Developing an Actionable Framework for the Digital Transformation towards Industry 4.0

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Abstract

The recent developments in technology have propelled humanity forward at all levels of society. In the industrial sector, the development in sensor technology, Big Data, Artificial Intelligence (AI) and Internet of Things (IoT) have enabled the fourth industrial revolution: Industry 4.0. With such a transformational concept, however, many doubts and challenges may arise, especially for "traditional" organisations, with little expertise and capabilities to keep up with technology developments. This inertia to act can even challenge the very survival of some organisations.

This research aims to develop an actionable framework and roadmap to serve as a foundation for the transition towards Industry 4.0. This type of holistic and practical view of the digital transformation was lacking in the literature and could prove useful for practitioners and academics alike. The framework was developed taking into account the vast literature on the Industry 4.0 topic, but also leveraging expertise of consulting firms and technology start-ups. Furthermore, other concepts such as change management and the Agile methodology were combined with the more technical Industry 4.0 body of knowledge to create these tools. The framework is complemented with a practical case study to illustrate its application in a real case, in the automotive industry. With all these tools, organisations facing the digital transformation challenge can find some guidelines and accelerate the change process.

The framework developed looks at enablers and barriers across the people, processes, technology triad and translates those enablers and barriers to Industry 4.0 characteristics, such as: connectivity, visibility, transparency, forecasting capabilities and adaptability, among others. The focus of the roadmap lies in the first steps in this incremental change process. However, properly executing these first steps can already unlock large benefits for organisations: reduction of non-valued added activities, 20% increase in cost savings associated with continuous improvement initiatives and one percent point increase in efficiency metrics (according to a baseline scenario). Other benefits such as quality and transparency improvements and more sustainable operations are also achieved.

Resumo

Desenvolvimento de um *framework* prático para a transformação digital rumo à Indústria 4.0

Os recentes desenvolvimentos tecnológicos têm impulsionado a humanidade a todos os níveis da sociedade. No setor industrial, o desenvolvimento de tecnologia de sensores, *Big Data*, Inteligência Artificial e *Internet of Things* (IoT) permitiu o surgimento da quarta revolução industrial: a Indústria 4.0. Com um conceito tão transformacional, contudo, muitas dúvidas e obstáculos podem surgir, especialmente para organizações mais "tradicionais", com pouca experiência e conhecimento para acompanhar os desenvolvimentos tecnológicos. Esta inércia de ação pode mesmo desafiar a sobrevivência de algumas organizações.

Este estudo visa desenvolver um *framework* e um *roadmap* práticos que sirvam como base para a transição rumo à Indústria 4.0. Este tipo de visão holística e prática da transformação digital estava em falta na literatura e pode provar-se útil tanto para os praticantes, como para académicos. O *framework* foi desenvolvido tedo em conta a vasta literatura no tema da Indústria 4.0, mas também alavancando os conhecimentos de empresas de consultoria e *start-ups* do ramo tecnológico. Para além disso, outros conceitos como o de gestão de mudança e a metodologia *Agile* foram combinados com o corpo de conhecimento mais técnico sobre a Indústria 4.0 para criar estas ferramentas. O *framework* é complementado com um caso de estudo prático que ilustra a sua aplicação num caso real, na indústria automóvel. Com todas estas ferramentas, organizações que enfrentam os desafios da transformação digital podem encontrar algumas orientações e acelarar o processo de mudança.

O *framework* desenvolvido aborda os pontos facilitadores e barreiras ao longo da tríade pessoas, processos, tecnologia e traduz estes aspetos em características da Indústria 4.0, como: conectividade, visibilidade, transparência, capacidades preditivas e adaptabilidade. O foco do *roadmap* encontra-se nos primeiros passos deste processo incremental de mudança. Contudo, a execução correta destes primeiros passos pode desde logo trazer grandes benefícios para as organizações: redução do número de atividades sem valor acrescentado, incremento de 20% de poupanças relacionadas com iniciativas de melhoria contínua e aumento de um ponto percentual nas métricas de eficiência (de acordo com um cenário base). Outros benefícios como melhorias de qualidade, transparência e sustentabilidade de operações são também alcançados.

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"Missing a train is only painful if you run after it! Likewise, not matching the idea of success others expect from you is only painful if that's what you are seeking."

Nassim Nicholas Taleb

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Acronyms and Symbols

AI	Artificial Intelligence
API	Application Programming Interface
CPS	Cyber-Physical Systems
ERP	Enterprise Resource Planning
FTE	Full-Time Equivalent
IoT	Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
MES	Manufacturing Execution System
MQTT	Message Queuing Telemetry Transport
MVP	Minimum Valuable Product
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OPC	Open Platform Communications
OT	Operation Technology
PDCA	Plan-Do-Check-Act
PDSA	Plan-Do-Study-Act
PLC	Power Line Communication
RFID	Radio Frequency Identification
RPA	Robotic Process Automation
SaaS	Software as a Service
SCADA	Supervisory Control and Data Acquisition
SMO	Smart Manufacturing Object
UX	User Experience
WIP	Work-in-Progress

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Chapter 1

Introduction

1.1 Context and Motivation

With the emergence of new technologies and the increase in computing capacity allowing the processing of large amounts of data, new doors open for companies to excel and use the new technologies to achieve competitive advantage. This is reflected in the digitisation of factories, towards the much-vaunted Industry 4.0. This is such a central issue today that, according to a study by Deloitte and MAPI, 86% of industrial companies consider that smart factories will be the main driver of competitiveness in the next 5 years (Wellener et al., 2019). However, according to the same study, about 50% of the companies surveyed are still not actively investing in initiatives in this field.

The theme of Industry 4.0 becomes even more striking when looking at the numbers that characterize the secondary sector. Data at European level reveal that in 2014 there were about 2.1 million companies in this sector, employing almost 30 million people and generating 1 710 billion euros of added value (Manufuture High-Level Group, 2018) . However, the industrial sector in the European Union has been losing competitiveness vis-à-vis other countries, notably China and even the United States of America. The contribution of the European industry to the overall value added has decreased by around 6 percentage points from 1995 to 2013 (Manufuture High-Level Group, 2018). This is another reason for the European Union to invest in technology and another reason to start mobilising efforts to digitise factories. Manyika et al. (2015) point to a \$3.7 trillion impact on the economy by 2025 from the application of the Internet of Things (IoT) in the industrial sector, while Bradley et al. (2013) estimate \$5 trillion in value added by 2022 due to improvements in asset utilization and increased worker productivity.

The road to full integration of all machines with each other, employees and systems is still long. However, this journey towards the factory of the future begins with one small step: digitise the shop floor in order to receive a continuous flow of data about what goes on in each machine, production line, and the entire factory. This first step allows the factory to start "talking" with the operators, supervisors and managers in order for them to have control over the current state of production. Only after this visualization and monitoring system is operational can it begin to automate some tasks, predict disruptions in operations and finally have the ability to respond to these changes without (or with minimal) human intervention.

According to Burke et al. (2017) there are several reasons that explain this trend of the smart factory: (1) the rapid evolution of technological capabilities; (2) the increasing complexity of supply chains and their global fragmentation; (3) the growth of competitive pressure, especially of start-ups with higher digital skills; and (4) the challenges at the level of human resources and trained labour for industrial work. The environment is then conducive to digitisation, and the benefits extend from improving the efficiency of its assets by around 10% (Wellener et al., 2019), to increasing the quality of its products, reducing costs and improving security and sustainability (Burke et al., 2017).

Given the disruption in this area, it is imperative for companies to start modernising, not only as a way to expand the business, but even to protect themselves from their competitors, both the traditional ones with more resources to invest in this digital transition, as well as from new competitors whose business models are already native to the digital world (Hanley et al., 2019; Burke et al., 2017). Despite this urgency to invest in the smart factory, the investment and choice options at the technical level can be overwhelming, leading organizations to get stuck in a state of inertia. According to Hanley et al. (2019), most organizations still use traditional productivity tools, such as spreadsheets, to access, analyse and process the data collected from their assets (about 88% of the organizations surveyed). On the other hand, sensor technologies and Robotic Process Automation (RPA) are only used by 26% and 31% of the respondents, respectively, while data visualization technologies are already starting to be used more frequently (about 62%), but still far from being a ubiquitous practice, especially when combined with reading data through sensors in real time. It is precisely at this early stage of the transformation of traditional factories into intelligent ones that there is enormous potential to add value.

1.2 Deloitte and the Project

This project was carried out by Deloitte, a leading consulting firm which helps its clients achieve better results in various areas, namely in business and operations. Due to the Industry 4.0 potential, it is only natural that Deloitte would be one of the leading enablers and sponsors of this digital transformation. In partnership with proGrow, a start-up enabling shop floor digitisation tied with continuous improvement and collaboration, Deloitte is helping its clients make this transition to the smart factory in the most effective manner. proGrow developed a web-based platform that allows organisations to monitor indicators and production in real-time, while also enabling continuous improvement initiatives and collaboration throughout the organisation in a centralized manner. Deloitte's role is to understand the client's needs and to implement and tailor the platform according to those needs.

The project developed intends to help a company in the automotive industry to take the first steps towards the smart factory paradigm, through the implementation of the proGrow platform. The situation in the shop floor of the company was that of a traditional manufacturing company, with a low level of automation in data acquisition and KPI (Key Performance Indicator) tracking. Furthermore, the digitisation of workflows and continuous improvement initiatives was non-existent. This situation leads to the commitment of valuable employee-hours to tasks like inputting data into legacy systems, tracking indicators and filling in continuous improvement boards and checklists. This is not the most optimal utilisation of the workforce, especially with the availability of tools that allow the shop floor to be more automated and digital.

1.3 Objectives

The aim of this report is to establish a roadmap for industrial companies with low-levels of digitisation to take the first steps towards the smart factory paradigm. The proGrow platform is a key enabler of this change and the project described is used as a case study to support the recommendations related to the digital transformation of the company. The increased visibility and enhanced collaboration enabled by the platform are expected to not only reduce administrative hours spent in non-value adding activities, but also to improve overall efficiency throughout the company. These improvements can be realised due to the increased visibility and transparency in the KPIs.

This framework is developed based on the existing literature on the Industry 4.0 topic. However, an important contribution to this roadmap comes from the empirical evidence acquired while working on the case study and experiencing the challenges of this digital transformation. By combining both academic and practical knowledge, this framework is intended to serve as a tool to direct practitioners towards the digitisation of their organisations in an effective manner.

1.4 Methodology

The project described here involves various organisations and stakeholders. Thus, the first month of this project was used to get acquainted with Deloitte and proGrow, the developers of the proposed solution. At the same time, a literature review was conducted to establish a foundation to develop the intended framework and roadmap.

The next phase of the project was focused on developing the framework while systematically gathering the requirements and needs of the client organisation and assessing the current situation. The feasibility of each of the requirements was evaluated and configurations were tested in the proGrow platform. This led to various adaptations regarding the scope of the project. In the final months, the Deloitte and proGrow teams started developing the customised solution, taking into account the roadmap built throughout this time. Figure 1.1 highlights the timeline and distribution of the tasks in a Gantt chart.

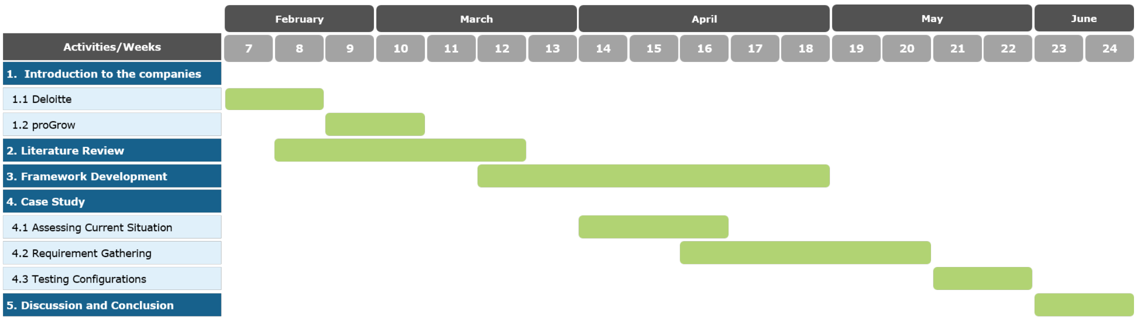

Figure 1.1: Gantt chart of the project development

The methodology followed to build the framework and to develop the case study falls under the area of conceptual research, combined with applied research, which is more action-oriented and problem-centric (Chawla and Sondhi, 2015). In this case, the problem is to define actionable guidelines to carry out the digital transformation in the industrial sector. The role of the case study in this context is to instantiate the ideas presented in the framework, making them easier to grasp, especially for practitioners.

1.5 Structure

This dissertation is organized as follows: in section 2 a literature review is presented to understand the state of the art on the major issues surrounding the project, namely Industry 4.0 and the concepts of shop floor digitisation. Section 3 presents the developed framework and roadmap for the digital transformation towards Industry 4.0. Section 4 describes a practical application of the framework on a case study in the automotive industry. Finally, section 5 discusses the framework and its advantages and limitations, as well as future work that could be developed to improve upon this tool.

Chapter 2

Literature Review

This section was structured in a top-down perspective, starting with more comprehensive concepts such as Industry 4.0, Internet of Things and Smart Factories, gradually narrowing the focus, reaching the concept of the digitisation of the shop floor as the initial phase of the process to reach the intelligent factory. In this process, the concepts of connectivity, visibility and transparency (Joppen et al., 2019) are highlighted and, within each one of them, more specific topics. The following scheme (Figure 2.1 demonstrates the structure adopted for the literature review.

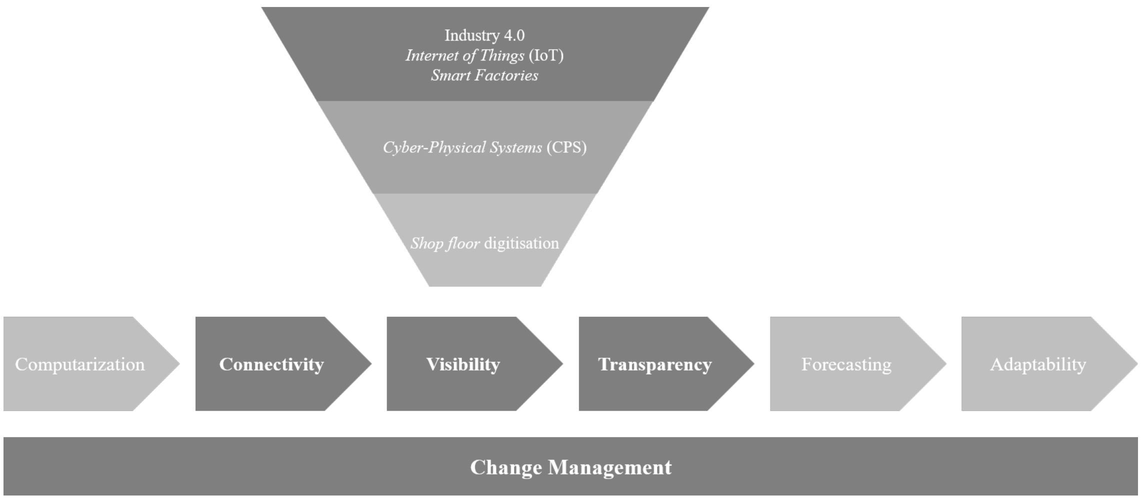

Figure 2.1: Literature Review structure, based on Joppen et al. (2019)

2.1 Industry 4.0 and Smart Factories

Industry 4.0 and Smart Factories are often discussed and have been gaining more and more recognition, both in the academic field and in the business fabric. With so much attention around the topic, it can be difficult to understand the basic concept and its implications for companies.

To approach the topic of Industry 4.0 one needs first to understand the concept that gave rise to it and enables the emergence of this new "type" of industry: the Internet of Things. According to Atzori et al. (2010), it is possible to look at this concept both from the point of view of the connection (Internet) and from the point of view of the objects subject to that connection (Things). From the connection point of view, the concept of the Internet has existed for many years and refers to the connection of several networks between them. The expansion of this concept to all "things" is where the revolution resides. This leap is allowed by the growth of the presence of technologies such as RFID (Radio Frequency Identification) that allow more objects to communicate with each other. This communication is even more complex due to the heterogeneity of objects that can now communicate (Atzori et al., 2010). In the case of the intelligent factory, not only do the machines communicate with the supervisory systems, but machines can also communicate with each other and even with the products (which can absorb information about their current state, transmitting it through RFID tags). Atzori et al. (2010) also highlight the focus on linked objects, which end up taking advantage of advances in Artificial Intelligence (AI) to achieve new capabilities, such as autonomous, proactive and context-conscious behaviour.

Amer et al. (2009) highlight three categories of IoT for enterprise application, namely for (1) monitoring and control; (2) big data and enterprise analytics; and (3) information sharing and collaboration. It is through the application of IoT in these categories that value can be created for enterprises. The monitoring and control category, for example, can add value by enabling the detection of inefficiencies and acting on them, improving productivity and reducing costs (Amer et al., 2009). This dissertation is mainly concerned with this subject, with the issue of big data and business analytics being based on the ability to collect data and monitor it at an early stage. The opportunity for information sharing and collaboration is also addressed.

Industry 4.0 is synonymous with the "fourth industrial revolution" and is usually framed against previous industrial revolutions: (1) the invention of steam machines at the end of the 18th century; (2) the use of electricity and the creation of the production line in 1870; and, finally, (3) the use of electronics and information technology to automate the production process (Kagermann et al., 2013). Today the world is living this fourth industrial revolution, which stems from the concept of the Internet of Things to allow machines and systems to communicate between themselves, minimizing the need for human intervention. It is difficult to reach a consensual definition of the concept due to its scope, but Hermann et al. (2016) define the intelligent factory as one where "cyber-physical systems (CPS) communicate through IoT and assist people and machines to perform their tasks". Monostori (2014) advocates a similar definition, focused on communication between CPS, but without specifying IoT as the means of communication between these cyber-physical systems. As it is visible, the concept of CPS is one of the basic concepts that allows the emergence of Industry 4.0, so it will be analysed in more detail in the next section (2.2).

As for the current state of the art, Wellener et al. (2019) studied various organisations currently in the transition to the Industry 4.0 and divided these organisation in three main groups: Trailblazers, Explorers and Followers. Frank et al. (2019) also proposed a similar division, based on clustering the results from a survey they conducted. In both studies, the smallest group is the Trailblazers (or advanced adopters), while most of the organisations are just taking their first steps towards this new manufacturing paradigm. According to Wellener et al. (2019), the advanced adopters are allocating around 65% of the global factory budget to smart factory initiatives. Frank et al. (2019) find that their advanced adopters group is mostly composed by large size companies (over 500 employees), which is in accordance with Wellener et al. (2019) findings on capital allocation, since bigger companies might have more available resources to allocate to such disruptive initiatives. As it would be expected, Wellener et al. (2019) find that this group is reaping the most benefits in production output, capacity utilization and employee productivity (around 20% increase in the last three years, compared to 8% in the Followers group). Frank et al. (2019) take a deeper look at the technology maturity inside each of the groups, and the major differences are in the traceability of products, in the usage of Artificial Intelligence for production and predictive maintenance and in the usage of information systems like MES (Manufacturing Execution System) and ERP (Enterprise Resource Planning).

Wellener et al. (2019) also look at the obstacles companies are facing when launching their smart factories initiatives and find that the first steps are the hardest. Even though most of the respondents have thought about launching these types of initiatives, this hasn't reflected in tangible projects mostly due to their lack of experience. The best strategy for the late adopters is to replicate the successful initiatives of the Trailblazers and make targeted investments in pilot projects and proofs of concept. The early adopters, on the other hand, are advised to scale their initiatives to the external ecosystem (Wellener et al., 2019).

There are still some reservations and concerns about this paradigm shift, particularly with regard to safety. As equipment communicates over the network, it is more vulnerable to attacks. In addition, the computing and energy capabilities of many of the equipment are very limited, so it is complicated to create a support and defence structure against cyber-attacks (Atzori et al., 2010). In addition, the interconnection between the real world and the virtual world, between IT (Information Technology) and OT (Operational Technology), makes it even more difficult to mitigate these security risks (Haji et al., 2020). There are also unanswered questions on the subject of privacy and data processing, which touch on not so much technological, as social and legal aspects (Atzori et al., 2010). Lee and Lee (2015) also mention the problems associated with the large amount of data generated, which has to be stored, but also accessible and usable, as well as the problem of the rapid evolution of these technologies, with which communication standards cannot keep up. This cyber-security challenges are especially important for the aforementioned Trailblazer group (Wellener et al., 2019). Finally, another obstacle is related to the skills now required for data processing and analysis. Nowadays, skilled labour for this type of tasks is also a restriction to be taken into account (Manyika et al., 2011).

2.2 Cyber-Physical Systems (CPS)

Cyber-Physical Systems can be characterized as systems in which virtual entities (computers) are constantly connected to the physical environment, receiving, processing and issuing information (Monostori, 2014). The concept translates into a "marriage" between the physical and the virtual world, using sensors to emit the data to the virtual system, which in turn processes them and determines the best way to act, transmitting this information again to the physical actuators. These systems give the plant equipment the ability to adapt and react proactively to changes in the production environment. Lee et al. (2015) propose a deconstruction of a CPS into two main components: (1) connectivity to ensure real-time data collection from the physical world in conjunction with a feedback system, and (2) data management and storage capabilities from which analysis can be performed.

There are several models defined for the CPS, starting with the ISA-95 architecture, with the purpose of integrating the enterprise control system and divided into 5 levels (from 0 to 4), this standard refers mostly to the connection between levels 3 and 4 (Jiang, 2018):

- Level 0 deals with the physical production process;
- Level 1 deals with the use of sensors and handling the production process;
- Level 2 refers to the production control, monitoring and supervising the process, already with some level of automation (here are inserted systems like PLCs and SCADA);
- Level 3 refers to the management of operations, how to create production schedules, control the production flow and optimize this same process (here's where systems such as MES come into play);
- Level 4 already links production to the rest of the business, namely the logistics part, establishing schedules for production, distribution and delivery, as well as inventory control (here are inserted systems like ERP).

There are other types of architectures in the literature besides this standard, of which 5C (Lee et al., 2015) and later 8C (Jiang, 2018) stand out. Lee et al. (2015) present the 5C architecture, which intends to be a comprehensive guide for the development and implementation of cyber-physical systems of industrial application. The levels are organised in the form of a pyramid, with the first levels focusing mainly on real-time data acquisition and gradually the focus shifts to analysis and data processing for decision-making (Figure 2.2).

At a first level of connectivity, the focus is on data acquisition and it is critical that data collection and transfer are done in a uniform and integrated manner. The choice of appropriate sensors for real-world data collection is also a critical area within this first tier (Lee et al., 2015). This first tier is one of the main focus of this dissertation, and is a prerequisite for further transformation of a traditional factory into a smart factory.

At the conversion level, it is necessary to transform the data into information that can be used to create value and improve plant efficiency. Examples of this transformation are the self-diagnosis of the machine. Levels III, IV and V are more oriented towards the virtual part of the process and towards data processing and decision-making. While level IV (cognition) aims to support human decision-making, level V (configuration) focuses on the ability of the machine itself to make decisions and adapt to the information it receives in real time (Lee et al., 2015).

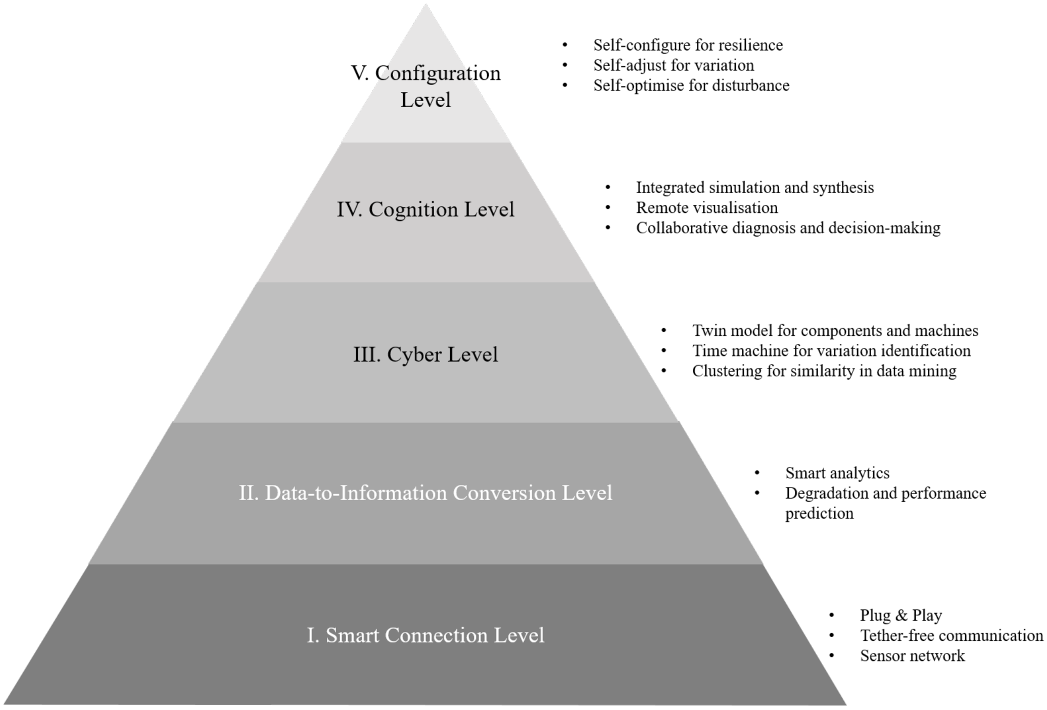

Figure 2.2: 5C architecture, adapted from Lee et al. (2015)

Jiang (2018) complements the 5C architecture with three more "facets" to make the architecture more horizontally integrated. These new concepts are coalition, customer and content. These are not more layers to be added to the model of Figure 2.2, but "facets" transversal to 5C. Coalition (or alliance) refers to the integration of CPS along the supply chain and not only in the production process, which allows flexibility in production scheduling, taking into account the rest of the chain. The customer facet is focused on the customer, taking into account their specifications and even after-sales services. This is an important component given the trend towards mass customisation that is currently observed (Zhong et al., 2017a). Finally, it looks at the traceability of the product and all its inputs and production conditions, as well as information on after-sales services for a given product, which extends the horizon of the architecture to the entire life cycle of the product (Jiang, 2018).

There are, however, some difficulties in implementing CPS on a large scale in order to achieve its potential, namely the complexity of operating a large sensor network, the collection, processing and storage of the large amount of data received in real time, as well as the transformation of all this data into presentable and perceptible information for users. The issue of security is again one of the major obstacles that should be taken into account (Monostori, 2014).

2.3 Shop Floor Digitisation

As it is perceptible by the various CPS architectures (Jiang, 2018; Lee et al., 2015) there are different levels of implementation and autonomy of the smart factory. The scanning of the shop floor is transversally recognized as one of the first steps both in these architectures and in other models (Joppen et al., 2019). Following the development model presented by Joppen et al. (2019), it is possible to divide this digitisation into different phases (Figure 2.3). In the case of this project, the focus is on connectivity, visibility and transparency. In this section, each of these phases is explored in more detail.

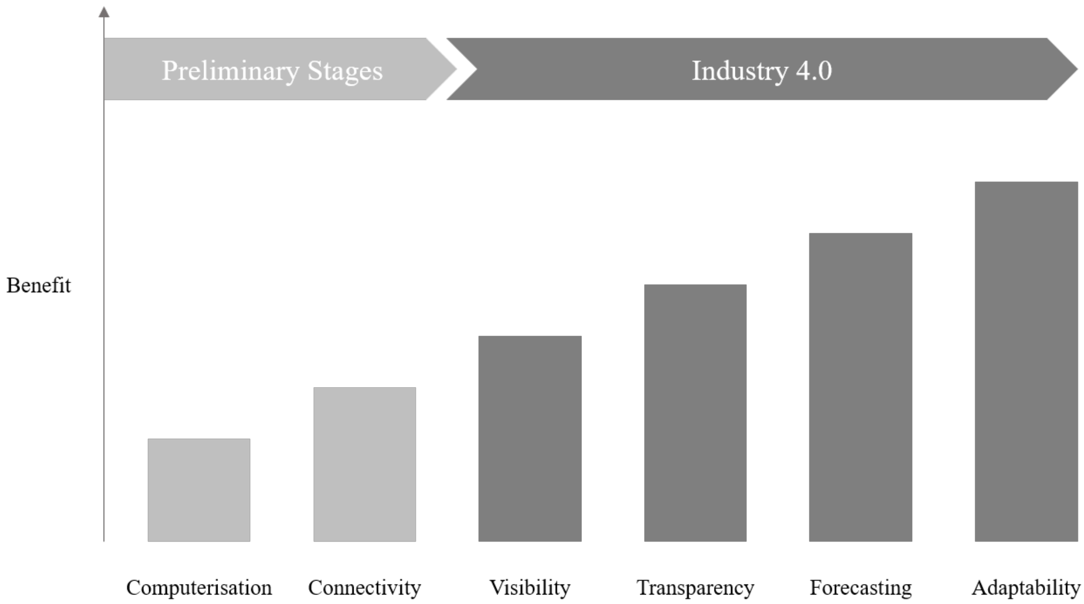

Figure 2.3: Industry 4.0 Development Phases, adapted from Joppen et al. (2019)

2.3.1 Connectivity

At the first level of connectivity, the focus is on bringing information technology (IT) and operational technology (OT) together. OT can be defined as hardware and software that detects or causes a change in equipment, processes or events (Gartner, 2020b), which can be translated into the set of sensors and actuators installed on the shop floor. It is precisely on the issue of sensors and real-time data acquisition that companies starting their digitisation efforts should focus. According to a Deloitte study, companies that are further "behind" in this race for Industry 4.0 tend to allocate only 13% of their budget to implement initiatives related to Industry 4.0 (Wellener et al., 2019). Hence, an initial investment in sensor and data acquisition technology can be a great opportunity with a good cost-benefit ratio.

However, even this step raises some questions, with the "use and understanding of sensor technology" being classified as one of the most important skills to be developed for the digitisation of plants (Mogos et al., 2019). Given the variety of sensors and communication protocols behind data acquisition (Khemapech et al., 2012) it is normal that this is an area of improvement for many companies.

A sensor network consists of several components, namely the sensing unit, processing unit, transceiver and power unit (Khemapech et al., 2012). Today, all of these components have undergone considerable improvements, particularly in terms of the size and processing capacity of the sensors, making them ubiquitous in the smart factory environment. However, there are still some limitations, namely in terms of power consumption and the communication protocols to be used to ensure the transmission of data in real time (Khemapech et al., 2012).

There are several types of technologies suitable for different monitoring and data acquisition needs in the manufacturing environment. The most used technologies for this data collection are sensors, barcodes, RFID, GPS, laptop computers, among others (Liu et al., 2020). Throughout the literature review for the preparation of this document, the most mentioned technology was RFID, namely due to its capacity to capture and upload data in real time (Liu et al., 2020), its small size, enhancing the creation of Smart Manufacturing Objects (SMO), all of them connected to each other and in constant communication with human operators (Atzori et al., 2010; Zhong et al., 2017b).

Industrial networks are one of the crucial components for data acquisition, especially given the ubiquity of networked devices in the new IoT paradigm (Bradley et al., 2013). These networks are divided into several levels, as stated in the ISA-95 standard, which communicate with each other through different protocols, each level having different specificities and objectives. Field networks refer to the layer where there is a high number of equipment of little complexity, namely sensors, actuators, PLCs and embedded systems. These systems communicate with the upper levels through short messages, but with great frequency, allowing the acquisition of data in real time (for example, when the PLC of a mechanical arm sends an electrical signal to lower it, this means that a product has passed that phase and that information is registered). Above these networks, there are cell networks, which are characterized by having less equipment connected (cell controllers, SCADA systems, PCs). Finally, factory networks are those with less equipment, but these are more complex, namely MES, PCs, Mainframes and databases.

2.3.2 Visibility

The visibility phase is crucial throughout the process, as it is from here that it is possible to take advantage of the data collected and use this information to improve the efficiency of the shop floor and reduce costs. The collection of the data as an end in itself is one of the big mistakes that many companies tend to make, as can be seen from a survey of Norwegian companies in the industrial area. This study showed that there is still a lot of untapped potential in the use of the collected data (Mogos et al., 2019). In this section topics related to the visualisation of information as a support to decision making are discussed, namely the concept of MES and KPIs, with emphasis on the most commonly used indicators in the context of Industry 4.0.

After the analysis of the data acquisition process in the previous section, it is also necessary to mention the role of MES in the aggregation and presentation of this data, as well as its importance in the management of operations on the shop floor. According to the Gartner (2020a) glossary, MES manages and monitors the real time execution of the production processes on the shop floor, integrating the production scheduling with higher-level systems. The connection of the data collected on the plant floor to this system allows real-time visualisation of the production process, achieving the goal of visibility and decision support. With MES, it is possible to manage processes, labour, quality, maintenance, analyse the performance in real time and define the states of the resources in the plant floor and their allocation.

MES systems have evolved greatly since their inception, when they were very rigid and centralised on-site and represented only the organisation in its current state. However, over time, these systems began to "migrate" to web-based applications, becoming more modular and offered as Software as a Service (SaaS). With this, it was possible to make the MES much more customisable to fit the specific needs of each organisation, being able to provide much more granular data across the various areas of the organisation (Critical Manufacturing, 2013). The use of the cloud also allowed smaller companies to have access to simpler versions of MES, increasing and adding functionality later according to their needs (SME, 2018). In addition, these systems became more integrated with more holistic management systems of the company, namely with the ERP systems, which allows a better optimization of production processes, according to the rest of the areas of the organisation and business objectives (SME, 2018). It is from this need for integration that the previously mentioned ISA-95 standard arises.

The concept of Key Performance Indicators (KPIs) is essential when addressing the issue of visibility. KPIs serve to evaluate the performance of systems and processes, serving as a basis for comparisons and deeper analysis to explain any differences from the objectives (Ante et al., 2018). Samir et al. (2018) classify KPIs as the translation of critical success factors into values. Figure 2.4, proposed by Ante et al. (2018), also shows the importance of KPIs throughout the organisation's hierarchy, aligning the organisation's objectives at all levels.

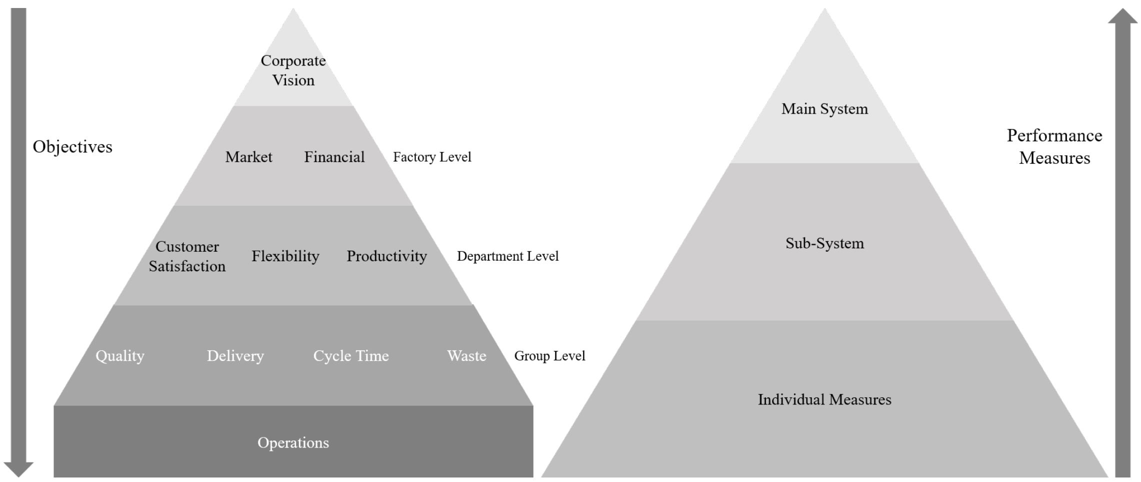

Figure 2.4: Objectives and KPI hierarchies in an organisation, adapted from Ante et al. (2018)

Due to the importance of KPIs in the business and industrial world, the ISO 22400 standard has been implemented, which proposes a framework for defining, building and using KPIs in industrial operations. This standard indicates the parameters that a KPI must follow, namely its name, the formula, the units, but also the timing of data acquisition (real-time, on-demand or periodically), the audience to which it is directed (operators, supervisors or managers), among others (Ferrer et al., 2018).

The use of performance indicators is especially critical in times of change, as it's currently the case in the industry seeking to digitise and achieve the smart manufacturing paradigm. Capgemini's study of smart factories highlights the fact that 93% of companies at the forefront of digital transformation use KPIs at various levels to assess the measures they are implementing (Petit et al., 2019).

Among the most widely used KPIs in production and industry, OEE (Overall Equipment Effectiveness) stands out. This indicator, as its name indicates, translates the effectiveness of the usage of equipment into a percentage. The OEE calculation takes into account three main pillars: Availability Rate, Performance Efficiency and Quality Rate (Sohal et al., 2010). The OEE can be computed as follows:

$$OEE = A \times P \times Q$$

Where,

$$A = Availability\ Rate = \frac{Operating\ Time(h)}{Planned\ Production\ Time(h)}$$

$$P = Performance\ Rate = \frac{Theoretical\ Cycle\ Time(h) \times Actual\ Output(units)}{Operating\ Time(h)}$$

$$Q = Quality\ Rate = \frac{Total\ Production(units) - Defect\ Amount(units)}{Total\ Production(units)}$$

Figure 2.5 helps to understand and visualise where the effectiveness and efficiency losses in production are. Note that scheduled losses (in lighter grey) do not enter into the OEE calculation as they are necessary and expected. Nakajima (1988) proposed a list of six major losses affecting the OEE: (1) low productivity and cadence loss due to poor quality; (2) setups; (3) losses due to temporary failures; (4) differences between the theoretical speed of the equipment and the speed in practice; (5) defects due to equipment malfunctioning; and (6) losses due to startup at the beginning of production. Of these losses, setups and longer failures are more associated with availability losses, speed losses go into performance losses and quality losses are related to defective products.

According to Sohal et al. (2010), in several case studies, the main motivations for the implementation of this KPI in companies are the identification of waste and for benchmarking (both internal and external). The main factors for the success of the implementation of the OEE are the visibility and use of the data collected, as well as the training of operators to understand the concept of OEE and its components. On the other hand, the major barriers to implementation are related to the company culture and the need for change (Sohal et al., 2010). Another obstacle is usually related to data acquisition, so Leachman (1997) addresses some of the sources for data collection, such as databases that record changes in equipment states, WIP (Work in Progress)

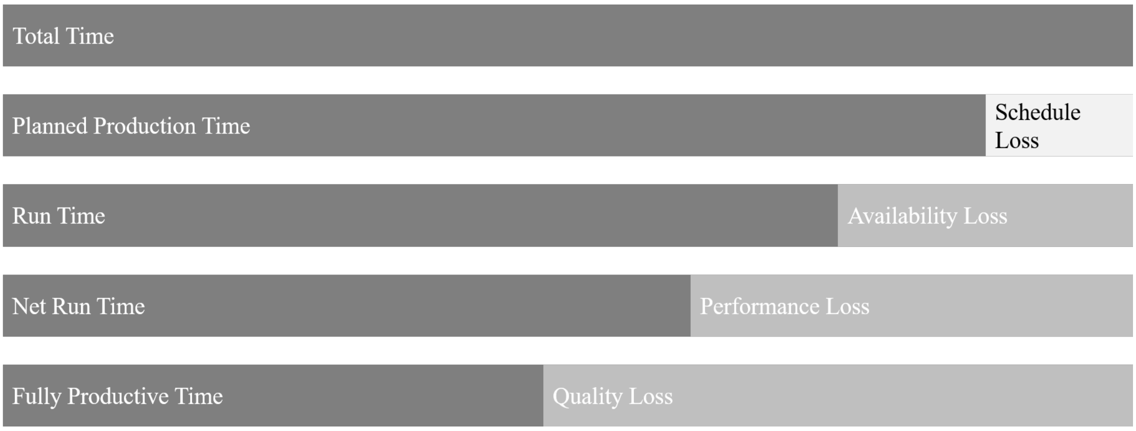

Figure 2.5: Illustration of the main OEE components

databases and the event histories of each equipment. The data has to be sufficient to calculate downtimes (and their causes) and operation times, as well as the number of units in production and the number of units accepted at the end (Leachman, 1997). The author focuses on the importance of using a closed-loop for data acquisition to avoid disruptions of the productive process and automate this function.

2.3.3 Transparency

In this context, the focus on transparency will emphasise understanding the processes and, consequently, deriving value from the data obtained. As such, the themes of continuous improvement fit into this phase, where the data collected and presented (in the connectivity and visibility phases) are now used to support decision-making and process improvement. In the Industry 4.0 paradigm, lean management is tightly connected with the technological evolution and these proven methodologies are management practices that can benefit from increased transparency provided by new technological solutions. As such, this section deals mainly with continuous improvement methodologies and tools, such as the PDCA cycle and 5S methodology.

Lean management has been around for many years and has shown its value in making organisations more efficient. However, with the advent of big data and IoT, there are even more data from which lean initiatives can be implemented and controlled. In fact, Tortorella and Fettermann (2018) argue that organisations with a solid background in lean management can more easily implement new methodologies and concepts, like Industry 4.0. On the other hand, Sanders et al. (2016) point to the enabling role of Industry 4.0 on the adoption of lean practices. All around, these two concepts seem to be tightly connected, yielding great results for the organisations which can successfully implement them. Kupper et al. (2017) recognise the synergies created by applying both lean and digitisation principles in factories, leading up to 40% cost reduction.

The PDCA cycle is one of the best-known concepts in the area of continuous improvement and quality management, serving as a basis for improvement efforts in a wide range of industries and situations (Bamford and Greatbanks, 2005). The initials PDCA symbolise the Plan-Do-Check-Act cycle, which are the various phases of a continuous improvement initiative. The planning phase involves defining the problem and hypotheses about possible causes and solutions. The Do phase is the implementation phase of the proposed recommendations. The Check phase deals with evaluating the results. Finally, the Act phase reacts on the Check's conclusions, standardising the process if the recommendations have achieved the objective, or returning to the planning phase if not (Moen and Norman, 2010). There is also the PDSA version, which replaces Check (which conveys a more passive idea), with Study (which is associated with a more proactive posture). The planning phase is crucial in this cycle, since here the data collected is used to reach the root-causes of the problems (through tools such as the Ishikawa diagram and the Pareto diagram). In the Check phase, the importance of data collection and visualisation is again highlighted, to evaluate the implemented solutions.

Lodgaard et al. (2013) studied the factors for the success of the implementation of PDCA in an organisation, of which the commitment and support of the leadership in these initiatives, the training and education on the subject and the internal marketing of the subject with success cases were highlighted. These factors are very similar to those presented by Kotter (1996) in the field of change management, namely the need for leadership commitment for change to occur, motivation and the creation of quick wins in the change process. The PDCA is, in itself, a process of change (not drastic, but gradual) whose objective is the continuous improvement of the organisation. As such, these concepts are closely intertwined with the theme of smart factories (which constitutes a major change from the more traditional views of a factory), as a basis for continuous improvement through the automation of decision making for the improvement of efficiency on the shop floor.

The A3 report is a tool designed to support the PDCA methodology and the continuous improvement projects as a whole. This report is a summary of some of the main questions about a project, like context, current situation, objectives, analysis, countermeasures, plan of action, follow up and improvements. According to Bordin et al. (2018), the implementation of A3 reports has a positive impact in accelerating the decision-making process. This is due to the fact that past projects and their learnings are well-documented, supporting future continuous improvement actions and spreading actions throughout other areas in the organisation.

Another usual continuous improvement concept is that of 5S. This tool is many times equivalent to "housekeeping", but can also be defined as a problem-solving tool (Gapp et al., 2008). The steps in this system are: (1) sort, (2) set in order, (3) shine, (4) standardize, and (5) sustain. The first two are mostly concerned with orderliness, reducing human errors through simplification. The following two are concerned with cleanliness, which aims to achieve greater transparency and safety. Finally, the last step is all about discipline: the focus is on making the changes permanent through training and education (Gapp et al., 2008).

2.4 Change Management

So far, most of the themes covered in this literature review have been mostly focused on technology and processes. However, the digital transformation towards Industry 4.0 is, at its core, a change process. Thus, the change management theme assumes great importance in this transformation, especially since it offers a perspective on people, which is one of the main pillars for change to occur.

Considering that research suggests that about 66% to 80% of organisational change initiatives fail (Appelbaum et al., 2012), considerable efforts have been made to provide effective guidelines for change management. From the extensive literature on the topic, the eight step model developed by Kotter (1996) is still one of the most influential and successful guides to organisational change. These eight steps are:

1. Establish a sense of urgency;
2. Create a guiding coalition;
3. Develop a vision and strategy;
4. Communicate the change vision;
5. Empower broad-based action;
6. Generate short-term wins;
7. Consolidate gains and produce more change;
8. Anchor new approaches in the corporate culture.

Starting with the first step, the sense of urgency is created through communication and support from top management (Kotter, 1996). The organisation may employ various techniques, like the use of external sources, like consultants (Armenakis et al., 1993), or simply rely on a project team built internally. Oakland and Tanner (2007) propose some drivers for change and divide them between external and internal factors. Customer requirements, market competition and regulation are some of the external drivers, while improvements in efficiency and quality of products and services are considered internal drivers. However Oakland and Tanner (2007) also argue that most of the times, the internal drivers are a manifestation of the external ones.

Creating a guiding coalition is another enabler of change, according to Kotter (1996). Armenakis et al. (1993) argues for the same concept, classifying individual attributes as one of the cornerstones to make an organisation ready for change. These attributes are inherent to people, that behave in different ways when faced with change. However, creating a team dedicated to the project, with facilitators and top management support, can be a powerful influence over those individuals who might not be as prone to change by themselves. Kotter (1996) suggests that this guiding coalition must be composed by individuals with position power, expertise, credibility and leadership skills. In the context of the transformation towards Industry 4.0, some of these soft skills might be overlooked in favor of technical capabilities. However, people with decision power and inter-personal skills are critical for business intelligence activities. These are the people who can make decisions on behalf of the organisation regarding the needs that should be implemented during this transformation. In the project team, some people are also responsible for establishing the vision and communicating it (which ties in with the third and fourth steps of the change process), which drives work group members to act and follow the direction set (Appelbaum et al., 2012).

Step five is critical since it goes beyond communication, which cannot solve all the problems and hurdles the team will face throughout the process (Appelbaum et al., 2012). Kotter (1996) identifies four major obstacles: structures, skills, systems and supervisors. Thus, in this step, some autonomy and decision-making power should be transferred to the work groups who are dealing with the day-to-day change process, enabling them to deal with some of the challenges they may encounter.

Step six also goes beyond communication, but this time as a tool to engage stakeholders. Kotter (1996) argues for the importance of short-term wins as a tool to evaluate the change process and to demonstrate to stakeholders that the process is paying off. However, Boga and Ensari (2009) point to the difficulty of finding the right balance between short-term wins and the long-term perspective of the change process.

The last two steps are more forward-looking and the first goal is to avoid regresses in the changes implemented (Kotter, 1996). Secondly, the objective is to create a corporate culture accustomed to change, making the whole organisation more flexible. To achieve these goals, organisations usually rely on workshops, one-on-one coaching and documenting the new processes, structures and systems (Oakland and Tanner, 2007).

Chapter 3

Framework for the transition towards Industry 4.0

A lot of the concepts presented in the previous chapter can be hard to translate into actual business-changing initiatives. With the popularity of Industry 4.0, the amount of information might be overwhelming for organisations just starting their journey in digital transformation, towards the smart factory paradigm. Hence, the main goal of this chapter is to dive deeper into the topics discussed in the previous chapter and translate them into a more actionable framework, to serve as a roadmap for practitioners. The scope of this framework is not to address the whole transformation towards a smart factory developed to its full potential, but instead to focus on the first steps towards it. This is an area of the literature that has not been fully developed and translated into a more operational approach (Kamble et al., 2018).

The schemes presented in Figures 2.2 and 2.3 are the starting points for the development of this more actionable framework. In both of these schemes, the concepts of connectivity, data-to-information conversion (or business intelligence), visibility and information analysis are present. These concepts precede the more advanced stages of a smart factory, related to predictive analytics, self-optimisation and adaptability. Both figures represent an incremental evolution from the first set of concepts to the second one. This can be considered the first finding towards the construction of this roadmap: even such a disruptive innovation (Industry 4.0) is based on incremental steps that build upon existing capabilities and infrastructure.

Based on the literature review and on the challenges faced during the implementation of the project described in the following chapter, a framework was developed. A high-level representation of this framework is presented in Figure 3.1. This high-level representation is mostly based on the work of Joppen et al. (2019), but with the addition of the business intelligence step, based on the data-to-conversion layer of the 5C architecture proposed by (Lee et al., 2015). This framework is also based on the practical experience developed during the project described in the case study, as well as in other sources from the Industry 4.0 literature (Kamble et al., 2018; Kiang et al., 2019; Gartner, 2018).

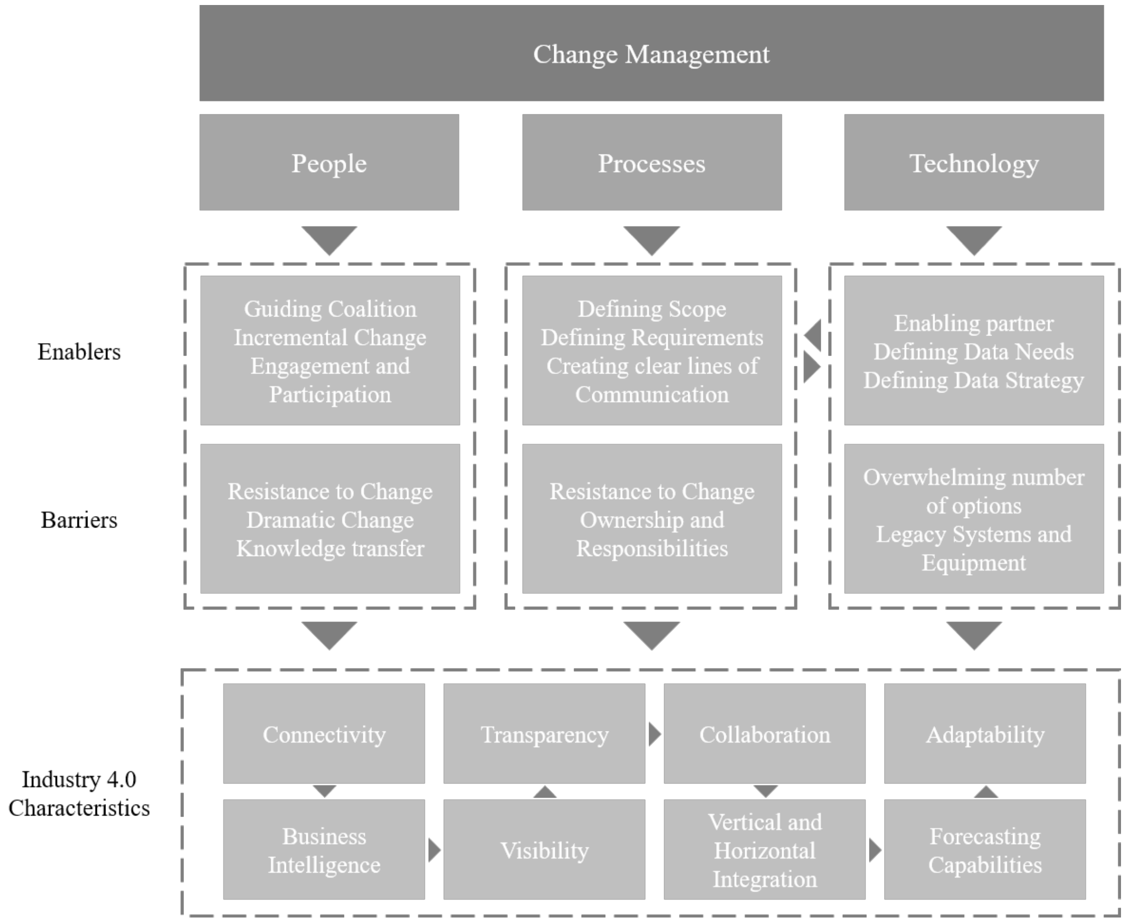

Figure 3.1: Framework for digital transformation towards Industry 4.0

This framework presents the key enablers and challenges that organisations face when embarking on the digital transformation process. These enablers and challenges are based around the overarching change management concept and the people, processes and technology triad. The interaction between all three of these areas is evident, but the tight connection between processes and technology is highlighted, since the definition of requirements is conditioned by the data strategy and vice-versa. The change process culminates in the implementation of the Industry 4.0 main characteristics.

Looking at Figure 3.1 from a top-down perspective, the role of change management is clearly visible as a cornerstone of the digital transformation process, since this transition is nothing more than a complex and extensive change process. Here, the change happens by redefining and redesigning processes and people's roles with the help of technology, in order to create a more effective and efficient organisation, based on the Industry 4.0 characteristics. Thus, the change process is supported by the people, processes and technology triad, which offers both enablers and barriers throughout the transformation process. In Figure 3.1, some enablers are suggested to tackle the most common challenges inside each pillar (people, processes and technologies) and to help achieve the Industry 4.0 characteristics presented in the bottom of the Figure. On the other hand, the barriers present common challenges found in the literature and in real life scenarios that can arise in such a process. The culmination of these enablers and barriers is their integration in the most common characteristics associated with Industry 4.0. This framework and the roadmap presented bellow (Figure 3.2) take a look at these enablers and barriers through the lens of each Industry 4.0 characteristic. Even though each of these characteristics encompasses elements of all three dimensions, some characteristics (such as Connectivity) might be more heavily impacted by one of the three main pillars (in the case of Connectivity, technological enablers and challenges are the most critical ones).

In summary, this framework takes a top-down approach to understanding the digital transformation towards Industry 4.0. It starts with a general understanding of the guidelines for change processes (the concept of change management) and the relevant pillars for change (people, processes and technology) and gradually narrows the focus to specific issues (enablers and barriers) associated with the transition towards the Industry 4.0 paradigm. Finally, a list of the most important characteristics of this transformation is presented in an incremental manner and, inside each of these stages, the enablers and barriers are explored in more detail. Thus, an actionable framework for the Industry 4.0 transformation is achieved, since each stage is populated with guidelines and common pitfalls in this type of projects.

In order to facilitate the digital transformation, a roadmap can be derived from this framework. This roadmap (Figure 3.2) presents an action plan to implement each of the smart factory characteristics and highlights the iterative nature of the process and the importance of delivering incrementally more complete solutions at all levels, instead of moving from phase to phase without turning back. All of the enablers and barriers are then discussed inside each of the stages. The role of change management throughout this roadmap is to act as an enabler across all stages.

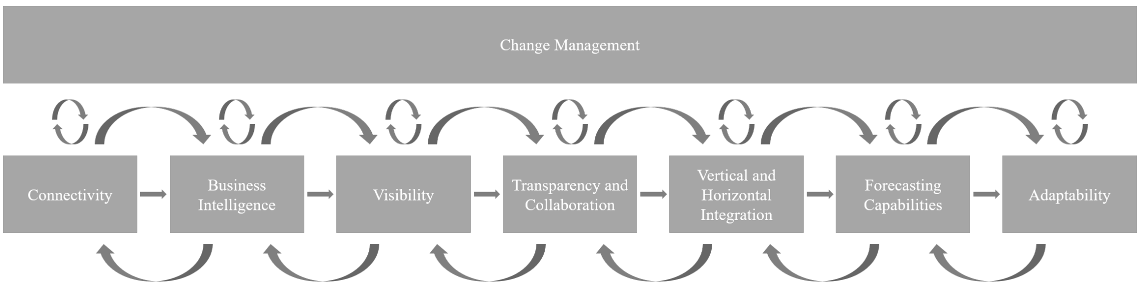

Figure 3.2: Roadmap for digital transformation towards Industry 4.0

The concept of iterating inside and between phases comes from the real life constraints related to such a dramatic change. When implementing a new aggregating platform that will help connect all the devices to all the information systems in an organisation, it is not feasible to implement every requirement at once. This concept is the foundation of the Agile approach to software development. The Agile principles, as defined by the Agile Manifesto (2001), state that agile software development should be a dynamic and iterative process, always welcoming change. The main objective is to deliver working software, which is then gradually updated and perfected according to new requirements. This style of work is designed to make organisations more flexible and more communicative.

The Agile approach is very common among software startups, and it is based on sprints and the delivery of MVPs (Minimum Viable Products), allowing startups to be quicker and more flexible to deliver value to their customers. These MVPs are then incrementally improved throughout time, reflecting this iterative approach, proposed in this framework. Since the Industry 4.0 transformation is still uncharted territory for most organisations, taking this startup-like approach while developing their solution will provide organisations with multiple solutions that are incrementally more robust and complete and that can be adapted to other needs that might come up as this transition is taking place.

There are two options for an organisation to start working towards the Smart Manufacturing paradigm: outsourcing the development of the solution or develop it in-house, via a dedicated team. The choice mainly depends on the level of in-house expertise, the budget and timeline. However, any of the options will require a supplier-customer relationship based on communication. Even the in-house implementation will deal with internal customers that present their needs and vision for the solution. This is another advantage of the Agile approach, since it enhances communication and flexibility.

Now that the overall framework has been presented, the next sections focus on each of stages of this roadmap, diving deeper into the processes and challenges faced in each of them. The main goal of the following sections is to provide practical guidelines for the implementation of Industry 4.0 solutions across the whole roadmap.

3.1 Connectivity

The first step of this roadmap is connectivity, which mainly concerns data acquisition and integration between different information systems, equipment and people. Figure 3.3 takes a closer look at the common challenges that have to be addressed in this stage.

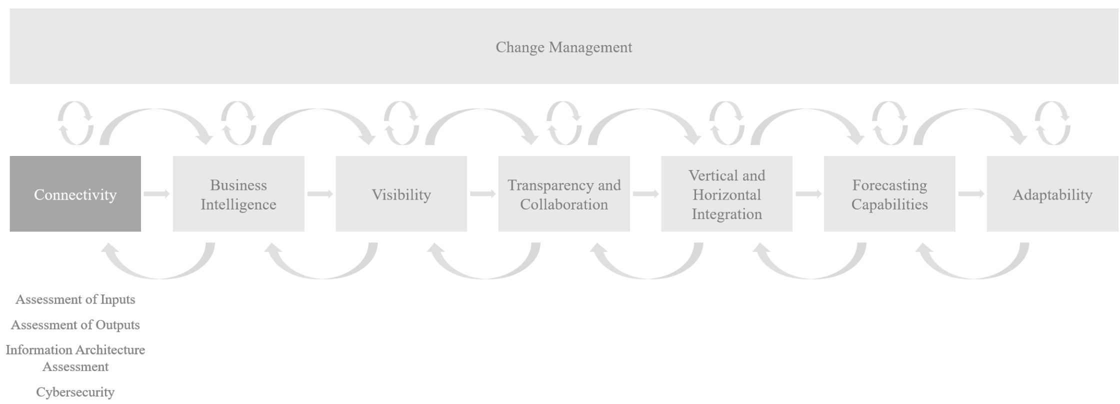

Figure 3.3: Roadmap for digital transformation towards Industry 4.0 - Connectivity

For this stage, the main tasks that should be carried out are related to understanding which inputs are needed for the solution. This assessment effort is highly related to the next two stages (business intelligence and visibility). These next stages define which type of information should be controlled, namely which KPIs in which scope (for example, should the OEE be aggregated across the whole factory or just by section). Throughout the iterative process, new needs might arise, which leads to a redefinition of the inputs needed.

After defining the inputs needed, the next step is to identify the data sources. Typically, these sources can be either the equipment itself, information systems, like the ERP, or even manually imputed data. For most industrial areas, namely the automotive sector, operational data like number of actions each machine performs is critical to record KPIs. This information can be accessed through the PLC outputs (electric signals) or by installing sensors that actually record the number of times an action is performed. This type of information might be the cornerstone for the calculation of most KPIs, but it still needs some contextualization. Not every action translates into a piece being produced for example. And even if that piece is produced, PLC signals and regular optical sensors might not detect a defective unit. In this iterative process, a first implementation of the solution might use manual inputs to provide context to the production and even to stop it if necessary, following the *Jidoka* principle of automation with human intervention (Lean Enterprise Institute, 2020). However, with the development of the solution, next iterations might rely on other sensors that communicate with the products themselves, through RFIDs, so that the defective unit is automatically identified.

The role of information systems as data sources is usually related with operations planning and production contextualisation. For example, by accessing the ERP, the platform can identify which orders are currently being carried out and which ones are planned to follow. By combining all of these data sources, most of the information can be defined within a certain scope, which will later be used to support decision-making.

The same process takes place when defining outputs. The information compiled in a central platform must be transmitted to other information systems and even to different machines. This requires understanding the interfaces of communication between the central platform and the surrounding things (people, equipment, information systems and even the products themselves). This is where the information architecture is defined, namely by choosing the right devices for acquiring and transmitting data and by choosing the right communication protocols for each application. These protocols can range from internet protocols, with higher ranges and transmission rates, to other protocols like Zigbee, with smaller ranges. It is also important to choose the right interface to transfer information between information systems: either developing APIs (Application Programming Interfaces) or through direct access to databases. Choosing an API might be more laborious at first, but it will provide a stable and future-proof connection between different information systems. This means, for example, that the organisation might decide to change from one ERP provider to another with no consequences to the central platform, since it is communicating with the interface and not directly with the ERP.

Finally, in the connectivity stage, there is a new challenge emerging: cybersecurity. This is not an isolated issue and it must be tackled in tandem with the definition of the information architecture. According to Haji et al. (2020), cyber attacks pose serious risks, not only by disrupting the operations, but also by making organisations vulnerable to intellectual property theft and even by disrupting physical safety systems, endangering employees in the shop floor. Taking all of these risks into consideration, the average financial impact of cyber attacks to smart factories can mount up to $330 000. According to this same study, the vulnerabilities reside in the connection between IT and OT, where there might be an overlap of different processes and systems (Haji et al., 2020). Most of decisions regarding OT are made in the shop floor by the operation managers with little input from central IT and cybersecurity departments. This can cause a strain in these technical departments to adapt to different types of machines, vendors and protocols. Furthermore, software updates and patching can cause serious disruption in the physical production, creating more friction between OT and IT managers. Finally, there's the issue of legacy systems and equipment, which are more prone to breaches due to cyber attacks.

All in all, there are a lot of vulnerabilities that can be exploited if organisations aren't aware of them. The first step to prevent it from happening is understanding these limitations, by performing a cybersecurity maturity assessment (Haji et al., 2020). Haji et al. (2020) also recommend that a formal cybersecurity governance team is put in place, facilitating accountability and communication. The final recommendation is to set cybersecurity as a priority from early on the project life cycle, making sure every decision takes into account the risks and opportunities regarding cybersecurity.

3.2 Business Intelligence

Although this roadmap is very similar to the scheme presented by Joppen et al. (2019), the "Business Intelligence" stage wasn't a part of the original scheme. This stage was based on the 5C architecture, proposed by Lee et al. (2015), namely the data-to-information conversion layer. This stage is worth being included in this framework and described more thoroughly since the explosion of data and information is a trending topic in the literature. However, terms like data, information and even knowledge are often used interchangeably. In this section, the aim is to clarify the terms data and information, explain the importance of a clearly defined data strategy and the requirements to transform data into information that can be used and manipulated by other people and systems downstream. Figure 3.4 summarizes the main issues related to this stage.

In general, data is defined as unstructured facts, simple observations that haven't yet been interpreted. Information is seen as structured data with some meaning. Finally, knowledge is bound to human experience attached to information (Stenmark, 2002). These definitions are useful to understand the importance of the conversion from data to information. The data gathered by sensors doesn't have meaning by itself. Only when data from different sources is combined and contextualized can it become information. Although this might seem a trivial step, there are a lot of components that play a key role in this conversion: how is data stored, protected, and made accessible; which type of information is needed; which pieces of data need to be combined and

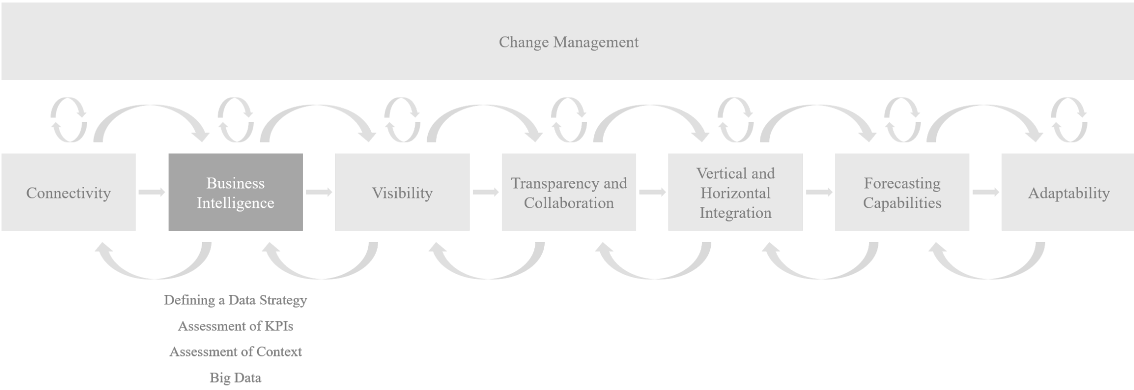

Figure 3.4: Roadmap for digital transformation towards Industry 4.0 - Business Intelligence

contextualized, among other issues. All these questions and many more must be answered so that organisations can effectively extract information from the large amounts of data generated everyday. Thus, the first step to correctly convert data into information is defining a data strategy.

The process of collecting, storing and making data available is usually a role attributed to the IT department. However, they can't be responsible for decisions that turn data into value for the company (Beath et al., 2012). Especially with the explosion of data in the last few years, IT is overwhelmed with all these challenges and decisions regarding data, even though that some of those decisions should be made by business managers, who understand the information needs of the business. Thus, a solid data strategy has to start by clearly defining roles and accountability, promoting the collaboration between the IT department and the business managers. Business managers should be responsible for identifying mission-critical data and they should be the ones determining if the value that can be derived from the data outweighs the cost of its acquisition and storage (Beath et al., 2012). Summarising, the organisation has to define the workflows related to acquiring, storing and using data, in order to be effective in deriving value from data and information.

The interaction between IT and business turns this whole process into a very iterative one (Beath et al., 2012), leading back to the connectivity phase. This idea is represented in the high-level framework (Figure 3.1), which highlights the connection between defining a data strategy and defining requirements. The choice of the key indicators that should be controlled is a business decision that has to be taken into account when deciding the technical infrastructure to acquire the data that will be needed for those requirements. When assessing the KPIs to be controlled, it's also necessary to define in which context such KPIs need to be controlled. For example, when designing the solution, it is not sufficient to say that the OEE needs to be calculated. Instead, it should be defined in which machines, areas, sections and even plants the OEE should be calculated and in which time frame. Furthermore, there's also the need to define the method to calculate the KPIs used by each organisation and how to aggregate this information. If this information is not already set in stone, the digital transformation provides a good opportunity to revise the current KPIs and improve upon the existing structure, following the best practices. For example, implementing a

KPI tree to measure the performance and understand the link between each indicator will not only facilitate the visibility, but also help derive insights in the other stages downstream (Ante et al., 2018).

Finally, the concept of Big Data should also be addressed in this stage. This topic is already addressed when defining a data strategy, but it should be highlighted due to the relevance of this concept in today's world. According to a survey by Deloitte Insights (2020), Big Data is one of the Industry 4.0 technologies that organisations find the most impactful. According to Kaynak and Yin (2015), Big Data can be decomposed in five dimensions (the five V's): volume, variety, velocity, veracity and value. This structure can be used to assess the capabilities inside the organisation to handle data. Starting with volume, organisations need to have the right software and hardware in place to handle such large amounts of data. Furthermore, the issue of variety is an increasingly complex one since much more data nowadays is unstructured (Beath et al., 2012; Kaynak and Yin, 2015). These issues of volume and variety are tightly connected with other Industry 4.0 technologies, like using cloud solutions to store data. If volume and variety are concerned with how data is stored, veracity and velocity are connected with how data is made available. The acquisition of data is not an end in itself: if decision-makers can't access correct and trustworthy data in a timely manner, then there's little value to derive from the data. This final V (Value) can only be achieved when all the other dimensions are managed correctly and the decision-makers can derive insights from the data, which are expected to have the most impact in customer-centric activities and in operational efficiency (Kaynak and Yin, 2015).

The volume dimension of Big Data is one of the most troublesome ones, and technologies to store these data should be addressed. Solutions like data warehouses in combination with data marts can be used to tackle this volume challenge. These data warehouses are based on the analysis dimensions needed for the company (Madera and Laurent, 2016), which again highlights the iterative nature of the roadmap. After assessing the information needed, data integration plans are developed to accommodate various data sources and then, all the information is grouped in the warehouse. This information is mostly used for data analysis to support decision-making (Madera and Laurent, 2016; Bonifati et al., 2001). The information is retrieved from the data warehouse through data marts, which are smaller schemas concerning a specific analysis activity (Bonifati et al., 2001).

3.3 Visibility

The visibility stage is focused around the concept of providing users with useful information in a timely manner, in order to support decision-making and facilitate daily tasks. The concept of user experience (UX) can be a great driver to achieve this visibility, making the information more "digestible" for the users. According to Gartner (2020c), UX is "the sum of the effects caused by a person using a digital solution". For organisations on the road towards Industry 4.0, this concept describes the way that stakeholders interact with the solutions implemented and with the smart factory itself. This term can be applied to managers relying on dashboards and digitised analysis to conduct their meeting and decisions, but also to shop floor operators interacting with the machines and even the smart products themselves. The user experience can make or break the potential benefits from Industry 4.0, especially considering that this new paradigm is still very dependent of human capital. In fact, the user experience serves not only as a tool to achieve the full potential of Industry 4.0, but to facilitate the change process as well, by engaging employees (Hanley et al., 2019). The importance of user experience is shown in a survey conducted by Hanley et al. (2019), where the authors ranked the greatest talent needs for companies embarking in this digital transformation. The top ranked skill was user interface design. Figure 3.5 displays the key issues to be addressed in the visibility stage, all of them related to the concept of UX.

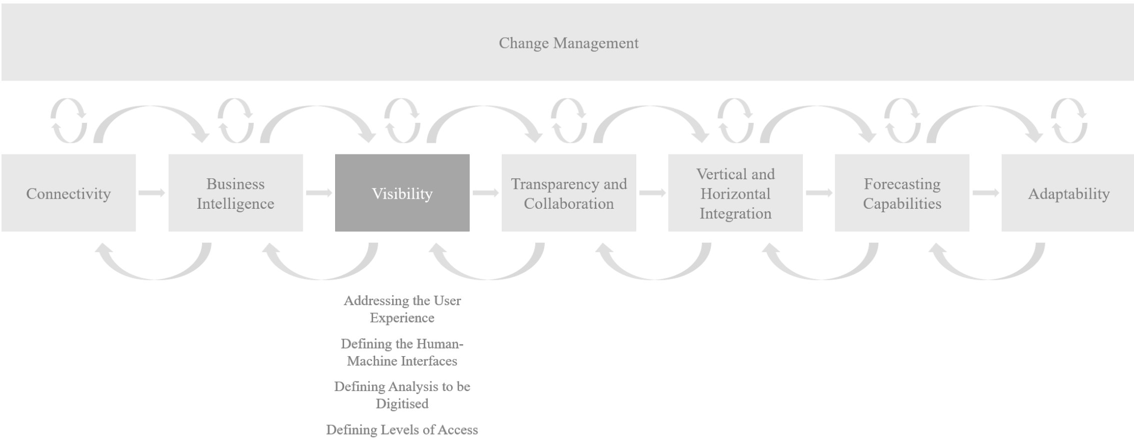

Figure 3.5: Roadmap for digital transformation towards Industry 4.0 - Visibility

Addressing the user experience concept is not only impactful in the visibility stage, but also in the other stages downstream. Defining the user experience impacts how stakeholders collaborate and derive insights from the information presented, as well as the adaptability and flexibility of the whole platform (Peissner and Hipp, 2013). Even though this topic is very industry and company-dependent, there are still some guiding principles that organisations should take into account during the visibility stage.

The first guideline should be to recognise the dependencies between the information chosen in the previous stage and the possibilities for displaying such information. Once again, the iterative nature of this roadmap comes into play. Organisations should start by defining critical information and understanding how to display it in a first stage. Later, the solution can be gradually improved by adding new KPIs, new analysis and new dimensions. This is a flexible approach that provides quick feedback on what the dashboards and interfaces are going to look like.

Some other guiding principles are described by Kumar and Prajapati (2019). According to the authors, visual and task complexity should be avoided, mainly by omitting accessory information that isn't critical for the user of that interface. This will ensure that the user is not subject to a great cognitive load, which could hinder his productivity. The interfaces and dashboards should also be designed in order to promote and facilitate interoperability and collaboration. Since one of the main characteristics of Industry 4.0 is flexibility and adaptability, stakeholders should have access to flexible ways to access and visualise information. When defining human-machine interfaces, Pfeiffer et al. (2016) argue for a user-centered design, based on Agile principles and the usage of personas or user profiles that describe the use cases for some types of users. This type of approach is better described in the case study, where the use of mock-ups and prototypes helps software developers understand the real needs of the end users.

The existing workflows and processes in an organisation don't have to be completely restructured when they opt to embark on the transformation towards Industry 4.0. Existing analysis and reports can be digitised and automated by the platform, displaying the information gathered by the various sources. This eliminates the need to create these reports every time they are needed and ensures a standardized structure. Furthermore, each report can be tailored to certain types of users and permissions can be managed so that sensitive information isn't available to everyone. The same principle can be applied to the human-machine interfaces, which can be used to collect data in the shop floor. The case study serves as a good example of defining the information needs and designing an interface that facilitates data imputation.

3.4 Transparency and Collaboration

In the context of this framework, transparency is focused on making the processes and initiatives crystal clear to everyone in the organisation. After making the information available, the end goal is not just to display it, but to act on it. The transparency stage should bridge the gap between visibility and action. Continuous improvement initiatives are omnipresent in industries today and they do precisely what is needed: turning data and information into improvements. In this section, the focus is on the combination of technology and continuous improvement methodologies so that organisations can make their journey for continuous improvement even more efficient and integrated with their operations. Figure 3.6 presents the main issues addressed in this stage of the roadmap.

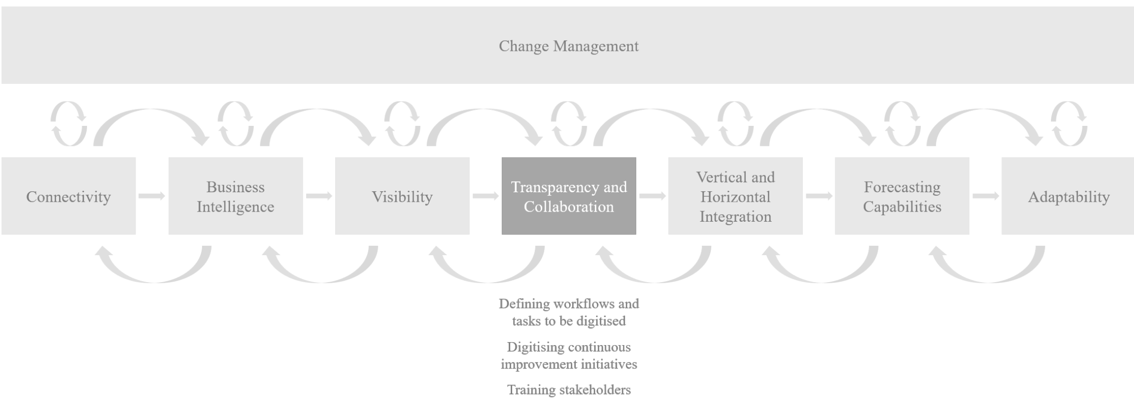

Figure 3.6: Roadmap for digital transformation towards Industry 4.0 - Transparency

The first step in this phase is to understand the workflows that are currently carried out across the organisation. Some examples are regular meetings to discuss operational issues or even continuous improvement teams. In summary, when there are decisions to be made, these decisions can be backed up by the data and information gathered in the various information systems and equipment. By centralising this information in one platform with various dashboards and interfaces, these workflows can be digitised and the lessons learned can be more easily shared across departments. This digitisation is not restricted to production. In fact, support areas like Human Resources or Procurement can also benefit from such a platform, not only by having transparency to understand what is happening in the core business, but also by centralising communication and past projects.

The second issue highlighted in Figure 3.6 is concerned with continuous improvement initiatives. Across the literature there are numerous articles regarding the importance of lean practices in tandem with Industry 4.0 (Kolberg and Zühlke, 2015; Wagner et al., 2017; Sanders et al., 2016). Wagner et al. (2017) proposes a Industry 4.0 impact matrix on lean production systems, classifying which lean principles most benefit from Industry 4.0 technologies. The *Kaizen* principle is greatly influenced by technologies in data acquisition, in machine-to-machine and human-machine interactions. Other principles such as man-machine separation and teamwork are also enhanced since the smart factory can free labour hours to more fulfilling tasks of analysis and decision-making. Finally, standardisation and waste reduction can also be achieved in the factory of the future, always based on data acquisition and processing. All of these improvements can be achieved through teamwork and through analysis facilitated by digital workflows. On the other hand, Kolberg and Zühlke (2015) give the example of the integration between the factory and the operators, through the use of the *Andon* system, greatly enhanced by the principles of Industry 4.0. In the case study, a similar use case is put into practice, enhancing the visibility of the *Andon* system across various levels of control, enabling faster reaction to deviations from the optimal state.

The digitisation of the continuous improvement initiatives is enabled by technology, but the main issues arise in the people and processes dimensions. In order for these changes to have an impact in the efficiency of the projects, the processes have to be adapted to the digital workplace and the stakeholders have to adopt these new practices. Thus, training is critical in this stage. Stakeholders need to get acquainted with the platform and learn how to manage tasks and projects they are involved in. Including productivity tools can help with this issue. The proGrow platform described in Chapter 4 includes some of these tools like a digital *Kanban* where each user easily understands the status of tasks and projects in the PDCA cycle.

In conclusion, transparency is an important characteristics for every level of an organisation making its transition to Industry 4.0. The focus here is to provide guidelines to digitise workflows and initiatives (most commonly, continuous improvement initiatives), making them available across various levels of the organisation. This enables the spreading of lessons learned and promotes analysis and action across different functional areas and management levels.

3.5 Vertical and Horizontal Integration

The concepts of vertical and horizontal integration have been associated with Industry 4.0 since its inception (Stock and Seliger, 2016). In the context of this roadmap, it can be seen as the scalability phase. As mentioned before, in the transparency and collaboration stage, the solution can be adopted by different areas and departments taking advantage of all the data collected to support decision-making across all of those areas. This is what vertical integration means in the context of Industry 4.0 (Stock and Seliger, 2016). Figure 3.7 briefly highlights the main ideas behind horizontal and vertical integration.

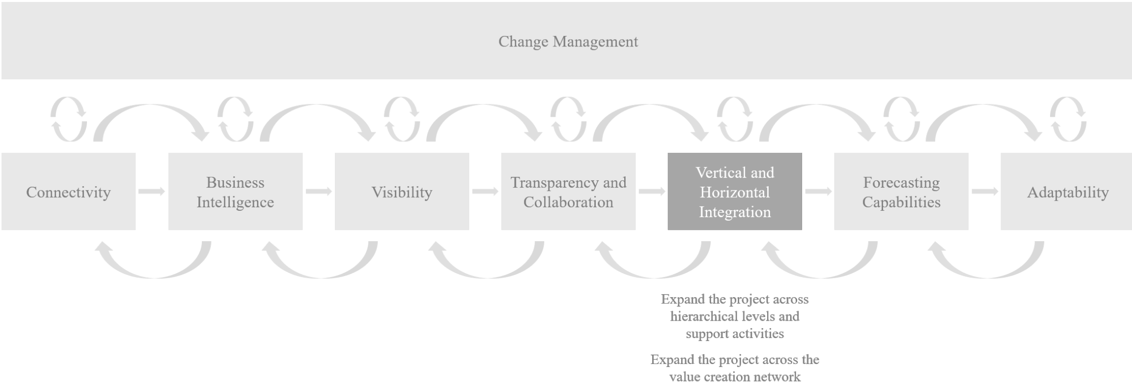

Figure 3.7: Roadmap for digital transformation towards Industry 4.0 - Vertical and Horizontal Integration

Starting with the concept of vertical integration, the benefits of Industry 4.0 can only be fully realised when there's an integration beyond the production area itself. There is data across all levels of the organisation, namely Sales and Marketing for example. By expanding the connectivity to these other areas and relating the data from various departments, greater benefits can be achieved. Sony (2018) makes some arguments about the importance of vertical integration in Industry 4.0 and the relationship with lean management. According to the author, vertical integration enables to take a more customer-centric point-of-view across the organisation. Furthermore, cooperation across hierarchical levels in the organisation is also enabled by vertical integration.

Horizontal integration, on the other hand, is focused on the value creation network. The journey towards the smart factory should start with a pilot project and proofs-of-concept and improve incrementally from there. This can be seen as horizontal integration: expanding the scope of the project incrementally across the operational level. However, the end goal when it comes to horizontal integration in Industry 4.0 is to expand the digitisation to suppliers and customers and eventually, across the whole supply chain (Stock and Seliger, 2016). This is achieved by setting up lines of communication and providing visibility to the relevant stakeholders across the supply chain.

In summary, this stage represents the scaling out of the project, both horizontally and vertically. At this point in the digitisation journey, the solution is already mature and valuable to the organisation, leading to the expansion. Even if characteristics like forecasting capabilities and autonomous adaptability are not yet in place, the solution is already mature enough to represent a great improvement when compared to the "traditional" factory. At this stage, critical data is being collected and converted into valuable information. This information is readily available and visible to the appropriate stakeholders. These stakeholders are able to act upon the information and cooperate and monitor the results in real-time. The project presented in the case study is precisely at this stage of development and the value it brings to the organisation is already considerable. At this stage, the foundations are laid down for Industry 4.0: processes, people and technology are aligned.

3.6 Forecasting Capabilities

These last stages are heavily focused on technology and the development of specific software that can be integrated with the solution presented so far. The roadmap here becomes highly dependent of the markets where the companies operate and the specificities of their business. However, there are some guiding principles that can be followed. At this point, the organisations already have in place a strategy to collect and store data and to transform it into relevant KPIs that can be analysed. The forecasting capabilities are achieved when algorithms can take the existing data and derive insights in real-time about the operations (for example, if a certain machine is about to breakdown). Figure 3.8 presents the main challenges of this stage.

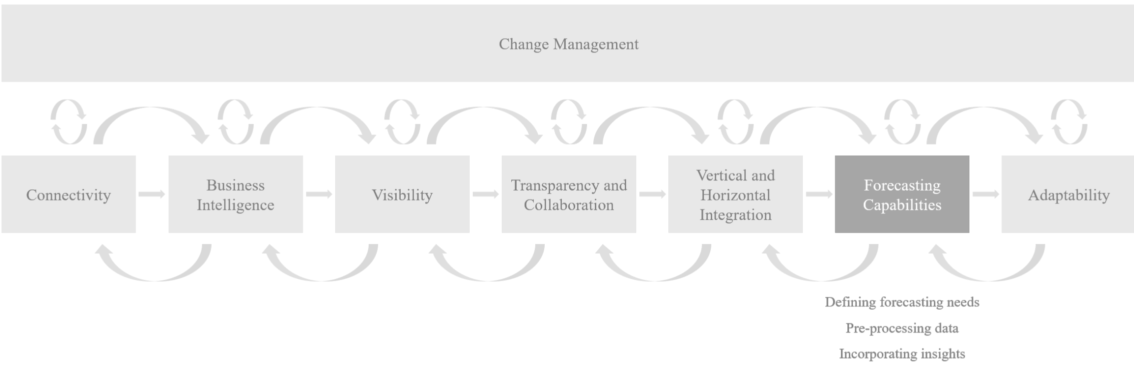

Figure 3.8: Roadmap for digital transformation towards Industry 4.0 - Forecasting Capabilities

The fist step in this stage is to address the business needs regarding forecasting. This step must be integrated with previous decisions, namely in the connectivity and business intelligence stages. These business needs should be understood from the beginning and the proper data must be collected and made available to the software that will analyse it and use it to forecast certain occurrences or certain metrics. Common use cases include data-driven design of products and processes, predictive maintenance, inventory planning (Schroeck et al., 2019), as well as predicting bottlenecks in production (Subramaniyan et al., 2018). The potential for forecasting reaches other areas of the value chain, like Logistics and Marketing. Each organisation needs to map its needs and understand how to integrate all of these analyses. Forecasting is not the end goal by itself: it should serve as a support for decision-making tied to the organisation's strategy.

The second challenge is to process the data, making it suitable for analysis. Once again, the connectivity stage is deeply integrated with this challenge. The aim of the sensors and devices deployed in the connectivity stage is to provide accurate data in real time. However, some disruptions might happen and some outliers might occur. The first objective is to minimize such situations and deploy a fail-safe mechanism to avoid downtime in the data collection efforts. If inconsistencies in the data still persist, the software deployed to forecast certain attributes needs to handle these inconsistencies. The most common problems are related to large amounts of instances and attributes, missing values, noisy data, among others.

Finally, the output of the forecasting algorithms should be incorporated in the solution developed so far. This integration connects the visibility and transparency stages with the forecasting capabilities. The insights provided by the algorithms need to be made readily available so that decision-makers can act based on this information. For example, a production manager on the shop floor could, so far, control the production metrics in real time and quickly react if any deviation occurred. With the forecasting capabilities, the manager can take a more proactive stance and act before a malfunction occurs.

3.7 Adaptability

The last stage of adaptability is the culmination of all the improvement efforts carried out throughout the digital transformation journey. The timeline for these last two stages might be more extensive than the previous ones, since most of these solutions have to be adapted to each organisation and the stakes are higher: the algorithms previously deployed have to be thoroughly tested in order to allow the software to make decisions by itself.

Reaching this stage of the roadmap requires not only high commitment from leadership and high investments, but also a solid foundation laid down in the previous stages. If an organisation can get this far in the roadmap, the benefits are already substantial. The goal of this framework was to guide organisations through the early stages of the digital transformation journey. The adaptability comes from deploying the analyses and forecasts previously presented to human decision-makers and automating this process. In this paradigm, the output of the analyses has direct consequences in the physical world, without the need for human intervention. Here, machine-to-machine connectivity takes on a bigger role in the operations while users can take a more complementary role in the decision-making process.

3.8 Change Management

The role of the change management in this roadmap is a critical one to address all the issues beyond the technical aspects. It aligns the whole transformation process with the organisation's strategy and the need for change. It is also a critical element to ensure the motivation of the people directly and indirectly involved in the process. This framework is very focused on iterative processes and communication, which can only be achieved when the vision is clearly set for all the stakeholders.

The first step in change management, according to Kotter (1996), is establishing a sense of urgency. The organisation must find a reason that propels it to change and to start the digitisation process of its operations. This can be either to protect the company's current position in the market and to improve profitability and efficiency, or to respond to competitors leading the change towards Industry 4.0 (Hanley et al., 2019; Burke et al., 2017). Furthermore, companies like Deloitte and other consulting firms in the forefront of innovation can also be respected sources of knowledge that drive this sense of urgency. The presence of outside sources in the organisation can help create this climate for change (Armenakis et al., 1993).

This project management team (or guiding coalition) is responsible for setting the vision and strategy for the transformation (Kotter, 1996; Appelbaum et al., 2012). Without a clear direction and a vision of the "to be" processes, the change process will not be effective nor efficient and it might even fail. This theme is particularly important in the visibility stage, but it is present across the whole roadmap. When designing the solution, the use of mock-ups, prototypes and MVPs turns these ideas and concepts into tangible solutions which can be tested by the relevant stakeholders. This iterative process meets the attributes of the Agile approach and is supported by Kotter (1996), who advocates for a two-way communication process. Using this type of artifacts can also fill some gaps in the original model proposed by Kotter (1996). According to Appelbaum et al. (2012), there is criticism of this focus on vision instead of execution. These artifacts are key in both developing the vision and communicating it to stakeholders, as is demonstrated in the case study.

Empowering broad-based action is usually achieved through training as a complement to the traditional means of communication (Kotter, 1996; Appelbaum et al., 2012). However, in this framework, the use of mock-ups and prototypes is recommended, not only because it enhances communication and makes the development process more agile, but also because these tools can be used to start the training process even before the final solution is fully developed. Furthermore, by using prototypes to collect stakeholders' feedback and suggestions and incorporating them into the solution, they will feel some control over the transformation process, making them more receptive to a change that might be challenging. This is particularly important considering that Industry 4.0 is usually seen as a disruptive event that can lead to the elimination of jobs. This worry should be addressed by leadership and it should be addressed when setting the vision for the transformation. According to a study conducted by Deloitte Insights (2020), "training and developing workforce" is at the forefront of priorities for Industry 4.0. This study also argues that the Industry 4.0 transformation should be beneficial for the workforce, by eliminating repetitive work and moving those employees towards more satisfying and human-centric jobs.

Another impact of the use of artifacts and milestones coupled with the Agile approach to Industry 4.0 transformation lies in creating short-term wins. The Agile approach is a broad concept that includes a lot of methodologies. One of the most widely used methodologies is Scrum, which is based on sprints: "time-boxes of one month or less during which a 'Done', usable, and potentially releasable product increment is created" (Schwaber and Sutherland, 2017). This type of approach with consistent deliveries of product increments meets the need for creating short-term wins during a transformation process. These quick-wins are essential to motivate the organisation in pursuing and investing in the transformation towards Industry 4.0. Furthermore, these incremental improvements don't compromise the long-term goals and objectives at the expense of short-term gains, which is a common critic of Kotter's model (Boga and Ensari, 2009).

Consolidating the gains and making sure that change sticks in the organisation can be as tough as the change itself. In this context, these last two steps are crucial in every stage of the Industry 4.0 transformation framework. Every time an improvement is achieved and a new process is defined (for example, start recording causes for stoppages directly in a new information system instead of manually in a decentralized manner), the organisation has to make sure this new way of doing things sticks. Across every stage, changes need to be consolidated and become routine, in order for the gains to materialize. The promise of improved efficiency and reduced non-added value time cannot be achieved solely by technology, but also through the stakeholders that interact with the technology. Kotter (1996) argues the importance of momentum to keep change going and making it stick, which involves celebrating short-term wins with sobriety, always keeping in mind the long-term shifts.

Chapter 4

Case Study

This chapter is dedicated to a case study developed by Deloitte in partnership with proGrow in a company operating in the automotive sector. This chapter is divided in three main sections: (1) a description of the initial situation in the client company; (2) an application of the framework developed in the previous chapter; and (3) a description of the proGrow platform, which acted as the technological enabler in this case study. It is important to note that in this case study, the last three stages of the roadmap are not addressed, due to the scope and timeline of the project. However, regarding the horizontal and vertical integration, a following project was being considered to scale the digital transformation to other areas and plants of the company.

4.1 Current situation at the client company

The client company is well-established in the automotive industry, with various plants. In such a group, small inefficiencies can build up and have a big impact in overall costs. In this section, the data acquisition processes are analysed and quantified in terms of time and costs. The continuous improvement situation is also highlighted. This company is an Original Equipment Manufacturer (OEM), which supplies components for vehicles. In the automotive industry, suppliers are tightly connected with the vehicle manufacturers, operating at the same pace as the latter. This type of production has similarities to a "pull" system, but in this case, the OEM can build up stock if needed.

One of the main activities of the company is the production of plastic products for the vehicles' interior. The productive process is based on plastic injection into a mold, creating either the final product or intermediate products, which can later be assembled together. Each station has an injection machine and corresponding molds to create the desired product. The employees responsible for each station are usually highly trained with the mold being used and are aware of the common failure modes and problems associated with it. Their job is to guarantee that the equipment is running at the objective cycle time and to inspect the production (both visually and through the use of scales and other tools that simulate the working conditions for the product). There are also setup teams, responsible for taking care of the change between molds: this operation requires not only the replacement of the molds, but also fine-tuning the equipment to deal with the new mold.

4.1.1 Data and Analytics

Most of the tracking of production orders executed on each machine is done manually. This is a non-value added activity that employees have to carry out everyday. Furthermore, the nature of manual records makes them more prone to error or to be lost. That's where a platform such as the one proposed can help: not only centralizing communication and registration into the platform, but also making the recording and tracking of production orders easier and more error-proof.

Currently, each workstation has a board where the main KPIs of each equipment are manually inserted. These KPIs are grouped by mold and by shift, describing the operational performance of the machine (number or parts produced, number of defective units, downtime, etc.) and the causes for each rejection and stoppage. An employee is responsible for going through all workstations and collecting the data every shift and then insert it in the company's daily record information system. Manually inserting these indicators in the board and then transfer the data to the information system are non-value adding activities, which should be eliminated. These two activities currently account for nearly 50 000 hours per year throughout the whole company.

4.1.2 Continuous Improvement and Collaboration

Regarding collaboration and continuous improvement initiatives, the current situation is based on four teams focused on specific KPIs. Each team pursues certain initiatives in an effort to improve their respective KPI, summarizing their efforts and results and manually generated reports. This situation leads to a lack of homogeneity across teams and initiatives. Furthermore, the decentralized nature of the process does not allow for more comprehensive improvements to be conducted on a regular basis and creates silos across the company, limiting knowledge sharing.

Furthermore, there are various workflows across the organisation that have the potential to be digitised, especially those which are based on checklists. Every time there is a setup, various stakeholders (machine operators and setup teams) have to fill out a checklist that attests the conformity of the machine and the new mold. Digitising such a checklist allows for quicker access to this information and facilitates collaboration. The company currently uses other types of checklists, for example when starting a new manufacturing order, among others. These workflows can be digitised and made easier to fill out, reducing non-value added activities and facilitating further analysis of these checklists.

4.2 Applying the framework in a real life case

After assessing the initial situation in the company, the framework can be deployed. The main focus in this initial stage was to understand and put in place all the enabling strategies described in the framework, starting with people and processes. The client company assembled a team and a project manager to handle the digital transformation, creating a guiding coalition that could engage the remaining stakeholders. proGrow and Deloitte also set up teams solely responsible for the project, handling the communications and the implementation of the platform. The project scope was also defined from the beginning, setting up clear milestones and deliverables throughout the project timeline, as well as defining the responsibilities from each organisation involved. These foundations eliminate future challenges by proactively addressing responsibilities and setting up milestones in an incremental manner, as recommended throughout the previous chapter.

4.2.1 Change Management

These enabling strategies described above, fall under the encompassing stage of change management, following the eight steps defined by Kotter (1996). The client company created the project team and developed the case for embarking on the digital transformation. This vision was communicated internally and the feedback from various stakeholders was taken into account. Short-term wins were constantly being achieved, according to the scope and timeline previously determined. These included mock-ups and incrementally delivering more functionalities to the platform. Training of employees in order to make the changes stick was also determined in the original timeline of the project.

The project team was constantly in talks with proGrow and Deloitte, addressing specific issues and new requirements and tweaks to the proposed interfaces and mock-ups. This was an habit formed since early on in the project life cycle, with weekly meetings where expectations were aligned and potential barriers were address. The main example of addressing these barriers happened when designing an interface for shop floor employees to register certain aspects of the production. The requirements for the project involved developing some new functionalities on the platform. These meetings helped clearly defining the requirements in order to avoid unnecessary rework further down the project. The usage of mock-ups and use cases translated the vision into tangible resources, leaving little room for misinterpretations. By establishing these clear lines of communication supported by mock-ups and stakeholders' contributions, the team was able to improve the solution according to the business needs.

4.2.2 Connectivity

After building this foundation, a more technical approach is required. Here, the integration between the machines and the platform is developed. There are two main sources of data: either directly from the machines and devices or through information systems (like the ERP, for example). Diving deeper into the machines as a data source, there are various ways to collect the data: internally (through PLCs or industrial PCs associated with the machines) or externally (through IoT protocols and sensors and gateways). On the information systems side, the connection can be done through manually updated files, or by accessing the corporate databases (either directly, via APIs, or through automatically generated documents).

In this project, there are four different sources of data: machine signals, sensor signals, ERP databases and manual imputation. Furthermore, there is also the need to write data collected in the platform in an information system that the company currently uses, which records the daily production indicators. The machine signals are acquired using IoT devices which detect the signals from the machines and store the data in an OPC (Open Platform Communications) server. Through a virtual machine, the proGrow team can read and write data from this server. This data is then accessible to the platform in the cloud by using the MQTT (Message Queuing Telemetry Transport) protocol to push and pull data from the virtual machine. This solution enables the real-time monitoring of the shop floor and is used to compute various performance indicators, displayed across the platform. For this project, the data collected are related to the number of injections performed by the machine and to the presence/absence of the mold. The product used to acquire the machine signals is the Flexy eWon industrial router, while the presence of the mold was verified by using a proximity sensor.

The ERP databases contain other complementary data, namely the manufacturing orders and all the information associated with them: planned quantity, product reference, mold reference, theoretical cycle time, etc.. These databases also provide other information, related to human resources and manufacturing orders planning. To access this information, the client company provided proGrow a user account that can access directly to the ERP database and extract this information, using SQL.

Data regarding stoppages and defects is inserted directly by the employees working on the machine at the moment of the occurrence. The employees can register the occurrence and associate a motive for the stoppage or defect. The employees are also responsible for registering the manufacturing order they are performing at the moment, using a bar-code scanner that identifies the manufacturing order and the information associated with it. This information cannot be directly inferred from sensors or machine signals, which means that the employees themselves have to provide the context to go along the data generated automatically. There are technologies and sensors that might enable to automatically detect defective units and even their causes, but in the scope of this project, such technologies were not used. As the company moves further along the development phases, these capabilities might be added in the future.

Finally, there is also the need to integrate the information gathered in the platform with the company's information system of daily records. The solution adopted to fulfill this need was the development of an API that makes this information readily available to be collected on the client side. This solution guarantees the robustness of the integration, since even with the gradual changes of the platform, the API will remain the same. Furthermore, this solution also allows to clearly separate responsibilities between proGrow and the client company, enhancing future support after the implementation.

4.2.3 Business Intelligence

The previous section described the technical aspects of the integration between the platform and the data sources required to feed it. Once this first step is defined, the information needs to be made available in a manner that provides value to the client company. This is done through the various modules of the platform, namely the "KPI", the "Shop Floor" and the "Reports" modules. However, all of these modules need to be configured according to the specifications of the client company. For example, each machine currently has one summary board of the production carried out during the that day and shift. This information has to be digitised in the platform, keeping its functionality for the employees and plant managers.

The client company already has in place a set of KPIs that track the performance of the operations, facilitating the process of defining which KPIs should be presented in the platform. The challenges in this stage are mostly focused on calculating these KPIs with the data gathered previously and defining the context in which they should be calculated. In this case, the most important metrics are related to the OEE and its components: quantity produced, quantity rejected, downtime, production time, etc.. However, the granularity of the data has to be defined: in some cases, these indicators need to be presented in real-time, while in other instances, the indicators should be grouped by shift and by area or plant. Furthermore, each defective unit is complemented by a cause (chosen from a fixed set of causes) and each stoppage is also complemented by a certain reason. This information needs to be grouped in order to understand which are the main modes of failure and which are the most common causes for defective units. Later, in the visibility and transparency stages, this information can be used to diagnose problems and deploy continuous improvement initiatives.

To summarise all these requirements, a document was built where each KPI was dissected to understand its components data sources, the analyses required and the objectives for each analysis. After presenting the document to all the relevant stakeholders for approval, the KPIs and their components were configured in the platform. The KPIs are mainly related to operational efficiency, like the OEE and it's various components (Availability Rate, Performance Rate and Quality Rate). There was also the analysis of a "Synthetic " OEE, which also penalises the planned stops. Table 4.1 presents these KPIs and their objectives. Furthermore, setup times and downtime were also defined, but with a higher granularity level for analysis: each stoppage had to be characterised by a reason from a pre-defined set of failures. The distinction between a stop and a micro-stop was also determined here, since micro-stops affect the Performance Rate, and not the Availability Rate. All of these indicators and their components (such as the number of produced parts, number of rejections, total available time, etc.) were defined and can be analysed in the platform. However, these main KPIs need to be subject to deeper analysis, which were also defined in the Business Intelligence stage. These requirements included analyses by plant, by area and by machine and mold. The traceability of information was also addressed, since management needs to be able to trace downtime and rejections to each employee, so that the proper training can be provided to the people who need it.

Table 4.1: List of KPIs and respective objectives

KPI	Objectives
"Synthetic" OEE	Analysis by plant, module and mold
OEE	Analysis by plant, module and mold
Availability Rate	Analysis by plant, module and mold
Performance Rate	Analysis by plant, module and mold
Quality Rate	Analysis by plant, module and mold
Total Stop Time	Analysis by plant, module, mold and type of stop
Number of Stops	Analysis by plant, module, mold and type of stop
Average Stop Duration	Analysis by plant, module, mold and type of stop
Total Setup Time	Analysis by plant, module, mold and type of setup
Number of Setups	Analysis by plant, module, mold and type of setup
Average Setup Duration	Analysis by plant, module, mold and type of setup
Theoretical Cycle Time	Real-time display for machine operators
Effective Cycle Time	Real-time display for machine operators
Total Micro-Stop Time	Analysis by plant, module and mold
Number of Micro-Stops	Analysis by plant, module and mold
Average Micro-Stop Duration	Analysis by plant, module and mold
Number of Components Produced	Analysis by plant, module, mold and reason
Number of Rejected Components	Analysis by plant, module and mold and reason

4.2.4 Visibility

The visibility stage allows not only to display the curated information to the users, but also to facilitate the data imputation into the platform. In fact, the first concern was in designing the user interface for this imputation, since many KPIs require metrics like the number of defective products, which in the current stage can only be inserted manually.

The proGrow platform enables the creation of this type of interface using easily configurable widgets. Each widget can contain some tags. Most of the tags are connected to the information received from the ERP and from the machine signals, but some can be edited by the user, like the causes for defects and stoppages. These are edited through the icons at the bottom of each card. Figure 4.1 presents a mock-up of this interface. The colors are connected to the Andon system currently used by the company, so every time there is a stoppage, the cards change color according to the reason for that stoppage (setup, logistics problem, quality problem or production problem). The OEE card color is defined by the comparison between the current OEE value and its objective.

After defining this user interface, the priority shifted to another user interface which summarizes the performance of each machine in real time and transfers this data to another information system used by the company. This activity was very time-consuming when done manually, making it a priority for digitisation.

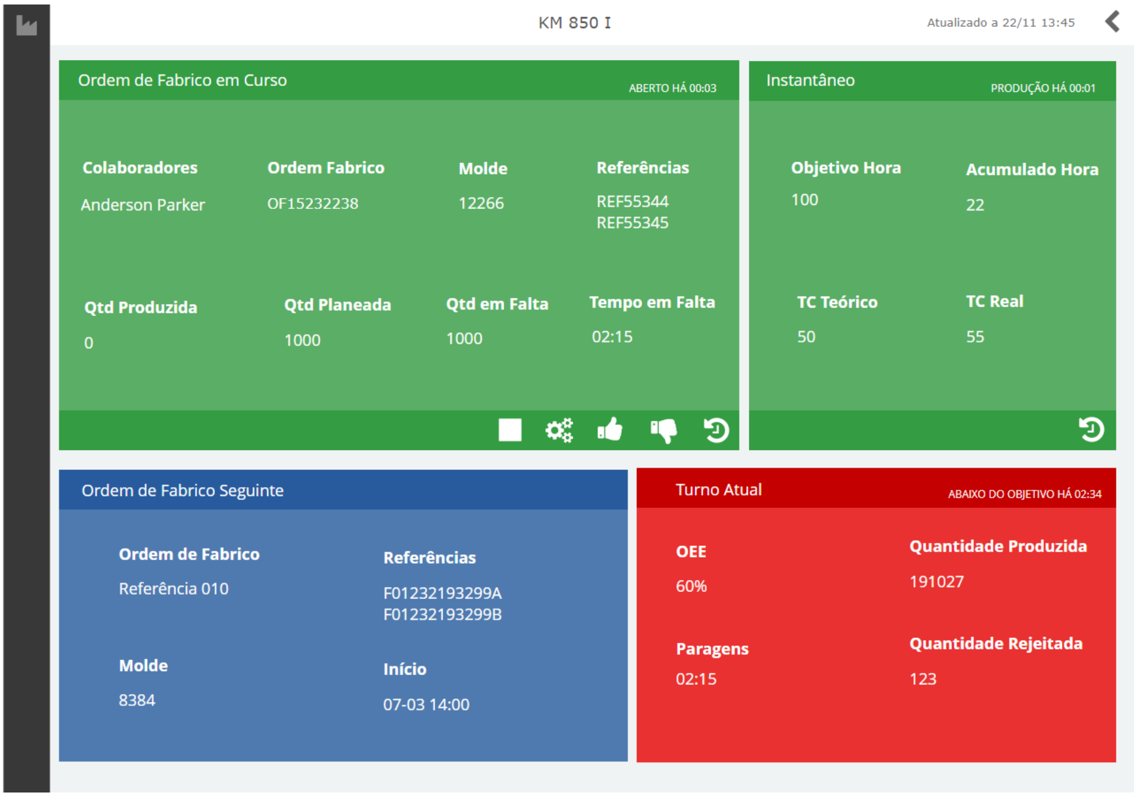

Figure 4.1: Mock-up of the user interface for data imputation

The next step was to assess which reports and analysis were carried out normally in the company and understand how to digitise them. The company had a variety of reports regarding different KPIs, different levels of aggregation (section, plant, company) and different time intervals. All of these reports were adapted to the platform capabilities and digitised. This adaptation focused on understanding the key information that had to be presented and extracting it from the various data sources. The result were clean reports, based on charts and indicators (like the example presented in Figure 4.2). These reports are now automatically generated and made available only to the relevant stakeholders who use them for their meetings, eliminating some non-value added activities like the creation of the reports manually. Once again, the usage of mock-ups and prototypes was the foundation to build the digital reports. The process was iterative and took into account the pain points felt by the users of these reports.

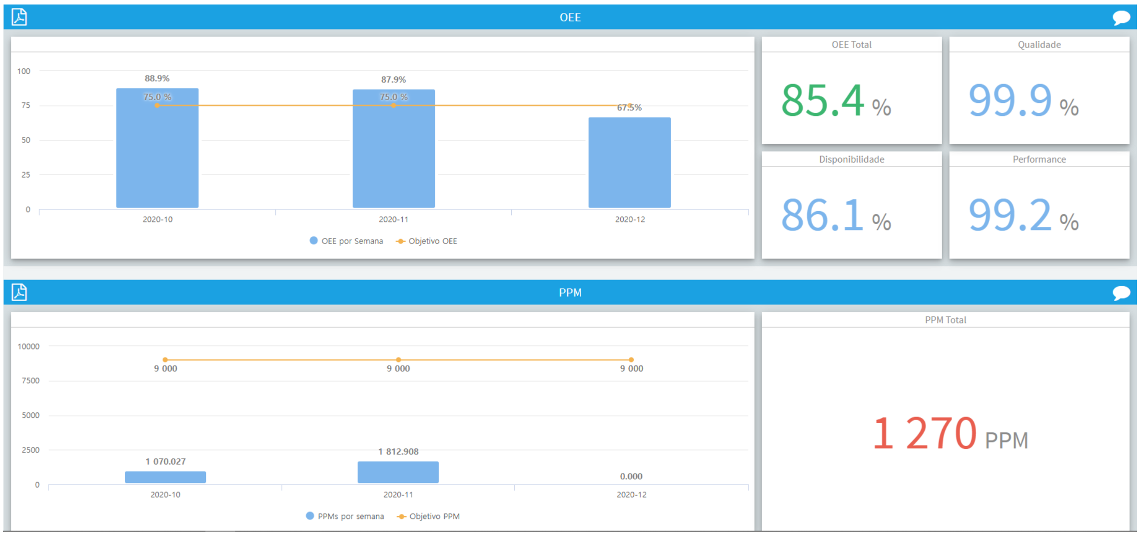

Figure 4.2: Mock-up of one of the digitised reports

4.2.5 Transparency and Collaboration

The transparency stage in this project was focused on connecting KPIs to continuous improvement initiatives and digitising some workflows and checklists. Collaboration was addressed by enabling comments in every report, centralising relevant information with the associated report. Some collaboration functionalities were also added in the more operational interfaces, such as the one in Figure 4.1. These operator interfaces were connected to a high-level view of the shop floor, which summarised the most important information of each machine and each section. In the display, managers and supervisors can control in real time which machines are down and why (mainly through the Andon color scheme) and can also access a quick summary of the most critical machines in terms of downtime, rejected units and overall efficiency. If these issues persist, the supervisors would have a visual feedback, allowing for a quicker reaction to the problems.

Setups are also critical in this industry, and collaboration is key when fine-tuning the machines for new molds. Thus, the setup stage was a priority for improvement and digitisation of the workflow. By understanding the routine carried out every time a setup occurred, a checklist was developed in the proGrow platform. Using the platform to fill the checklist gave other stakeholders the transparency to understand what went right and what went wrong with each setup and to track these results over time.

Finally, the pipeline for the project included training and workshops with the platform for the users. The goal was to create the habit of using the platform during the setup process and when implementing continuous improvement actions and projects.

4.3 proGrow

Even though the framework developed in the previous chapter is technology-agnostic, the case study was carried out by a technology start-up, which developed a platform that addresses most of the issues in the first stages of the digital transformation roadmap. proGrow fills the role of the enabling partner presented in Figure 3.1, under the technology enablers section. In order to provide a better understanding of the case study and the capabilities implemented at the client company, a brief overview of the proGrow platform is presented here.

The proGrow platform intends to digitise the shop floor of a company, by acquiring and presenting data, while at the same time enabling collaboration and improvement opportunities based on that data. The platform was created with the idea that it could make the digital transformation easier and enable more companies to transition to the Industry 4.0 paradigm.

The platform is divided in seven main modules, each one of them focused mainly on data visualisation or continuous improvement and collaboration. proGrow was designed to be flexible, customisable and user-friendly, not only in its utilisation, but also in its "installation": the platform is provided through the web, with minimal involvement of the client's IT department.

The first module is focused on KPIs. Here, the users can easily visualise KPIs, calculated automatically from the equipment's signals (like production time or downtime) or through manual imputation from the employees (like the number of defects). These indicators can be matched against certain objectives defined by the company and can be viewed in different time horizons (yearly, quarterly, monthly, daily, by shift) or levels (plant, section, machine, etc.). Figure 4.3 shows an example of this module.

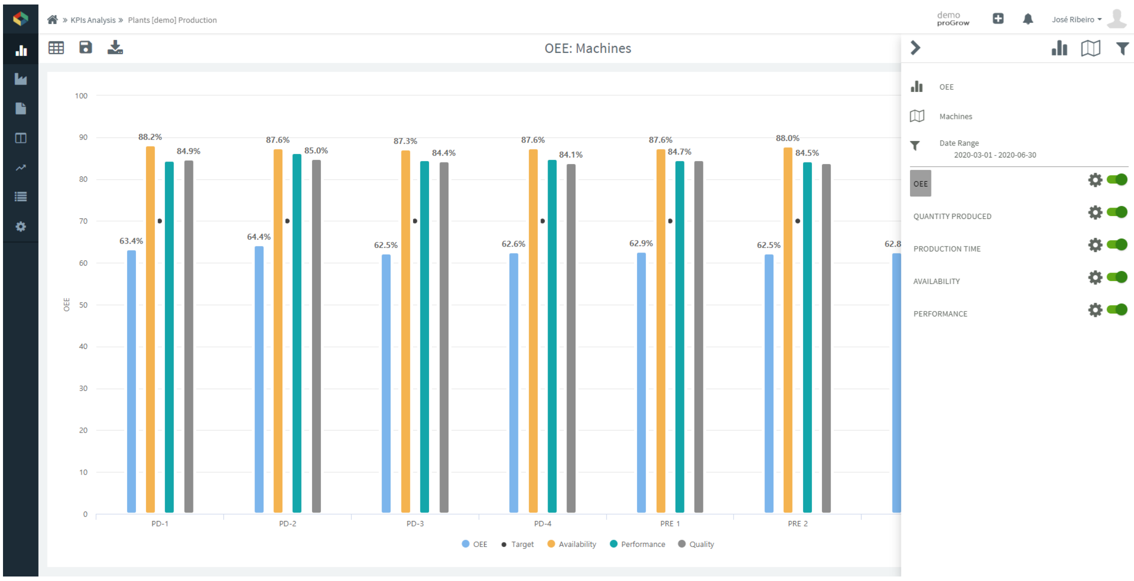

Figure 4.3: Example of the KPI module interface

The shop floor module presents a digital representation of the client's shop floor. It is highly customisable and shows real time data of each machine and/or section. This module is also available to employees working directly in the shop floor, where they can interact with the platform and insert more qualitative data that complements the equipment signals. Employees can, for example, notify that there was a certain defective part produced and insert the reason for this defective unit. Figure 4.4 presents an overview of this module and its capabilities.

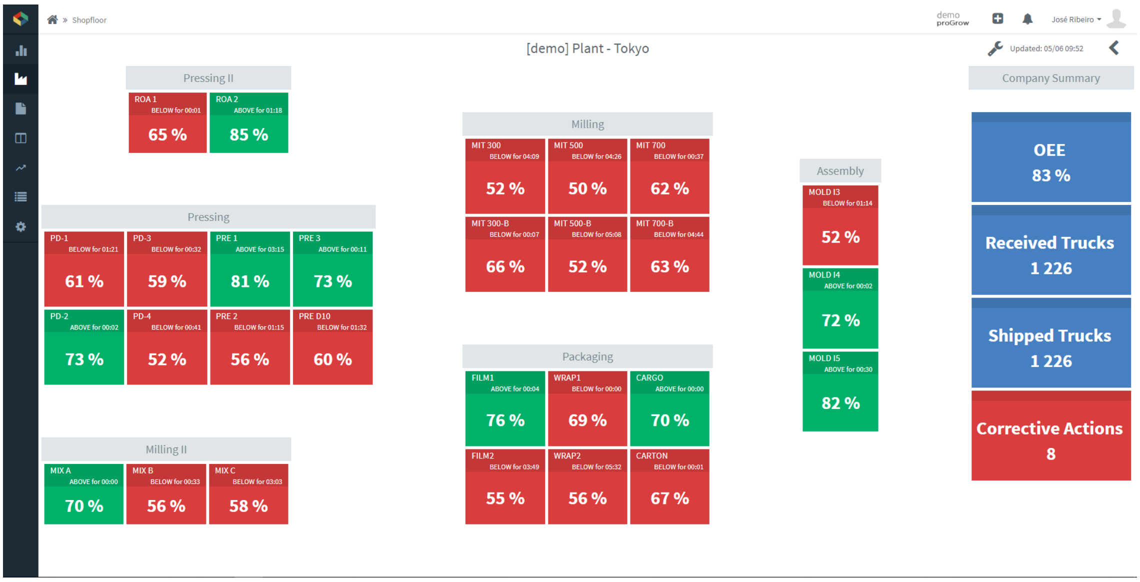

Figure 4.4: Example of the Shop Floor module interface

The third module is named "Reports" and provides useful tools for top-management to get a sense of the situation in the company, at various levels and time horizons. Based on the KPIs being monitored by the platform, this module can automatically generate reports that summarise the performance of each section or plant or even the whole company. This module also enables collaboration, in the sense that different users can comment on a report. This comment will stay pinned to the report, ensuring that no relevant information is lost. Figure 4.5 shows an example of a possible report configuration.

Figure 4.5: Example of a Report

The remaining modules are more focused on continuous improvement and collaboration.

There is a *Kanban* module, where the user can see the different continuous improvement initiatives (isolated actions or more comprehensive projects) or different workflows specified by the client (like audits, incident responses, etc.). All these different tasks are organized following the PDCA cycle. The continuous improvement initiatives are created and managed in the "Improvement" module, while the remaining workflows are managed in the "Tasks" module. Figure 4.6 presents an example of a project. It is visible the current status of this project in the top right corner of the screen, and the various tabs show some of the features of the project. In the monitoring tab, certain KPIs can be selected for monitoring throughout the implementation of the project. These KPIs are then measured against their base value and the goals set at the start of the project. The platform also allows quickly exporting PDF files with Ishikawa diagrams and A3 reports.

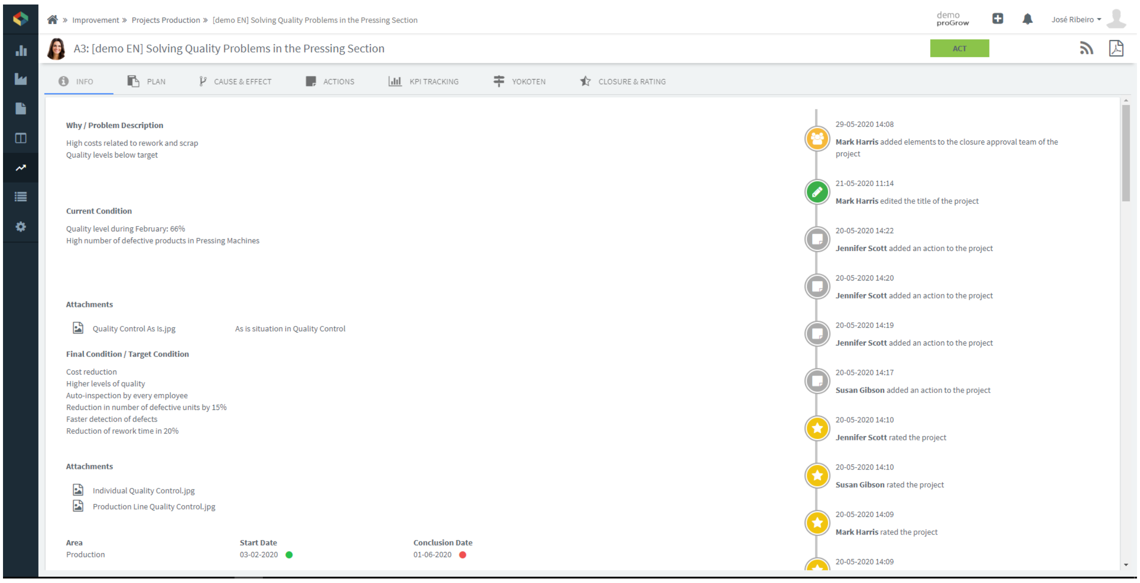

Figure 4.6: Example of an Improvement project

The final module is the "Configuration" one. In this tab, selected users can define which KPIs to track throughout the platform, the different areas in the company, among other technical details. Throughout the other modules, users with configuration permissions can also edit layouts and specific fields inside that module.

Chapter 5

Discussion and Conclusion

The fourth industrial revolution is already under way, and organisations must adapt quickly in order to compete with the leading players in the digital transformation. However, with the frenetic pace at which changes are occurring in the sector, this transformation might seem overwhelming to most organisations with little experience in such projects. Thus, this paper aims to develop and present a simple and actionable framework for organisations to follow and base their decisions. Furthermore, with the inclusion of a practical case study, practitioners can better grasp some concepts and challenges that might be lost in a more theoretical approach.

In this paper, a comprehensive and actionable framework and roadmap were developed. These tools were the result of a conceptual and applied research through the literature, combined with the in-house experience of Deloitte and proGrow and with the business sense developed in this particular case study, presented in Chapter 4. This framework is based on various sources from Industry 4.0 literature, but also from the change management area and from the literature on Agile methodology for software development. The result is an holistic view of the digital transformation, based on different areas beyond just the technical aspects that tend to receive more focus in the Industry 4.0 literature.

Even though the development of the framework is very conceptual, the enablers and challenges faced in each stage are grounded in practical applications, with the help of the case study to help visualise the change process. Furthermore, despite the project not being fully implemented in the client company at the time of writing, based on Deloitte and proGrow's past experience, some benefits can be expected. This project adds value to the client company in three different pillars: (1) Reduction in the number of administrative FTEs; (2) Increase in the number and effectiveness of continuous improvement initiatives; and (3) Increase in performance metrics, such as OEE. The estimated baseline benefits for each of these three pillars are the following:

1. Reduction of 3 administrative FTEs per plant;
2. 20% increase in saving associated with continuous improvement initiatives;
3. Increase of performance metrics by one percentage point.

The combination of the savings created across these three pillars account for almost 1% of the company's revenues. If the project were to be expanded to all the other production areas of the company and to other support activities (Horizontal and Vertical Integration stage) and if the last characteristics were realised (Forecasting Capabilities and Adaptability), these savings could be even more substantial. Furthermore, other benefits can arise besides cost savings, namely improvements in product quality and sustainability of the operations.

This case study and these forecasts illustrate the potential that can be unlocked simply by taking the first steps towards Industry 4.0. That's the reason why the framework was built: to provide a flexible and comprehensive action plan, that can facilitate these first steps. Major benefits can be realised throughout the roadmap, and not just on the last stages, which are normally the most hyped and scrutinised in the literature associated with IoT and Industry 4.0.

However, the work developed here could still be improved upon. The last phases of the roadmap were not fully explored in this project, mainly due to timeline restrictions. Further research could be carried out regarding the last phases (Vertical and Horizontal Integration, Forecasting Capabilities, and Adaptability), proposing a complement to the framework and the roadmap here presented. Furthermore, the framework is mainly focused on enablers and challenges in each of the areas associated with change management (people, processes and technology), but this scope could be widened. Even though most of the stakeholders are involved in each phase, further work could dive deeper into the roles and responsibilities of each stakeholder across the roadmap.

There are also some inherent limitations to the model proposed, namely the connection between stages across the roadmap. It is difficult to clearly establish milestones for each of these stages and these milestones can be very different across projects. The iterative nature of the movement between stages creates this difficulty, which can lead to an unclear sense of progress across the project. The solution would be to clearly define deliverables and milestones across each stage and each iteration of the project, right from the start. This definition of the scope of the project would be carried out by the project management team. The case study tries to highlight this solution, while still leaving some room for minor tweaks and adaptations, in light of the Agile methodology.

The digital transformation towards Industry 4.0 is a comprehensive endeavour, surpassing boundaries between departments and people. Each project will have its specificities, making it difficult to produce a "one-size-fits-all" solution. However, this framework tries to lay some foundations which organisations can build upon and adapt to their own situation. Such framework was lacking in the literature, which mostly focused on high-level strategic outlooks (and thus not actionable or practical) or in disconnected case studies and guides for detailed applications (for example, focusing only on the connectivity stage).

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