de la prise de décision en un seul ou plusieurs points d'une organisation.	☐	Centralisation ☐	☐	☐	☐	Décentralisation ☐	Centralisation ☐	☐	☐	☐	Décentralisation ☐
Formalisation (Formalization)	Le degré auquel il existe des règles et des règlementations pour guider les employés et les dirigeants.	☐	Haute formalisation ☐	☐	☐	☐	Formalisation basse ☐	Haute formalisation ☐	☐	☐	☐	Formalisation basse ☐
Le franchissement des frontières (Boundary Spanning)	Quand des individus forment des relations en dehors des groupes qui leur sont officiellement assignés.	☐	Pas de relations en dehors du groupe ☐	☐	☐	☐	Interaction fréquente avec d'autres groupes ☐	Pas de relations en dehors du groupe ☐	☐	☐	☐	Interaction fréquente avec d'autres groupes ☐

Section 2 : Changements dans la structure organisationnelle.

**Veuillez vérifier, corriger ou compléter les informations si nécessaire.

Changement	Description	Essentiel pour la digitalisation ?	Initiative de TD			Commentaires des Chercheurs	Commentaires de l'Entreprise
			Smart Manufacturing	Smart Products	Data-Driven Services		
		☐	☐	☐	☐		
		☐	☐	☐	☐		
		☐	☐	☐	☐		

. . .

Competences
Competencies are mainly characterized as a combination of knowledge, skills, abilities that an individual possesses for performing his or her work responsibilities

Dans cette compilation des compétences associées au contexte de la digitalisation nous présentons celles qui ont été introduites pendant la TD, mais aussi de celles qui sont nécessaires pendant la mise en œuvre et de celles qui sont nécessaires pour suivre l'évolution technologique, selon les informations recueillies lors du premier interview.

Les résultats sont affichés dans la section "APRES la digitalisation", en les considérant comme l'état actuel, mais pour identifier le changement, merci de remplir la section "AVANT la digitalisation".

**Veuillez compléter les informations de la section "AVANT la numérisation" (si nécessaire) et vérifier les informations de la section "APRÈS la numérisation", veuillez les corriger (si nécessaire) et compléter en choisissant une valeur dans l'échelle et les rôles associés.

Les informations ne doivent être remplies que pour les compétences concernées par le TD.

Big Eight	Competency Dimensions	Competencies	Essentiel pour la digitalisation ?	Niveau de developpement AVANT de commencer la digitalisation					Niveau de developpement APRES la digitalisation				
				Pas de développement	Faible développement	Developpement moderé	Developpement considérable	Developpement fort	Pas de développement	Faible développement	Developpement moderé	Developpement considérable	Developpement fort
Leading & Deciding	Deciding and Initiating Action	Decision Making	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Taking Responsibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Leading and Supervising	Leadership Skills	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Supporting and Cooperating	Working with People	Teamwork	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Collaborating with Others	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Communicating with People	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Adhering to Principles and Values	Respecting Ethics	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Environmental Awareness	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Awareness for Ergonomics	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

...

Culture
Culture is the pattern of shared beliefs and values that give members of an institution meaning, and provide them with the rules for behaviour in their organization

La liste des traits culturels guidera la caractérisation de la culture organisationnelle de l'entreprise et la manière dont ses caractéristiques ou son évolution ont aidé à faire face aux changements apportés par la TD.

**Veuillez compléter les informations de la section "AVANT la digitalisation" (si necessaire) et de la section "APRÈS la digitalisation", étant donné que ce sujet n'a pas pu être exploré en détail lors du premier interview.

Caractéristiques génerales	Description brève	Essentiel pour la digitalisation ?	Niveau de developpement AVANT de commencer la digitalisation					Niveau de developpement APRES la digitalisation				
			Pas de développement	Faible développement	Developpement moderé	Developpement considérable	Developpement fort	Pas de développement	Faible développement	Developpement moderé	Developpement considérable	Developpement fort
Innovation	Le degré d'encouragement des employés à l'innovation.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Prise de risques	Le degré d'encouragement des employés à prendre des risques.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Attention au détail	Le degré avec lequel les employés sont censés faire preuve de précision, d'analyse et d'attention aux détails.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Orientation vers les résultats	Le degré auquel la direction se concentre sur les résultats ou les effets plutôt que sur les techniques et les processus utilisés pour les atteindre.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Orientation vers les personnes	Le degré auquel les décisions de gestion prennent en compte l'effet des résultats sur les personnes au sein de l'organisation.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Contribution des Dimensions

Importance des changements dans las dimensiones de l'entreprise pour le success de la Transformation Digitale.

**Veuillez compléter les informations en fonction de votre expérience dans la TD de l'entreprise.

		Initiative de TD		
Dimension de l'entreprise	**Description**	Smart Manufacturing	Smart Products	Data-Driven Services
Technologie	Quelle est la contribution de la **dimension technologique** au succès de chaque type d'initiative de TD ?	%	%	%
Processus	Quelle est la contribution de la **dimension processus** au succès de chaque type d'initiative de TD ?	%	%	%
Structure organisationnelle	Quelle est la contribution de la **dimension structure organisationnelle** au succès de chaque type d'initiative de TD ?	%	%	%
Compétences	Quelle est la contribution de la **dimension compétences** au succès de chaque type d'initiative de TD ?	%	%	%
Culture organisationnelle	Quelle est la contribution de la **dimension culturelle** au succès de chaque type d'initiative de TD ?	%	%	%
	Total	**0%**	**0%**	**0%**

<-- Enregistrez les pourcentages avec les décimales.

<-- La somme de chaque colonne doit être de 100%.

Appendix 4.6

Case Study descriptions

Company SME1

Case Study

Case background

Company SME1, a French SME with expertise in designing complex mechatronic systems for customers in the aerospace, automotive and health industries, was established in the late 50s. An overview of the company's main information is shown in Table A.1.

Table A.1 Overview of Company SME1

Attribute	Information (data from 2020)
Industrial Sector	Mechanical or industrial engineering
Staff	~120 employees
Turnover	~8M€
Exports	~5% of the turnover
R&D Investments	~7% of the turnover
Size	Small and Medium Enterprise (SME)
Company locations	Two sites in France and one manufacturing site in Tunisia.
Product offerings	Complex systems, developed in-house or in collaboration, integrating mechanical, electrical, and electronic engineering.
Markets	Aerospace, automotive and health industries

Company's context

External environment

The factors in the external environment identified by the company are presented in Table A.2.

Table A.2 Company SME1's External Context's factors and potential triggers of a DT.

ID	External Factor	Triggers of the Digital Transformation
EC01	**Technology**	The high-speed development of digital technologies and the opportunities it represents.
EC02	**Economy**	The value of the digitalization of the industrial companies for countries' economic growth.
EC03	**Market**	The market for smart products is driving the DT of the companies that manufacture the components that will eventually integrate these digital products.
EC04	**Politics**	No factors identified.
EC05	**Regulation**	The rules and regulations of the high-tech markets they serve, such as aerospace or medical.
EC06	**Resource**	No factors identified.
EC07	**Environment**	No factors identified.

Internal context

The state of the factors in the company's internal context before beginning its DT is presented in Table A.3.

Table A.3 Company SME1's internal context description before beginning the DT.

ID	Features	Value=1 (Worst)	Value =5 (Best)	Score (based on a Likert scale)
IC01	Access to resources for transformation and innovation	Insufficient	Sufficient	4
IC02	Adoption of new technologies	Low	High	4
IC03	R&D investment	Low	High	3
IC04	Product Customization Capability	Low	High	5
IC05	Consideration of processes and standards	Low	High	5
IC06	Leadership engagement	Low	High	5
IC07	Organizational culture flexibility	Low	High	5
IC08	Strategy definition	Dictated by leadership instinct	Based on market research and analysis	1
IC09	Decision-making	Restricted to the manager	Board of Directors	1
IC10	Organizational Structure formality	Low	High	5
IC11	Organizational Structure agility	Low	High	5
IC12	Human Resources engagement	Several domains	Specific domain	1
IC13	Exposure to human resources development (inside the industry)	Low	High	5
IC14	Exposure to human resources development (outside the industry)	Low	High	5
IC15	Industry knowledge and experience	Focused on a specific area	Dispersed in different areas	5
IC16	Alliances with universities	Low	High	5
IC17	Alliances with research institutions	Low	High	1
IC18	Performance of key activities	Outsourcing	Within the company	5
IC19	Dependence on the collaborative network	Low	High	5
IC20	Customer relationship	Weak	Strong	5
IC21	Supplier relationship	Weak	Strong	5
	Digital Willingness component			3.60
	Digital Preparedness component			3.94
	Digital Readiness			**4.05**

Figure A.1 presents the change between the factors of the company's internal context before and after beginning its DT.

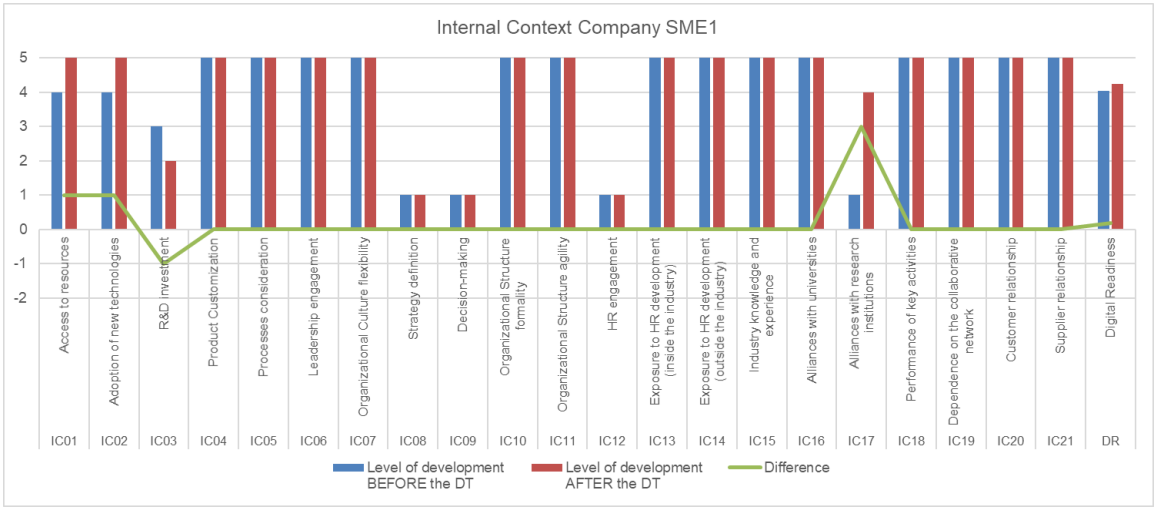

Figure A.1 State of the factors in the internal context of Company SME1 before and after beginning its DT.

Digital strategy

The company considers that its transformation started with the creation of its mechatronics subsidiary, an entity dedicated to the design of advanced mechatronics. Therefore, the company manufactures components that are enriched and made more mechatronic, but those components are ultimately integrated into machines and equipment in which mechatronics pieces contributes to their digitization. Therefore, the business strategy is to target the commercial customers who create the so-called digital products.

In this strategic position, it is vital for them to go to the customers with a suitable offer and the digital strategy follows this direction. There is no formal sponsorship identified, but within management, digitalization is seen as the way for the company to be a leader in its field.

The company does not have a formally documented digital strategy or roadmaps for its digital initiatives. Its digitalization objective is to co-create high-tech digital solutions with its potential customers by developing the mechatronicity of its products. They target higher revenues through new digitized products and new markets (e.g., medical). Currently, the company's customers are shaping the roadmap as they go along. The company prepares a 10-year technology roadmap to define what it wants to do and then identify the events that will lead it to be able to achieve the aspirations of its roadmap.

According to the company, there are no new business models associated with the new products yet. Nevertheless, the operation of their Design Studio can itself be seen as a new business model. The company has invested significant resources in the creation of its Mechatronics subsidiary, but today its financial situation does not allow it to devote more resources to radical changes such as a complete DT. The company also considers that it is in the process of consolidating a business base through its Smart Actuator product.

Digital initiatives

The company is focusing on its product digitization initiative. In fact, the company has already defined its core business, which it is currently consolidating. Nevertheless, it is not pursuing smart manufacturing beyond the implementation of elements such as ERP, which is needed for product traceability, a feature required by customers in areas such as medical. Even though there are opportunities to pursue the possibility of a smart factory to upgrade its production facilities using government assistance to the aerospace sector, there are no plans to do so at present.

Figure A.2 shows the level of digitalization of the company’s production process, and Figure A.3 shows the level of digitization of its main smart product.

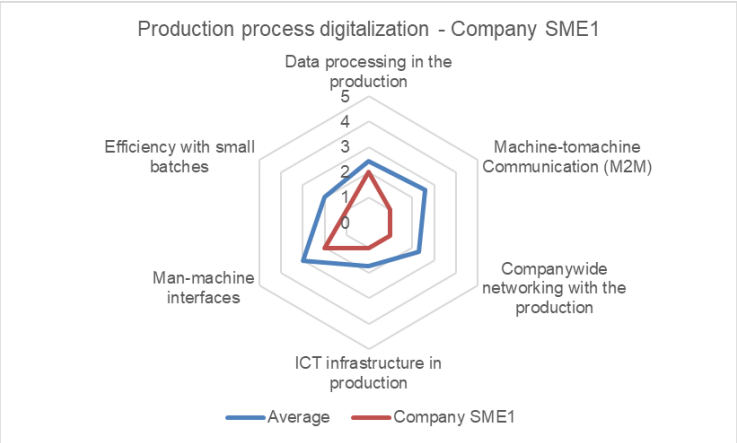

Figure A.2 Level of digitalization of the production process.

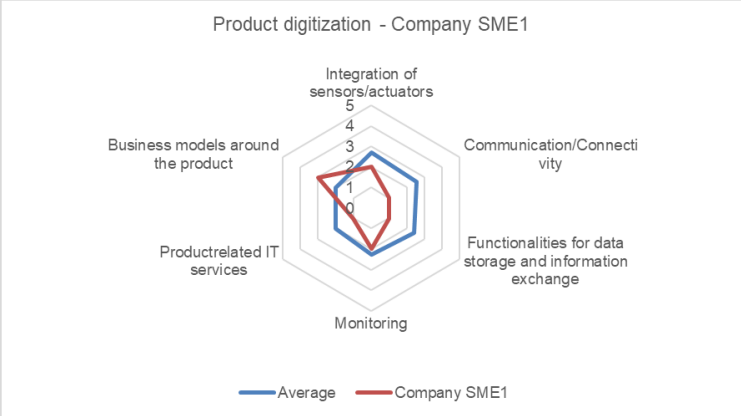

Figure A.3 Level of digitization of the product.

Digital Transformation

There was no information provided on the level of awareness of the DT among the company's employees. The company is focusing on the digitization of products, and the initiatives implemented are still in the process of being implemented. As a result, it has not been identified an implementation process for the changes involved in all the business dimensions. The company, however, follows a business process-oriented approach in its new product developments.

Technology dimension

The company has developed a technology roadmap and annual technology key development plan for the potential customers scheduled according to market expectations.

Table A.4 presents the technologies considered by the company and their status inside the company. The table's information also shows the technologies that are considered key for the company's DT and in which digital initiatives they are included.

Table A.4 Digital technologies implemented by Company SME1.

ID	Technology	Status	Key for the DT	SM	SP	SS
2	**Intelligent control**	Implemented	●		●	
3	**Energy saving/efficiency**	Implemented	●		●	
16	**Smart sensors**	Implemented	●		●	
17	**Smart product/part**	Implemented	●		●	
23	**Simulation**	Implemented			●	
25	**Enterprise Resource Planning (ERP)**	Implemented		●		
31	**Smart Materials**	Implemented	●		●	
37	**Knowledge decision making techniques**	Implemented	●		●	

Figure A.4 presents another perspective of the company's use of digital technologies that shows the digital initiative they are associated with and the complexity level of its implementation, according to Frank et al., (2019)'s framework.

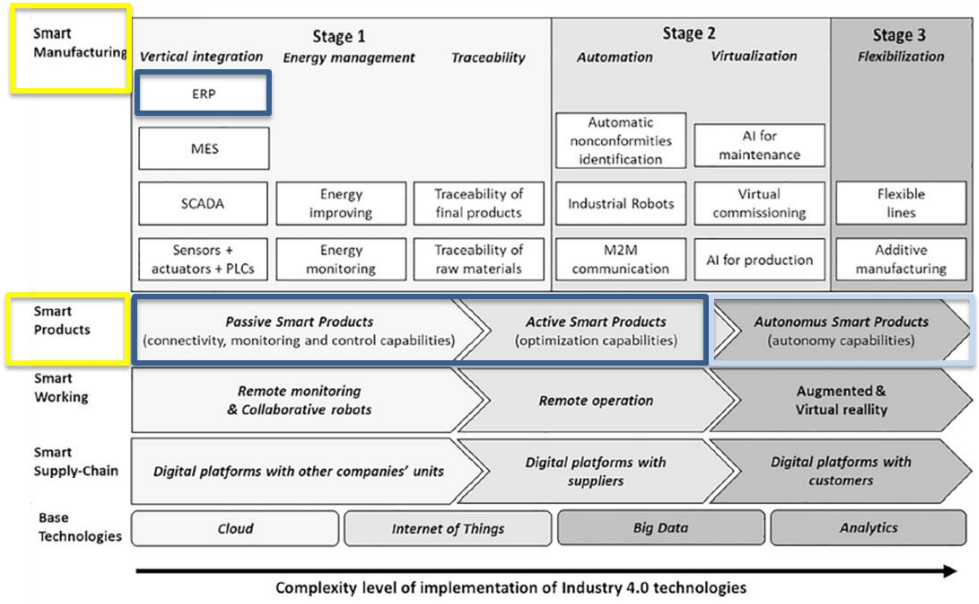

Figure A.4 Company's use of Industry 4.0 technologies (framework by Frank et al., 2019).

Color code: **Yellow** - initiatives underway; **Dark blue** - technologies deployed; **Light blue** - technologies deployed locally or under consideration.

Business process dimension

The formal documentation of the company's processes is based on the frameworks used for the quality certifications the company has and which require formal documentation of the processes. The company's process mapping is based on the aeronautical processes, where there are systematic risk analysis phases in product development.

Table A.5 presents the business process that the company has affected as a result of its DT. The table's information also shows the processes that are considered key for the company's DT and in which digital initiatives they are included.

Table A.5 Business processes modified by Company SME1.

ID	Process	Status	Key for the DT	SM	SP	SS
2.0	**Develop and Manage Products and Services**	Not documented practice	•		•	
3.0	**Market and Sell Products and Services**	Not documented practice	•		•	
4.0	**Deliver Physical Products**	Modified process			•	
13.0	**Develop and Manage Business Capabilities**	Not documented practice				
NA	**Technology Scanning**	Not documented practice		•	•	•

Organizational structure dimension

The company has a formally documented organizational structure. In Figure A.6, the level of development of its characteristics is shown.

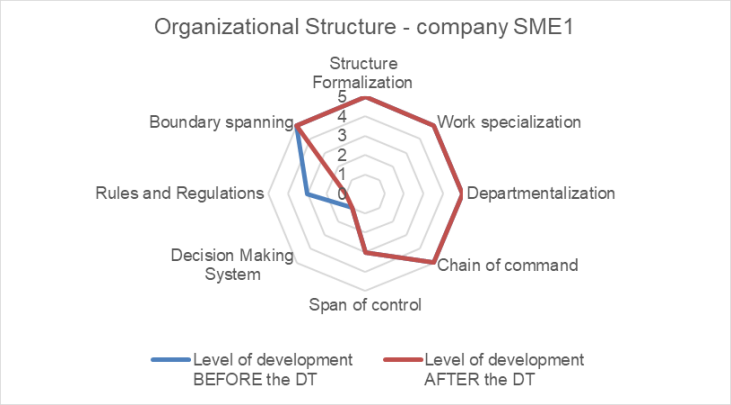

Figure A.6 Level of development of characteristics of the company's organizational structure.

The following changes have been implemented in the organizational structure concerning the DT:

- Creation of the Mechatronics subsidiary to pursue new opportunities based on product digitization.
- New roles will be added in the production process as well as in the engineering part, where today's multi-skilled positions will be complemented by competencies such as biomechanics.

Competencies dimension

The company has documented a skills matrix as part of the ISO requirements.

Table A.6 presents the competencies that the company has introduced as a result of its DT. The table's information also shows the competencies that are considered key for the company's DT and in which digital initiative they are included.

Table A.6 Competencies modified by Company SME1.

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
4	**Teamwork**	●	4	5	1
5	**Collaborating with Others**	●	4	5	1
6	**Communicating with People**	●	4	5	1
12	**Maintaining Customer Relationships**		5	5	0
15	**Presentation and Communication Ability**		4	5	1
35	**Modeling and Programming**	●	2	3	1
41	**Problem Solving**		5	5	0
42	**Optimization**		5	5	0
46	**Knowledge Management**		5	5	0
56	**Management Ability**		5	5	0
58	**Customer Relationship Management**		5	5	0
69	**Entrepreneurship**		5	5	0
70	**Biomechanics**		1	4	3

Organizational culture dimension

The company has documented its organizational culture as it is an ISO requirement as well. The culture is being consolidated after ten years of existence.

Figure A.7 presents the level of development of both basic traits and digital traits of the company's culture.

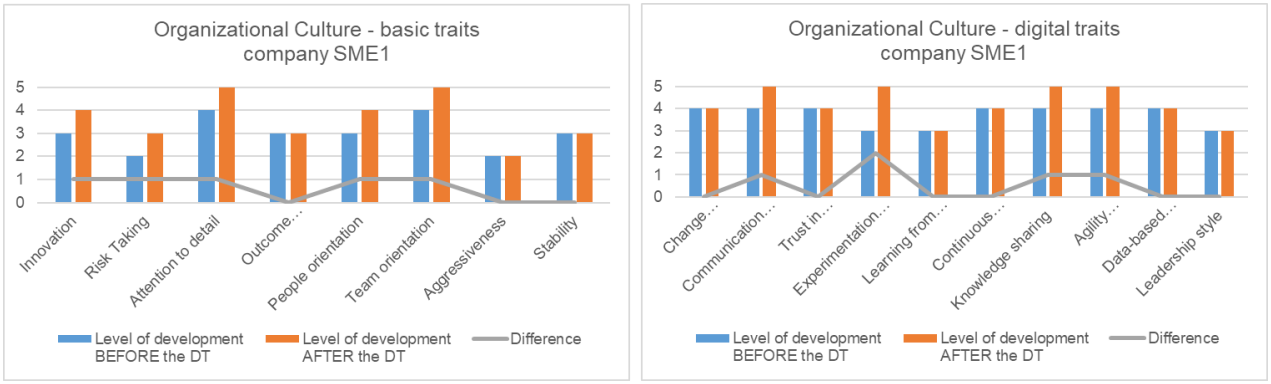

Figure A.7 Level of development of the traits, basic and digital, of the company's organizational culture.

Performance measurement and management

Resources used to guide the DT

The company uses networks, such as Artema, or meetings with companies at industrial fairs because some are very advanced in subjects related to DT even though they are in different fields, such as the agricultural sector.

The company is also following the evolution of the production line of some of its main customers, such as GE Medical Systems, even if they do not produce the same machinery at all. It is essential for them to see

the significant trends. The big groups are focusing on the factory of the future models, for example, and they have enormous resources, especially human resources, to think about this.

Key performance indicators (KPIs) for the DT

As each change is made to increase turnover, this KPI is used to determine the success of the initiatives. On the other hand, regarding identifying the KPIs used to manage and monitor the digital initiatives, specific measures are yet to be identified.

Main challenges

Regarding the selection of technologies, the company acknowledges that it is essential to know what you want to find and to be able to understand that a significant level of expertise is needed. Because in the process of identifying technologies, the most substantial issue is the risk associated with its degree of maturity and complexity of integration. Customers in fields such as the medical field require a high level of involvement to define their needs.

In the company, it is also necessary to give meaning to employees, and this meaning must be shared. The challenge is to put in place a mechanism that allows the company to retain the knowledge absorbed by its employees. It is through this aspect of loyalty and the sense of belonging that the company's project is defined, because the ones who do not find meaning will not stay.

Finally, the company considers that the need to create a digital company is about survival. For SMEs, the result of the DT is essential to their survival.

Company SME2

Case Study

Case background

Company SME2, a French SME that manufactures mainly high-performance vacuum components, was established in the 80s. An overview of the company's main information is shown in table A.7.

Table A.7 Overview of Company SME2

Attribute	Information (data from 2018)
Industrial Sector	Industrial automation
Staff	~135 employees
Turnover	~12M€
Exports	~49% of the turnover
R&D Investments	~7% of the turnover
Size	Small and Medium Enterprise (SME)
Company locations	A main production site located in France, and 5 sales subsidiaries in the USA, Italy, Spain, Germany and China.
Product offerings	High-performance vacuum components and systems for industrial applications.
Markets	50% of its customers are in the food/packaging sector, but also in the automotive and aeronautical sectors.

Company's context

External environment

The factors in the external environment identified by the company are presented in Table A.8.

Table A.8 Company SME2's External Context's factors and potential triggers of a DT

ID	External Factor	Triggers of the Digital Transformation
EC01	**Technology**	No factors identified.
EC02	**Economy**	No factors identified.
EC03	**Market**	No factors identified.
EC04	**Politics**	No factors identified.
EC05	**Regulation**	No factors identified.
EC06	**Resource**	No factors identified.
EC07	**Environment**	No factors identified.

Today, the company does not feel the urgency to move quickly towards its DT but strives to develop its products as digitally as possible. The feeling is that their particular context is not yet ready for the radical change that a DT can bring.

Internal context

The state of the factors in the company's internal context before beginning its DT is presented in Table A.9.

Table A.9 Company SME2's internal context description before beginning the DT.

ID	Features	Value=1 (Worst)	Value =5 (Best)	Score (based on a Likert scale)
IC01	Access to resources for transformation and innovation	Insufficient	Sufficient	**2**
IC02	Adoption of new technologies	Low	High	**3**
IC03	R&D investment	Low	High	**1**
IC04	Product Customization Capability	Low	High	4
IC05	Consideration of processes and standards	Low	High	1
IC06	Leadership engagement	Low	High	**3**
IC07	Organizational culture flexibility	Low	High	**3**
IC08	Strategy definition	Dictated by leadership instinct	Based on market research and analysis	2
IC09	Decision-making	Restricted to the manager	Board of Directors	2
IC10	Organizational Structure formality	Low	High	3
IC11	Organizational Structure agility	Low	High	3
IC12	Human Resources engagement	Several domains	Specific domain	2
IC13	Exposure to human resources development (inside the industry)	Low	High	3
IC14	Exposure to human resources development (outside the industry)	Low	High	3
IC15	Industry knowledge and experience	Focused on a specific area	Dispersed in different areas	2
IC16	Alliances with universities	Low	High	2
IC17	Alliances with research institutions	Low	High	2
IC18	Performance of key activities	Outsourcing	Within the company	1
IC19	Dependence on the collaborative network	Low	High	1
IC20	Customer relationship	Weak	Strong	4
IC21	Supplier relationship	Weak	Strong	3
	Digital Willingness component			2.20
	Digital Preparedness component			2.29
	Digital Readiness			**2.38**

Figure A.8 presents the change between the factors of the company's internal context before and after beginning its DT.

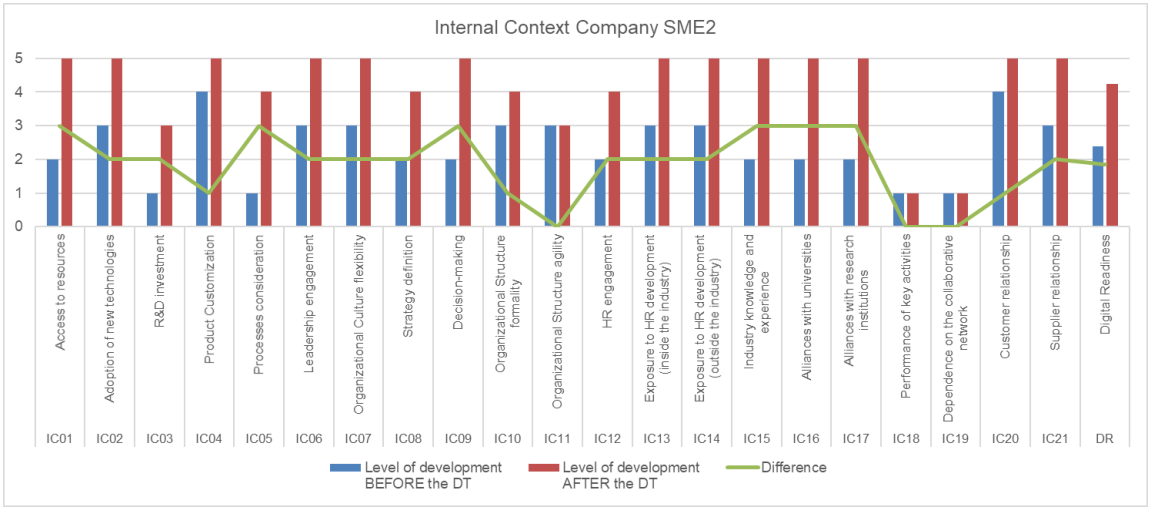

Figure A.8 State of the factors in the internal context of Company SME2 before and after beginning its DT.

Digital strategy

The current focus is on the digitization of products and the introduction of digital tools to improve the company's performance and prepare for the DT. There is no official sponsorship for the project, but within the management, digitalization through mechatronics is one of the key topics. The company has roadmaps for its DT projects. There are no new business models associated with the DT yet, but it is envisaged that this will be done in the future. The resources assigned to the DT are outsourced externally.

Digital initiatives

The company is an assembler, so for it, a smart manufacturing initiative is not urgent at the moment. The company explored the subject of production digitalization ten years ago in an unsuccessful and costly project promoted by a technical advisor. However, they understand the importance of process digitalization; they have implemented an ERP and are considering introducing more digital tools, but not for the moment.

On the other hand, the company, as a component producer today, has the idea that their products will be able in the long run to be sufficiently autonomous on their customers' machines. However, they will be able, first of all, to advise them, but also to make their own diagnosis, to act on the machine parameters. Globally, thanks to their products, their customers will be able to improve their performance.

In this sense, the company already has a fairly sophisticated digital product ready to be marketed through new business models. The company has not made the preparations for this because it believes that the ecosystem is not ready yet and that the level of effort it will have to invest will be high. It will therefore wait until the whole chain is ready. Currently, the company is working in forums such as Factorylab to gain end-user support to succeed in this initiative.

Figure A.9 shows the level of digitalization of the company’s production process, and Figure A.10 shows the level of digitization of its main smart product.

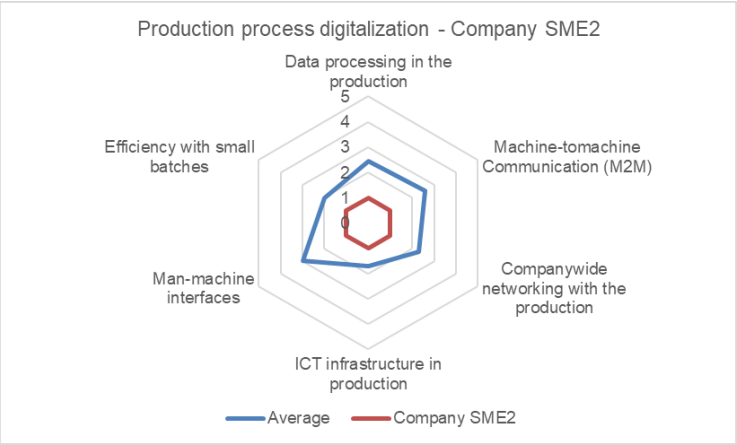

Figure A.9 Level of digitalization of the production process.

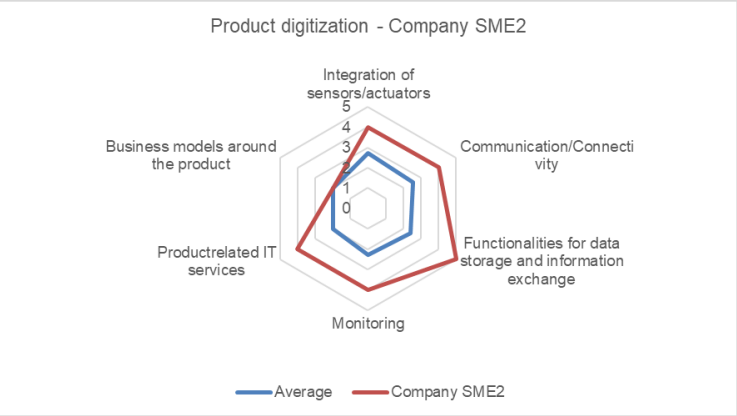

Figure A.10 Level of digitization of the product.

Digital Transformation

Usually, the company's employees are informed of DT-related actions (digital initiatives) when those are implemented. The company focuses on the digitization of products, and the initiatives implemented did not follow a specific process because they did not go too far beyond the technological aspect.

Technology dimension

The company has documented its technology architecture.

Table A.10 presents the technologies considered by the company and their status inside the company. The table's information also shows the technologies that are considered key for the company's DT and in which digital initiatives they are included.

Table A.10 Digital technologies implemented by Company SME2.

ID	Technology	Status	Key for the DT	SM	SP	SS
14	**Cloud computing/cloud manufacturing**	In experimentation	•		•	•

ID	Technology	Status	Key for the DT	SM	SP	SS
15	**3D printing/additive manufacturing**	In experimentation	•		•	
16	**Smart sensors**	Implemented	•		•	
17	**Smart product/part**	Implemented	•		•	
25	**Enterprise Resource Planning (ERP)**	Implemented	•	•		
30	**Product Lifecycle Management (PLM)**	In consideration	•		•	
31	**Smart Materials**	In experimentation	•		•	
33	**CAM, CAD, CAx**	Implemented	•		•	
34	**Operations planning**	Implemented	•	•		
39	**Cloud-based collaboration platform**	In consideration	•		•	•

Figure A.11 presents another perspective of the company's use of digital technologies that shows the digital initiative they are associated with and the complexity level of its implementation, according to Frank et al., (2019)'s framework.

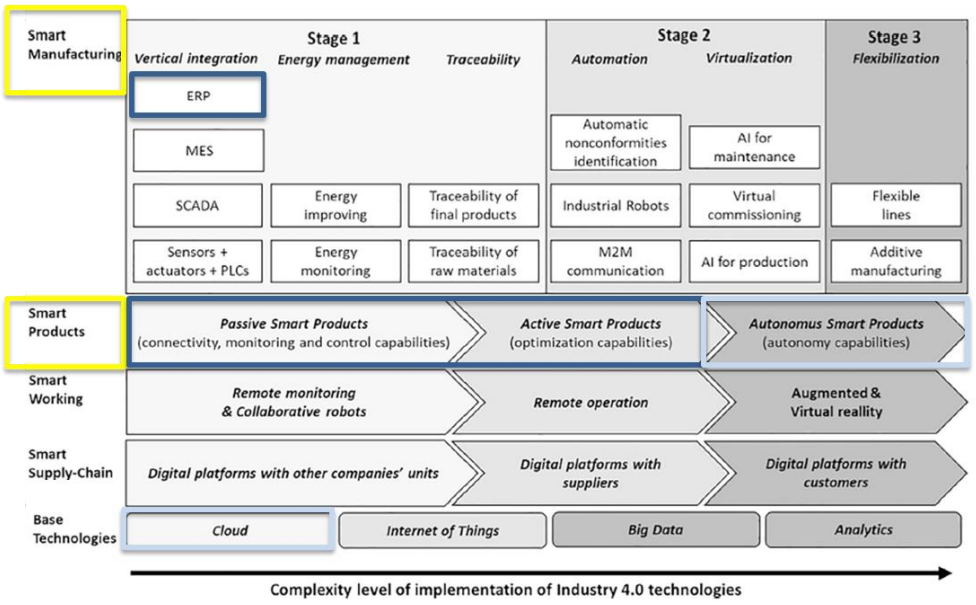

Figure A.11 Company's use of Industry 4.0 technologies (framework by Frank et al., 2019).

Color code: **Yellow** - initiatives underway; **Dark blue** - technologies deployed; **Light blue** - technologies deployed locally or under consideration.

Business process dimension

The formal documentation of the company's processes is based on the frameworks of the quality certifications it has and which require formal process documentation.

Table A.11 presents the business process the company has affected due to its DT. The table's information also shows the processes that are considered key for the company's DT and in which digital initiatives they are included.

Table A.11 Business processes modified by Company SME2.

ID	Process	Status	Key for the DT	SM	SP	SS
2.0	**Develop and Manage Products and Services**	Modified process	•		•	
3.0	**Market and Sell Products and Services**	Modified process	•		•	
4.0	**Deliver Physical Products**	Modified process	•		•	
7.0	**Develop and Manage Human Capital**	Modified process	•		•	
13.0	**Develop and Manage Business Capabilities**	Modified process	•		•	

Organizational structure dimension

The company has a formally documented organizational structure. In Figure A.12, the level of development of its characteristics is shown.

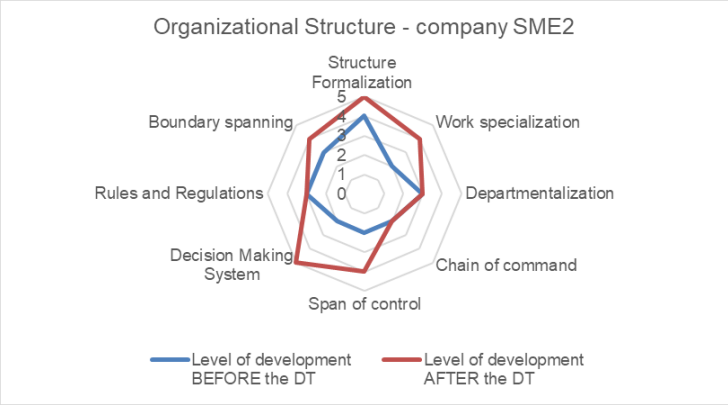

Figure A.12 Level of development of characteristics of the company's organizational structure.

The following changes have been implemented in the organizational structure concerning the DT:

- creation of a mechatronics design office following the digital evolution of their products. The structure includes engineers specialized in electronics, software, and mechanical engineering.
- the management of the mechatronics design office was given to an electronics engineer in order to ensure a transversal link between all the disciplines involved in the products design.
- the company has hired a salesperson specifically for the automotive sector, who is also involved in the design and development of products for this sector.
- the company expects that a DT will lead to a change in the structure of the organization. It is therefore starting to prepare for this step by step, but now is not the priority.
- the information systems department is integrating the responsibility for establishing the technological building blocks such as the enterprise cloud required for its DT.

Competencies dimension

The company has documented the competency matrices necessary for its proper functioning, and its monitoring is based on the results of individual interviews and evaluations of its employees.

Table A.12 presents the competencies that the company has introduced as a result of its DT. The table's information also shows the competencies that are considered key for the company's DT and in which digital initiative they are included.

Table A.12 Competencies modified by Company SME2.

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
12	**Maintaining Customer Relationships**	●	3	5	2
16	**Targeted/Technical Communication**	●			
18	**IT and Technology Affinity**	●	2	4	2
25	**Network Security**	●	2	5	3
26	**IT Architectures**	●	2	5	3
28	**System Development**		2	5	3
29	**Integrating Heterogeneous Technologies**		2	4	2
30	**Mobile Technologies**	●	1	4	3
31	**Sensors/Embedded Systems**	●	2	5	3
35	**Modeling and Programming**	●	1	5	4
37	**Cloud Computing /Architectures**	●	1	3	2
40	**Data Security**	●	2	4	2
50	**Change Management**	●	2	4	2
53	**Managing Complexity**	●	2	4	2
54	**Project Management**	●	3	5	2
58	**Customer Relationship Management**	●	3	5	2
65	**Adaptability and Ability to Change Mind-set**	●	3	5	2
68	**Business Model Understanding**	●	2	4	2

Organizational culture dimension

The company has documented on its website that it has a culture of continuous innovation, quality, and service. Its culture is described as open, rigorous, agile, and flexible. This is something that is well measured at the HR level, in individual interviews and appraisal interviews. But the company does not have a Culture Deck or other tool to document its organizational culture. Indeed, there are no documents that present the company's culture.

Figure A.13 presents the level of development of both basic traits and digital traits of the company's culture.

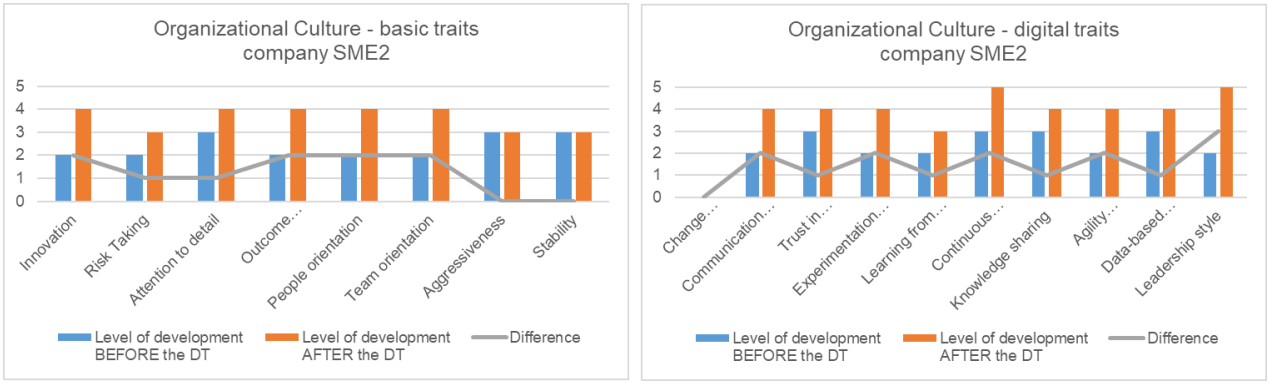

Figure A.13 Level of development of the traits, basic and digital, of the company's organizational culture.

Performance measurement and management

Resources used to guide the DT

The company is guided in its current DT efforts by using the following resources:

- Participation in the Factorylab collective.
- Exchanges with other companies in industry groups, unions or associations.
- Formal and informal exchanges to obtain information on customer needs.
- Exchanges with the sales team.

Key performance indicators (KPIs) for the DT

The company measures the following elements related to its DT:

- The commercial success of certain products.
- The perception of the company as a member of industry groups, trade unions, or similar groups.
- How well the company matches the needs of its customers.

There is also a barometric dashboard based on the ERP information that gives the possibility to integrate a set of indicators that help the company in its decision-making process.

Main challenges

For the company, implementing and proposing the services of tomorrow that the digitization of products can bring to end users is a challenging task as they feel its markets are not prepared for such a change.

As new smart products will require integrating or training the sales force in the challenges of the industry of the future, naturally, they feel the implications for the company will be extensive. So extensive that it will require them to build a culture of change, both internally and externally (customers).

Company SME3

Case Study

Case background

Company SME3, a French SME that manufactures products for engine manufacturers in the aerospace, automobile, railway, and nuclear industries, was established in the 90s. An overview of the company's main information is shown in table A.13.

Table A.13 Overview of Company SME3

Attribute	Information (data from 2019)
Industrial Sector	Industrial mechanics
Staff	~120 employees
Turnover	~20M€
Exports	~85% of the turnover
R&D Investments	~20% of the turnover
Size	Small and Medium Enterprise (SME)
Company locations	Corporate office and main production site are located in France, a 2nd production site in Poland, and an international sales office in the United States.
Product offerings	Fasteners and innovative locks for engines (core business)
Markets	Aerospace and automobile industries mainly

Company's context

External environment

The factors in the external environment identified by the company are presented in Table A.14.

Table A.14 Company SME3's External Context's factors and potential triggers of a DT

ID	External Factor	Triggers of the Digital Transformation
EC01	**Technology**	The high-speed development of digital technologies and the opportunities it represents.
EC02	**Economy**	The value of the digitalization of the industrial companies for countries' economic growth.
EC03	**Market**	New competition based on a digital economy and customers that demand smart and connected products/solutions.
EC04	**Politics**	Government programs promoting the digitalization of industrial companies.
EC05	**Regulation**	Strong regulations and standards governing the aeronautics and automotive sectors.
EC06	**Resource**	No factors identified.
EC07	**Environment**	No factors identified.

Internal context

The state of the factors in the company's internal context before beginning its DT is presented in Table A.15.

Table A.15 Company SME3's internal context description before beginning the DT.

ID	Features	Value=1 (Worst)	Value =5 (Best)	Score (based on a Likert scale)
IC01	Access to resources for transformation and innovation	Insufficient	Sufficient	**1**
IC02	Adoption of new technologies	Low	High	**3**
IC03	R&D investment	Low	High	**3**
IC04	Product Customization Capability	Low	High	3
IC05	Consideration of processes and standards	Low	High	3
IC06	Leadership engagement	Low	High	**1**
IC07	Organizational culture flexibility	Low	High	**1**
IC08	Strategy definition	Dictated by leadership instinct	Based on market research and analysis	1
IC09	Decision-making	Restricted to the manager	Board of Directors	1
IC10	Organizational Structure formality	Low	High	1
IC11	Organizational Structure agility	Low	High	5
IC12	Human Resources engagement	Several domains	Specific domain	1
IC13	Exposure to human resources development (inside the industry)	Low	High	5
IC14	Exposure to human resources development (outside the industry)	Low	High	1
IC15	Industry knowledge and experience	Focused on a specific area	Dispersed in different areas	1
IC16	Alliances with universities	Low	High	1
IC17	Alliances with research institutions	Low	High	1
IC18	Performance of key activities	Outsourcing	Within the company	1
IC19	Dependence on the collaborative network	Low	High	1
IC20	Customer relationship	Weak	Strong	5
IC21	Supplier relationship	Weak	Strong	5
	Digital Willingness component			1.80
	Digital Preparedness component			2.12
	Digital Readiness			**2.14**

Figure A.14 presents the change between the factors of the company's internal context before and after beginning its DT.

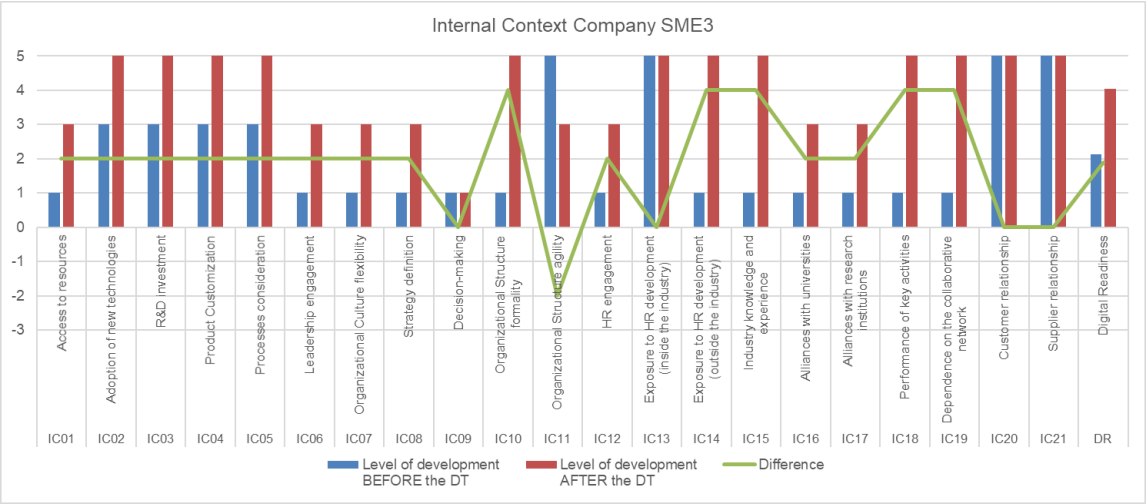

Figure A.14 State of the factors in the internal context of Company SME3 before and after beginning its DT.

Digital strategy

The objectives of the company's DT are focused on the areas of the business strategy related to innovation and diversification of the company. The objectives are decreasing the production costs through a smart factory and higher revenues through new markets, new products, and new services.

At the management level, the CEO (Chief Executive Officer) coordinates the digitalization projects. The DT is a key issue for the company. However, at the beginning of the TD there was no roadmap designed to plan the digitalization initiatives. The company plans to introduce a new business model for its new smart service.

The company resources dedicated to the digitalization of the company are gradually increasing, but at the same time, it is clear that the whole company is involved in some way in its DT.

Digital initiatives

Figure A.15 shows the level of digitalization of the company's production process, and Figure A.16 shows the level of digitization of its main smart product.

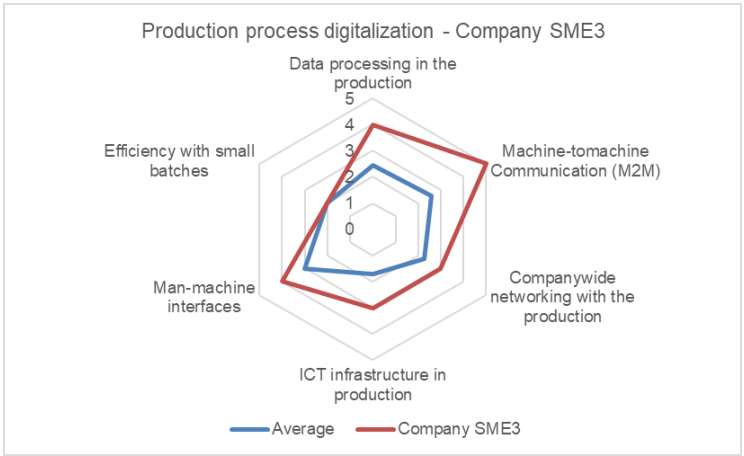

Figure A.15 Level of digitalization of the production process.

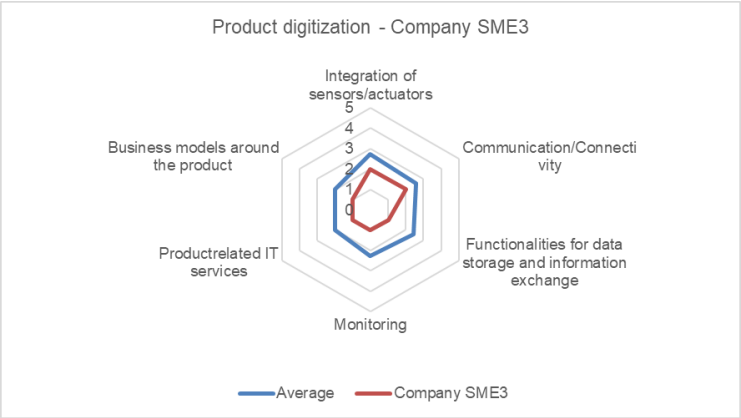

Figure A.16 Level of digitization of the product.

Digital Transformation

There was no information on the level of awareness of the project among the company's employees and the means of communication. The company followed different implementation processes for each initiative, as their nature was different, and the changes covered several business dimensions and not only the technological dimension. More recently, technology implementations have been handled with the help of the CETIM project management processes.

Technology dimension

The company has not documented a technological framework with its IT solutions currently implemented.

Table A.16 presents the technologies considered by the company and their status inside the company. The table's information also shows the technologies that are considered key for the company's DT and in which digital initiatives they are included.

Table A.16 Digital technologies implemented by Company SME3.

ID	Technology	Status	Key for the DT	SM	SP	SS
1	**Intelligent**	Implemented	•	•		
4	**Cyber security**	Implemented				•
8	**Real-time communication/data**	Implemented	•	•		•
9	**Big data**	Implemented	•	•		•
10	**Cyber-physical infrastructure**	Implemented		•		
11	**CPS/CPPS**	Implemented		•		
12	**IoT/IoS/IIoT**	Implemented	•	•		
14	**Cloud computing/cloud manufacturing**	Implemented		•		•
15	**3D printing/additive manufacturing**	Implemented		•		
16	**Smart sensors**	Implemented		•	•	
17	**Smart product/part**	Implemented		•	•	
25	**Enterprise Resource Planning (ERP)**	Implemented	•	•		

ID	Technology	Status	Key for the DT	SM	SP	SS
27	**Machine learning**	Implemented		●		
29	**Manufacturing Execution System (MES)**	Implemented	●	●		
30	**Product Lifecycle Management (PLM)**	Implemented	●	●		
36	**Tracking and tracing**	Implemented	●	●		

Figure A.17 presents another perspective of the company's use of digital technologies that shows the digital initiative they are associated with and the complexity level of its implementation, according to Frank et al., (2019)'s framework.

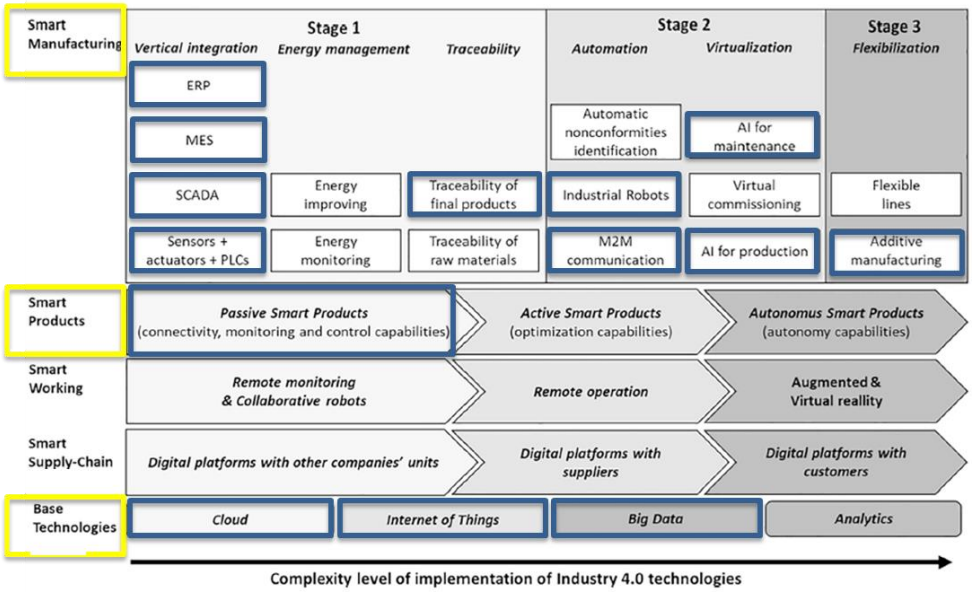

Figure A.17 Company's use of Industry 4.0 technologies (framework by Frank et al., 2019).

Color code: **Yellow** - initiatives underway; **Dark blue** - technologies deployed; **Light blue** - technologies deployed locally or under consideration.

Business process dimension

The company formally documents its processes according to the major international standards (ISO 9001 / EN9100 / NADCAP Welding). However, they are currently working on the documentation of other less technical processes such as product and service design and development.

Table A.17 presents the business process the company has affected due to its DT. The table's information also shows the processes that are considered key for the company's DT and in which digital initiatives they are included.

Table A.17 Business processes modified by Company SME3.

ID	Process	Status	Key for the DT	SM	SP	SS
1.0	**Develop Vision and Strategy**	Not documented practice	●	●	●	●

ID	Process	Status	Key for the DT	SM	SP	SS
2.0	**Develop and Manage Products and Services**	Process to be developed	•		•	•
3.0	**Market and Sell Products and Services**	Process to be developed			•	•
4.0	**Deliver Physical Products**	Process to be developed	•		•	
5.0	**Deliver Service**	Process to be developed				•
6.0	**Manage Customer Service**	Process to be developed			•	•
7.0	**Develop and Manage Human Capital**	Modified process	•	•	•	•
8.0	**Manage Information Technology**	Process to be developed	•	•	•	•
13.0	**Develop and Manage Business Capabilities**	Not documented practice	•	•	•	•
NA	**Technology Scanning**	Not documented practice	•	•	•	•
NA	**Innovation & Co-creation**	Not documented practice	•		•	•
NA	**Research & Development**	Not documented practice	•	•	•	•
NA	**Patents & Contracts**	Not documented practice			•	•

Organizational structure dimension

The company has a formally documented organizational structure. In Figure A.18, the level of development of its characteristics is shown.

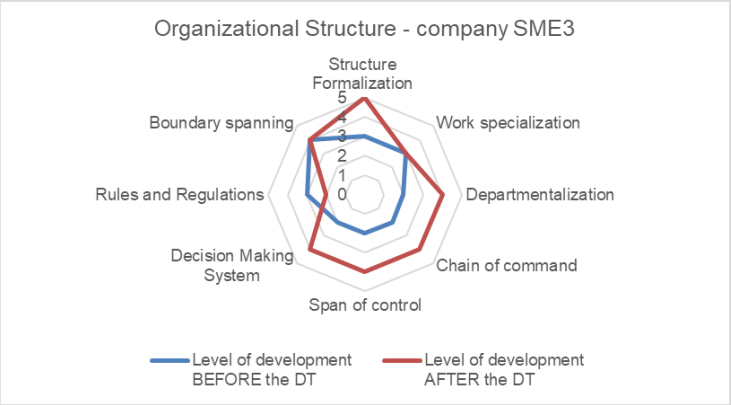

Figure A.18 Level of development of characteristics of the company's organizational structure.

The following changes have been implemented in the organizational structure concerning the DT:

- as a result of the automation of the production line, in terms of size, the structure of the line operators has been halved, and the few roles left have evolved to perform higher-value tasks.
- the changes that have supported the design of these products are limited to a few new roles, as commercialization has not yet started, but they are very significant, such as for example a new position for an innovation manager and the introduction of electricians to the team.

- a new branch of the company has been created to manage the new department with a completely new organizational structure. New roles are also introduced, such as IT, marketing, and data management experts.

Competencies dimension

The company has not documented a competency map with the competencies of its employees.

Table A.18 presents the competencies that the company has introduced as a result of its DT. The table's information also shows the competencies that are considered key for the company's DT and in which digital initiative they are included.

Table A.18 Competencies modified by Company SME3.

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
2	**Taking Responsibility**	●	3	4	1
4	**Teamwork**	●	3	4	1
6	**Communicating with People**	●	4	5	1
9	**Awareness for Ergonomics**	●	2	3	1
10	**Compromising**		3	4	1
11	**Creating Business Networks**		3	4	1
13	**Negotiating**		3	4	1
14	**Emotional Intelligence**	●	3	4	1
15	**Presentation and Communication Ability**		3	4	1
16	**Targeted/Technical Communication**		3	4	1
17	**Literacy**		3	4	1
18	**IT and Technology Affinity**	●	3	5	2
20	**Extract Business Value from Social Media**		3	4	1
21	**Service Orientation/ Product Service Offerings**	●	3	4	1
22	**Business Process Management**		3	4	1
23	**Business Change Management**		3	4	1
24	**Understand and Coordinate Workflows**	●	3	4	1
25	**Network Security**	●	2	4	2
26	**IT Architectures**	●	2	4	2
27	**Machine Learning**		1	4	3
28	**System Development**	●	1	4	3
29	**Integrating Heterogeneous Technologies**	●	2	4	2
30	**Mobile Technologies**		1	3	2
31	**Sensors/Embedded Systems**		1	4	3
32	**Network Technology /M2M Communication**	●	1	4	3
33	**Robotics/Artificial Intelligence**	●	1	4	3
34	**Predictive Maintenance**		1	3	2

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
35	**Modelling and Programming**		2	3	1
36	**Big Data/Data Analysis and Interpretation**	●	1	4	3
37	**Cloud Computing /Architectures**		1	4	3
38	**In-Memory DBs**		1	3	2
39	**Statistics**	●	2	4	2
40	**Data Security**	●	3	4	1
41	**Problem Solving**	●	2	4	2
42	**Optimization**	●	2	4	2
43	**Analytical Skills**	●	2	4	2
44	**Cognitive Ability**		2	4	2
45	**Life-long Learning**		2	3	1
46	**Knowledge Management**		2	3	1
47	**Innovating**		3	4	1
48	**Creativity**		3	4	1
49	**Critical Thinking**		3	4	1
50	**Change Management**		2	4	2
54	**Project Management**	●	2	4	2
55	**Planning and Organizing Work**	●	2	3	1
56	**Management Ability**		2	3	1
59	**Legislation Awareness**		2	3	1
60	**Safety Awareness**		2	3	1
61	**Individual Responsibility**		2	3	1
62	**Work in Interdisciplinary Environments**	●	2	3	1
63	**Intercultural Competency**	●	2	3	1
64	**Flexibility**	●	3	4	1
65	**Adaptability and Ability to Change Mind-set**		3	4	1
66	**Work-Life Balance**		2	3	1
67	**Self-management and -organization**	●	2	3	1
68	**Business Model Understanding**		2	4	2
69	**Entrepreneurship**		2	4	2
71	**Electronics**	●	1	4	3
72	**Software Engineering**	●	2	4	2
73	**Data Science**	●	1	4	3
74	**Sales and Marketing for smart products**		1	3	2
75	**Sales and Marketing for data services**		1	3	2

Organizational culture dimension

The company does not have a "Culture Deck" or another tool to document its organizational culture or core values.

Figure A.19 presents the level of development of both basic traits and digital traits of the company's culture.

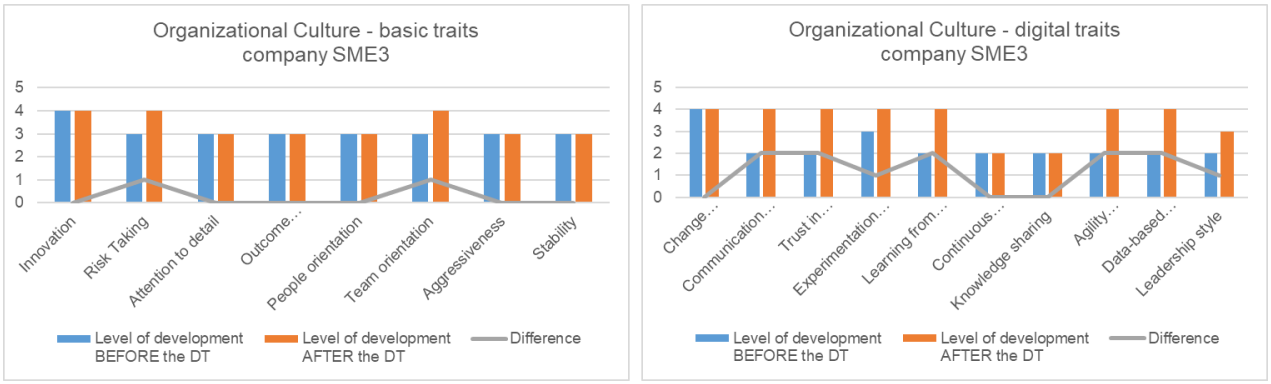

Figure A.19 Level of development of the traits, basic and digital, of the company's organizational culture.

Performance measurement and management

Resources used to guide the DT

The company is guided in its current DT efforts by using the following resources:

- participation in the bpifrance SME Acceleration program;
- exchanges with other companies in industry groups or at conferences;
- formal and informal exchanges to obtain information on customer needs.

Key performance indicators (KPIs) for the DT

In the case of Company SME3, the CEO states that he has not found the right KPIs to measure innovation, a concept closely linked to DT's initiatives in the company. According to him, measures such as patents are indicators of innovation, but the real impact occurs when the actions implemented are reflected in the company's balance sheet. The difficulty in measuring the economic impact of a company's DT initiatives is that they can take many years. This problem highlights the importance of using PMM systems to monitor initiatives to ensure their success and also to find the right indicators to measure the success of a DT.

Main challenges

The company's main challenges regarding its DT are the maturity of some digital technologies and the limited resources with the knowledge to develop them. In different scenarios, the company was also faced with a lack of technical solutions to meet its needs. Whether it was communication protocols for their production machines or efficient and easy-to-use monitoring solutions, in each case, the company had to create its own solution.

Company MSE1

Case Study

Case background

Company MSE1, a French MSE that assembles electric actuators and control systems for the automation of industrial valves in the nuclear, energy, water, industrial, and oil & gas markets, was established in the 30s. An overview of the company's main information is shown in table A.19.

Table A.19 Overview of Company MSE1

Attribute	Information (data from 2019/2020)
Industrial Sector	Electrical and electronic manufacturing
Staff	~500 employees
Turnover	~55M€
Exports	~80% of the turnover
R&D Investments	Confidential information
Size	Medium-Sized Enterprise (MSE)
Company locations	1 Corporate Headquarters, 17 Operating Units in Asia, Europe, India - Middle East - Africa and America, and three plants in France, China, USA.
Product offerings	Electric actuators and control systems for the automation of industrial valves.
Markets	Nuclear, Energy, Water, Industrial, and Oil & Gas markets.

Company's context

External environment

The factors in the external environment identified by the company are presented in Table A.20.

Table A.20 Company MSE1's External Context's factors and potential triggers of a DT

ID	External Factor	Triggers of the Digital Transformation
EC01	**Technology**	The high-speed development of digital technologies and the opportunities it represents.
EC02	**Economy**	No factors identified.
EC03	**Market**	The nuclear market is seen as a place of innovation and rigor. The DT should enable us to expand our market by developing services.
EC04	**Politics**	No factors identified.
EC05	**Regulation**	Nuclear industry regulations that must be taken into account in the design and production of the product.
EC06	**Resource**	No factors identified.
EC07	**Environment**	Manufacture of products that are increasingly involved in automation reduce CO_2.

Internal context

The state of the factors in the company's internal context before beginning its DT is presented in Table A.21.

Table A.21 Company MSE1's internal context description before beginning the DT.

ID	Features	Value=1 (Worst)	Value =5 (Best)	Score (based on a Likert scale)
IC01	Access to resources for transformation and innovation	Insufficient	Sufficient	**2**
IC02	Adoption of new technologies	Low	High	**3**
IC03	R&D investment	Low	High	**2**
IC04	Product Customization Capability	Low	High	5
IC05	Consideration of processes and standards	Low	High	4
IC06	Leadership engagement	Low	High	**5**
IC07	Organizational culture flexibility	Low	High	**5**
IC08	Strategy definition	Dictated by leadership instinct	Based on market research and analysis	2
IC09	Decision-making	Restricted to the manager	Board of Directors	1
IC10	Organizational Structure formality	Low	High	3
IC11	Organizational Structure agility	Low	High	3
IC12	Human Resources engagement	Several domains	Specific domain	5
IC13	Exposure to human resources development (inside the industry)	Low	High	5
IC14	Exposure to human resources development (outside the industry)	Low	High	1
IC15	Industry knowledge and experience	Focused on a specific area	Dispersed in different areas	1
IC16	Alliances with universities	Low	High	2
IC17	Alliances with research institutions	Low	High	3
IC18	Performance of key activities	Outsourcing	Within the company	1
IC19	Dependence on the collaborative network	Low	High	5
IC20	Customer relationship	Weak	Strong	5
IC21	Supplier relationship	Weak	Strong	5
	Digital Willingness component			3.00
	Digital Preparedness component			3.12
	Digital Readiness			**3.24**

Figure A.20 presents the change between the factors of the company's internal context before and after beginning its DT.

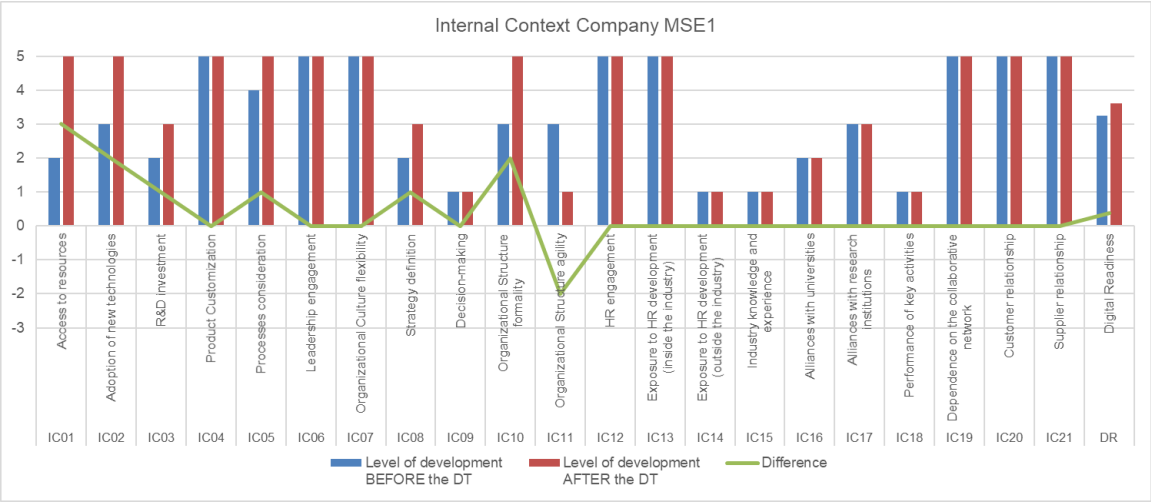

Figure A.20 State of factors in the internal context of Company MSE1 before and after beginning its DT.

Digital strategy

The DT has two main objectives: to increase the margin of products and services and to shorten delivery times. A strong focus of the DT for the company is to automate low-value-added tasks in order to deliver quickly, but also to increase the turnover (via services, for example). The target is to decrease production costs through task automation.

At the management level, the CIO (Chief Innovation Officer) coordinates the digitalization projects (digital initiatives). The company has a digitalization roadmap with all the digital projects that are prioritized and spread over the next 2 to 3 years. The strategy is supported by this roadmap.

The company has no new business models at the moment but has developed features in the product that can be further exploited and is working on topics such as predictive maintenance, which will require thinking about new ways of doing business.

There are resources dedicated to digitization, such as the VP in charge of digitalization, and there are also people in the company who participate in the digitalization teams. The VP of IT & Digital as well as two dedicated people in each R&D unit are in charge of writing the specifications of digital projects, coordinating the teams locally, and providing training.

Digital initiatives

There are initiatives to digitize or mechatronize products, but the company has minimal automation in their production lines. The company has one line that is semi-automated, which is in Beijing, China, to manufacture small devices and verify the assembly of the semi-automated device. However, the settings part of the device is fully automated. Process automation is seen as an objective associated with production growth, but at present, the quantities produced do not justify a smart factory.

However, the company has an ERP and has also identified the need for a PLM, which is on its roadmap but is not yet the priority as it is a complex project that will require a lot of time and resources. For now, the priority is the evolution of their ERP.

Figure A.21 shows the level of digitalization of the company's production process, and Figure A.22 shows the level of digitization of its main smart product.

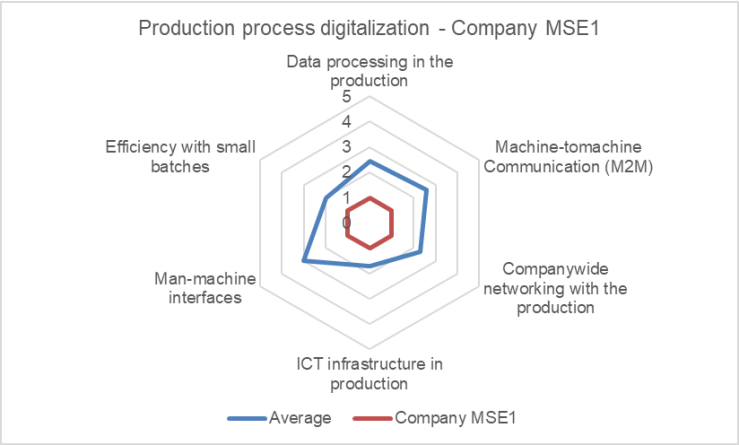

Figure A.21 Level of digitalization of the production process.

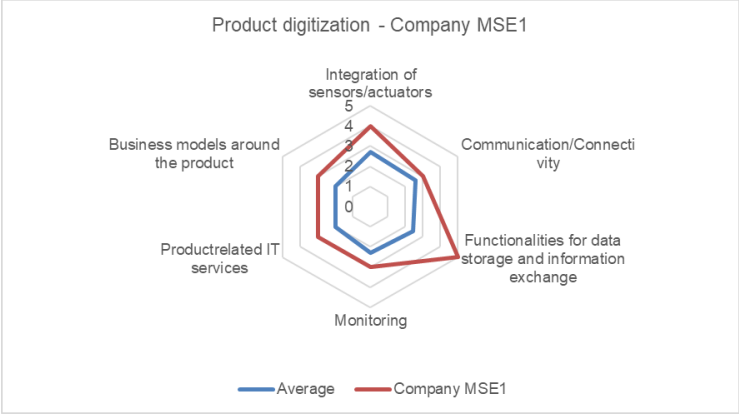

Figure A.22 Level of digitization of the product.

Digital Transformation

The DT's objective is communicated via a newsletter to the whole company. For each process to be digitized, a BPO (Business Process Owner) was identified, as well as the key users who were an integral part of the project. A kick-off of the project was carried out for all these players, who represent approximately 80 people, i.e., 1/6 of the company.

The company uses the services of a consulting firm for the implementation of the new ERP version. This is more than just a project for a new ERP version, it is recognized as a project to digitalize all their processes. The method used is based on the Business Process Reengineering (BPR) approach to identify the current and future state in order to define the actions needed to make the change.

Technology dimension

The company's technology architecture is formalized.

Table A.22 presents the technologies considered by the company and their status inside the company. The table's information also shows the technologies that are considered key for the company's DT and in which digital initiatives they are included.

Table A.22 Digital technologies implemented by Company MSE1.

ID	Technology	Status	Key for the DT	SM	SP	SS
9	**Big data**	In consideration		●	●	●
12	**IoT/IoS/IIoT**	Implemented			●	
15	**3D printing/additive manufacturing**	In consideration		●		
16	**Smart sensors**	Implemented			●	
17	**Smart product/part**	Implemented			●	
18	**Data analytics/big data analytics**	Implemented	●	●		
19	**Predictive analytics**	In consideration			●	
20	**Data visualization**	Implemented	●	●	●	
21	**Modelling**	Implemented	●	●	●	
25	**Enterprise Resource Planning (ERP)**	Implemented	●	●		
27	**Machine learning**	In consideration			●	
28	**Supply Chain Management (SCM)**	In consideration	●	●		
30	**Product Lifecycle Management (PLM)**	In consideration	●		●	●
33	**CAM, CAD, CAx**	Implemented	●	●	●	
34	**Operations planning**	In consideration	●	●		
42	**Product Data Management (PDM)**	Implemented	●		●	●

Figure A.23 presents another perspective of the company's use of digital technologies that shows the digital initiative they are associated with and the complexity level of its implementation, according to Frank et al., (2019)'s framework.

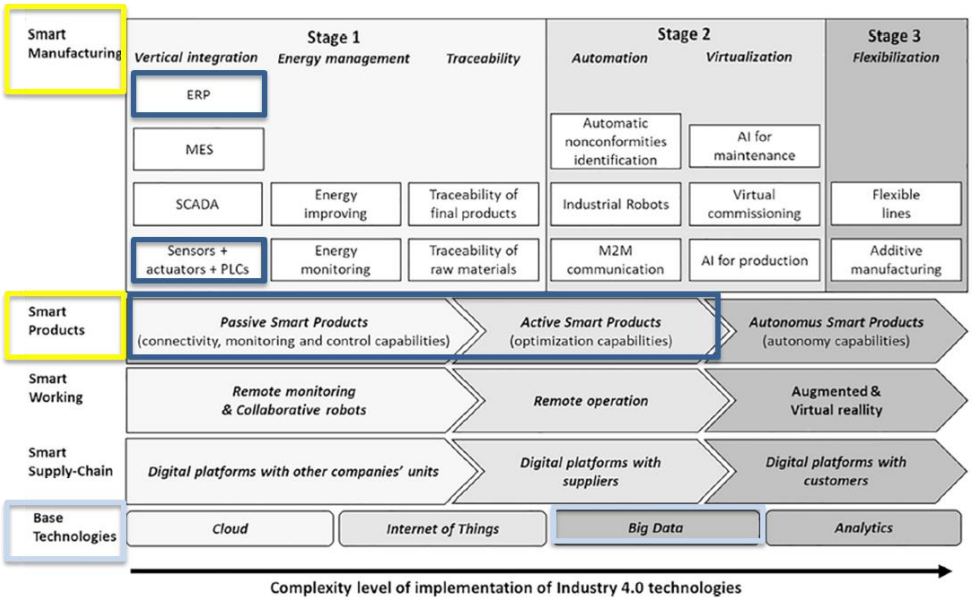

Figure A.23 Company's use of Industry 4.0 technologies (framework by Frank et al., 2019).

Color code: **Yellow** - initiatives underway; **Dark blue** - technologies deployed; **Light blue** - technologies deployed locally or under consideration.

Business process dimension

The company formally documents its processes according to the major international standards (ISO 9001, ABS, ATEX, EAC CUSTOMS UNION, IEEE, INMETRO, GERMANISCHER LLOYDS, NEMA, RCC-E...).

Table A.23 presents the business process the company has affected due to its DT. The table's information also shows the processes that are considered key for the company's DT and in which digital initiatives they are included.

Table A.23 Business processes modified by Company MSE1.

ID	Process	Status	Key for the DT	SM	SP	SS
1.0	**Develop Vision and Strategy**	Process to be developed			•	•
2.0	**Develop and Manage Products and Services**	Modified process			•	
3.0	**Market and Sell Products and Services**	Modified process			•	
4.0	**Deliver Physical Products**	Modified process		•		
6.0	**Manage Customer Service**	Modified process		•		
7.0	**Develop and Manage Human Capital**	Modified process		•	•	

Organizational structure dimension

The company has a formally documented organizational structure. In Figure A.24, the level of development of its characteristics is shown.

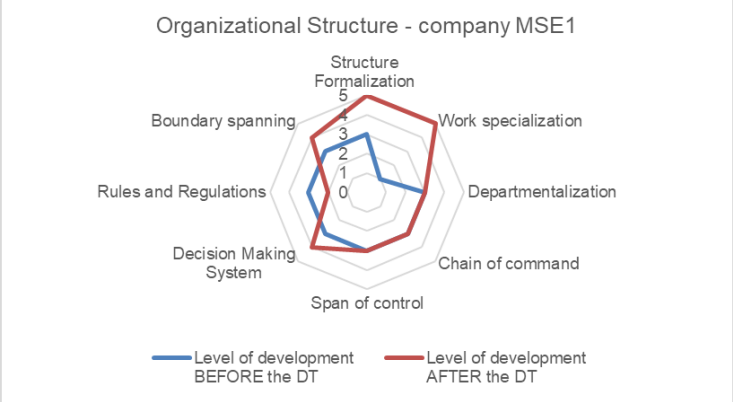

Figure A.24 Level of development of characteristics of the company's organizational structure.

The following changes have been implemented in the organizational structure concerning the DT:

- creation of an R&D department to coordinate all development and industrialization of new products and to increase the skill level of the technical teams.
- creation of local R&D to provide local technical support to factories and subsidiaries and to industrialize product designs in the factories.
- the new product creation roadmap is steered by a VP of Marketing who is responsible for the development of the company's products.

- the VP of Digitalization has full responsibility for the IT function of the group, but he is also responsible for digitalization. The VP of Digitization is in charge of steering the digitization roadmap.
- the VP of Digitalization is basically a project manager whose role is to digitize to carry out digitalization projects at both local and regional levels.
- the company defined business owners for each process for the ERP upgrade project.
- the project teams were set up to write down the company's needs. This will lead to specifications for each major process to enable automation to be achieved.

Competencies dimension

There was no information on the existence of the documentation of a competency map of the company.

The company focuses on the internalization of the basic, classic competencies, mainly related to the design, industrialization of new products, and the associated project management. The competencies far from these are outsourced at the beginning because it is simpler and more agile to do so in order to concentrate on mastering the functional aspect. The company has no problem finding on the market the required competencies that it does not have.

Table A.24 presents the competencies that the company has introduced as a result of its DT. The table's information also shows the competencies that are considered key for the company's DT and in which digital initiative they are included.

Table A.24 Competencies modified by Company MSE1.

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
3	**Leadership Skills**	●	2	4	2
4	**Teamwork**	●	3	4	1
9	**Awareness for Ergonomics**	●	2	4	2
18	**IT and Technology Affinity**	●	4	4	0
22	**Business Process Management**	●	2	4	2
23	**Business Change Management**	●	2	4	2
24	**Understand and Coordinate Workflows**	●	2	4	2
28	**System Development**	●	3	4	1
29	**Integrating Heterogeneous Technologies**	●	3	4	1
31	**Sensors/Embedded Systems**	●	3	4	1
35	**Modelling and Programming**	●	2	4	2
36	**Big Data/Data Analysis and Interpretation**	●	2	5	3
43	**Analytical Skills**	●	2	4	2
50	**Change Management**	●	2	4	2
53	**Managing Complexity**	●	3	4	1
54	**Project Management**	●	4	4	0
62	**Work in Interdisciplinary Environments**	●	3	4	1
63	**Intercultural Competency**		3	4	1
65	**Adaptability and Ability to Change Mind-set**	●	3	4	1

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
67	**Self-management and - organization**	•	2	4	2

Organizational culture dimension

There was no information yet on the existence of documentation of their organizational culture, but the company has documented its core values:

- invest in control(s)
- invest in relationships
- invest in expertise
- invest in loyalty
- invest in innovation
- invest in education
- invest in confidence

The company has a culture at home that has a role to play in the social fabric.

In this culture and on the initiative of the CEO, the company is participating in the creation of an association made by a group of companies capable of facing tomorrow's challenges, working in networks, and achieving international success. These companies identify themselves with a transparent and assumed project, in particular by the shareholders. The association has the wilĺ to develop the employability of the personnel and the commitment of the whole management to these two creeds.

Figure A.25 presents the level of development of both basic traits and digital traits of the company's culture.

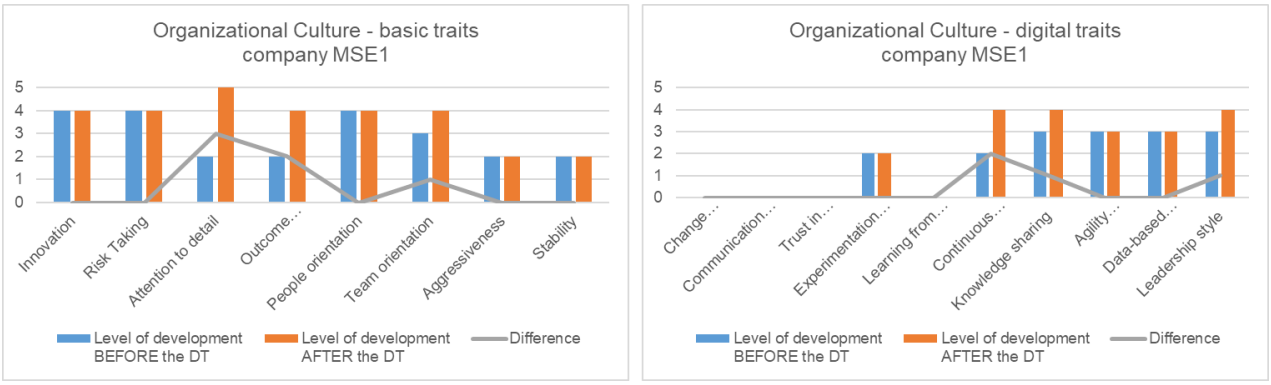

Figure A.25 Level of development of the traits, basic and digital, of the company's organizational culture.

Performance measurement and management

Resources used to guide the DT

The company is guided by the services of the consulting firm Ernst & Young (EY) in its current digitalization efforts focused on the evolution of its ERP. In addition to the work of EY, they also have the support of an integrator of the MS D365 solution. Internally, the digital transformation is also supported operationally by the VP of IT & digital as well as by two project managers who are responsible for drawing up the specifications for the digital projects, coordinating the teams locally, and providing training.

Key performance indicators (KPIs) for the DT

The company's digitalization efforts are currently focused on reducing the delivery time of their products, from design to delivery to the customer. Therefore, delivery time is one of the performance indicators related to their DT. The topic of performance indicators used for managing DT initiatives was not explored further during the interview.

Main challenges

For the company, being flexible is not really the issue, but being efficient in the future with the least possible effort. If possible, with flexibility too.

The company acknowledges that a digitalization project is very energy-consuming for the internal teams and can only be done with them. The challenge is to carry out this project correctly in parallel with daily operational activities and the production of turnover. The availability of resources is therefore essential. This can only be done with the sponsorship of the management and the involvement of middle management.

Company MSE2

Case Study

Case background

Company MSE2, a French MSE that manufactures motors, pumps, valves, and hydraulic and electronic power units in agriculture, construction, and public works markets, was established in the 80s. An overview of the company's main information is shown in table A.25.

Table A.25 Overview of Company MSE2

Attribute	Information (data from 2018)
Industrial Sector	Mechanical or industrial engineering
Staff	~2500 employees
Turnover	~380M€
Exports	~85% of the turnover
R&D Investments	~6% of the turnover
Size	Medium-Sized Enterprise (MSE)
Company locations	9 plants on 3 continents (France, USA and Czech Republic) and 21 sales subsidiaries and representative offices.
Product offerings	Motors, pumps, valves, hydraulic and electronic power units.
Markets	Agriculture, construction and public works, materials handling, industrial and road system sectors, environment, and many others.

Company's context

External environment

The factors in the external environment identified by the company are presented in Table A.26.

Table A.26 Company MSE2's External Context's factors and potential triggers of a DT

ID	External Factor	Triggers of the Digital Transformation
EC01	**Technology**	Technological trends that present the possibility to add value to the company's products.
EC02	**Economy**	No factors identified.
EC03	**Market**	The competition has started its digital transformation and the company believes that it is behind in its digitalization.
EC04	**Politics**	No factors identified
EC05	**Regulation**	Regulation of the automotive industry.
EC06	**Resource**	No factors identified.
EC07	**Environment**	No factors identified.

Internal context

The state of the factors in the company's internal context before beginning its DT is presented in Table A.27.

Table A.27 Company MSE2's internal context description before beginning the DT.

ID	Features	Value=1 (Worst)	Value =5 (Best)	Score (based on a Likert scale)
IC01	Access to resources for transformation and innovation	Insufficient	Sufficient	**4**
IC02	Adoption of new technologies	Low	High	**5**
IC03	R&D investment	Low	High	**2**
IC04	Product Customization Capability	Low	High	5
IC05	Consideration of processes and standards	Low	High	4
IC06	Leadership engagement	Low	High	**4**
IC07	Organizational culture flexibility	Low	High	**4**
IC08	Strategy definition	Dictated by leadership instinct	Based on market research and analysis	4
IC09	Decision-making	Restricted to the manager	Board of Directors	5
IC10	Organizational Structure formality	Low	High	5
IC11	Organizational Structure agility	Low	High	4
IC12	Human Resources engagement	Several domains	Specific domain	3
IC13	Exposure to human resources development (inside the industry)	Low	High	4
IC14	Exposure to human resources development (outside the industry)	Low	High	4
IC15	Industry knowledge and experience	Focused on a specific area	Dispersed in different areas	3
IC16	Alliances with universities	Low	High	5
IC17	Alliances with research institutions	Low	High	5
IC18	Performance of key activities	Outsourcing	Within the company	5
IC19	Dependence on the collaborative network	Low	High	4
IC20	Customer relationship	Weak	Strong	5
IC21	Supplier relationship	Weak	Strong	4
	Digital Willingness component			4.20
	Digital Preparedness component			3.94
	Digital Readiness			**4.19**

Figure A.26 presents the change between the factors of the company's internal context before and after beginning its DT.

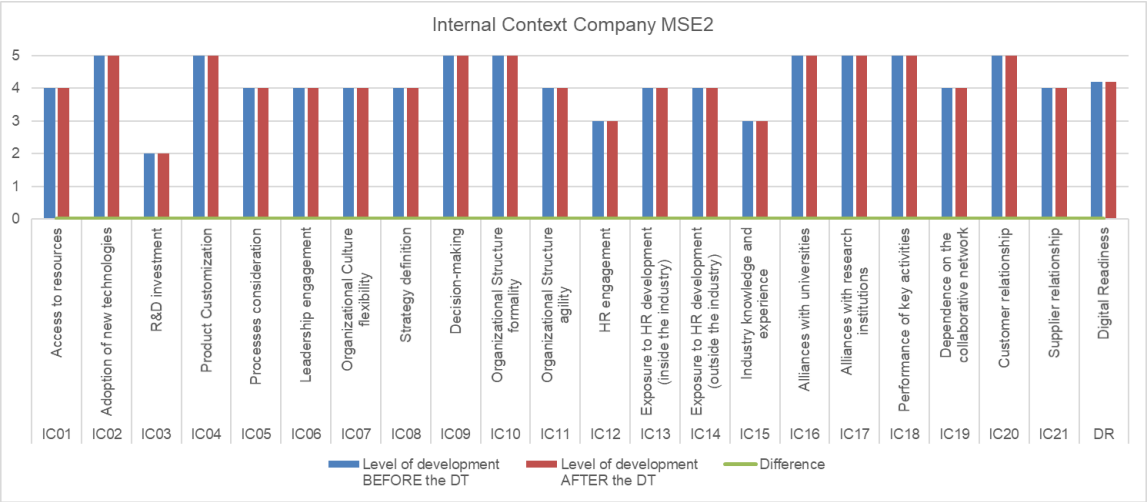

Figure A.26 State of factors in the internal context of Company MSE2 before and after beginning its DT.

Digital strategy

There are no targets set for the DT yet; the company is in the process of detailing the plans.

However, revenue growth through services, particularly those associated with connected products, is seen as one of the objectives, as it is the efficiency in production processes.

Specifically, the objectives are defined as follows:

- value creation,
- productivity gains,
- efficiency gains,
- quality improvement.

The target is to decrease production costs, through efficiency and productivity and higher revenues, through new markets, new products, and new services. There is no sponsorship for the DT, but there has been a reorganization of the company so that the DT is brought to the forefront. For the top management or even for the executives in the company, DT is one of the key topics.

There are project roadmaps with a 5-year vision. The horizon is 2025. The roadmap sets out the main topics that the company will work on in a macro way and the potential benefits they will bring to the company. Planning horizons are short, and roadmaps are reassessed quarterly due to the speed of technological change.

There are no new business models associated with the DT yet, but it is envisaged that there will be in the future. Resources are available, but it is unclear if they would be sufficient for what will be proposed in the future plans. The resources allocated to the DT depend on the company's priorities and the speed at which it wants to catch up with the level of digitalization of its competition. Now the focus is on the early stages of developing the transformation. The digitalization project (smart manufacturing), for example, works with a self-financing model where the first successes provide positive cash flow for the next steps.

Digital initiatives

There were initiatives to digitalize products and production systems before, but the company accelerated its efforts last year (2020) to build digital tools internally to transform the business and improve performance. Therefore, the project is at the beginning.

The company has three crucial IT bricks that have a good level of maturity and homogeneity within the group:

- an ERP that is globalized at the group level;
- a PLM for all product lines and all sites;
- a common CRM for all sites.

Before implementing a Manufacturing Execution Systems (MES), the company decided to set up a standard platform to homogenize communication between the various data sources (machines, software packages, automats, etc.) (Operational Technology - OT), and the upper layers (Information Technology - IT) and MES.

The company is exploring the following topics:

- there are local initiatives for certain energy management solutions, but the company is not committed to a very strong, structured approach to this area;
- there are also traceability efforts with the ERP, but with the MES, it could become more flexible;
- the company is equipped for the automatic identification of non-conformities, but this is not yet consolidated;
- the company is doing flexible robotization, but the high diversity of product typology makes robotization complex;
- AI is a transversal subject for Smart Manufacturing and Smart Products with a Data Science group;
- the company validates solutions for Machine Vision with partners;
- additive manufacturing is seen as a new way of designing products, so the company has an approach that is being launched on the product innovation side;
- in the smart product approach, the company is at the beginning and is rather inclined to go towards embedded intelligence, but the industry to which it belongs (agriculture, mining) has an influence on design decisions;
- in terms of core technologies, the company is well involved in all these topics; there are people working on these topics, but only a small group.

Figure A.27 shows the level of digitalization of the company's production process, and Figure A.28 shows the level of digitization of its main smart product.

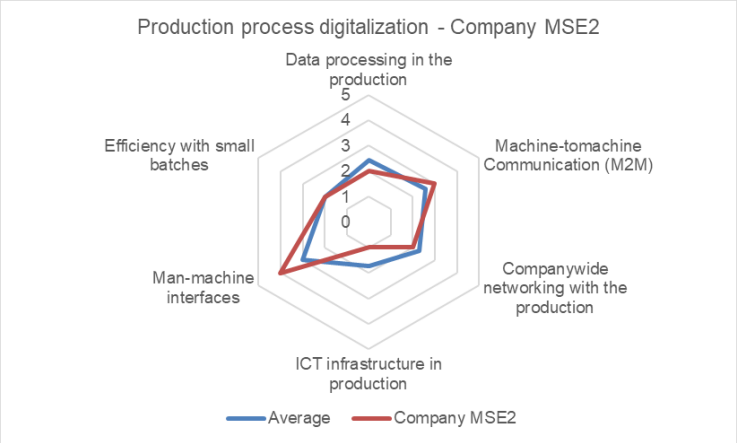

Figure A.27 Level of digitalization of the production process.

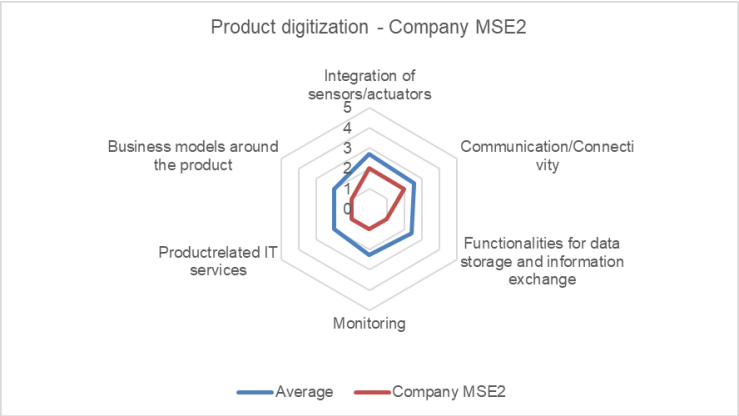

Figure A.28 Level of digitization of the product.

Digital Transformation

The level of knowledge of the project among the company's employees is not very high at the moment. There will be sessions at the beginning of the year to communicate the DT efforts.

The company is at the beginning of its DT, and the initiatives implemented have not followed a specific process. Steering committees are used to identify the needs of each initiative according to the maturity of the processes and the organization.

Technology dimension

The company has not documented a technological framework with its IT solutions currently implemented.

Table A.28 presents the technologies considered by the company and their status inside the company. The table's information also shows the technologies that are considered key for the company's DT and in which digital initiatives they are included.

Table A.28 Digital technologies implemented by Company MSE2.

ID	Technology	Status	Key for the DT	SM	SP	SS
1	**Intelligent**	In experimentation	●	●	●	●
2	**Intelligent control**	In consideration			●	
3	**Energy saving/efficiency**	In experimentation		●	●	
4	**Cyber security**	Implemented	●	●	●	
6	**Virtual Reality (VR)**	In experimentation				
7	**Augmented Reality (AR)**	In implementation				
8	**Real-time communication/data**	In experimentation	●		●	●
9	**Big data**	In implementation	●	●	●	●
12	**IoT/IoS/IIoT**	In implementation	●	●	●	●
13	**Advanced manufacturing**	In implementation		●		
14	**Cloud computing/cloud manufacturing**	In implementation	●	●	●	●
15	**3D printing/additive manufacturing**	In experimentation		●		
16	**Smart sensors**	In consideration	●	●	●	●

ID	Technology	Status	Key for the DT	SM	SP	SS
17	**Smart product/part**	In consideration			●	
18	**Data analytics/big data analytics**	In experimentation	●	●	●	●
19	**Predictive analytics**	In experimentation		●	●	●
20	**Data visualization**	In experimentation		●	●	●
21	**Modeling**	In consideration			●	
22	**Geographic Information Science (GIS)**	In experimentation			●	●
23	**Simulation**	Implemented			●	●
25	**Enterprise Resource Planning (ERP)**	Implemented		●		
26	**Radio-Frequency IDentification (RFID)**	Implemented		●		
27	**Machine learning**	In experimentation		●	●	●
29	**Manufacturing Execution System (MES)**	In consideration		●		
30	**Product Lifecycle Management (PLM)**	Implemented		●	●	●
31	**Smart Materials**	In consideration		●		
32	**Interface (SCOR, DCOR, MESA, ISA 95/88)**	In experimentation		●		
33	**CAM, CAD, CAx**	Implemented	●	●	●	
34	**Operations planning**	In consideration		●		
35	**IT-based production management**	In consideration		●		
36	**Tracking and tracing**	In consideration		●	●	
38	**Statistical Process Control (SPC)**	In experimentation		●		
40	**Edge Computing**	In consideration		●	●	●
41	**Industrial Vision**	In consideration		●		

Figure A.29 presents another perspective of the company's use of digital technologies that shows the digital initiative they are associated with and the complexity level of its implementation, according to Frank et al., (2019)'s framework.

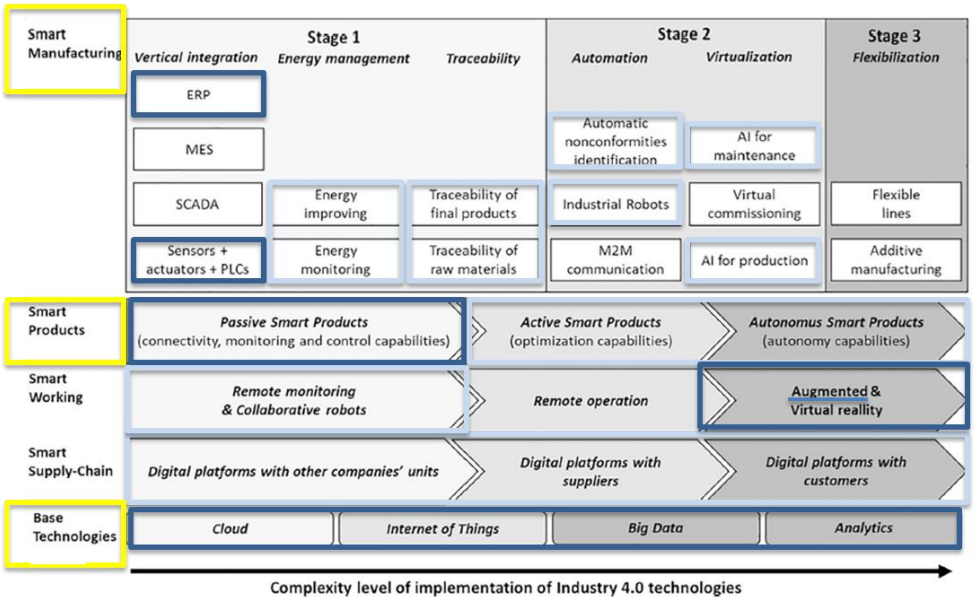

Figure A.29 Company's use of Industry 4.0 technologies (framework by Frank et al., 2019).

Color code: **Yellow** - initiatives underway; **Dark blue** - technologies deployed; **Light blue** - technologies deployed locally or under consideration.

Business process dimension

The company has a process map in operation.

Table A.29 presents the business process the company has affected due to its DT. The table's information also shows the processes that are considered key for the company's DT and in which digital initiatives they are included.

Table A.29 Business processes modified by Company MSE2.

ID	Process	Status	Key for the DT	SM	SP	SS
1.0	**Develop Vision and Strategy**	Not documented practice	•	•	•	•
2.0	**Develop and Manage Products and Services**	Not documented practice			•	•
3.0	**Market and Sell Products and Services**	Not documented practice			•	•
4.0	**Deliver Physical Products**			•	•	•
5.0	**Deliver Service**	Process to be developed				•
6.0	**Manage Customer Service**	Process to be developed				•
7.0	**Develop and Manage Human Capital**	Not documented practice	•	•	•	•
8.0	**Manage Information Technology**		•	•		•
10.0	**Acquire, Construct, and Manage Assets**	Process to be developed		•	•	•
11.0	**Manage Enterprise Risk, Compliance, Remediation, and Resiliency**	Not documented practice			•	•

ID	Process	Status	Key for the DT	SM	SP	SS
12.0	**Manage External Relationships**	Process to be developed		•	•	•
13.0	**Develop and Manage Business Capabilities**	Not documented practice	•	•	•	•

Organizational structure dimension

The company has a formally documented organizational structure. In Figure A.30, the level of development of its characteristics is shown.

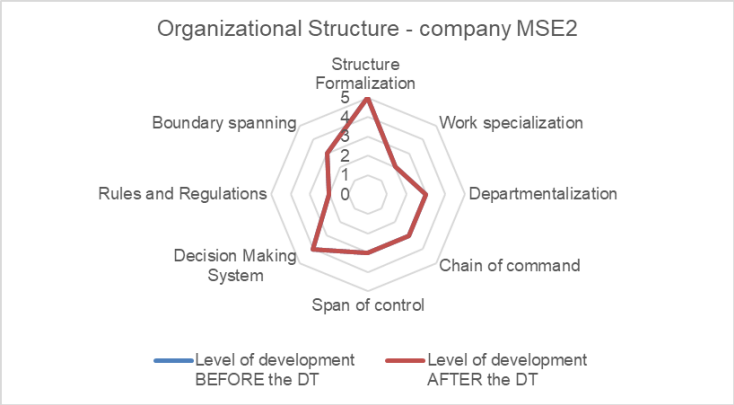

Figure A.30 Level of development of characteristics of the company's organizational structure.

The following changes have been implemented in the organizational structure concerning the DT:

- reorganization of the company so that the DT is brought to the fore;
- areas involved: sales & marketing, engineering, operations, and support; one digital leader per area with process experts to identify and evaluate opportunities;
- a services program structure;
- the project benefits from resources in each of the plants that are able to support the pilots;
- data science group that will develop AI solutions for Smart Manufacturing and Smart Products.

Competencies dimension

The company does not have a competencies map documented with the competencies that its employees have.

Table A.30 presents the competencies that the company has introduced as a result of its DT. The table's information also shows the competencies that are considered key for the company's DT and in which digital initiative they are included.

Table A.30 Competencies modified by Company MSE2.

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
1	**Decision Making**	•	3		
4	**Teamwork**	•	3		

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
5	**Collaborating with Others**	•	3		
11	**Creating Business Networks**	•	4		
18	**IT and Technology Affinity**	•	3		
24	**Understand and Coordinate Workflows**	•	2		
25	**Network Security**	•	4		
26	**IT Architectures**	•	4		
36	**Big Data/Data Analysis and Interpretation**	•	5		
37	**Cloud Computing /Architectures**	•	2		
40	**Data Security**	•	4		
51	**Business Strategy**	•	4		
68	**Business Model Understanding**	•	5		
69	**Entrepreneurship**	•	5		

Organizational culture dimension

The company does not have a Culture Deck or any other tool to document its organizational culture, but it has documented its core values:

- the people,
- independence,
- innovation,
- internationalization.

Figure A.31 presents the level of development of both basic traits and digital traits of the company's culture.

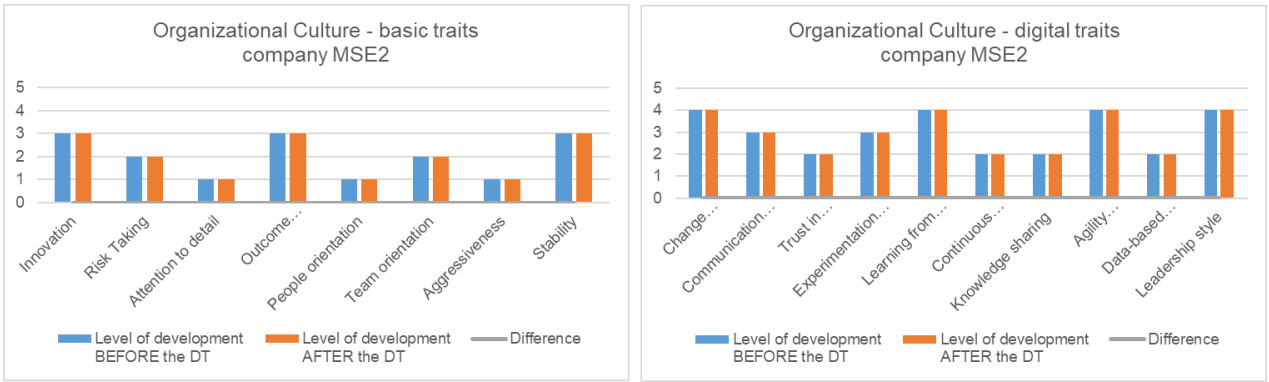

Figure A.31 Level of development of the traits, basic and digital, of the company's organizational culture.

Performance measurement and management

Resources used to guide the DT

The company does benchmarks and also obtains information about the DT by using the following resources:

- exchanges with other companies with the “Vitrine Industrie du Futur” label;
- exchanges with other companies belonging to the same industrial associations;
- exchanges with companies from other industrial sectors;
- "Voice of the Customer" surveys;
- internet.

Key performance indicators (KPIs) for the DT

The company measures the following elements related to its DT:

- the identified opportunities are evaluated according to different criteria such as profitability, but also their contribution to digital continuity or to the attractiveness of the company as an employer;
- other indicators related to the maturity of digital initiatives:
  - proof of concepts (volumetry, to ensure a certain dynamism);
  - projects to be launched or industrialized (volumetry and overall profitability, overall project payback).

It does not, however, have indicators for the follow up of the overall DT.

Main challenges

The company has identified many challenges during its DT. The most important is having the ability to catch up with the DT of the competition and finding the right (perhaps external) partners to rely on during the transformation. It has also been proving difficult to identify the level of turnover expected from smart products and services.

Another critical challenge is the maturity of the organization's processes in a broad sense, including competencies. For example, the evolution of the salespeople to sell new solutions away from the ones they sell today will require significant resources. Another example is the limitations of information systems that do not evolve at the necessary speed and impose many challenges on technology projects.

Company MSE3

Case Study

Case background

Company MSE3, a French MSE that manufactures drive systems and automation solutions in the automotive, beverage and liquid filling, transport and logistics, and airport baggage handling industries, was established in the late 90s. An overview of the company's main information is shown in table A.31.

Table A.31 Overview of Company MSE3

Attribute	Information (data from 2018)
Industrial Sector	Industrial automation
Staff	~2300 employees
Turnover	~450M€
Exports	~85% of the turnover
R&D Investments	Not available
Size	Medium-Sized Enterprise (MSE)
Company locations	Three production plants in France, one distribution plant, and five assembly and service centers.
Product offerings	Drive systems and automation solutions
Markets	Automotive, beverage and liquid filling, transport and logistics, airport baggage handling.

Company's context

External environment

The factors in the external environment identified by the company are presented in Table A.32.

Table A.32 Company MSE3's External Context's factors and potential triggers of a DT

ID	External Factor	Triggers of the Digital Transformation
EC01	**Technology**	No factors identified.
EC02	**Economy**	No factors identified.
EC03	**Market**	The main catalyst identified for the company's DT is the need to achieve a constant optimization challenge of the flow from order to delivery of their product.
EC04	**Politics**	No factors identified
EC05	**Regulation**	No factors identified.
EC06	**Resource**	No factors identified.
EC07	**Environment**	No factors identified.

Internal context

The state of the factors in the company's internal context before beginning its DT is presented in Table A.33.

Table A.33 Company MSE3's internal context description before beginning the DT.

ID	Features	Value=1 (Worst)	Value =5 (Best)	Score (based on a Likert scale)
IC01	Access to resources for transformation and innovation	Insufficient	Sufficient	**3**
IC02	Adoption of new technologies	Low	High	**3**
IC03	R&D investment	Low	High	**3**
IC04	Product Customization Capability	Low	High	5
IC05	Consideration of processes and standards	Low	High	5
IC06	Leadership engagement	Low	High	**4**
IC07	Organizational culture flexibility	Low	High	**4**
IC08	Strategy definition	Dictated by leadership instinct	Based on market research and analysis	5
IC09	Decision-making	Restricted to the manager	Board of Directors	4
IC10	Organizational Structure formality	Low	High	5
IC11	Organizational Structure agility	Low	High	5
IC12	Human Resources engagement	Several domains	Specific domain	5
IC13	Exposure to human resources development (inside the industry)	Low	High	5
IC14	Exposure to human resources development (outside the industry)	Low	High	5
IC15	Industry knowledge and experience	Focused on a specific area	Dispersed in different areas	5
IC16	Alliances with universities	Low	High	4
IC17	Alliances with research institutions	Low	High	4
IC18	Performance of key activities	Outsourcing	Within the company	4
IC19	Dependence on the collaborative network	Low	High	3
IC20	Customer relationship	Weak	Strong	5
IC21	Supplier relationship	Weak	Strong	5
	Digital Willingness component			3.60
	Digital Preparedness component			4.29
	Digital Readiness			**4.33**

Figure A.32 presents the change between the factors of the company's internal context before and after beginning its DT.

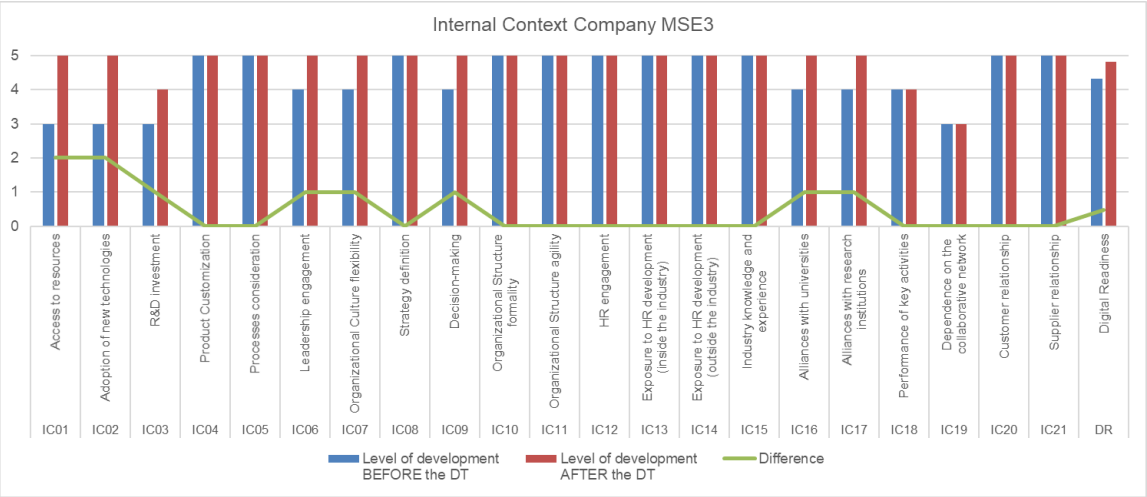

Figure A.32 State of the factors in the internal context of Company MSE3 before and after beginning its DT.

Digital strategy

The company's stated objective is twofold: to increase productivity and improve the comfort of its employees. The aim is also to be a Lean Organization allowing delivery of the product in 5 days for each order and improving the processes permanently. There is no formal sponsorship identified for the DT, but within management, digitalization is seen as the way to be a leader in their field.

There is no information yet on the existence of roadmaps for the digitalization projects. There is also no new business models associated with the DT, but the company has planned to do so with the introduction of a family of new smart products.

The company operates on a self-financing basis in France. It is from their results that the company allows itself to reinvest in order to remain the leader in its field, which represents a substantial investment. The decision-making processes for validating investments are very fast.

Digital initiatives

The company has been transforming itself since the 1970s, but since then, it has used different tools to achieve its goal of continuous improvement based on the principles of Lean Organizations and business process management (BPM). In the digital age, the company also relies on technology to achieve this goal. That is why its smart manufacturing project is based on this objective.

On the smart product side, the company has new product lines that aim to facilitate the configuration of their motors with their controllers. This will allow them to have greater ease in commissioning their driving solution. This is the first brick of smart products that the company is developing, and a second brick is the integration of services that can go towards predictive maintenance.

Figure A.33 shows the level of digitalization of the company’s production process, and Figure A.34 shows the level of digitization of its main smart product.

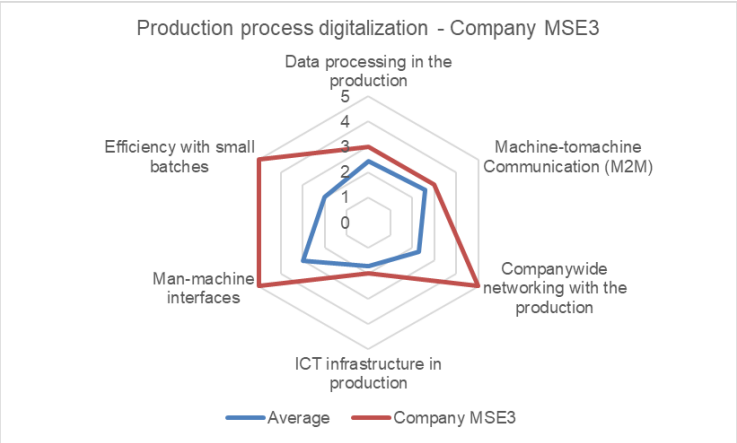

Figure A.33 Level of digitalization of the production process.

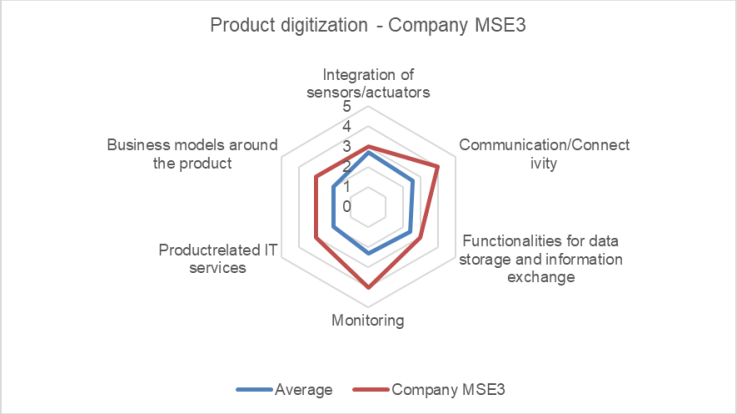

Figure A.34 Level of digitization of the product.

Digital Transformation

The communication of DT is done through training, by the communication of the hierarchical levels. The company organizes training whenever it implements new technologies to make employees aware of the changes involved.

The implementation of all projects follows the continuous improvement approach. There are people dedicated to leading these types of projects. The company also considers itself to be a process organization, so all changes are managed by using its process map.

In terms of product design, historically, the strategy with their suppliers has also been one of collaboration. Their suppliers are involved in the optimization of the product for which they will eventually need to supply them with inputs or parts. Through this collaboration, the company ensures that the manufacturing of the products is as cheap and simple as possible.

The company also uses different tools when implementing new technologies, and now they are analyzing a Fab Lab that allows them to give their employees access to these technologies so they can discover them.

Technology dimension

The company has its technology architecture defined.

Table A.34 presents the technologies considered by the company and their status inside the company. The table's information also shows the technologies that are considered key for the company's DT and in which digital initiatives they are included.

Table A.34 Digital technologies implemented by Company MSE3.

ID	Technology	Status	Key for the DT	SM	SP	SS
1	**Intelligent**	In experimentation	●	●		
3	**Energy saving/efficiency**				●	
4	**Cyber security**	Implemented	●	●		
6	**Virtual Reality (VR)**	Implemented	●	●		
7	**Augmented Reality (AR)**	Implemented			●	
8	**Real-time communication/data**	Implemented	●	●		
9	**Big data**	In implementation	●	●		
11	**CPS/CPPS**	In consideration		●		
12	**IoT/IoS/IIoT**	In consideration	●	●	●	
14	**Cloud computing/cloud manufacturing**	Implemented			●	●
15	**3D printing/additive manufacturing**	Implemented		●		
16	**Smart sensors**	In implementation			●	
17	**Smart product/part**	In implementation			●	
18	**Data analytics/big data analytics**	In implementation			●	
19	**Predictive analytics**	In experimentation		●	●	
21	**Modelling**	In implementation				
23	**Simulation**	Implemented		●		
24	**Forecasting**	Implemented				
25	**Enterprise Resource Planning (ERP)**	Implemented		●		
26	**Radio-Frequency IDentification (RFID)**	In implementation		●		
27	**Machine learning**	In experimentation		●		
28	**Supply Chain Management (SCM)**	Implemented		●		
29	**Manufacturing Execution System (MES)**	Implemented		●		
30	**Product Lifecycle Management (PLM)**	Implemented		●		
36	**Tracking and tracing**	In consideration				
38	**Statistical Process Control (SPC)**	Implemented		●		

Figure A.35 presents another perspective of the company's use of digital technologies that shows the digital initiative they are associated with and the complexity level of its implementation, according to Frank et al., (2019)'s framework.

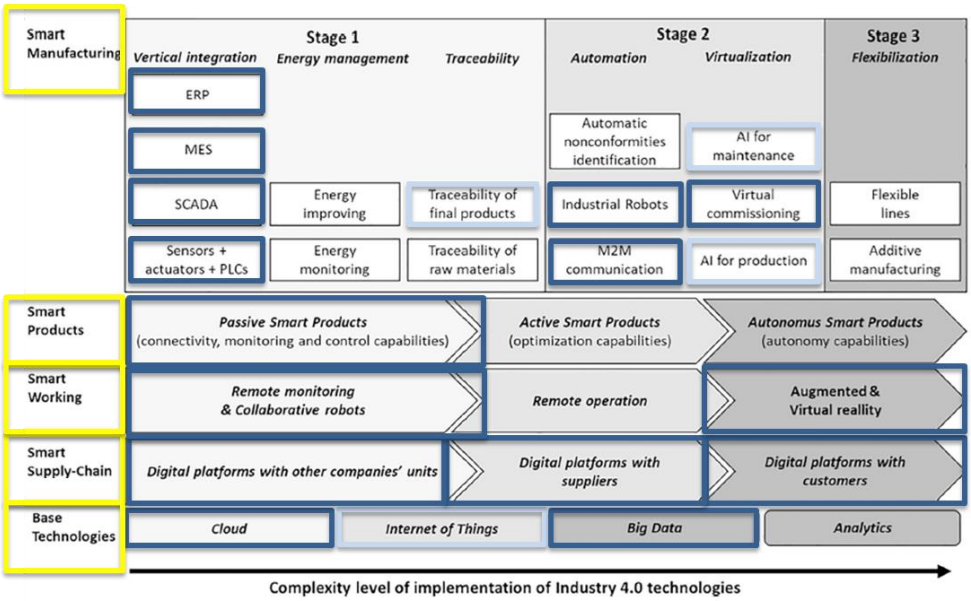

Figure A.35 Company's use of Industry 4.0 technologies (framework by Frank et al., 2019).

Color code: **Yellow** - initiatives underway; **Dark blue** - technologies deployed; **Light blue** - technologies deployed locally or under consideration.

Business process dimension

The company has a process map in operation and also considers itself a process-based organization.

Table A.35 presents the business process the company has affected due to its DT. The table's information also shows the processes that are considered key for the company's DT and in which digital initiatives they are included.

Table A.35 Business processes modified by Company MSE3.

ID	Process	Status	Key for the DT	SM	SP	SS
1.0	**Develop Vision and Strategy**				•	•
2.0	**Develop and Manage Products and Services**	Modified process	•		•	•
3.0	**Market and Sell Products and Services**	Modified process	•		•	•
4.0	**Deliver Physical Products**	Modified process	•	•	•	•
5.0	**Deliver Service**	Process to be developed	•	•		•
NA	**Technology Scanning**	Not documented practice				

Organizational structure dimension

The company has a formally documented organizational structure. In Figure A.36, the level of development of its characteristics is shown.

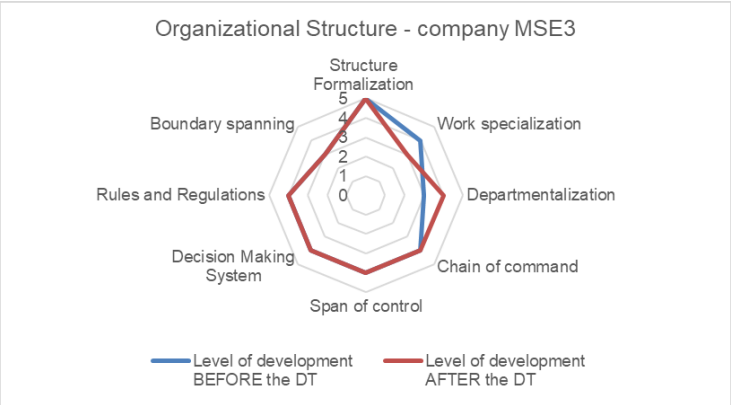

Figure A.36 Level of development of characteristics of the company's organizational structure.

The following changes have been implemented in the organizational structure concerning the DT:

- the company is organized into mini-factories, groups of manufacturing standards that are globally composed of about 50 employees. Transformation projects are piloted by the mini-factories.
- the new range of smart products will require new skills from the sales force. But as the company hardly goes through distributors, its sales structure is already very strong and technically competent too.
- IT has been identified as a strategic part of the company. It was created more than 20 years ago, close to 30.
- for some years now, the company's organization has become very flat. The factories have been broken down into mini-factories, and there are now only three hierarchical levels: the employees, the managers of the mini-factories, and the plant manager.

Competencies dimension

The company has a competency matrix documented by domain. The company has also defined core professions that are enriched with complimentary digital-oriented competencies.

Table A.36 presents the competencies that the company has introduced as a result of its DT. The table's information also shows the competencies that are considered key for the company's DT and in which digital initiatives they are included.

Table A.36 Competencies modified by Company MSE3.

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
2	**Taking Responsibility**	•	5	5	0
4	**Teamwork**	•	5	5	0
5	**Collaborating with Others**	•	5	5	0
6	**Communicating with People**	•	5	5	0
7	**Respecting Ethics**		5	5	0
8	**Environmental Awareness**		5	5	0
9	**Awareness for Ergonomics**		5	5	0
10	**Compromising**		3	4	1
11	**Creating Business Networks**		4	5	1
18	**IT and Technology Affinity**	•	3	4	1

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
21	**Service Orientation/ Product Service Offerings**	●	4	5	1
22	**Business Process Management**	●	4	5	1
23	**Business Change Management**	●	4	5	1
25	**Network Security**		4	5	1
26	**IT Architectures**		4	5	1
27	**Machine Learning**		4	5	1
28	**System Development**		4	5	1
29	**Integrating Heterogeneous Technologies**		4	4	0
31	**Sensors/Embedded Systems**		3	4	1
32	**Network Technology /M2M Communication**		3	4	1
33	**Robotics/Artificial Intelligence**		3	4	1
34	**Predictive Maintenance**		2	4	2
35	**Modelling and Programming**		3	4	1
36	**Big Data/Data Analysis and Interpretation**		2	4	2
37	**Cloud Computing /Architectures**		2	4	2
40	**Data Security**		4	5	1
45	**Life-long Learning**		4	5	1
47	**Innovating**		3	4	1
48	**Creativity**		3	4	1
50	**Change Management**		3	4	1
61	**Individual Responsibility**		4	5	1
64	**Flexibility**		3	4	1
65	**Adaptability and Ability to Change Mind-set**		3	4	1
68	**Business Model Understanding**		3	4	1

Organizational culture dimension

The company's culture is based on the core concept of a unifying project born in 1989 that is based on values, principles, and behavior. The culture is also characterized as an autonomous culture, with autonomy and accountability at all levels.

Figure A.37 presents the level of development of both basic traits and digital traits of the company’s culture.

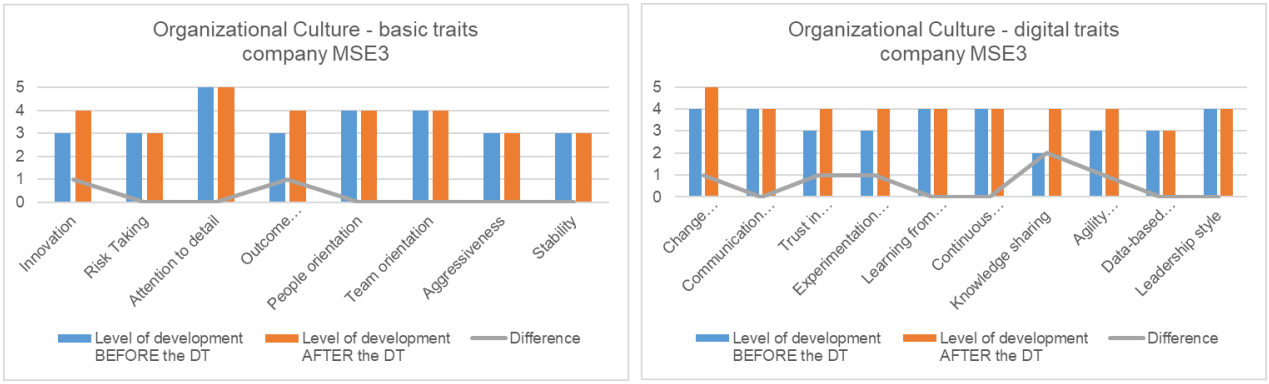

Figure A.37 Level of development of the traits, basic and digital, of the company's organizational culture.

Performance measurement and management

Resources used to guide the DT

To guide its DT, the company is in contact with universities and research and technology institutes to be constantly aware of new technologies.

Key performance indicators (KPIs) for the DT

The DT is seen as a way to optimize the company's processes and expand the range of its products and services, not as a business area measured by KPIs. The assumption is that if each change is made with the objective of process optimization, the process KPIs are used to determine the success of the initiatives. Therefore, their processes are monitored by general indicators such as service rate, throughput time, manufacturing costs, quality, etc.

Main challenges

The biggest challenge the company identifies is to accompany the employees. People are reluctant because they are moving into the unknown, into something more complex. The management considers that the company has to move forward in stages. The evolution must be supported by a management team that is open to innovations in methods and technologies.

The process of involving employees, whatever the sector, is the most important during a DT, and that is why their organizational culture project is key for the DT success and also in its continuous improvement process.

Company LE

Case Study

Case background

Company LE, a French LE that manufactures mainly a range of bearings for the aerospace, automotive, and heavy-duty industries, was established in the 10s. An overview of the company's main information is shown in table A.37.

Table A.37 Overview of Company LE

Attribute	Information (data from 2019)
Industrial Sector	Industrial mechanics
Staff	~5250 employees
Turnover	~1010M€
Exports	~85% of the turnover
R&D Investments	~20% of the turnover
Size	Large Enterprise (LE)
Company locations	Nine production sites (six in France) and 18 sales offices.
Product offerings	Range of bearings, housings, linear guides, constant velocity joints, encoders, vehicle spare parts, and maintenance products.
Markets	Aerospace, Automotive, and Heavy Duty industries mainly.

Company's context

External environment

The factors in the external environment identified by the company are presented in Table A.38.

Table A.38 Company LE's External Context's factors and potential triggers of a DT

ID	External Factor	Triggers of the Digital Transformation
EC01	**Technology**	Technological trends in the industry, new techno.
EC02	**Economy**	No factors identified.
EC03	**Market**	Trends and developments in the markets in which the company operates.
EC04	**Politics**	No factors identified
EC05	**Regulation**	Regulation of the automotive and aeronautical industries. Especially the evolution of regulations.
EC06	**Resource**	No factors identified.
EC07	**Environment**	No factors identified.

Internal context

The state of the factors in the company's internal context before beginning its DT is presented in Table A.39.

Table A.39 Company LE's internal context description before beginning the DT.

ID	Features	Value=1 (Worst)	Value =5 (Best)	Score (based on a Likert scale)
IC01	Access to resources for transformation and innovation	Insufficient	Sufficient	**2**
IC02	Adoption of new technologies	Low	High	**3**
IC03	R&D investment	Low	High	**1**
IC04	Product Customization Capability	Low	High	4
IC05	Consideration of processes and standards	Low	High	5
IC06	Leadership engagement	Low	High	**1**
IC07	Organizational culture flexibility	Low	High	**1**
IC08	Strategy definition	Dictated by leadership instinct	Based on market research and analysis	4
IC09	Decision-making	Restricted to the manager	Board of Directors	5
IC10	Organizational Structure formality	Low	High	5
IC11	Organizational Structure agility	Low	High	1
IC12	Human Resources engagement	Several domains	Specific domain	5
IC13	Exposure to human resources development (inside the industry)	Low	High	5
IC14	Exposure to human resources development (outside the industry)	Low	High	1
IC15	Industry knowledge and experience	Focused on a specific area	Dispersed in different areas	4
IC16	Alliances with universities	Low	High	5
IC17	Alliances with research institutions	Low	High	5
IC18	Performance of key activities	Outsourcing	Within the company	4
IC19	Dependence on the collaborative network	Low	High	5
IC20	Customer relationship	Weak	Strong	5
IC21	Supplier relationship	Weak	Strong	5
	Digital Willingness component			3.00
	Digital Preparedness component			3.59
	Digital Readiness			**3.62**

Figure A.38 presents the change between the factors of the company's internal context before and after beginning its DT.

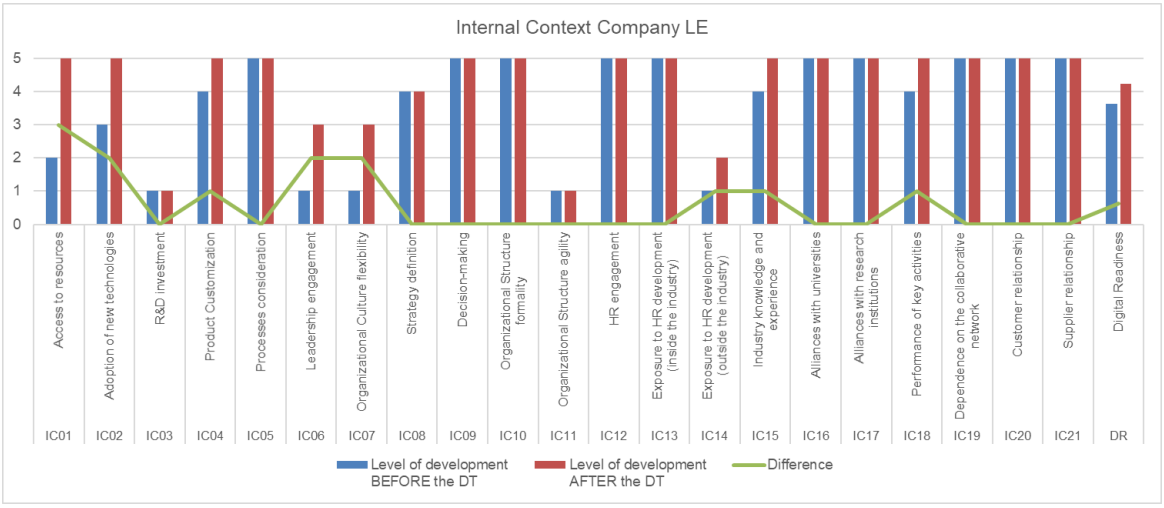

Figure A.38 State of factors in the internal context of Company LE before and after beginning its DT.

Digital strategy

The objective of the digitization of products is to be able to propose to customers the exploitation of the data gather by the sensors provided to them, and to monetize the service associated. This is what is being done through the development of monitoring services: to be able to provide customers with equipment control and failure prediction. The increase of the company's sales in the aftermarket is another related objective.

Regarding the digitalization of processes, the objective of the digitization of production tools, for example, is to reduce machine breakdowns by controlling processes with supervision. The target is to reduce costs through task supervision and new revenues through digitized products and services.

The digitalization of processes, products, and services is part of the eight transformation projects included in the company's global strategy. Specifically, the Internet of Things (IoT) development is included in the company's strategic plan for the next three years. For the processes' projects, there is a digitalization roadmap. For the products' projects, there is a roadmap with a rise in digital maturity and commercialization of connected products. It is part of the development process of their innovations.

There are no new business models associated with the DT yet, but there are plans to do so in the future. The aim of developing new connected products is to bring additional added value and to offer this added value for the customer in a different way, i.e., subscription systems for things. New connected products open other perspectives on rental, subscription, and levels of service that can be variable depending on what the products and services bring to the customer.

As soon as the digitalization projects are part of the company's strategic plan, they manage to obtain sufficient funding. The current constraint for the company is the lack of availability of the relevant human resources which prevents them from dedicating their time to smart products and services projects.

Digital initiatives

As a part of the operational excellence program launched in 2015 at three of its French sites, the company has deployed a more connected production tool, where human intervention is focused on value-added tasks.

The company does not have any connected products or IoT products on the market yet. It is something that is still in the development phase. The company has two IoT projects in development. The first IoT subject is monitoring, which is an object that is connected to the cloud, a box that does edge computing, i.e., local processing, and that sends indicators directly to customers via the cloud. The company is currently testing the product on the market. The other subject is the development of connected lubrication, lubrication in machines that incorporate bearings. Lubrication is essential for the life span and the reduction of

maintenance operations. Therefore, the company is working on several projects around lubrication, but these are solutions that are connected to the cloud, which will allow customers to manage their lubrication on machines more easily.

Figure A.39 shows the level of digitalization of the company's production process, and Figure A.40 shows the level of digitization of its main smart product.

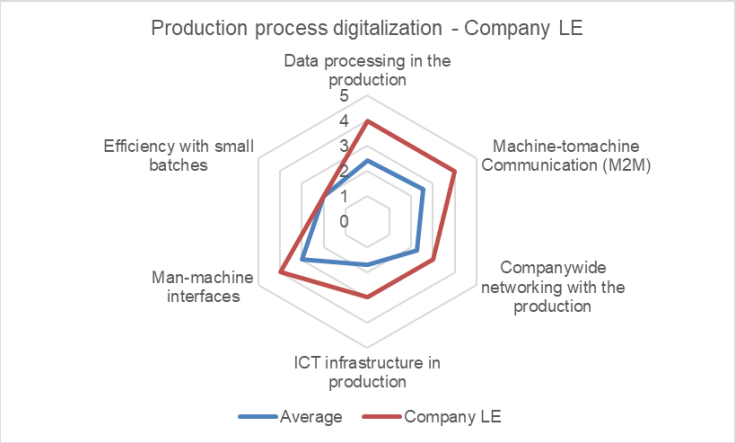

Figure A.39 Level of digitalization of the production process.

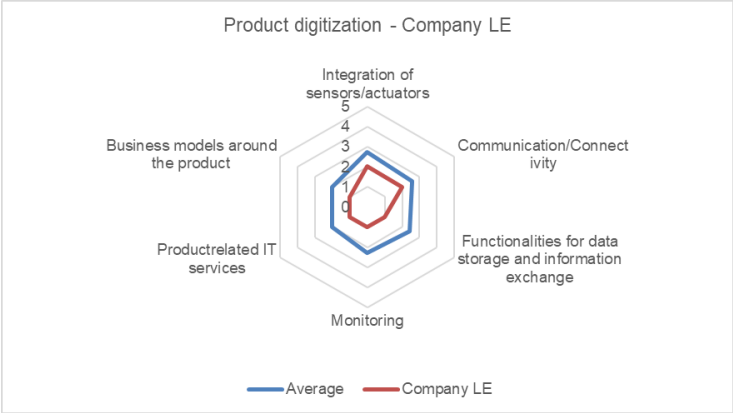

Figure A.40 Level of digitization of the product.

Digital Transformation

The communication of the DT project among the company's employees is planned to be deployed through the communication of the new strategic plan.

The implementation of new smart products and processes follows the process "Research and innovation, products, processes."

Technology dimension

There is no information if the company has a technology architecture in which all technologies and their interactions are documented, but the company documents each technology implemented at the end of each project.

Table A.40 presents the technologies considered by the company and their status inside the company. The table's information also shows the technologies that are considered key for the company's DT and in which digital initiatives they are included.

Table A.40 Digital technologies implemented by Company LE.

ID	Technology	Status	Key for the DT	SM	SP	SS
2	**Intelligent control**	In implementation		●	●	●
4	**Cyber security**	In implementation			●	●
7	**Augmented Reality (AR)**	In experimentation		●		
8	**Real-time communication/data**	Implemented		●		
9	**Big data**	In implementation		●	●	●
12	**IoT/IoS/IIoT**	In implementation	●		●	●
14	**Cloud computing/cloud manufacturing**	In implementation	●	●	●	●
16	**Smart sensors**	In implementation	●		●	
17	**Smart product/part**	In implementation	●		●	
18	**Data analytics/big data analytics**	In implementation		●		
19	**Predictive analytics**	In implementation	●		●	●
20	**Data visualization**	In implementation		●	●	●
23	**Simulation**	Implemented			●	
25	**Enterprise Resource Planning (ERP)**	Implemented	●	●		
26	**Radio-Frequency IDentification (RFID)**	In implementation			●	●
29	**Manufacturing Execution System (MES)**	Implemented		●		
30	**Product Lifecycle Management (PLM)**	In implementation	●	●	●	
33	**CAM, CAD, CAx**	Implemented	●	●	●	●
34	**Operations planning**	Implemented		●		
35	**IT-based production management**	Implemented		●		
36	**Tracking and tracing**	Implemented		●		
40	**Edge Computing**	In implementation			●	●

Figure A.41 presents another perspective of the company's use of digital technologies that shows the digital initiative they are associated with and the complexity level of its implementation, according to Frank et al., (2019)'s framework.

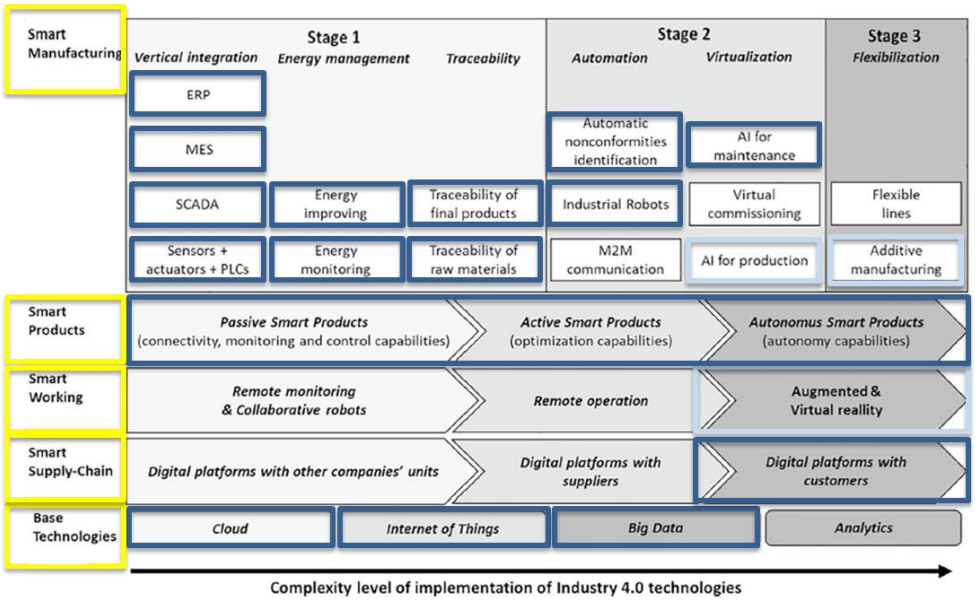

Figure A.41 Company's use of Industry 4.0 technologies (framework by Frank et al., 2019).

Color code: **Yellow** - initiatives underway; **Dark blue** - technologies deployed; **Light blue** - technologies deployed locally or under consideration.

Business process dimension

The company has a process map in operation. All the company's activities are included in an official business process. The company's process map has about ten processes that manage all the company's activities, which are those necessary for the quality certifications that the company has today.

However, as the company's processes are different (not homogeneous), projects such as the implementation of a PLM software take much longer than necessary to converge towards the system specifications.

Table A.41 presents the business process the company has affected due to its DT. The table's information also shows the processes that are considered key for the company's DT and in which digital initiatives they are included.

Table A.41 Business processes modified by Company LE.

ID	Process	Status	Key for the DT	SM	SP	SS
1.0	**Develop Vision and Strategy**	Modified process	•		•	•
2.0	**Develop and Manage Products and Services**	Modified process			•	•
3.0	**Market and Sell Products and Services**	Modified process	•		•	•
4.0	**Deliver Physical Products**	Modified process		•	•	
5.0	**Deliver Service**	Process to be developed	•			•
6.0	**Manage Customer Service**	Modified process	•		•	•
7.0	**Develop and Manage Human Capital**		•			
8.0	**Manage Information Technology**	Modified process	•		•	•

ID	Process	Status	Key for the DT	SM	SP	SS
11.0	**Manage Enterprise Risk, Compliance, Remediation, and Resiliency**		•			
12.0	**Manage External Relationships**	Modified process	•		•	•
13.0	**Develop and Manage Business Capabilities**		•			

Organizational structure dimension

The company has a formally documented organizational structure. In Figure A.42, the level of development of its characteristics is shown.

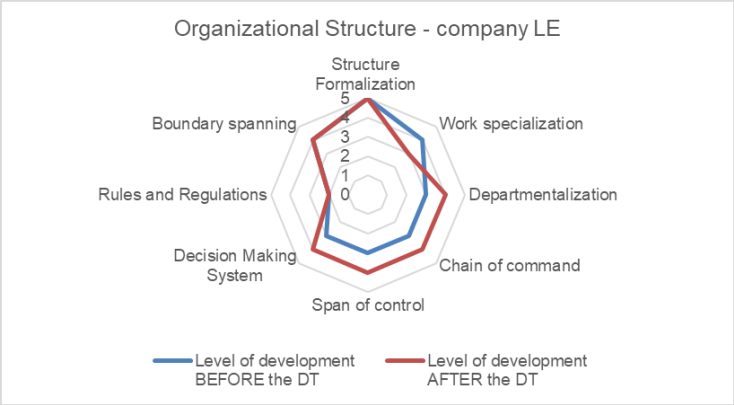

Figure A.42 Level of development of characteristics of the company's organizational structure.

The following changes have been implemented in the organizational structure concerning the DT:

- there is one person in the Innovation team who is assigned to help employees with the phases of development of new products, both in terms of creativity and to facilitate the use of agile methods;
- for the really specific skills linked to the DT, the company hires new people, so new positions are created with this objective;
- the company's structure is going to evolve in each of the Business Units to be prepared for the marketing of smart products and services;
- a new job position, responsible for monitoring the implementation of new smart products and services, is going to be created;
- new business developers focused on smart products are being integrated to the team to handle the IoT-related developments.

Competencies dimension

The company has defined competency matrices and their evolution. These matrices are evaluated to identify the competencies that are rare and the competencies that need to be secured. In this respect, the company has now clearly identified the professions it wants to integrate and the associated competencies. The question is: Is it necessary to have them internally, or can they be found externally or by subcontracting them? Nevertheless, concerning the evolution of the competencies dimension, the process of analysis is well structured.

Table A.42 presents the competencies that the company has introduced as a result of its DT. The table's information also shows the competencies that are considered key for the company's DT and in which digital initiative they are included.

Table A.42 Competencies modified by Company LE.

ID	Competency	Key for the DT	Level of development BEFORE the DT	Level of development AFTER the DT	Difference
5	**Collaborating with Others**	•			
21	**Service Orientation/ Product Service Offerings**	•	2	4	2
27	**Machine Learning**	•	2	3	1
30	**Mobile Technologies**		2	3	1
31	**Sensors/Embedded Systems**	•	3	4	1
33	**Robotics/Artificial Intelligence**		2	3	1
34	**Predictive Maintenance**		2	4	2
36	**Big Data/Data Analysis and Interpretation**		1	4	3
37	**Cloud Computing /Architectures**	•	1	4	3
40	**Data Security**		1	2	1
46	**Knowledge Management**		2	3	1
47	**Innovating**		3	4	1
48	**Creativity**		3	4	1
68	**Business Model Understanding**	•		3	3
76	**Magnetism**		3	3	0
77	**General Digital Competencies**		2	3	1

Organizational culture dimension

The company does not have a Culture Deck or another tool to document its organizational culture, but it has documented an ethical charter and its core values:

- performance, as measured by customer satisfaction;
- proximity, through a global presence;
- team spirit, through the solidarity that unites the teams;
- respect, for the rules and for the company;
- professionalism, a guarantee of quality.

Figure A.43 presents the level of development of both basic traits and digital traits of the company's culture.

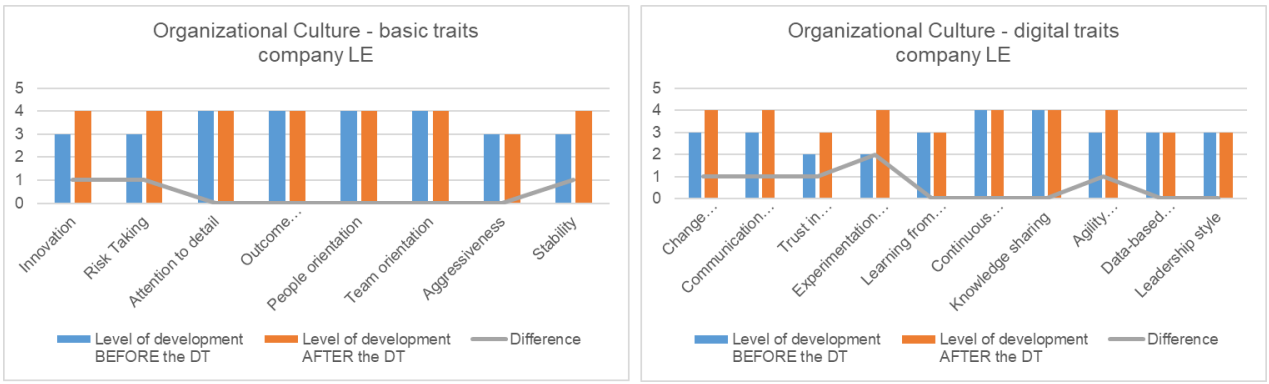

Figure A.43 Level of development of the traits, basic and digital, of the company's organizational culture.

Performance measurement and management

Resources used to guide the DT

The company is not currently using resources to guide its DT process, e.g., business consulting, benchmarking, etc. However, it is in the process of setting up support for a change in the organization with a new IoT business developer.

Key performance indicators (KPIs) for the DT

The company measures the following elements related to its DT:

- regarding the Smart Manufacturing initiative, it has to meet plant performance targets with indicators that are already in place;
- regarding the Smart Products and Services initiatives, there are objectives defined in the roadmap for the evolution of their turnover. The turnover of products and the turnover of services are both quantified.

Main challenges

The company's main challenges lie in the lack of an overall strategy that consolidates all digitalization efforts, mainly those related to products and processes because there are common topics that can be optimized and right now are disconnected. It also struggles with its organizational culture, that is not very flexible, something that affects the agility of the company, especially in innovation projects. The rigidity of the company is a problem. There is, however, a willingness to change the situation.

The company is configured at the image of a mechanical company, so it has difficulty attracting new digital-related talents in its historical, mechanical environment. Changing this will take time, according to management. Right now, people with unique skills in the company can feel a bit disconnected from their world and, after a while, feel that they are perhaps losing competence in their domain because they are not in an environment where there is enough activity to maintain a sufficient level. A competency action plan around digitalization is currently being implemented to address this issue.

Finally, the business units and areas that are going to take the smart products to market are not prepared. The interface between the innovation and the marketing teams becomes complicated because marketing will receive a product from the innovation team that they know little about, that is new to them, and, above all, one that may require a different business model. The sales force will also have to approach the commercialization of new smart products with a different perspective as well.

Appendix 4.7

Within-Case Analysis of case studies

Company SME1

Within-Case Analysis

The DT and the objective that it pursues

The objective of the DT is the digitization of products. The company's digitalization objective is to co-create high-tech digital solutions with its potential customers by developing the “mechatronicity” of its products.

DT’s main elements and their role during the transformation

Digital Strategy element

The company does not really have a proper DT planned in the sense of a company-wide effort. The company is using its mechatronic branch to enter the digital market, but the limited resources available are forcing it to adopt a strategy that depends on new customers to finance the initiatives.

The project-based functioning limits the planning horizon of the DT; therefore, the company does not have the visibility of what can be achieved regarding this effort in the long term. Consequently, the elements are not formally presented before the implementation of the initiatives. Those are handled individually as customer projects. That does not represent a management problem as the team is small and the projects are not numerous. Nevertheless, this case can hardly be classified as a DT.

Digital Transformation element

The projects the company has are developed along with the customers and are strongly centered on technology. The management of projects followed a business process-oriented approach as the type of products developed needed to comply with the many requirements of certifications. Regarding the development of the business dimensions, there is a strong link between the technologies to develop and the competencies needed to develop them. In any case, the focus is on the immediate needs, and the development is partial and short-term.

Performance Measurement and Management System element

The company uses industrial networks and some key customers as references, but mostly for technology development. Its KPIs for the DT remain the turnover, and no assessments are used to follow up on the success of the digital initiatives or to manage the efforts.

The business dimensions involved in the company’s DT and their interactions

The company's focus on technology is strong, and the team in charge of the digital initiatives is small. These two conditions, in part, determine that the changes performed in all the other dimensions are only the minimum required. The planning of all the dimensions and their interactions is not performed. On the other hand, the current state of all its business dimensions is formally documented as it is a requirement of current certifications.

The DT process and the trajectory towards a successful DT

The company performs only four of the five steps of the proposed DT process, and it does so in a partial way.

Regarding the context analysis, the company is very informed of the trends in the external environment, but the low availability of resources to invest in new projects of the magnitude of a DT inhibits any action to respond to any menace identified. Additionally, there are other factors that are not considered formally and can represent opportunities lost as the government programs to incentive manufacturing SMEs digitalization (EC04 political factors). On the contrary, the company does not perform any analysis of the state of its internal context.

The strategy definition then does not benefit from the useful information that can shape their DT efforts, and that leaves the evolution of the business dimensions without a unified direction. The development of the business dimensions during the company's DT is performed in a reactive way, depending on what is needed at the moment by the projects with customers.

The performance measurement and management are still linked to the business KPIs like turnover, but at the same time, the lack of long-term planning makes follow-up less useful. Accordingly, the concept of a digital company as a target is not envisioned.

The trajectory towards an eventual DT is made up of the development of smart products. The company, however, now is facing the problem of having to produce the smart products that had been designed along with the customers. With proper long-term planning, the company could have identified that the current capabilities of its production line will not be able to manufacture a highly-advanced product or that digitizing it could have brought more advantages in this situation.

The influence of the company's context on the development of the DT

The influence of the external environment is identified, especially of the regulation and technology factors. The markets served by the company make the consideration of regulation and technology developments critical to the development of smart products.

The internal context that has not formally been assessed is very polarized, with factors extremely favorable and others with very low development. To highlight the effect of this situation, it is observed that the strategy definition (IC08) and decision making (IC09) that represent instinctive strategic planning has not benefited the company's last efforts. The lack of previous acknowledgment of the low exposure of the employees' development outside their industry (IC14 = 1) is an example of this, as the company intends to explore new markets.

Company SME2

Within-Case Analysis

The DT and the objective that it pursues

The objective of the DT is the digitization of products. The current focus is on the digitalization of products and the introduction of digital tools to improve the company's performance and prepare it for a DT.

DT's main elements and their role during the transformation

Digital Strategy element

The company does not consider a DT an urgent need according to its strategic plans. Nevertheless, current projects are focusing on using technology to improve process performance and technically preparing their products for an eventual change in the market needs.

Accordingly, a digital strategy per se is not defined, but the digital initiatives in progress are formally defined and have a corresponding roadmap. The shortcomings are centered on the association of the documentation of business models only with scenarios in which value creation is totally different from what is currently in place in the company.

Digital Transformation element

The company has not totally engaged in a DT, but it has taken important measures to start the development of the business dimensions. The clarity of the business strategy has given more direction to those efforts. Consequently, the company has implemented significant changes in all dimensions, especially in the organizational structure. The strategic changes to integrate new roles not only to develop but also to commercialize the smart products that the company is developing indicate a look into the long-term needs of the digital initiatives.

Performance Measurement and Management System element

The company is very active in groups that provide references for technological solutions for the industry of the future. It also uses exchanges with industry associations to keep the team updated on new solutions, while the sales teams keep the company informed about the customer needs.

The company still relies mainly on business KPIs such as the commercial success of products but also uses other indicators like the perception of the company by customers and partners. Nevertheless, specific measurement of the development of the business dimension that determined the company's DT is still missing.

The business dimensions involved in the company's DT and their interactions

The company has partially developed all its business dimensions, and a strong focus on technology is not identified, even though it has been focused on developing its smart products. The company, however, has made significant changes in its organizational structure as it considers that this dimension is key in facing a DT. Nevertheless, the planning of all the dimensions and their interactions is not performed. Even though the current state of all its business dimensions is formally documented, dimensions like the organizational culture are described in a general way, a situation that inhibits the identification of the individual traits to develop.

The DT process and the trajectory towards a successful DT

The company performs only four of the five steps of the proposed DT process, and it does so in a partial way.

The company does not analyze its external context formally, and though it belongs to several associations related to the digital context, they do not translate any factor in the environment as a threat that triggers the urgency of its DT. The company does not perform an analysis, formal or informal, of the state of the factors of its internal context.

On the other hand, the company is very structured regarding its strategy definition, even though the process is guided by the leader's instinct. There is congruency between what is interpreted in the external environment and the actions taken inside the company. Consequently, even if the development of the business dimensions is partial and does not involve all the required changes, there is a balance in that development.

The performance measurement and management are still linked to the business KPIs like the commercial success of products, and others are more linked to the company's image, like the external perception of the company or customer satisfaction. Accordingly, the concept of a digital company as a target is not envisioned.

The trajectory towards an eventual DT is made up of the development of smart products. The company, an assembler, declared that digitalization of its production processes is not a priority as it has already evaluated the benefits of such a project, and it was not worth it. This evaluation, however, took place ten years ago.

The influence of the company's context on the development of the DT

The influence of the external environment is identified; however, there are no factors considered as triggers of the DT. The company has started its digital initiatives without any urgency, just to be prepared for an eventual change in the environment.

The internal context has not formally been assessed, but in the evaluation of this study, the willingness component of the digital readiness indicator is in the lower end. Most of the factors that constitute the digital readiness indicator have grown considerably, a possible indication of the effect of each of them on the development of changes within the business dimensions.

Company SME3

Within-Case Analysis

The DT and the objective that it pursues

The objective of the company's DT is to solve problems or take advantage of business opportunities. Its objectives are focused on realizing the business strategy related to the innovation and diversification of the company.

DT's main elements and their role during the transformation

Digital Strategy element

The road towards a DT of Company SME3 started as a trial and error but planning and implementation have been improved thanks to the definition of a formal strategy that has started to give a sense of direction to current DT efforts. Even though there is a trajectory of digital initiatives defined for the DT of the company, there are no roadmaps or business models documented.

Digital Transformation element

The company has evolved very rapidly in the type of changes it is implementing in its business dimensions and how it is managing those changes. The improvement of the digital strategy element is providing better guidance to the DT, and the support of technical advisors from CETIM is helping with managing the projects more appropriately. The changes in each dimension with each digital initiative are starting to go beyond the technology aspect to consider changes in other dimensions and with a long-term vision. However, these changes that are also an answer to the growth of the company due to its success (e.g., organizational structure) are affecting the flexibility and agility of the company.

Performance Measurement and Management System element

The company actively participates in industry associations which enabling it to keep up-to-date with new technology developments. It also has developed a strong relationship with government institutions that have helped with the formalization of its digital strategy. The company has capitalized on this strong bond, taking advantage, especially of government funds for the realization of its digital initiatives.

The company relies on the business KPIs related to the digital initiatives in progress. However, as it advances with its DT efforts, it recognizes that other types of indicators are needed to control the transformation process. Nevertheless, it has not found the appropriate indicators that can help to manage and control its DT.

The business dimensions involved in the company's DT and their interactions

The company's focus on technology is strong, as it was also the development of the appropriate organizational culture to face the company's DT. Even though the development of its business dimensions, in general, is still partial, the evolution of its capabilities is transcending the minimum required changes to involve more fundamental and long-term changes. However, the planning of all the dimensions and their interactions is not performed to optimize results. A highly probable reason is the lack of documentation on the current state of the business dimensions, which affects the visibility of the company's situation.

The DT process and the trajectory towards a successful DT

The company performs only four of the five steps of the proposed DT process, and it does so in a partial way.

Regarding the context analysis, the company is very informed of the trends in the external environment and takes advantage of this knowledge to drive its choices regarding its DT. The availability of financial resources through government programs (EC04 political factors) has funded its digital initiatives, and the fact that the markets it serves were in the process of digitalizing (EC03 market factors) led it to propose new smart products and services. The company does not perform an analysis, formal or informal, of the state of the factors of its internal context.

The strategy definition is still very much guided by the leader instinct, but it is an informed instinct, and it has become more formal with the participation of the CEO in different strategic programs and with the growth of the organizational structure. The development of the business dimensions during the company's DT is strongly focused on technology and is performed in a reactive way, depending on what is needed at the moment of implementation. With each initiative, this situation is also evolving, and even though it is still technology-focused and partial, the type of changes included are starting to become more planned for the long-term.

The performance measurement and management are linked to existing business and process performance. More recently, the company is looking to integrate other KPIs more related to subjects relevant to the digital context, such as Innovation. Officially, the concept of a digital company as a target is not defined, but with each digital initiative, the company is gradually acquiring the capabilities needed to introduce new technologies in a faster manner.

The trajectory towards an eventual DT is made up of what is known in the literature as a typical trajectory for a manufacturer: the development of smart manufacturing, smart products, and services. The company has succeeded in developing three key digital initiatives, and continues to develop more as its DT progresses.

The influence of the company's context on the development of the DT

The influence of the external environment on the DT of the company is strong. The consideration of the relevant external factors when shaping its digital strategy represented for the company the right input for its digital strategy. It also translated into resources, and the right choice of products to be developed through customer collaborations, among others.

The internal context has not formally been assessed, but in the evaluation of this study, the digital readiness indicator is in the lower end (2.14). From the outset, the need to improve the factors that were severely affecting its agility was clear, therefore, the company managed to double its digital readiness (4.05). Nevertheless, the company's growth and the consequent changes in the organizational structure dimension are generating an adverse effect; as it happened with the formalization and growth of the structure, the company is losing its flexibility which was key for the success of its first initiatives.

Company MSE1

Within-Case Analysis

The DT and the objective that it pursues

The objective of the DT is the digitalization of operational processes. The DT has three main objectives. First, to increase the margin and shorten delivery times by automating low-value-added tasks to deliver quickly. Secondly, to increase turnover via the smart or smart or data-driven services, for example.

DT's main elements and their role during the transformation

Digital Strategy element

The company has a specific digital strategy in which the defined digital initiatives are included, each with clear objectives to achieve. Important issues arise from the lack of documentation of the business models of the digital initiatives as the changes in the business dimensions are left without direction. Resources are also a problem, as especially the human resources needed are not available as planning in this regard focuses mostly on financial resources.

Digital Transformation element

The company follows the Business Process Reengineering (BPR) approach to implement the digital initiatives that constitute its DT. The evolution of its business dimensions is only partial, focusing on the immediate changes needed to develop the initiatives. Nevertheless, the company is supported by consulting firms that help in managing its initiatives. As it concentrates on developing the competencies needed to industrialize the new smart products, the company outsources other highly specialized competencies to gain agility.

Performance Measurement and Management System element

The company's main support and reference during its DT is a consulting firm and integrators of technical solutions needed for implementing its digital initiatives. However, the company also participates in industry associations.

The performance measurement is centered on process performance; hence the development of other business dimensions is overlooked. The company, however, is not pressed to evolve as it has access to external support and its efforts are very much limited to achieving shorter delivery times for its products.

The business dimensions involved in the company's DT and their interactions

The company has a good balance in the development of its business dimensions, though the slight predominance of the technology dimension is still present, and it relies strongly on the support of third parties. The company, however, has made significant changes in its organizational structure to formalize its commitment to a DT. Nevertheless, the planning of all the dimensions and their interactions is not performed. The company does not have full visibility of the current state of its business dimensions as the employees' competencies and its organizational culture are not formally documented.

The DT process and the trajectory towards a successful DT

The company performs only four of the five steps of the proposed DT process, and it does so in a partial way.

Regarding the context analysis, the company is very informed of the trends in the external environment, especially those that represent opportunities to expand its market position (EC03 market factors, EC07 environment factors).

The company is very structured regarding its strategy definition, even though the process is guided by the leader's instinct as it is an MSE but in the low end regarding its size. The company's strategic intentions are clear, and that direction guides the digital initiatives, but the lack of completeness of the strategy sub-elements affects the development of the business dimensions. Their development, in consequence, is partial, and even though it is balanced, for the most part, there is a stronger focus on the development of the organizational structure.

The performance measurement and management are strongly linked to process performance, as the main objective of the company's DT is to reduce the delivery time of its products. Accordingly, the concept of a digital company as a target is not envisioned.

The trajectory towards an eventual DT is made up of the initiatives to improve delivery time and the development of new smart products. The company, an assembler, stated that digitalization of its production processes is not a priority as the type of products and the quantity they produce do not require a digital solution.

The influence of the company's context on the development of the DT

The influence of the external environment is identified, especially of the market and environmental factors. The markets they serve represent new business opportunities for the digitization of products and services. Additionally, technology is helping to improve the delivery times of their products.

The internal context has not formally been assessed, but in the evaluation of this study, the willingness component of the digital readiness indicator is very acceptable in general (3.24). Nevertheless, there are certain factors that have seen a significant increase since beginning the DT. An example of this is the access to resources (IC01) and the ability to adopt new technologies (IC02) factors that were considered for the development of the DT.

Company MSE2

Within-Case Analysis

The DT and the objective that it pursues

The objective of the DT is the digitalization of production processes and digitization of products and services. Revenue growth and value creation through services, especially those associated with connected products, are seen as one set of objectives, as are the efficiency, productivity, and quality improvement of production processes.

DT's main elements and their role during the transformation

Digital Strategy element

Company MSE2 had been experimenting with new technologies for some years before defining a formal digital strategy. The strategy formalization was followed by the definition of objectives, digital initiatives, and their roadmaps. Nevertheless, the high-level state of those definitions, along with the lack of description of business models and the allocation of only a part of the necessary resources, are not providing the output needed give direction to the efforts of the DT element.

Digital Transformation element

The teams in charge of the digital initiatives are responsible for identifying the development needed in each of the business dimensions. The process does not follow a particular methodology, but the analysis is based on the business processes of the company. Nevertheless, the development of the business dimensions is still superficial as the teams are centered on understanding the technology. Apart from the technology dimension, only the organizational structure has substantially changed to formalize the importance of the DT. Unfortunately, the shortcomings of the digital strategy, especially the lack of the required resources, are hindering the efforts of the digital initiatives, even from its beginning.

Performance Measurement and Management System element

The company uses industrial associations to keep informed of technological developments inside and outside the industry in which it participates. However, it strongly relies on benchmarking to identify possible menaces to its competitive position. In fact, the reason for its recent focus on DT comes from the advancement of their competitors in this regard.

The company focuses its performance measurement of its DT on indicators that are centered on its digital initiatives. The indicators used can be classified into two types. The first one focuses on the evaluation of potential opportunities, and the second one measures what the company calls maturity of digital initiatives. Both rely on business or operational KPIs.

The business dimensions involved in the company's DT and their interactions

The company's focus on technology is strong, and this situation affects the proper development of the rest of the business dimensions. Consequently, the planning of all the business dimensions and their interactions is not performed. This situation is aggravated by the fact that the company does not have documented the

current state of its business dimensions, aside from the organizational structure and its process map, which affects the visibility of the company situation and potential needs.

The DT process and the trajectory towards a successful DT

The company performs only four of the five steps of the proposed DT process, and it does so in a partial way.

Regarding the context analysis, the company's use of benchmarking is a probable reason that the trigger of its DT is the fact that the competitors have already started theirs (EC03 market factors). On the contrary, the company does not perform any analysis of the state of its internal context.

The strategy definition is formal and based on market research and analysis. However, the lack of definition of the strategy sub-elements makes it difficult to handle the development of the business dimensions in its completeness. The company's focus is on the development of the technology aspect, and this focus affects the development of the rest of the dimensions.

The performance measurement and management are still linked to the business KPIs like the profitability of the digital initiatives, but also their contribution to the attractiveness of the company as an employer. It also considers the number of proofs of concept and projects to be launched as, according to the company, those represent the maturity of its digital initiatives. Accordingly, the concept of a digital company as a target is not envisioned.

The trajectory towards an eventual DT is made up of what is known in the literature as a typical trajectory for a manufacturer: the development of smart manufacturing, smart products, and services. The company develops all three initiatives at the same time but without any coordination between the teams, as it considers them independent subjects. More recently, informal collaboration is taking place following situations that have revealed common issues that need to be handled in coordination.

The influence of the company's context on the development of the DT

The influence of the external environment is identified, especially of the market factors. The trigger of the DT is the digitalization of the competitors, a fact that shaped the company's digital strategy and the type of digital initiatives that constitute it.

The internal context has not formally been assessed, but in the evaluation of this study, the digital readiness indicator is on the higher end (4.19). The level of its digital readiness indicates a good state to begin its DT. Nevertheless, the low level of its R&D investment (IC03=2.0) is an issue that can potentially be linked to the fact that the company does not feel comfortable dealing with the complexity associated with the digital context.

Company MSE3

Within-Case Analysis

The DT and the objective that it pursues

The objective of the DT is the digitalization of operational processes. The company's stated objective is twofold: to increase productivity and improve the comfort of its employees. But the aim is also to be a Lean organization allowing the delivery of its main product in five days for each order and continuously improving its processes.

DT's main elements and their role during the transformation

Digital Strategy element

The digital strategy of Company MSE3 is well defined, particularly for the digital initiatives that constitute it, but lacks documentation of the associated roadmaps and business models. The company also has a model for the allocation of resources based on the reinvestment of what is gained from previous DT efforts, a strategy that links the advancement of the projects to the capitalization of new opportunities. Even though this is a powerful control to ensure success, it also inhibits the visibility of future projects.

Digital Transformation element

The company supports its DT process with a combination of continuous improvement and business process-oriented approaches. Its DT has evolved for many years now, and though it is strongly focused on technology, the development of the rest of the dimensions is not only centered on the immediate needs of the digital initiatives. The organizational structure, for example, has started to resemble a more flexible organic structure, and the technical competencies developed are enriched with complementary ones that provide them with supporting characteristics. The business dimension that is perhaps less evolved and that is now their most important project is the organizational culture. Aware of its importance, the company is focusing on efforts to promote a culture that is not afraid of the unknown.

Performance Measurement and Management System element

The company has a strong link with universities and research institutions that are the reference for guiding its digital initiatives.

The performance measurement of its DT relies entirely on its processes' performance, as the DT is seen as a medium to improve the performance of its processes. However, measuring results rather than developing critical traits of its organizational culture, for example, inhibits the process of building the company's capabilities to prepare it for the implementation of the targeted digital initiatives.

The business dimensions involved in the company's DT and their interactions

The company has a strong focus on the technology and process dimensions, especially on developing the operational processes. It also relies on its work in the rest of the dimensions as a result of its continuous improvement approach. The development of the business dimensions, however, is partial in general and its organizational culture is underdeveloped, which is now becoming an opportunity area during the DT. The

planning of all the dimensions and their interactions is not performed to optimize results, even when the current state of its business dimensions is formally documented.

The DT process and the trajectory towards a successful DT

The company performs only four of the five steps of the proposed DT process, and it does so in a partial way.

Regarding the context analysis, the company is informed of the trends in the external environment, but it only recognizes as the trigger of its DT the need to fulfill the requirements of the customers (EC03 market factors). The company does not perform an analysis, formal or informal, of the state of the factors of its internal context.

The strategy definition is formal and based on market research and analysis. However, the lack of definition of the strategy sub-elements makes it difficult to handle the development of the business dimensions in its completeness. The company's focus is on the development of the technology aspect and this focus affects the development of the rest of the dimensions.

The performance measurement and management are still linked to the business KPIs like the service rate, manufacturing costs, quality, etc. Accordingly, the concept of a digital company as a target is not envisioned.

The trajectory towards an eventual DT is made up of what is known in the literature as a typical trajectory for a manufacturer: the development of smart manufacturing, smart products, and services. The company develops all three initiatives at the same time, with a team in France handling the smart manufacturing initiative and a team in Germany handling the development of new smart products and services. Coordination exists between the two teams as the products must be later industrialized by the French team.

The influence of the company's context on the development of the DT

The influence of the external environment is identified, especially of the market factors. The main trigger of the DT is the need to satisfy the customer's requirements regarding delivery times.

The internal context has not formally been assessed, but in the evaluation of this study, the digital readiness indicator is on the higher end (4.33). The level of its digital readiness indicates a good state to begin its DT. The company, however, significantly improved its access to resources (IC01) and the ability to adopt new technologies (IC02) factors to better face its DT.

Company LE

Within-Case Analysis

The DT and the objective that it pursues

The objective of the DT is the digitalization of production processes and the digitization of products and services. For the product the aim is to be able to propose exploitation of the data gathered by the sensors provided to the customers and to monetize the service associated. This is what is being done through the development of the monitoring service: to be able to provide customers with equipment control and failure prediction. Regarding the processes, the aim is the digitization of production tools to reduce machine breakdowns by controlling processes with supervision.

DT's main elements and their role during the transformation

Digital Strategy element

The company has a well-defined digital strategy that is part of its global business strategy. However, it manages the digital initiatives separately. This scheme creates a disconnect between teams for whom collaboration should be a must. The company has documented roadmaps for each initiative, but does not have documented its business models. Regarding the resources, the company assigns them systematically to all its official projects; however, there is an issue with those that are not considered such as the official participation of the operations personnel in the projects.

Digital Transformation element

The company guides its DT with the process "Research and innovation, products, processes." This process is used to guide the initiatives of smart manufacturing and smart products. There is not a process, however, that guides the DT as a whole, with all its implications.

This same problem, the lack of a consolidated vision of a DT, inherited from the digital strategy, along with the rigidity of a company of its size, inhibits the identification of changes and its swift implementation. Especially affected is the organizational culture dimension that struggles to evolve to become more open and flexible to change. The company is also stuck in planning the initiatives and has not developed other capabilities for commercializing what it is currently building (i.e., smart products and related services).

Performance Measurement and Management System element

The company does not rely on other sources as a reference for its DT, though it is an active member of industrial associations. More recently, in this regard, the company is looking to introduce a position of business developer that can be responsible for the Internet of Things (IoT) related products and services.

The performance measurement relies on the commercial success and process performance of the digital initiatives. Consequently, there is no management of the success of the evolution of the business dimensions that, in the end, define the company's DT.

The business dimensions involved in the company's DT and their interactions

The company's focus on technology is strong, but as the digital initiatives are part of its business strategy, it has plans for developing the rest of the dimensions, except for the organizational culture. The company's

origins and dependence on the Japanese corporate office made up for a very rigid organizational culture that is currently affecting the company's flexibility. Additionally, the planning of all the dimensions and their interactions is not performed to optimize results, even when it has the current state of almost all its business dimensions formally documented, with the exception of the organizational culture.

The DT process and the trajectory towards a successful DT

The company performs only four of the five steps of the proposed DT process, and it does so in a partial way.

Regarding the context analysis, the company is informed of the trends in the external environment. Currently, the company is centered, however, on capitalizing on new technologies by providing new solutions that will give it an edge in the market it participates. On the other hand, the company does not perform an analysis, formal or informal, of the state of the factors of its internal context.

The strategy definition is formal and based on market research and analysis. However, the lack of definition of the strategy sub-elements makes it difficult to handle the development of the business dimensions in its completeness. The company's focus is on the development of the technology aspect, and this focus affects the development of the rest of the dimensions.

The performance measurement and management are linked to process performance concerning its smart manufacturing initiative and to the commercial success (turnover) of new smart products and services. Accordingly, the concept of a digital company as a target is not envisioned.

The trajectory towards an eventual DT is made up of what is known in the literature as a typical trajectory for a manufacturer: the development of smart manufacturing, smart products, and services. The company develops all three initiatives at the same time but with two different teams.

The influence of the company's context on the development of the DT

The influence of the external environment is identified especially in the technology and market factors. The trigger for the company's DT is the combination of the trends of the markets in which it operates and the technology developments that offer plenty of opportunities to fulfill the market needs.

The internal context has not formally been assessed, but in the evaluation of this study, the willingness component of the digital readiness indicator is very acceptable in general (3.62). Even though the company still lacks some development on certain factors, it had to substantially improve the level of its access to resources (IC01) and the ability to adopt new technologies (IC02) factors to better face its DT.

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