UNIVERSIDADE CATÓLICA PORTUGUESA

Industry 4.0

Effect on the value chain of the Portuguese footwear industry

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Resumo

Atualmente, os mercados são caracterizados por uma procura dinâmica e em constante mudança, o que cria grandes desafios para os fabricantes. Com o surgimento da indústria 4.0, os processos industriais têm vindo a sofrer mudanças significativas ao adotar tecnologias de informação modernas. A indústria 4.0 compreende a digitalização da cadeia de valor de uma empresa de manufatura, adotando tecnologias como sistemas ciber-físicos ou a internet das coisas. A indústria portuguesa do calçado apresenta uma grande variedade de procura de modelos, o que requer sistemas de produção avançados e flexíveis.

A presente investigação tem em consideração esta premissa e centra-se em investigar de que forma é que a implementação das tecnologias 4.0 da indústria afeta os fabricantes portugueses de calçado ao longo da cadeia de valor, criando oportunidades de inovação na experiência do cliente, produção inteligente e qualificação dos colaboradores.

De forma a criar bases para esta investigação, foi realizada uma extensa revisão da literatura. Posteriormente, foi realizada uma investigação qualitativa e exploratória com base em entrevistas de três especialistas do setor e dez representantes de empresas de calçado. Foi possível perceber que as empresas, de forma geral, estão a investir na implementação de novas tecnologias em diferentes departamentos para se tornarem mais competitivas e produtivas. No entanto, existem alguns constrangimentos relativamente à rigidez de algumas tecnologias e à atração de novos trabalhadores para o setor do calçado.

Palavras-chave: Indústria 4.0; Indústria Portuguesa do Calçado; Fabrico inteligente; Interoperabilidade; Força de trabalho; Sustentabilidade; Inovação da experiência do cliente.

Abstract

Nowadays, markets are characterized by their dynamic and ever-changing requests, creating big challenges for manufacturers. With the emergence of industry 4.0, industrial processes have been suffering significant changes by implementing modern information technologies. Industry 4.0 comprises the digitization and smartization of the entire value chain of a manufacturing company by introducing technologies such as cyber-physical systems or internet of things. The Portuguese footwear industry presents a large variety of different models' requests, which requires flexible advanced production systems.

The present investigation takes this premise into account and focuses in pursuing how the implementation of industry's 4.0 technologies affects the Portuguese footwear manufacturers along the value chain, creating opportunities to innovate client experience, smart production and employees' qualifications.

With the main purpose of creating foundations for the research, an extensive literature review was conducted. Afterwards, a qualitative and exploratory investigation was performed based on interviews to collect insights of three industry experts and ten footwear companies' representatives. It was possible to notice that companies, in general, are investing in the implementation of new technologies in different departments in order to become more competitive and productive. However, there are some constraints regarding the rigidity of some technologies and the attraction of new workers to the footwear sector

Keywords: Industry 4.0; Portuguese footwear industry; Smart production; Interoperability; Workforce; Sustainability; Customer experience innovation

Index

List of Acronyms

APICCAPS – Portuguese Footwear, Components, Leather Goods Manufacturers' Association

AM – Additive Manufacturing

CEO – Chief Executive Officer

CNC – Computer Numerical Control

CPS – Cyber Physical Systems

COO – Chief Operating Officer

CTCP – Portuguese Footwear Technological Center

GPS – Global Positioning System

INESCTEC – Institute of Systems and Computer Engineering, Technology and Science

IoT – Internet of Things

IT – Information Technology

RFID – Radio-Frequency Identification

Index of Tables

Chapter 1
Introduction

1.1 Contextualization

The beginning of the fourth industrial revolution was in 2011, during the Hannover fair event, when a new concept, industry 4.0, was presented by the Germans (Qin, Liu, & Grosvenor, 2016). The paradigm of industry 4.0 can be described as the digitization and smartization of factories, distribution channels and value chain members, through the introduction of new technologies such as cyber-physical systems (CPS) or internet of things (IoT).

Industry's 4.0 technologies make the interconnection and communication between components, machines and humans possible by exchanging large amounts of information automatically. Consequently, factories will be able to control and make reasoned decisions about the entire value chain of the life cycle of products.

1.2 Study Motivation

In today's dynamic and ever-changing market requests, there is a tendency to shift from mass production to customized and personalized production, creating some challenges to manufacturers. Industry's 4.0 technologies give visibility to product information and production in real time to all the agents involved in the value chain, from the customer to the acquisition of raw materials. In this sense, manufacturers are able to create a faster and more active collaboration with consumers, resulting in new business models in order to meet customers individualized demand.

The Portuguese footwear industry is internationally recognized as a source of fashion and designer footwear has been significantly growing throughout the years. Taking into account that the footwear sector contributes significantly to the Portuguese economy, for this investigation, the motivation was to study how industry's 4.0 technologies create immense opportunities to improve efficiency, flexibility, time of response, product customization and the customers' engagement and loyalty, and what type of investment has been done within this topic.

1.3 Objectives of the Investigation

With the emergence of the 4th industrial revolution, industrial processes have been suffering significant changes by implementing modern information technology (IT). The use of smart machines not only transforms the conventional production methods into automatic ones, but it also automatically shares information about stock levels, machine breakdowns, changes in orders, i.e., relevant data for decision making of an efficient factory.

The dissemination of industry's 4.0 technologies and concepts in the Portuguese footwear companies have a great impact in what regards technological development and competitivity in the sector. The footwear industry is characterized by a large variety of different models' requests, which requires flexible advanced production systems (APICCAPS, 2020a).

In this study, the focus is to analyze how the implementation of industry's 4.0 technologies affects the Portuguese footwear manufacturers in all different stages of the value chain, creating opportunities to innovate client experience, smart production and employees' qualifications.

After defining the research question, there are some concrete and more specific objectives that are going to be addressed throughout this study. The first objective is to analyze how the adoption of industry's 4.0 technologies create new ways of interaction with clients in a digital context.

The following objective is to analyze how smart manufacturing may improve flexibility, time of response and sustainability. The third objective is to analyze the level of interoperability of the Portuguese footwear companies. The fourth and final objective is to investigate the influence of industry 4.0 on workforce challenges regarding the footwear sector's attractiveness and social sustainability.

1.4 Investigation Methodology

The methodology adopted to answer the research question of this study, "How does the implementation of industry's 4.0 technologies affect the Portuguese footwear manufacturers in all different stages of the value chain?", is qualitative, since this methodology approaches both the objectively quantifiable happenings, and the mode people construct, interpret, and give meanings to the experiments. Moreover, this investigation follows an exploratory nature, to seek new insights and assess phenomena in a new light, in the form of a survey. Additionally, the data collection will consist of thirteen interviews, ten Portuguese footwear companies and three institutions that work along with the footwear industry.

1.5 Thesis Structure

The structure of this study is divided in six chapters. The first chapter corresponds to the Introduction. The following two chapters, i.e., industry 4.0 and the footwear industry, correspond to the literature review. Additionally, the fourth and fifth chapters are concerned to the methodology and, the results and data analysis, respectively. Finally, the sixth chapter refers to the conclusion.

The literature review is allusive to the themes industry 4.0, with a main focus on the Portuguese footwear sector, which is in accordance with the objectives of the study. In the second chapter, the theme industry 4.0 is explored and is divided in six parts. Firstly, the reader can find a description of how the industry has evolved throughout the years in terms of the industrial revolutions, followed by a contextualization and a special focus on the concept of industry 4.0. Afterwards, the main technological concepts within industry 4.0 are presented. The last three parts of the first chapter, namely information integration and interoperability, workforce implications of industry 4.0, and opportunities for sustainability, are explored.

The third chapter, also related to the literature review, has its main focus on the footwear industry and is divided in three parts. In the first part, a description of the footwear industry and an economic analysis is performed. In the second part, the reader may find an explanation of how the Portuguese footwear cluster has evolved over the years as well as an overview of the sector. The last part of this chapter explores the opportunities derived from the implementation of industry’s 4.0 technologies in the Portuguese footwear sector.

In the fourth chapter of this study, the reader may find the methodology, which is divided in seven parts. After the introduction, both the research objectives and the research question are presented. Thereafter, the most adequate research methodology for this study is discussed and, later, the research strategy is presented. In the last three parts of this chapter the data collection method, the design methodology, and the data analysis methodology are presented.

In the fifth chapter, the reader may find the results and data Analysis. The aforementioned chapter begins with a brief introduction, followed by the data collection methodology and a brief characterization of the chosen interviewees. Posteriorly, the results and data extracted from the performed interviews are presented and analyzed.

Lastly, in the sixth and final chapter, not only are the main conclusions of this investigation exposed, but also its limitations and recommendations for future investigations.

Chapter 2
Industry 4.0

2.1 Introduction

The fourth industrial revolution, also known as industry 4.0, is a representation of the current trend of implementing emerging automation technologies in the manufacturing industry, evolving from embedded systems to cyber-physical systems. The new generation of industrial systems, for example smart factories, is increasing in order to cope with the complexity of production in cyber-physical environments. Industry 4.0 represents the path towards internet of things, data and services, meaning that industrial production equipment goes from simply processing the product to a new reality where the product communicates with the equipment to tell it exactly what to do (MacDougal, 2014).

The first sector will focus on how the industry and manufacturing methods have been evolving throughout the years, from the first industrial revolution to the fourth industrial revolution, which is one of the main focus of this study.

The second subject will focus on the paradigm of industry 4.0 and the concept of “smart manufacturing” associated with it. Moreover, the main drivers, challenges and benefits of implementing industry 4.0 in a manufacturing organization will be explored. The following topics will discuss the main technological concepts associated with the concept of industry 4.0. Furthermore, it is important to explain the importance of information integration and interoperability when implementing the emerging industry's 4.0 technologies.

The final two topics will explore and discuss the workforce implications of industry 4.0, and the main opportunities towards social, economic and environmental sustainability, in both micro and macro perspectives, enabled by industry 4.0 and its adjacent technologies.

2.2 Industry Evolution

The industry, as we know it, has been suffering considerable changes and evolving throughout the years. In this sense, it is important to understand the four industrial revolutions and how traditional manufacturing and production methods have been suffering a digital transformation.

The first industrial revolution began in England in the 1760s and lasted until the 1880s, extending to western Europe and the new United States. In Industry 1.0, there were high volumes of products' demand and the supply could not satisfy these requirements with its traditional manufacturing (Yin, Stecke, & Li, 2018). Consequently, the introduction of water and steam powered machines made the evolution from manual work to manufacturing processes possible (Rojko, 2017) and the ability of producing bigger quantities. This phenomenon was considered one of the most important developments ever. Characterized by the industrialization, it changed the world and improved the quality of people's lives, which was one of the main drivers of this revolution (Stearns, 2021).

The second industrial revolution, also known as the American industrial revolution, went from the end of the nineteenth century to 1980s. There were major technological innovations in this period of construction of a modern industrial economy, such as electrical energy, electronic and mechanical devices, electrical communication technologies and cars (Mohajan, 2019). Volume and variety were features of Industry's 2.0 demand. In this regard, mass production assembly lines and the Toyota production system, developed by Henry Ford and Taiichi Ohno, were put into practice in order to be able to respond to the market changes of this phase (Yin et al., 2018).

The third industrial revolution had its beginning in the 1980s and is characterized by new information technologies and conventional automation, which had a great impact on the modernization of the economy by creating means of communication and interaction between business networks (Dosi & Galambos, 2013). Furthermore, industry's 3.0 demand requirements are distinguished by volume, variety and delivery time, which required the application of flexible manufacturing systems (Yin et al., 2018).

The beginning of the fourth industrial revolution was in 2011, when the concept of industry 4.0 was launched by a German initiative of the federal government in conjunction with universities and private companies, as a result of the previous industrial revolutions (Qin et al., 2016). The transition from industry 3.0 to industry 4.0 is marked by several manufacturing changes, triggered by the introduction of technologies such as the internet of things, big data, electric vehicles, 3D printing, cloud computing, artificial intelligence and cyber-physical systems (Yin et al., 2018). Veering into digital manufacturing facilitates the communication and exchange of information between machines and humans, allowing the manufacturers to meet the demand's requirements of customized and individualized production (Oztemel & Gursev, 2020).

2.3 Industry 4.0

Industry 4.0, as a new industrial stage, has been one of the most trending and relevant topics amongst professional and academic grounds since it appeared. This concept was introduced with the purpose of increasing productivity and efficiency of industries by developing advanced and smart manufacturing systems (Frank, Dalenogare, & Ayala, 2019). Smart manufacturing, i.e. "fully integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network and in customer needs" (Kusiak, 2018), is possible due to the collaboration between emerging technologies to generate digital solutions to the entire value chain.

Industries have the need to adjust their production strategy in order to be able to give response and constantly adapt to customers' dynamic demand (Erboz, 2017). Therefore, increasing flexibility and adaptability is possible with an integrated network, in which all parts of the value chain communicate with each other and constantly interchange relevant information. In this sense, it is important to understand and define the concept of Industry 4.0 and its impacts on the functioning of a factory. Industry's 4.0 paradigm relates to organizational and technological changes, with an integrated value chain and new business models adapted to the customers' requirements characterized by mass customization (Nosalska, Piątek, Mazurek, & Rządca, 2019). These changes are enabled by the innovative emerging technologies, connectivity and IT integration.

The main drivers for the adoption of industry 4.0 can be divided into four categories: organizational, technological, innovation and operational (Santos et al., 2017). The organizational drivers are associated with new methods of work and collaboration, whereas technological drivers are the outcome of the merging of multiple streams. Regarding the innovation drivers, they are related to the need of developing new business models and innovation networks. Lastly, the operational drivers result from the constant necessity of companies to have a better operational performance with the view to remain competitive.

Implementing industry 4.0 is not a simple mission, it brings several challenges and difficulties with significant impact on the manufacturing industry such as scientific, technological, and economic challenges, social problems and political issues (Mamad, 2019). However, this paradigm has also a positive impact on companies, with numerous benefits and opportunities for improvement in several different areas of the entire value chain.

One of the most relevant challenges of adopting this new concept is the qualification and skills of the workforce when dealing with new and more complex technologies and the analysis of big data (Unger et al., 2017). Moving towards industry 4.0 requires the investment in smart factory, which translates into severe changes in the development processes, marketing, manufacturing, logistics, after-sales services and security (Nunes et al., 2017). Therefore, this creates a challenge, specially to small and medium-sized companies, which are hesitant to start this digital transformation due to the uncertainty about financial benefits (D Wee et al., 2015). Another challenge to manufacturers is how to make sensible and rapid decisions about the whole functioning of the factory by extracting meaningful information on large amounts of data and analytics, without compromising long-term opportunities (Mamad, 2019).

The emergence of industry 4.0 and its adjacent technologies create numerous opportunities and benefits for companies. The smartization of products, procedures and processes allow the company to transform into a smart factory (Mamad, 2019). Consequently, smart factories are qualified to better manage complexity, less susceptible to disturbance and more capable to produce goods efficiently. Regarding the application of industry's 4.0 technologies in production processes, manufacturing can be more flexible, respond to individualized customization requests, simplify business processes, reduce inventory inaccuracies and have control over logistics processes (Kayikci, 2018). Moreover, being able to extract pertinent and useful information out of the large amounts of data available is a great opportunity and a key element to intelligent and profitable decision-making along the entire value chain, from production to post-sales service.

2.4 Industry’s 4.0 Main Technological Concepts

2.4.1 3D Printing

3D printing, which has been suffering subsequent developments over the years, is a technology developed by Charles Hull in 1986. This process is an additive manufacturing (AM) technique by which a wide variety of products can be manufactured from three-dimensional model data (Ngo et al., 2018). In this system, products are created by printing successive layers of materials that are formed on top of each other (Bibby & Dehe, 2018).

The development of several methods and techniques of additive manufacturing was motivated by the need of producing prototypes quickly, minimizing printing defects, enhancing mechanical properties and the skills to print big structures (Ngo et al., 2018). The main technique of 3D printing used in industry is fused deposition modelling, which predominantly uses a continuous filament of a thermoplastic polymer to print consecutive layers of materials (Bhushan & Caspers, 2017). The remaining methods are “additive manufacturing of powders by selective laser sintering, selective laser melting or liquid binding in three-dimensional printing, as well as inkjet printing, contour crafting, stereo-lithography, direct energy deposition and laminated object manufacturing” (Ngo et al., 2018). It should be noticed that for each method of additive manufacturing or 3D printing, there are appropriate materials to use.

The application and utilization of 3D printing methods to create prototypes and products has increased over the last few years in several industries. This technology allows the decrease of costs related to the development of new products as well as the costs of customized and personalized products for end-users (Ngo et al., 2018). Moreover, 3D printing has the capability of producing small quantities of personalized products with low costs. Producing complex products with high precision, minimum material waste, flexible choice of design and size, and mass customization are some of the benefits of shifting from traditional to additive manufacturing technologies for several manufacturing industries (Berman, 2012).

There are still some existing challenges and improvements to the performance of this technology that should be taken into consideration in order to be competitive against traditional production methods. Some industries might not be able to use this technology due to the restricted number of materials available for 3D printing (Ngo et al., 2018). When printing micro-scale products, the resolution, surface finish and layer bonding might also be a challenge (Vaezi et al., 2013). The main drawbacks of 3D printing technology are high costs and reduced mechanical performance when compared to traditional methods. Regarding the improvements for 3D printing, manufacturing speed must be increased by improving 3D printing machine design (Ngo et al., 2018).

2.4.2 Big Data

Industry's 4.0 paradigm involves a change in production, transforming traditional production methods into smart manufacturing. Furthermore, this concept implies the communication, interaction and exchange of information between machines and humans, giving origin to autonomous and optimized devices (Gökalp et al., 2017). The use of several emerging industry's 4.0 technologies and more complicated production methods, equipment and products originate large volumes of data (Bibby & Dehe, 2018), which can be hard to store, process, and analyse using conventional database technologies (Hashem et al., 2015). Big data contains four dimensions: volume, which refers to the amount of data that require technological competences to be managed; variety, which refers to the several origins of dynamic and unstructured data such as transactional systems, social networking sites or internet; velocity, which refers to the speed of generation of new data and analysis and; value, the most significant dimension, which refers to extraction of the most valuable and important information for the organisation (Witkowski, 2017).

In today's competitive world, manufacturing companies face the need to extract valuable information out of the big and unstructured datasets for their business. Moreover, it is essential to process data in high speed so that enterprises may integrate that precious knowledge into their production methods and support decision making (Gökalp et al., 2017).

Big data can create several benefits for manufacturing companies. Firstly, big data allows organizations to analyze data at a more advanced level compared to traditional tools. In addition, it provides the ability to process data taken from different and incompatible sources, which are often unstructured and transform it into relevant information for the company's proper functioning. Besides data collected from the production systems, there are other significant sources of information such as the supply system, customer profiles, social networks, orders, market forecasts and geographical schemes. Collecting customer data may also be very favorable in the sense that it supports companies to predict clients' behavior and meet their expectations (Witkowski, 2017).

2.4.3 Cloud Computing

Cloud computing is a mighty and fast-growing technology with the capability of executing complicated computing tasks and encompasses a wide range of IT packages (Hashem et al., 2015). Cloud computing can be defined as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Ruparelia, 2016). In this sense, cloud solutions are a web-based application with the capability of storing a wide range of information on external services, which is predominantly accessible through the internet. This emerging technology may be very useful and beneficial for numerous organizations and individuals but mainly for manufacturing companies. These companies generate big volumes of data and, therefore, have the need to find a solution to store, process and analyze all that information (Liu, 2013).

Nowadays, markets are constantly changing and becoming more digitalized, which may create some technological challenges for some companies in what regards datasets. By adopting this technology, cloud computing, manufacturing enterprises may be rewarded with many benefits and opportunities. Cloud computing allows the virtualization of resources, parallel processing, security, and the incorporation of data service with data storage (Hashem et al., 2015). Additionally, it reduces the cost and limitation for automation and computerization, and infrastructure maintenance expenses. Cloud-based solutions also allow an efficient management, giving the opportunity for companies to focus on their core business activities (Lu et al., 2013).

There is a relationship between big data and cloud computing. Instead of using local storage such as computers, mobile devices or other electronic devices, big data may use a distributed storage technology prevenient of cloud computing. Hereupon, cloud-based applications simplify and smooth computation and big data processing, serving as a successful technology to store data necessary to conduct big data analysis (Hashem et al., 2015).

2.4.4 Internet of Things

The concept of Internet of Things, also known as the "internet of everything", has been broadly used in several areas and can be defined as a global infrastructure for information, which allows advanced systems through the interconnection, continually to exchange and make use of information of physical and virtual things based on, existing and evolving, interoperable information and communication technologies (Wortmann & Flüchter, 2015). Within the system of the internet of things, everything can be defined as variable, from objects to processes, data and people. The internet of things has three prominent characteristics, namely, context, omnipresence and optimization (Witkowski, 2017). Firstly, context is related to the capability of communication between an advanced object and the existing setting, allowing objects to provide immediate answers and information, such as location, physical condition or atmospheric conditions to possible changes. Secondly, omnipresence gives the insight that objects, in the future, will be able to communicate with each other on larger scales and will go beyond the interconnection with a user network of human-operators. Lastly, optimization refers to the functionalities of each object.

The Internet of things has plentiful and versatile fields of application. The most predominant areas of application are smart industry, smart home, smart energy, smart transport and smart city (Atzori et al., 2010). Focusing on smart industry, the development of intelligent production processes and linked production sites are usually a matter of discussion within industry 4.0. The introduction of this concept in manufacturing companies has been a tremendous innovation, being that the capability of objects embedded in the environment to act and give response to events is only possible thanks to the integration of new components with these objects (Pfisterer et al., 2011).

The world's economy is becoming more and more global and competitive, consumers' requests are more diverse and customized, which forces the manufacturing industry to evolve and adopt new technologies. The Internet of Things creates numerous opportunities and benefits for this industry. For example, smart machines and production facilities are connected and, therefore, are able to autonomously interchange information, generate actions and control each other independently. Moreover, the utilization of internet of things network enables and emphasizes the generation of large volumes of data, supporting decision-making to improve and ensure the proper functioning of manufacturing processes. Within this concept, big data and cloud computing are fundamental in managing the large volumes of data generated by manufacturing systems, giving the opportunity to identify better business opportunities and quickly adjust to change (Yang, Shen, & Wang, 2016).

Radio-frequency identification (RFID) is also a core technology that plays an important role in internet of things. It consists of the use of electromagnetic fields to transfer data to automatically identify and track tags attached to objects and can be applied in supply chain controlling and production programming (Juels, 2006). Furthermore, Wireless Sensor Networks is a complementary technology to RFID since it allows the control of the objects and environment, being able to support multi-hop wireless communication through spatially distributed autonomous nodes (Yang et al., 2016).

2.4.5 Cyber-Physical Systems

The concept of cyber-physical systems may be described as transformative technologies with the ability to manage and control integrated systems among its physical factory floor and the cyber computational space, being capable of communicating with humans through new modalities (Baheti & Gill, 2011). Cyber-physical systems reside in two principal elements: a network of objects and systems intersecting with one another through the internet with a designated address; and a virtual environment built via computer simulation of objects and actions in the real world (Oztemel & Gursev, 2020). It is crucial to have an effective communication between machines, products and humans, consequently, cyber-physical systems serve as enablers to a rapid and trustworthy data exchange between those different systems (Fatorachian & Kazemi, 2018).

Over the years, the manufacturing industry has been evolving and investing in new high-tech technologies such as sensors, data acquisition systems and computer networks in order to remain competitive. By using these new technologies, large volumes of data are generated, the so-called Big Data. In this sense, CPS can be implemented to manage big data and improve the interconnectivity of machines so that they become more intelligent and independent (Lee et al., 2015). Moreover, integrating CPS with production logistics and services in manufacturing practices enables the transformation of the manufacturing enterprises into smart factories with lots of potential to improve their manufacturing competitiveness and efficiency (Lee et al., 2013).

When implementing these technologies, there are various and different expectations regarding cyber-physical systems such as robustness, autonomy, self-organization, self-maintenance, self-repair, transparency, predictability, efficiency, interoperability, global tracking and tracing (Monostori et al., 2016). However, these expectations and the fact that cyber-physical systems are different from classical computational and information systems create some challenges such as the integration of traditional IT systems with operation technology systems (Serpanos, 2018). Security is a major challenge to the implementation of CPS in what regards trustworthy interaction with the physical environment and the privacy of users. Additionally, interoperability is also a matter of concern which needs to address two aspects: data interoperability, which focuses on the need of a correct and consistent interpretation of data across all levels of CPS; and computational interoperability, which requires appropriate machine interpretation for the purpose of enabling perfect integration and a correct and resilient overall process (Monostori et al., 2016). The combination of systems with different real-time requirements represents a challenge in computing, taking into account the dispersed structure of cyber physical systems.

2.4.6 Sensors

The transformation into a smart factory under the conception of industry 4.0 envisions a manufacturing system using sensors on both processes and equipment. The use of sensors enables the recovery, control and the ability of reporting information to the user in order to support reasoned and intelligent decision-making (Babiceanu & Seker, 2016). By applying smart sensors, manufacturing companies create a groundwork to connect products, equipment and physical facilities with the cyber systems and software network (Bibby & Dehe, 2018).

In manufacturing, data generated along the production activities is essential to improve product quality, flexibility and productivity. In order to generate this data, it is necessary to implement smart sensors, which are the source of data and also allow automatic monitoring, configuration and condition control of difficult processes (Babiceanu & Seker, 2016). Sensors are a key factor for innovation in regard to industry 4.0 but also enable the smartization of traditional factories and production processes. By utilizing sensors, it is possible to make wise and accurate decisions about complicated systems, detect errors without using sampling, which can hold numerous economic benefits and may be used for developing and testing new business models (Schütze et al., 2018).

Besides the benefits of using sensors in manufacturing, there are also some challenges that must be taken into consideration. Using sensors in a complex production translates into the generation of big amounts of data, including important and confidential information, which raises the problem of data security. For example, when the production of a component is being monitored, the raw data is produced by the factory, whereas the know-how for the interpretation of that raw data belongs to the component manufacturer. If the factory sends the raw data of the whole process to the component manufacturer, it will also include confidential information such as the production volume of the factory. In this sense, it is necessary to create a certain level of trust between the partners involved to ensure data security (Schütze et al., 2018).

2.4.7 Autonomous Robots

Throughout the years, robots have been evolving along with emerging technological innovations, serving as facilitators of the fourth industrial revolution. Robots may play a crucial role in the transformation of traditional manufacturing industries into modern ones. Autonomous production processes are possible with the use of robots, which are capable of not only performing tasks wisely, but also assure safety, flexibility, versatility and collaboration (Vaidya et al., 2018). In industry's 4.0 paradigm, smart robots do not need to work independently but must work together with humans with the goal to be more economical and productive. Autonomous robots have the possibility of being controlled remotely from a distance and have several fields of application such as production, logistics, and office management to distribute documents (Aiman et al., 2016).

Robotic industry 4.0 has a great impact and implies several changes on the manufacturing processes and business models. In this sense, mass customization, increased productivity, flexibility, speed of production and improved product quality and precision are some of the benefits for the manufacturing industry (Aiman et al., 2016). Moreover, autonomous robots can work in restricted places where human workers cannot perform their tasks safely and have the capability to work autonomously and adapt to unexpected scenarios (Vaidya et al., 2018). However, it should be noticed that in some industries, for example the footwear industry, master craftsmen are essential.

2.4.8 Simulation

Simulation is an enabling technology of industry 4.0, which can be widely used in plant operations to illustrate the physical world in a virtual model by taking advantage of real-time data (Vaidya et al., 2018). This process may include machines, products, and humans and, consequently, decrease machine setup times, improve quality and reduce production failures. This innovative technology is useful for manufacturing companies in the sense that it helps the development of planning models to improve decision making, product's design, and complicated and smart production systems (Ferreira et al., 2020). Moreover, it has the capability of simulating multiple scenarios, including the evaluation and transformation into a smart factory with industry's 4.0 technologies as well as the risks, costs, implementation difficulties and the effects on operational performance. Simulators are often compared to a replication of how humans think to imagine different situations before making decisions.

In the manufacturing industries, simulation may and should play a fundamental role. In this type of industries, when performing real-time operations there are several processes involved, namely, sensing, processing, data-transmission and performance. Therefore, if the previous methodologies have the ability to be modified after the appearance of new requirements, simulation can be applied (Lugaresi & Matta, 2018). However, there are some challenges that should be taken into consideration when implementing this type of technology in a factory. In order to implement simulation successfully, its underlying models are required to be able to adapt to changes in systems configurations, to automatically be generated if necessary and be validated online before making any decision, assuring that the whole process is not very time-consuming (Lugaresi & Matta, 2018).

2.4.9 Augmented Reality

Augmented reality consists of incorporating additional information, generated by computers, into a real-world environment. Augmented reality applications, such as the integration of graphical assembly instructions into the workers' vision of their surroundings, allow users to improve their experience in the performance of tasks that require the interaction with information spatially related to their current environment (Paelke, 2014). Graphical assembly instructions can be automatically adjusted and updated with knowledge from the manufacturers (Mekni & Lemieux, 2014). The base systems of this technology have the ability to reduce information overload and the training required for assembly operators. Furthermore, it may support a wide variety of tasks such as the selection of parts in a warehouse (Vaidya et al., 2018), and the understanding of the product assembly tasks to be carried out (Reinhart & Patron, 2003). In the manufacturing industry, augmented reality can be utilized to improve work procedures and decision making by providing real-time information. Moreover, in the case of malfunctions, workers have the possibility to receive repair guidelines on how to replace a specific piece while they are observing the actual system that needs repair (Rüßmann et al., 2015). These operations are possible by showing the information directly in the workers' field of vision using, for example, augmented-reality glasses.

Despite all the benefits provided by augmented reality, there are still some challenges and issues that need to be addressed in order to have a practical use of this technology. Firstly, the augmented reality system has to process a huge amount of information in reality, which creates some challenges for the hardware used. In this sense, the hardware should be miniscule, light, effortlessly portable and fast while displaying graphics. In addition, the battery life used by these complex devices is an issue for the utilization of this technology. Also, augmented reality tracking requires the use of a system hardware that guarantees marker accuracy and reliability such as, for example, Global Positioning System (GPS) (Mekni & Lemieux, 2014).

2.5 Information Integration and Interoperability

There are three main types of integration related to industry 4.0, namely, horizontal integration, vertical integration and end-to-end digital integration. Horizontal integration, across the entire value chain creation network, consists of the integration of the several IT systems utilized in distinctive phases of production and business planning processes, for example, inbound logistics, production, outbound logistics and marketing between various different companies. Vertical integration involves the integration of the various IT systems at the different aggregation and hierarchical levels from manufacturing stations via manufacturing cells, lines and factories, providing an end-to-end solution. Moreover, it integrates the related value chain activities such as marketing, sales and technology development. Lastly, the end-to-end digital integration consists of the integration and digitalization throughout all phases of the product's value chain, from the raw material acquisition to production system, product use and end of life, also including client requirements (Kusiak, 2018).

The majority of the current IT systems are not completely integrated and in most cases factories, suppliers, and clients are not linked. Moreover, the same situation is verified in the companies' departments such as engineering, production and service. Hereupon, by implementing industry 4.0 to become a smart factory, companies and its departments will become more consistent and enable automated value chains (Rüßmann et al., 2015). Industry 4.0 should achieve all the three main integrations described above and, moreover, hardware integration, software integration, and data and information integration in an efficient and effective way. In this sense, manufacturing companies will be able to support the automation in industry 4.0 and handle end-to-end management of activities throughout the industrial environment (Xu et al., 2018).

In the manufacturing system, the concept of interoperability consists of the capability of components, humans and organizations to exchange information and communicate with each other through the internet of things and cyber physical systems. Moreover, it also includes systems interoperability, which accommodate data flows (Zhou et al., 2014). In this industry, interoperability amongst a range of systems, in or across industry, has been considered as one of the main characteristics throughout the life cycle of a product. Therefore, it is crucial to have a horizontal vertical integration and guarantee efforts to align the technologies and organizational objectives in order to successfully be a "factory of the future" (Liao et al., 2017).

2.6 Workforce Implications of Industry 4.0

Today's economy is characterized by globalization, in which manufacturing companies' sustainability and competitive advantage relies on their capability of adapting to the constantly changing business requirements. Industry 4.0 has significant impacts on most industries' dynamics, imposing new digital skill requirements for the workforce due to the automation of processes and the emergence of new business models. In this sense, there is a need for companies not only to attract and develop new talent, but also re-skill present workers by providing training programs and re-designing work processes in order to reduce the skill discrepancy between jobs and employees (Ustundag & Cevikcan, 2018).

Industry 4.0 and digitization change the labor market, creating some concerns and challenges for society. In this sense, questions such as "Are we facing reduction of employment by automation rendering human work force uncompetitive with machines?" or "Can creation of new fields of employment, new types of jobs compensate for the loss of traditional labor market requirements?" arise. Usually, the loss of jobs related to the increase in productivity as result of automation in a manufacturing company are balanced by the increase in production volumes. Digitization will create new types of jobs and change the current jobs. However, this phenomenon will depend on the complexity of automation and business models implemented in a factory (Rajnai & Kocsis, 2017).

Nowadays, along with an already tight market for talent, one of the main priorities for companies is to develop upcoming workforce and be prepared for the upcoming transformations in the employment scenario. Hereupon, it is crucial that organizations are able to evaluate the changing content of work requirements and necessary skills with the view to successfully adapt to the implementation of new technologies. After performing this evaluation, they are able to look for new talented employees with the necessary skills or provide adequate training for the current employees (Ustundag & Cevikcan, 2018).

A smart factory needs all types of employees, including workers for low-skilled jobs. However, in order to have a successful performance in hard-skills and be able to do their jobs in hybrid operating systems, workers must have some soft-skills such as collaboration, communication, autonomy and adaptability. Workers who are able to continuously adapt are extremely valuable since they will probably deal with complex and complicated systems, which require some training (Ustundag & Cevikcan, 2018).

2.7 Opportunities for Sustainability

In today's competitive world, globalization is challenged to meet continuously rising worldwide demand for capital and consumer goods while ensuring sustainability in all three dimensions: social, environmental and economic sustainability. Therefore, the manufacturing companies must create industrial value focusing on sustainability (Stock & Seliger, 2016). In regard to the environmental factor of sustainability, if organizations base the allocation of resources such as products, materials, energy and water on cross-linked value creation units, they will be able to do it in a more efficient manner. Taking all three dimensions into consideration, industry 4.0 creates several opportunities for the macro and micro perspective.

Regarding the opportunities of sustainable manufacturing for the macro perspective, there are two main topics of study:

1) **Business Models:** the creation of new business models should be oriented towards sustainability, creating positive or reducing negative impacts for the environment and the society (Bocken et al., 2014) . Furthermore, business models based on sustainability are characterized by competitiveness in the long run, in which selling the functionality and accessibility of products rather than only selling tangible products will be a leading concept (Schaltegger & Wagner, 2011);
2) **Value Creation Networks:** the interconnection of value creation networks holds new opportunities for the realization of life cycles of products in closed cycle and industrial symbiosis. This allows to efficiently coordinate products, materials, energy and water flows along the life cycle of the product and between different factories. Closed-loop product life-cycles allow products in several use stages with remanufacturing or reuse in between (Stock & Seliger, 2016).

Regarding industrial symbiosis, there is a collaboration between different factories to create a competitive advantage by exchanging products, materials, energy, water and smart data (Chertow, 2007).

Concerning the opportunities of sustainable manufacturing for the micro perspective, there are five main topics of study:

1) **Equipment:** the manufacturing equipment in factories usually lasts up to twenty years or even more. By retrofitting the current production equipment, factories have an easy and cost-efficient opportunity to do an upgrade with sensor and actuator systems and control logics. Moreover, retrofitting can be used as an approach of CPS in a factory with previously existing manufacturing equipment, extending its use phase, therefore providing companies a low-cost alternative to buying new equipment (Stock & Seliger, 2016);
2) **Human:** there are three distinctive approaches to deal with the social challenge derived from industry 4.0. Firstly, organizations should combine new communication technology infrastructures, such as virtual reality head-mounted displays with learning instruments, in order to increase workers' training efficiency. Secondly, they must increase the inherent motivation and creativity by defining new CPS-based methods of work organization and design. Lastly, it is important to increase the extrinsic motivation by applying individual incentive systems for workers such as considering the smart data within the product life cycle for giving individual feedback tools (Stock & Seliger, 2016);
3) **Organization:** a smart factory, with a decentralized organization oriented towards sustainability, must focus on efficiently allocating the products, materials, energy and water by considering the

dynamic constraints of the CPS, for example, the smart logistics. The concept of a holistic resource efficiency is being considered as one of the most important benefits of Industry 4.0 (Stock & Seliger, 2016);

4) **Process:** the holistic resource efficiency should be addressed by designing processes in a sustainable way. This is possible, for example, by designing proper production process chains (Swat et al., 2014);

5) **Product:** in order to achieve a sustainable design of products in industry 4.0, the focus should rely on closed-loop life cycles for products by enabling the reuse and remanufacturing of the specific product. Moreover, other approaches also have as a focal point the designing for the consumer's well-being. These approaches may be supported with the implementation of identification systems, for example, adding new services to the product in order to improve the customer's well-being (Stock & Seliger, 2016).

Chapter 3
The Footwear Industry

3.1 Introduction

In the present section, some relevant data related to the world footwear industry and in particular, the Portuguese footwear, is highlighted. Even facing economic aversity, the Portuguese footwear sector is a success case with a constant capacity to adapt to market changes and be competitive.

The first topic will focus on the characterization of the footwear industry in general, analyzing the global market and the distribution of footwear production, exports and imports by continent.

The following subject will focus on the Portuguese footwear sector. The starting point is its evolution over the years, followed by an overview of the sector in terms of economic performance.

Finally, the last topic will focus on the opportunities created for the Portuguese footwear sector by the implementation of industry's 4.0 technologies, fomenting innovation, taking into consideration customer experience innovation, smart manufacturing and qualification.

3.2 The Footwear Industry

The fashion and lifestyle industry is considered to be one of the most profitable markets in the world, being described as a billion-dollar industry, which employs millions of professions all over the world (Majeed &

Rupasinghe, 2017). Within this industry, the footwear industry is included. The footwear industry comprises all organizations which are active in the production of all types of men's, women's, and children's shoes. It is considered to be a very complex industry with a fragmented value chain in which big organizations coexist with smaller and more specialized factories (Corbo et al., 2018).

The footwear industry is characterized by a competitive environment, mainly in regard to the relationship with the final consumer. Indeed, considering the footwear retailing, it may be observed that the industry is very fragmented, even though the market is dominated by big retail groups characterized by a strong rivalry. Regarding competition, price is one of the most relevant competitive factors. Pricing strategy is the main tactic to segment the market and attract niches of consumers as it is the reflection of the final product's quality. Furthermore, creating styles and brands is crucial in order to compete with rivals in this industry, which is based on design and creativity. This sector is characterized by a season-driven product lifecycle. However, today's market is constantly changing, and consumers require and expect diversity of models at a rapid rate. In this sense, manufacturing companies have to make managerial efforts in order to enable the creation, manufacturing and delivery of shoes based on real-time demand (Corbo et al., 2018).

Regarding the worldwide footwear production, an increase of 21.2% has been verified since 2010 at an average yearly growth rate of 2.2%. In 2019, the footwear industry growth rate slowed down to 0.6% over the previous year. Even so, a new production record of 24.3 billion pairs was established. As we can observe in table 1, the footwear industry is mainly concentrated in Asia, followed by South America, Europe, Africa, North America and Oceania with a residual percentage of 0.03% (APICCAPS, 2020c).

TABLE 1
Distribution of footwear production by continent in 2019

Rank	Continent	Footwear Production (Quantity)
1	Asia	87.4%
2	South America	4.7%
3	Europe	3.2%
4	Africa	2.9%
5	North America	1.8%
6	Oceania	0.0%

Source: APICCAPS, 2020c

Regarding the footwear consumption, it may be relevant to understand the market and which continents are the main consumers of shoes. Contrary to the footwear production, the consumption is more evenly distributed. However, as observed in table 2, Asia consumes more than half of all shoes in the world due to its demographic and economic dynamism, followed by Europe and North America, Africa, South America and Oceania. There are also some important geographic differences in terms of consumption patterns, namely, the footwear consumption per capita, varying from 1.6 pairs in Africa to 5.6 pairs in North America. Europe and Oceania approach North America patterns with 4.4 pairs per person. Although Asia is the biggest consumer in quantity of footwear due to its enormous population, it has one of the lowest consumption per capita, being closer to Africa with 2.6 pairs per person (APICCAPS, 2020c).

TABLE 2
Distribution of footwear consumption by continent in 2019

Rank	Continent	Footwear Consumption (Quantity)
1	Asia	54.0%
2	Europe	14.8%
3	North America	14.8%
4	Africa	9.5%
5	South America	6.1%
6	Oceania	0.8%

Source: APICCAPS, 2020c

In regard to footwear exports, 15 billion pairs, about 62% of the total footwear produced in 2019 were exported. As expected, Asia is the main exporter of footwear with a world share of 83.9%, as we can observe in table 2. However, Asia's exports steadily declined by 7% over the last decade, which also happened in nearly all of the continents with the exception of Europe. Between 2010 and 2019, Europe increased its exports world share by 2.6% (APICCAPS, 2020c). Within Asia, there are some interesting facts. Although China is the top footwear exporter, its market share declined 7% in the last decade, contrary to Vietnam's market share, which almost doubled over the same period. This might be explained by the fact that labor costs in Vietnam are still lower when compared to China and, consequently, many companies prefer to move production to lower-cost regions (Abdulkadir et al., 2020).

TABLE 3
Distribution of footwear exports by continent of origin in 2010 and 2019

Rank 2019	Continent	Footwear Exports (Quantity) 2010	Footwear Exports (Quantity) 2019
1	Asia	84.6%	83.9%
2	Europe	11.1%	13.7%
3	North America	1.7%	1.0%
4	South America	1.2%	0.8%
5	Africa	1.5%	0.5%
6	Oceania	0.0%	0.0%

Source: APICCAPS, 2020c

Regarding the footwear imports by each continent, both North and South America have been facing a decrease in imports. Nowadays, North America represents less than one quarter of the world's imports and South America only represents 2.6%. In the case of Africa and Asia, the imports have been facing an increase, in the latter case helped by a strong economic performance. Footwear imports are led by Europe, which is responsible for more than one third of the world's total imports. One particular interesting case within Europe is Germany, which holds the second place of the world's footwear importers and is also the biggest European footwear exporter, which is the result of their successful strategy of importing to reexport (APICCAPS, 2020b).

TABLE 4
Distribution of footwear imports by continent of origin in 2010 and 2019

Rank 2019	Continent	Footwear Imports (Quantity) 2010	Footwear Imports (Quantity) 2019
1	Europe	33.0%	35.4%
2	Asia	25.2%	26.0%
3	North America	26.7%	23.3%
4	Africa	8.4%	11.3%
5	South America	5.2%	2.6%
6	Oceania	1.4%	1.4%

Source: APICCAPS, 2020c

With respect to the evolution of the world's average export price per pair, the several value and quantity tendencies reflect changes in the prices. The world's average export price per pair has been facing an almost linear growth since 2010, establishing a new record of 9.72 dollars in 2009. Since 2010, the average export price per pair has already registered an increase of 43.8%, which corresponds to an average annual rate of 4.1% (APICCAPS, 2020b).

3.3 The Portuguese Footwear Cluster

The manufacture of leather shoes is the core of one of the indisputable industrial clusters of the Portuguese economy, the Portuguese footwear cluster, which fulfills the essential condition of geographical concentration. The footwear production, with a great impact on the regional economic activity, is strongly concentrated in two poles, Felgueiras and São João da Madeira. However, there are also some footwear manufacturing companies in other locations of the country. In addition to the geographical characteristic of the cluster, there is a complex network of formal and informal relationships among the companies located in the two poles of the sector, such as commercial relationships, namely subcontracting, relationships for sharing information and knowledge, predominantly through the circulation of personnel, among others (APICCAPS, 2013).

The Portuguese footwear cluster goes way beyond the leather shoes production. From the outset, horizontally, it extends to types of footwear that use other raw materials and technologies: safety, sports, footwear made of materials other than leather. Due to the similarity of raw materials, technologies and vertical relationships, the cluster also extends to the leather goods and footwear components industries. In this sense, they have a common associative representation. The cluster has its own, nationally and internationally recognized, network of institutional support, namely, a business association, a technological center and professional training center. In this regard, the footwear manufacturing organizations have a very close relationship with all the scientific and technological systems, with given proof (APICCAPS, 2013).

3.3.1 Evolution

The Portuguese footwear sector developed a progressive expansion process since the 70's, within the scope of the first phase of Portugal's integration into the European economic area. It should be noticed that during this phase, the industry was oriented towards mass and low-cost production, and the footwear exports were based on subcontracted production to Portuguese manufacturers by international companies. Furthermore, the sales of large foreign production units were installed in Portugal (DGAE, 2017).

With the liberalization of the international trade and the facilitated access to a large market, the great majority of the Portuguese footwear companies were relocated, especially to Asia. The relocation to the less developed countries, which had lower salaries and were more competitive, was due to the facility of the implementation of this type of industry with accessible technology and high labor used in production. Moreover, the entry of China in the World Trade

Organization in 2001 intensified the commercial imbalance in Europe. After the growth phase in the 90's, the employment in the footwear sector decreased because of the decrease in the number of companies. In this sense, the production and exports were also negatively affected (DGAE, 2017). In order to overcome this adverse context, the sector strategically opted to direct its operations towards products with greater added value, targeting the European market (DGAE, 2017).

Throughout the years, the Portuguese footwear industry was able to reorganize and modernize itself, investing on new strategies based on speed and flexibility. Consequently, the quality of the products increased, companies adapted to demand changes of each market and were able to meet delivery times. Therefore, the sector became strongly competitive and one of the most dynamic industries in the country. Nowadays, the Portuguese footwear is nationally and internationally recognized as source of products of quality and fashion, with its competitiveness based on the creation of their own collections and brands, without forgetting the valuable production know-how (DGAE, 2017). The sector is considered a success story in Portuguese industry, which was able face the economic adversities and is now the greatest positive contributor to the Portuguese trade balance (Batista et al., 2017).

3.3.2 Overview of the Sector

Footwear highly contributes to the Portuguese economy and industrial structure and is particularly relevant for the north region of the country where the majority of the companies are located. The footwear manufacturing companies, almost 1 500, employ approximately 40 000 people. In addition, 389 companies of footwear components and leather goods production employ more than 7 000 people (APICCAPS, 2019).

The capacity of the Portuguese footwear sector to adapt and the unceasingly search for better solutions to meet customers' requirements is the key for its success and positive results. Its innovation efforts are directed to flexibility and quick response capacity, even for small orders, without ever risking the quality of production. Therefore, this strategy distinguishes Portugal from its competitors, which would only be possible by implementing new technological systems and production processes (APICCAPS, 2019).

The Portuguese footwear sector is an industry opened to the world, with exports of 76 million pairs in 2019, representing a total of 2 002 million dollars. Taking into account the geographical and cultural proximity, as well as the purchase power of consumers, Portuguese footwear companies direct their exports to the European markets (APICCAPS, 2019). In 2019, Portugal's main exports, as can be observed in table 5, were registered in France, Germany, Netherlands, Spain and United Kingdom. However, throughout the previous five years there was a decrease in exports in general (APICCAPS, 2020b). In this sense, Portugal has been exploiting other markets recently, such as American, Asian and African markets (Batista et al., 2017).

TABLE 5

Exports to the main trade partners in 2019 and variations over the past 5 years

Export Markets	Millions USD	Value Share	Millions Pairs	Quantity Share	Variation Past 5 Years	Millions USD
France	436	22%	14.4	19%	-23%	-131
Germany	359	18%	12.7	17%	-20%	-90
Netherlands	278	14%	10.1	13%	-18%	-59
Spain	178	9%	14.5	19%	-28%	-71
United Kingdom	128	6%	4.6	6%	-27%	-47

Source: APICCAPS, 2020c

It is perceptible that European countries are characterized by having a high purchase power that seek products with high-quality and modern designs, and consequently are willing to pay more (Batista et al., 2017). In this sense, Portugal is able to answer this type of demand by producing high-quality footwear and by having the second highest average export price in the world of 26.26 dollars per pair (APICCAPS, 2020b).

Moreover, Portugal is the eighth world exporter of leather shoes and ranks among the main exporters of fashion footwear, claiming to have "the sexiest industry in Europe". Rubber and plastic shoes take the second position, with 14%, in terms of footwear exports in Portugal, followed by waterproof and textile footwear, both with residual percentages of 6% (APICCAPS, 2020b).

The Portuguese footwear sector is dynamic and is constantly trying to innovate. In this sense, conciliating tradition and know-how accumulated over several generations with the new emerging technologies might be a challenge for most companies (APICCAPS, 2019). The footwear industry transformation from labor-intensive to capital-intensive along with new technologies allowed companies to improve both production and labor productivity throughout the years, i.e., the average number of pairs of shoes per worker per year (Batista et al., 2017). Despite all the challenges the sector has been facing, there was an increase in the number of companies and, consequently, the number of employees from 2008 to 2018 (APICCAPS, 2019).

TABLE 6
Companies, employment, and productivity variation from 2008 to 2018

Footwear	2008	2018	Variation
Number of Companies	1 407	1476	5%
Number of Employees	35 398	39 602	12%
Production (pairs)	69 100 000	84 400 000	16,3%
Labor Productivity	1952,1	2131,2	9,2%

Source: APICCAPS, 2019

3.4 Opportunities for the Portuguese Footwear Sector

Nowadays, competition within the footwear sector, and fashion in general, is in the global networks. The main challenges companies are facing is how to develop and implement innovative management models with the capability of supporting collaborative, transparent and advantageous practices for the different actors in the value chain. Processes and information management between organizations and value chains is becoming increasingly critical to guarantee fast responses, quality and sustainability (CTCP, 2019).

Markets are rapidly and constantly changing along with a continuous technological development process, which forces manufacturers to implement easily upgradable manufacturing systems that can easily integrate new technologies and functionalities. Consequently, higher levels of productivity along the production processes are required, creating the necessity of new production management systems. In this sense, these systems must be capable of dealing with a higher complexity intrinsic in managing the variability and disturbances of products and processes effectively and efficiently. Traditional hierarchies and centralized planning and control processes are becoming incapable of responding to the constant changes in high variety and small series production environments and, therefore, automated and self-reconfiguring systems are fundamental (CTCP, 2019).

The dissemination and adoption of the industry's 4.0 technologies allow the introduction of significant gains along the value chain and to accomplish new factors of competitivity. Besides improving efficiency, industry 4.0 allows increased flexibility, time of response, product customization and client engagement. The Portuguese footwear sector has been focusing on high added value products and distinguishes itself from its competitors by its fast response, high quality and fashion products. In this sense, this was possible due to the footwear industry evolution over the last decades, the capacity of adapting and openness to implement new technologies, shifting from mass production to a high variety of products. In the current markets, mass customization requires companies to meet customers' individualized requests through advanced and highly flexible production systems (APICCAPS, 2020a).

In 2018, a project called "FOOTURE 4.0" was launched by the Portuguese Footwear, Components, Leather Goods Manufacturers' Association (APICCAPS) and the Portuguese Footwear Technological Center (CTCP) to explore the opportunities created and accelerate the adoption of industry 4.0 by small and medium-sized enterprises, making the footwear cluster in Portugal more competitive and reinforce its leadership in the markets in which it operates. This project contains 4 strategic goals. Firstly, create new ways of interacting with the customer in a digital and networked context. Secondly, improve flexibility, customer response time, business intelligence and sustainability. Thirdly, qualify the sector for Industry 4.0 making it more dynamic, innovative and capable of creating new businesses and, lastly, improve the sector's intelligence and image (APICCAPS, 2020a). The investments directed to FOOTURE 4.0 have a share of 36.8 million euros, corresponding to the following axes:

1) **Innovation of the customer experience:** 6.3 million euros (17%); These include CRM software, integrated value chain management and social

media management processes, e-commerce platforms for online sales and customized footwear, eco-innovation and environmental management, foot scanning, among others;

2) **Intelligent manufacturing:** 23.5 million euros (64%); Including new flexible production methods, automatic cutting programming, CAD / CAM systems, digital prototyping, 3D printing and 3D scanner, laser engraving, among others;
3) **Qualification:** 3.2 million euros (9%); Including international training projects, training in digital technologies, among others;
4) **Sectorial leadership and coordination:** 3.8 million euros (10%).

3.4.1 Customer Experience Innovation

Implementing industry 4.0 in a footwear company can lead to immense opportunities to innovate customer experience by creating new forms of interaction in a digital and networked context. Customer relationships and their positive experiences are crucial for the companies' success in today's highly competitive business environment. Companies must be aware of constant changes in customers' requirements and adapt their strategies to gain new customers (Bär et al., 2018)

Creating new business models may help companies to be able to identify new high added-value market segments better and also develop integrated system solutions for products and services that take advantage of industry 4.0. In the Portuguese footwear sector, companies are still investing in market segments that base their choice on good taste rather than on price and, consequently, face the need to explore new market niches with high purchase power. By implementing new data analysis technologies in this area, companies may collect systematic data which are accessible on the internet, for example, on social networks. In this sense, companies are capable of directing their products to specific consumers and defining footwear micro-segments such as fashion, safety, sports or health. Thereby, footwear companies are able to develop their products with the aim to meet specific market requirements. With all the technological developments, new forms of interaction between companies and customers have arisen such as websites, social media and mobile applications. In order to capture and manage information systematically through different channels, footwear manufacturing companies could introduce sensors so that the client can monitor their shoes' use and performance (APICCAPS, 2020a).

Customers have become more autonomous and active in the value co-creation through their constant feedback on products and services and also by sharing their opinions on social networks and online communities. In this sense, customers can provide very important information for companies, having a significant capacity to influence other customers by sharing their experiences and recommendations. In this way, brand managers and footwear manufacturers can support their new model conception processes, supply chain management and marketing campaigns with customers' preferences and tendencies collected on physical stores and social media (APICCAPS, 2020a).

3.4.2 Smart Manufacturing

The transformation of a traditional footwear manufacturing company into a smart factory, by implementing some industry's 4.0 technologies, can lead to immense opportunities to improve flexibility, customer's response time, business intelligence and sustainability.

The value chain of the Portuguese footwear industry is distributed by several organizations in a complex network of formal and informal relationships, encompassing not only the final customer, but also the manufacturer and even raw material suppliers. Based on industry 4.0, organizations have the opportunity to integrate customers and suppliers, upgrading their value chain to networks with multidirectional information flows. This transformation allows an improved collaboration and communication between customers, retailers, manufacturers and suppliers. The digitization of all parts of the value chain will provide companies the opportunity to perform a deeper analysis of more diverse information. Furthermore, with this information, companies will become more aware of social and environmental effects of footwear production (APICCAPS, 2020a).

The strategic positioning of the Portuguese footwear sector in producing high added-value products implies the production of small series of shoes, in the order of dozens or even units of pairs. Therefore, it is crucial that organizations are able to implement new technological advances in their production processes in order to become faster and more flexible. There are some advanced production technologies which enable very efficient and sufficiently flexible manufacturing processes capable of handling demand alterations in a low volume and high variety production environment. Some examples are systems of advanced production planning, internal logistics systems, critical equipment failure prediction system, fast programming for carding and handling robots, collaborative robots and augmented reality in assembly operations. Also, the production of samples and prototypes represents a significative part of a footwear company, implicating some relevant costs. One possible approach to improve efficiency in this area could be the implementation of rapid prototyping and 3D additive manufacturing in samples' production, and virtual reality systems that reduce the need of producing those samples (APICCAPS, 2020a).

The current footwear production systems consist of advanced cutting machines, sewing and assembly equipment, which have some gaps in terms of their interoperability, leading to a manual integration. This equipment has a relative level of sensing which provides it with the capacity to be monitored and controlled locally, but not globally. In this sense, the lack of connectivity between machines can limit the flexibility of the production system and its virtualization to support decision-making in terms of organization, planning and maintenance. Therefore, introducing sensors along the production systems, its integration with the company's computer system and further processing through cloud services allows the production manager to follow the production on mobile devices. Thereby, any worker in any place can verify the state of an order with an estimated time for the production operation and be alerted to eventual delays or cessations in specific work stations (APICCAPS, 2020a).

3.3.3 Qualification

Qualifying and rejuvenating the Portuguese footwear cluster is essential to maintain its world reference. Attracting young people with the adequate qualifications for the modern production processes requirements and qualifying the current workers is the way to qualify the sector for industry 4.0, making it more dynamic, innovative and capable of creating new businesses (APICCAPS, 2013).

With the introduction of new technologies, companies must adapt their training programs to include teaching the use of new technologies from industry 4.0 not only in the areas of product development and production but also at the sales management level. This way, professionals, in the future, will be trained not only to dominate how the factory works and how quickly to meet the market's necessities, but also translate the needs of micro-customers into feasible solutions in terms of operations management and logistics that can serve them efficiently and retain their loyalty (APICCAPS, 2020a).

Chapter 4
Methodology

4.1 Introduction

In this chapter, both research philosophy and methodology will be reviewed in order to select the most adequate approach to conduct the enquiry process. The reasons behind the choice of the type of methodology used to answer the research question "How does the implementation of industry's 4.0 technologies affect the Portuguese footwear manufacturers in all different stages of the value chain?" will be exposed. Furthermore, the design of the research strategies and the collection methods will be explained. After choosing the type of methodology, data collection process and sampling, distinctive study tools will be used to analyze the information.

4.2 Research Questions and Objectives

The industry has been evolving throughout the decades, manufacturing processes are constantly suffering substantial changes in terms of modernization and digitization, which is now in the fourth industrial revolution.

Within the concept of Industry 4.0, several technologies emerged and were studied in order to have a better understanding of this investigation. The main technological concepts are 3D printing, big data, cloud computing, internet of things, cyber physical systems, sensors, autonomous robots, simulation, and augmented reality. Furthermore, in the transformation into a smart factory, information must be integrated, and companies must invest in the capability of components, humans, and organizations to exchange information and communicate with each other, i.e., interoperability, in order to be as efficient and flexible as possible.

Derived from the industry's 4.0 paradigm, there are some workforce implications and challenges that companies may face. Industry 4.0 has major impacts on most industries' dynamics, requiring new digital skills due to the automation of processes and the emergence of new business models. In this sense, companies must not only attract and develop new talent, but also re-skill present workers. Furthermore, manufacturing companies may create industrial value through the implementation of industry's 4.0 technologies while creating a path towards sustainability in all three dimensions: social, environmental and economic sustainability.

In a traditional industry such as the Portuguese footwear industry, the implementation of technologies related to the industry 4.0 may create several opportunities to improve their relationship with customers, increase their production flexibility and efficiency and even help them to take steps towards social, environmental, and economic sustainability. Therefore, it is important to understand what their level of maturity in this area is and what the real impacts of some technologies already implemented by footwear companies are.

Formulating and clarifying the research question is the starting point of the study in order to be able to choose the most adequate research strategy and data collection and analysis techniques (Saunders et al., 2016). The research question of this study is "How does the implementation of industry's 4.0 technologies affect the Portuguese footwear manufacturers in all different stages of the value chain?". In this sense, the main objective of this research is to explore industry's 4.0 paradigm and its adjacent emerging technologies, with a focus on studying the technologies which are being implemented in the Portuguese footwear industry, its impacts on the different stages of the value chain and the opportunities created for sustainability.

In order to be able to answer the research question, the following objectives were defined:

- Analyze how the adoption of industry's 4.0 technologies create new ways of interaction with clients in a digital context;
- Analyze how smart manufacturing may improve flexibility, time of response and sustainability;
- Analyze the level of interoperability of the Portuguese footwear companies;
- Investigate the influence of industry 4.0 on workforce challenges regarding the footwear sector's attractiveness and social sustainability.

4.3 Research Methodology

The most common way to classify research methodologies is to identify the dissimilarities between qualitative and quantitative. Regarding the quantitative methodology, grounded on positivism, the main action is to set well-tested expertise about the world (Sale et al., 2002). The ontological position of this methodology is that there is only one verity and reality is objectively given regardless of human perception, considering the researcher and the researched independent entities. In this sense, the quantitative approaches consist of an underlying basis of premises and beliefs, with the presupposition that data needs to be highly confirmed by a theory in a research scenario. The objective of this methodology is to generate causal laws, using rigorous rules and procedures to originate data distinctive from common sense, reducing data to numerical indices (Robson, 2002).

Contrary to the quantitative methodology, the qualitative methodology is usually based on interpretivism (Secker et al., 1995). Taking into account this approach, the world must be studied systematically since it is seen as problematic. From an ontological point of view, multiple realities or truths exist and are based on the very construction of reality (Sale et al., 2002). Epistemologically, the access to reality depends on our minds and comparisons of truth statements are made taking into account external references (Smith, 1983). This approach regards both the objectively quantifiable facts or happenings, and the mode people construct, interpret and give meanings to the experiments (Gerson & Horowitz, 2002). Qualitative research is oriented to action, with the objective to simplify intervening to cause changes in the real world. In this sense, this methodology usually focuses on dynamic processes, with the purpose to understand what the variables involved are since they are complex and often not measurable (Mingers, 1984).

TABLE 7
How quantitative and qualitative research differ

	Quantitative Research	Qualitative Research
Purpose	Test hypothesis	Develop hypothesis
Literature Review	Done early	Done simultaneously
Responses	Predetermined, unbiased, and objective	Undetermined and biased
Measurement tools	Objective	Interviews, focus groups
Methods	Reliable and valid measurement tools	Interviews, focus groups
Outcomes	Statistical analysis	Rich narratives
Context	Context free	Context dependent
Generalizability	High	Low
Design and example	Empirical study	Case study

Source: Salkind, 2018

Taking into account all the information mentioned above, it is considered that, in order to answer the research question "How does the implementation of industry's 4.0 technologies affect the Portuguese footwear manufacturers in all different stages of the value chain?", the investigation should follow a qualitative methodology with an exploratory nature. In this sense, the research question is in regard to a subjective reality which may have multiple and diverse interpretations and analysis, depending on each person's point of view.

4.4 Research Strategy

The research strategy, in general terms, is a plan of action of how the researcher will answer the research question, methodologically linking the philosophy and the subsequent choice of methods to collect and analyze data (Saunders et al., 2016).

One way to select the appropriate research strategy is to take into consideration the research purpose. In this case, the purpose of this study follows an exploratory nature in order to seek new insights, find out what is happening and ask questions such as "How" or "What". In regards to the research strategy, there are two possible approaches, namely the case study and the survey. The case study focuses on gaining an understanding of the dynamics present within single settings, involving an exhaustive analysis of a small sample of interest, and usually also from a particular perspective. Surveys have both descriptive and exploratory purposes, depending on the enquiry purpose, and portray an account profile of people, events or situations, and usually collect data on a limited range of topics but from many people. Contrary to surveys, case studies may explore various themes and subjects but from a reduced sample (Marshall, 2018). In this sense, the most adequate research strategy for this study is the survey.

4.5 Data Collection

In this section, the methodology used for sample selection will be described and the data collection method which will be used within the selected strategy will be discussed.

Defining the research population clearly is important in order to be able to draw conclusions. Therefore, the selected sample must be related to the population that is highlighted in the research questions and objectives. There are two main groups of sampling strategies, namely probability sampling and non-probability sampling. Probability sampling means that each case has, usually, the same known probability of being selected from the target population. In this sense, it is possible to answer research questions and to achieve objectives that require a statistical estimation of the characteristic of the target population from the sample. This type of sampling is usually associated with survey and experimental research strategies. On the other hand, with non-probability samples, the probability of each case being selected from the target population is not known and not possible to answer research questions or meet objectives which require statistical estimations. It is possible to generalize about the target population, however, with recurring to statistics. This type of sampling is traditionally associated with qualitative research, where samples are not meant to represent large populations and is usually used in case studies and small-scale surveys (Saunders et al., 2016)..

Considering the two main groups of sampling strategies and the content of this study, the most adequate one for this study is the probability sample. Moreover, within this sampling strategy, the most appropriate non-probability sampling technique is the purposive sampling since, according to the researcher's judgement, cases that will best enable to answer the research question and to meet the objectives are selected (Saunders et al., 2016). In this sense, for this particular study the interviewees were chosen with the help of the CTCP in order to select the most adequate companies that have already applied some industry's 4.0 technologies and present some knowledge in this regard.

The next step in this section is choosing the most suitable data collection method for the research strategy chosen previously. Within the survey strategy, there are two main data collection methods, namely interviews and questionnaires. The interview focuses on what people say, whereas the questionnaire focuses on what people report (R. K. Yin, 1994). Therefore, for this study the data collection method chosen was the interview since not only is it essential in collecting human affairs and individual perceptions, but also in identifying other relevant sources of evidence.

4.6 Design Methodology

In this section the application of the research strategy and data collection methods will be described, discussing some general aspects of design and execution. In this sense, the main purpose is to present and discuss the enquiry research process, in this case, the interview design.

The research interview is a purposeful conversation between two or more people, which requires the interviewer to ask concise and unambiguous questions and establish connection so that the interviewee is willing to answer the questions and to listen attentively. Using interviews may help the researcher to gather valid and reliable information that is relevant for the research question and objectives (Saunders et al., 2016). Qualitative research interviews are the most appropriate for circumstances where individual perceptions of a process within a social unit are to be studied prospectively (Robson, 2002). There are three types of interviews depending on the levels of formality and structure, namely, structured interviews, semi-structured interviews, and unstructured or in-depth interviews (Saunders et al., 2016).

In regards to structured interviews, they are characterized by the use of questionnaires based on a predetermined and standardized or identical set of questions. In this type of interview there is social interaction between the researcher and the interviewee in order to provide previous explanations, however, the questions must be asked precisely as written and in the same tone of voice in order to avoid any bias. Structured interviews are usually referred to as “quantitative research interviews” since they are used to collect quantifiable data (Saunders et al., 2016).

Contrary to structured interviews, semi-structured and in-depth interviews are non-standardized and typically referred to as qualitative research interviews. Regarding semi-structured interviews, the researcher has a list of themes and some key questions to be asked, which may vary depending on the interviewee. Therefore, while some questions may be omitted, additional questions may also be required, in specific interviews, for a further exploration of the research question and objectives. Moreover, the order of questions may also differ depending on the flow of conversation. Concerning the unstructured or in-depth interviews, these are considered informal and are used to explore a general area of interest in depth. In this type of interview, despite not having a predetermined set of questions, the researcher needs to have a clear idea of the aspects that should be explored. In an informant interview, the interviewee is able to talk freely and give insights about the topic area, guiding the conduct of the interview. On the other hand, in a respondent interview, the interviewer assumes a higher control of the interview, in which the interviewee is allowed to give his or her opinion or respond to the questions of the researcher (Saunders et al., 2016).

Taking into account all the information mentioned above, the most adequate type of interview for the research question is the semi-structured interview since it captures the richness of the interviewees better and allows to ask questions and have a smooth conversation.

There are five main steps that should be taken to design a semi-structured interview, namely selecting the type of interview, writing the interview guide, scheduling the interviews, preparing the interview itself and, finally, performing the interview transcription and follow up (Gillham, 2000).

For this research, these interviews were conducted with internal and external informants. In regards to the internal informants, they included top and middle managers as well as engineers in order to gain insights and understand the functioning of the Portuguese footwear companies and their vision about the subjects of study in this research. In order to complement these interviews and help the interpretation of some results, interviews with external informants, namely industries experts from the CTCP, APICCAPS and the Institute of Systems and Computer Engineering, Technology and Science (INESCTEC) were conducted. The combination of these interviews, with both internal and external informants, were crucial in order to understand which technologies adjacent to industry 4.0 are being implemented in this industry and their impact along the value chain. These interviews were conducted through videocalls and, with the consent of the interviewees, were all recorded and later transcribed. At the beginning of the interviews, a brief explanation of the scope of this study was given as well as the context of each question asked.

4.7 Data Analysis Methodology

Data analysis involves examining, categorizing, tabulating, or then recombining the evidence to address the research question (R. K. Yin, 1994). Data in its raw form has little meaning and, therefore, an analysis of data must be performed by the researcher in order to summarize the mass of data collected and be able to present the most important features of the results. The main goal of data analysis is to find answers to the research question, by treating the evidences in a fair and unbiased way and compelling conclusions (Robson, 2002). In this sense, interpretation is strongly connected to the concept of analysis.

In the case of qualitative data, detailed descriptions, direct quotations in response to open-ended questions, and the transcript of opinions of groups are usually included. By performing a qualitative data analysis, content analysis, case studies analysis, and inductive analysis are often included. In this sense, all methods will probably produce descriptions, interpretations and explanations of patterns or tendencies. There are four techniques to qualitative analyses, namely quasi-statistical, template, editing, and immersion. For this research, the chosen technique was editing taking into account its key features such as being interpretive and flexible, having few or non-existing priori codes, codes being based on the researcher's interpretation and being typified with grounded theory (Robson, 2002). In this sense, it was possible to meet the goals of qualitative analysis, namely data reduction (selecting and simplifying the data obtained), data display (organizing and facilitating the visualization of the data) and finally, conclusions drawing and verification (Miles & Huberman, 1994).

Chapter 5
Results and Data Analysis

5.1 Introduction

After discussing and presenting the research method, the main purpose of this part of the study is to identify the investigation results which will help to answer the research question and permit the accomplishment of the research objectives.

The data collection was conducted with the main purpose of finding answers for the research question, "How does the implementation of industry's 4.0 technologies affect the Portuguese footwear manufacturers in all different stages of the value chain?", which is guiding the study. The first step was to perform an extensive revision of literature in order to be prepared do conduct the thirteen interviews with representatives from ten Portuguese footwear companies and with three experts from the CTCP, APICCAPS and INESCTEC.

Throughout the presentation and analysis of the results, five main sections will be covered according to the four principal groups of questions, which were asked during the interviews in order to have a better understanding of the connection between industry 4.0 and the Portuguese footwear companies. There are five main topics that will be addressed by analyzing the interviewees insights. Firstly, there will be an analysis on how the use of these technologies creates new ways of interacting with customers in a digital and network context. Secondly, the use of industry's 4.0 technologies can bring numerous benefits to manufacturers and, therefore, it is important to analyze how intelligent manufacturing can improve flexibility, response time, business intelligence and sustainability. Thereafter, there will be an analysis on the development of new models for the footwear industry, being that it is a process that involves the design and definition of the technology which will be used in the product and in the production equipment. Moreover, the current shoes production systems are characterized by advanced cutting, sewing and assembly equipment, fed and interconnected by dynamic warehouses. In this sense, in the fourth point it is important to analyze the gaps in terms of their interoperability, which leads to the integration being carried out manually. Finally, there will be an analysis of the main workforce challenges in terms of attractiveness and qualification.

In this sense, followed by the data collection methodology, the results will be presented using descriptive statistics in order to process the information in tables. In addition, the enquiry findings will be identified by performing an organized overview of the results of this study that will support the research objectives.

5.2 Data Collection Methodology

The methodology adopted to answer the proposed research question is qualitative, following an exploratory nature in the form of a survey. Within the data collection methodology, it was crucial to perform the sample selection and define the most appropriate data collection method that will be used within the selected strategy. For this study, after defining both sampling strategies, probability sampling and non-probability sampling, it was considered that the non-probability sampling is the most suitable for this investigation since it is a small-case survey. Moreover, within the non-probability sampling techniques, the one that most fits this research is the purposive sampling.

After defining the sampling strategy, the data collection method was chosen. In this sense, it was considered that the semi-structured interview is the most adequate method since it is less structured and has mainly open questions, which allows to collect personal opinions and believes, focusing on what the interviewee has to say.

In this study, representatives from ten footwear manufacturing companies and three industry experts from institutions in the footwear sector were selected to be interview. The main purpose behind the selection of the interviewees was to be able to have reasoned insights in regards to the real functioning of footwear companies, their technological maturity and vision towards innovation by implementing industry 4.0 technologies. Moreover, different points of view are important to take into consideration since each company has a different degree of industry's 4.0 maturity and willingness to risk. The interviewees were chosen with the help of the CTCP, who facilitated the contact with the companies' representatives and with APICCAPS. Moreover, the companies' selection was performed with the main goal of interviewing the most adequate companies that have already applied some industry's 4.0 technologies, therefore, presenting some knowledge in this regard. The data collection method consisted of videocall interviews, which were recorded and transcribed afterwards.

5.3 General Description of the Interviewees

To support the subsequent analysis of the results, it is crucial to perform a general description not only of the three associations interviewed and their relationship with the footwear sector but also the ten companies interviewed.

APICCAPS is a national business association with headquarters in Porto, founded in 1975, representing the footwear industry, the footwear components industry, the leather goods industry, and the industry that produces and commercializes equipment for the previously mentioned industries. Its main objective is to promote the sustainable development of the sectors and companies it represents. In addition to its activity in favor of the internationalization of the sector, APICCAPS promotes and encourages a policy of permanent innovation as a decisive instrument for strengthening the competitive capacity of companies and providing its members with services in several areas. In this sense, an interview with the communication director of APICCAPs was conducted.

CTCP is a non-profit organization, founded in 1986 by APICCAPS and two Institutes of the Ministry of Economy, Institute of Support to Small and Medium Enterprises and Innovation (IAPMEI) and the National Institute of Engineering, Technology and Innovation (INETI), from the Quality Control Laboratory created in 1981. Therefore, its main purposes are to technically and technologically support companies from the footwear cluster, promote technical and technological training of the companies' human resources, promote the improvement in both products and industrial process quality, prepare and spread technical information along the industry and, finally, carry out and streamline research, development and demonstration work. Taking this into consideration, it was crucial to conduct an interview with the head of the business organization and management unit of CTCP.

INESCTEC - The Institute of Systems and Computer Engineering, Technology and Science is an internationally oriented multidisciplinary associate laboratory with more than 30 years of experience in R&D and technology transfer. INESCTEC highly contributed to the footwear industry's process of innovation since the 1990's with the automation and computerization of existing systems and the development of new equipment. INESCTEC was able to identify the sector's needs and define a roadmap for the modernization of the sector in terms of production systems and more sophisticated management and optimization procedures. Taking into account the great impact of this association in the footwear sector, an interview with an administrator of INESCTEC was conducted.

AMF Safety Shoes is a Portuguese company based in Guimarães, founded in 1999, specialized in the development, manufacturing and marketing of high-quality technical footwear, developed for foot protection. This company presents two safety shoe brands that were conceived, created and produced by AMF, namely: To Work For and Too'l. With an average daily production of 3 500 pairs of shoes, AMF has been highly investing in the latest technologies with the power of innovation. In this sense, an interview with the Chief Executive Officer (CEO) and founder of AMF Safety Shoes was conducted.

Carité Calçados is a Portuguese company based in Felgueiras, founded in 1990, and is specialized in the designing, manufacturing and distribution of fine quality footwear with private labels. Carité employs more than 230 people and produces more than 3000 pairs of shoes per day. Throughout the years continuous investments in new equipment and technologies have been made and, in this sense, an interview with the Commercial Director of the company was conducted.

Felmini is a Portuguese company based in Felgueiras, founded in 1973, and is specialized in the design, manufacturing and in the marketing strategy of comfortable and quality female footwear with its own brand. The company employs 130 people and has an average daily production of 650 pairs of shoes. Felmini has been improving its production processes and equipment, updating and renewing the footwear design and training their employees. Therefore, an interview with the owner of the company was conducted.

Klaveness Portugal, based in Vila Nova de Gaia, was created in 1988, through the parent company, the Norwegian Klaveness Skofabrikk AS whose origin dates back to 1957. It is specialized in the production of medical, rehabilitation and individual footwear, with the collaboration of designers and orthopedic specialists in the product development. The company in Portugal employs 171 people and produces an average of 560 pairs a day. Klaveness is a company focused on the technological development of its several units and, therefore, an interview with the manager of the company in Portugal was conducted.

Kyaia - Fortunato O. Frederico & Ca. is the biggest footwear manufacturer in Portugal, based in Guimarães, and was founded in 1984. Kyaia leads a business group with a team of more than 600 people, which today extends beyond footwear production, including distribution and retail companies, and also, IT, real estate and tourism. Kyaia has their own successful footwear brands called Fly London and Softinos and a retail footwear brand called Foreva and, additionally, Kyaia also produces footwear with private labels. The company has been highly investing in innovative technologies and, in this sense, an interview with the owner and founder was conducted.

Luís Onofre is an international brand created in 1999, based in Oliveira de Azeméis, and is specialized in the luxury segment of women's shoes. The designer's relationship with footwear precedes that date, since the designer is the third generation of the Conceição Rosa Pereira family, which has been working in this industry since 1939. By producing luxury shoes, the brand combines innovation and technology with the level of detail of the handmade production. The company produces an average of 150 pairs of shoes per day of a small series of the Luís Onofre brand and an average of 350 pairs of shoes per day of a big series with private labels, counting on 45 employees. Therefore, an interview with the commercial director of the company was conducted.

Marisport Calçado is a Portuguese footwear manufacturer, based in Felgueiras, and was founded in 1988. It is specialized in safety and occupational footwear for men, women and children, focused on the development of the customers' proposed styles, carrying out all of the industrial process, from conception to the manufacture of the final product, quality control and shipping. Marisport has about 150 collaborators and an average daily production of 1 500 pairs of shoes, using high-tech equipment in what regards the technological innovation of this sector. An interview with the Export, Environment, Health and Safety and Quality Manager was conducted.

Martiape is a Portuguese manufacturer based in Felgueiras, founded in 2007, and is specialized in the design, production and distribution of mid- to high-quality footwear for both men and women with private labels. The company has not stopped growing since its inception, having recently launched their own brand called PREGIS. With 136 employees and an average daily production of 1 400 pairs of shoes, Martiape combines their know-how with innovative processes in all the different stages of the value chain. In this sense, an interview with Chief Operation Officer (COO) of the company was conducted.

Procalçado is a Portuguese company being one the largest European producers of footwear components and molded footwear, based in Vila Nova de Gaia, and was founded in 1973. The company's project started by producing soles with their brand called For Ever, however, throughout the years it also became specialized in the production of injected footwear with its own successful brands called WOCK and Lemon Jelly. The company has a team of 340 employees and has an average daily production of around 19 763 pairs of shoes and soles. Procalçado has been innovating and diversifying its range of products throughout the years. An interview with the Chief Executive Officer (CEO) of the company was conducted.

Savana Calçados is a Portuguese company based in Felgueiras and was founded in 1988. It is specialized in the manufacturing of high-quality children footwear for notoriously recognized international brands. The main focus of

Savana is to ally their specialized know-how with the innovative technologies and quality materials in order to offer products of excellence. The company has a team of 155 collaborators and has an average daily production of 1 200 pairs of shoes. In this sense, an interview with the administration assistant was conducted.

5.4 Customer Experience Innovation and Product Development

The creation of new forms of interaction with clients on a digital and networked context may create several opportunities for the footwear companies. In this sense, there is an intention to analyze how companies are interacting with their clients, the development process and their investments in this area.

TABLE 8
Customer Experience Innovation and Product Development

Interviewee	Citation
APICCAPS	"Yes, they are investing, but still in a very incipient way, because there still are few companies and because the investments are still not very significant."; "What we have tried to do on our side is to accelerate investments in terms of promoting our brands and, at the same time, to strengthen or support companies in the online business".

CTCP	"If we have a company with its own brand, business to consumer and sales online, what you need to sell and to produce is a certain type of technology. If you are an industrial company that works business to business for another industrial company, what you need is completely different. We have to see this in the light of different needs according to the positioning of companies in the market. This is to say that the fact that we say online sales website or customer connection platform are very important, it may be for certain types of companies".
INESCTEC	"These technologies, customization, connection to customers, etc., allow me to make a model that is more customers driven, that is, I only produce when the customer buys, what they buy and what they want to buy, and preferably close of the customer."

In terms of the collection of information about the real preferences of the customers, this process is mostly verified in the cases of companies who produce and commercialize their own brands. However, in most cases the choice of materials, colors and footwear design is made according to the fashion trends without recurring to advanced technologies or fully integrated systems. According to the CEO of Procalçado, "We do our research, a slightly more disintegrated system, where we are very attentive to the markets and then, from there, we bring a set of ideas into the creative process". This was also verified in the cases of Felmini, Kyaia and Luís Onofre when producing their own brands.

Luís Onofre has been able to complement their know-how and experience on high fashion fairs with a high investment on their website for online sales. This investment has provided them with relevant information about the markets by analyzing the number of clicks in each model on the website. In this sense, it is possible to identify the market trends such as the construction, color, heels and materials, the main clients, according to their geographical position and so on. According to the commercial director of Luís Onofre, "In addition to our know-how, all the information used on websites, all the maps that can be downloaded from a website are very important. However, it is not only necessary to have a sales website, but also to create a structure behind the photograph that allows us to take extract all these elements. It can define a station, a country, everything”. Furthermore, Luís Onofre has a future project in terms of footwear customization on their website. In the future, clients will be able to customize a model by changing the color or material according to their preferences. There are also four other companies that have sales websites, namely, Felmini, and the brands of Procalçado, AMF Safety Shoes and Kyaia.

In the case of Procalçado, they have recently introduced important technological tools for the future in the product development process. Nowadays, this company has a fully integrated development process in 3D, the design is made through digitalization, and they also have 3D scanners to develop, for example, the mold. Everything is built in the digital world to move on to the physical world afterwards. Through these technological innovations, Procalçado is often able to decide the collections without having even made a real physical prototype. Moreover, by using tools to perform renderings and real visualization of the products, they are able to create digital catalogs. According to CEO of Procalçado, “This whole area of product development is truly where we made the most effort to evolve and transform what was a traditional model into very digital processes. Today we have almost reached, but not yet, a time when we will customize from this. However, today, for example, even before developing the prototypes, I can already show the final ideas to clients with virtual products of the concepts they want, with colors, patterns and all that. This whole area is an important area”. Furthermore, these tools allowed for a considerable reduction of the development process deadline, having more research time to define the products for each collection faster and more assertively. According to the CEO of Procalçado, “For example, this whole part has eliminated a whole process, for example, of waste and sample development. We are often talking about collections that we developed 400, 500 prototypes to launch 100 and such. All this time, cost and industrial waste have disappeared".

Felmini has also developed a digital collection to present to the customers as a complement to their physical collection and support the salespeople with their interaction with possible and effective clients.

Klaveness is a company mostly oriented in the production of medical footwear and insoles whose final consumers are people who have problems with their feet. This company already develops a product based on industry 4.0 for their customers which is customized insoles made at a distance. According to the manager of Klaveness Portugal, "We distribute a foot scanner to our customers, where they scan the patient's foot in a 3D format, give instructions on the order form if they want changes or any additional elements. The software is based on Rhino and the customer can either model the insole himself or he can ask us to model the insole ourselves. This information is transmitted to a Computer Numerical Control (CNC) equipment, that is, it is an automatic cutter that cultivates the insole without the intervention of the human being".

AMF Safety Shoes is a company that has been highly investing in new technologies. In what regards to the collection of information concerning the real preferences of customers, they consider it to be very fashion oriented and little technological. However, they consider that there are technologies available in this sense. AMF Safety Shoes has a technology partnership in development with a university to launch a whole new innovative concept, an insole with sensing to measure the expressions of people's shoes or insoles, the walking process. According to the CEO of the company, "We will launch a trend of a new concept to measure the jobs, to measure the working conditions of the employees and so, in this sense, we can better balance the job position since the workers and the loads that are exerted on them cause immense lumbar diseases and immense casualties as well". This is a work that is being done on a European level with the main goal to avoid sick leaves.

Furthermore, AMF Safety Shoes is also preparing to introduce RFID or QR codes in all the footwear produced, which in the future, within the possible extent of interaction, if clients give feedback, they will start to be able to measure the durability and difficulties the shoes may have. In addition, it will allow customers to consult the product's datasheet, certificate, and receive post-sale assistance through the reading of that RFID or QR code. However, according to the CEO, "It is always dependent on the interaction of our customers and the goodwill of our customers, this is always the difficulty".

On the other hand, companies who produce their footwear with a private label usually have a different approach since the brands are the ones who choose the model design, materials, colors and all the aspects, and the manufacturers may give advice in some cases. According to the commercial director of Carité, "Being a private label system, all or almost all of the information comes to us from the client. With this information, we analyze it to make the product feasible. In other words, the analysis is done by the customers and the brands themselves, because they have marketing, commercial and market research departments. We do not have and do not need to carry out this analysis". This approach was also verified in other companies such as Kyaia, Marisport, Martiape and Savana. According to the administration assistant of Savana, "Most of the time, customers have, for example, the design person who sends the model with the materials they want, then our designer prepares the design, sends it to the client for approval and from there it proceeds to the creation of a prototype and future industrialization of the model". In the process of product development, it was verified that companies use a

CAD/CAM software to draw the models, project prototypes and program the manufacturing processes.

Martiape is also planning to develop a customer connection platform in the future. On this platform, each customer would have their password and would be able to consult the progress of their orders, i.e., to know in which stage of production the order is. According to the COO of the company, "We wanted to provide this information to the customer, so that he would know the progress of his order. But in this type of information and not exactly in terms of models, because they give us that information. We have the production all connected and whoever has the program, most people have it, including the commercials, get to know".

5.5 Smart Manufacturing

The implementation and use of industry's 4.0 technologies may provide several benefits for the manufacturers. In this sense, information regarding the development and implementation of advanced production systems, 3D additive manufacturing and opportunities for economic and environmental sustainability was collected through the interviews. In table 9, opinions of the interviewees from the three institutions are shown.

TABLE 9
Smart Manufacturing

Interviewee	Citation
APICCAPS	"Yes, companies are investing particularly in terms of production. It certainly makes companies more competitive and more productive too. I will give you an example. There is a Portuguese technology that is the water jet cutting system. These automatic systems for measuring leather and simultaneously cutting it using water jet, knife or laser systems, mean that there is a significant saving of these wastes, so companies are being faster and more profitable because they are fighting waste".
CTCP	"Technology and industry 4.0 are certainly relevant factors for the competitiveness of companies, even for quality because of the reproducibility of processes, with greater agility in some cases. But we have to take into account that there are shoes and shoes. I would even say more, clearly in the last few years there has been an evolution in the footwear sector, I am speaking in global terms, to escape intensive labor, this with a view to reduce costs and make the product more competitive".
INESCTEC	"It depends on the technologies we are talking about, there are technologies that are still rigid and, therefore, companies that make small series cannot invest in these technologies because they only work in large series. There are other technologies that are adapted precisely to allow small series, and it was a lot of those that we bet on in the development in Portugal".

5.5.1 Development and Implementation of Advanced Production Systems

TABLE 10
Advanced Production Systems Implemented

Company	Advanced Production Planning Tools	Internal Logistics Systems	Equipment Failure Prediction System	Augmented Reality
AMF Safety Shoes	X	X		X
Carité	X	X		X
Felmini	X			
Klaveness	X	X		
Kyaia	X	X	X	X
Luís Onofre	X	X		
Marisport	X	X		
Martiape	X			
Procalçado	X			
Savana	X	X		

It is possible to verify in table 10 that in terms of production planning, all the interviewed companies are able to plan their production processes, guaranteeing that all materials are available to start manufacturing. Some companies have management software that generate the production plans after they receive a client's order. According to COO of Martiape, "The customer's order is inserted in the program and from that order a production plan will come out, requisitions will come out to buy the materials. We know before starting to produce if all the materials are already here, which is important so that afterwards there is no stoppage in production". Moreover, according to the administration assistant of Savana, they are able to introduce the order deadlines into the software so that it is possible to manage the date of receiving materials, producing the order and when it is necessary to send it to the customer. Through the production planning tools, Felmini and Klaveness claimed that they are also able to group orders of products with the same reference, which allows them to avoid unnecessary equipment reprograming. According to the owner of the Felmini, "If we want to group, we do, which is what happens at the beginning of the year, instead of manufacturing order by order, we immediately manufacture 10 orders together, when they are the same reference, color and model".

Procalçado has their own production planning tools based on SAP - Systems Applications and Products in data processing, which is a very complex system. Taking into consideration that Procalçado has several product areas, they consider that this system is too rigid and not the best tool in terms of flexibility and intelligent process management. In this sense, they are working with parallel software where they have virtual showrooms in which the clients can introduce their orders and make suggestions about the whole process. Moreover, according to the CEO of the company, they are planning to develop a new software from scratch, "We also want to create a new software that can allow us to disassemble the product into components, to speed the purchase management so that we can have well-managed stocks, to be able to introduce the product in the market quickly. This is an area that we are still working on, it is a bit complex and there are no tools to our measure yet".

AMF Safety Shoes also has their own tools of advanced production planning and has an ongoing development project of new tools. This company, contrary to fashion-oriented footwear companies, has a big part of their production made to stock which is also possible by producing with its own brand. In this sense, they have been working with artificial intelligence to developed algorithms to forecast future sales for six months. According to the CEO of the company, “As a result, all management of planning and stock levels is carried out. So, we use a lot of technology, algorithms and artificial intelligence”. In this sense, they have a project with INESCTEC in the area of artificial intelligence in order to improve their algorithm in terms of assertiveness.

Kyaia is a company that has been highly investing in new technologies and created five years ago a technological company in partnership with INESCTEC. This company has six or seven engineers, with capabilities of programing and working with artificial intelligence, and was created with the main goal to create an algorithm to manage the production system. According to the owner of the company, “It is an algorithm that manages production on production lines, distributes tasks, records the time of tasks, etc. Therefore, we believe that new technologies are a great help, I do not say the solution to all problems, but it can, if well managed, help to solve many production problems”.

Regarding internal logistic systems, seven of the ten interviewed companies have automatic systems in terms of logistics. The most common system identified in the footwear companies is the conveyor belt for handling raw materials, components and semi-finished products throughout the manufacturing process. Some companies also have automatic logistic conveyors, for example, Savana has two of them. In the case of Savana, they use these automatic conveyors to transport products in the sewing warehouse. There is a collaborator responsible for the management of these conveyors that, according to the computer that indicates the box needed, the person takes the box with that specific number and puts it in the transporter, that reads the bar codes and goes to the correct post of the person who is going to do that process. As soon as the person finishes that task, the product is put inside the conveyor and is automatically transported to the next process.

Kyaia has all of its logistic operations automatized, having several types of internal logistic systems. According to the owner of the company, “We have all the systems, from lifting straps that take the shoe from one level to the next, we have processes that tell us that this car with this merchandise has to go to section A, we have technologies that tell us that in this car there is that specific model, the order number. All of this is done electronically”.

AMF Safety Shoes has conveyor belts and conveyors. According to the CEO of this company, “We did some experiments in the warehouse, but the carpets always become more interesting and faster, less costly in relation to investment”. At the moment, they are also doing experiments to start working with collaborative robots that will interact with people in the production lines.

Procalçado does not have internal logistic systems at the moment. However, the CEO of the company considers that this an area that they are going to start exploring in the near future, “Right now we are even going to start some projects with CTCP to study all the processes that we have set up in the footwear area, line automation. There is still a lot here that we are going to do”.

In regards to the implementation of critical equipment failure prediction systems, there is only one of the interviewed companies that already has this type of system. Kyaia, through the project developed with INESCTEC mentioned above, created a process that is able to read the position of the equipment, when they can break down or when they are sure to break down. The remaining companies have their own mechanicals or subcontract other companies to do preventive maintenance of equipment in order to avoid breakdowns. However, even though this preventive maintenance is done, there are still some unexpected breakdowns, and a curative maintenance of the equipment is required. In order to avoid a production stoppage due to breakdowns, there are companies that also have some alternate replacement equipment.

Concerning the augmented reality, there are three interviewed companies that already implement this technology. AMF Safety shoes uses the augmented reality in their showroom to communicate with their clients in the commercial area, to have a better view of the models and how the injection molds fit together. Moreover, this company also uses augmented reality with their equipment suppliers to make rectifications on some machines and it also has a scheme with a German client that according to the CEO of the company, "Our client uses one pair of glasses, we use another, and we can see the same thing. We do this sharing that works with few customers because people are not very available for these things". Carité implements augmented reality in the cut line that according to the commercial director of the company, "We have cameras that change the position of the shoe and is enlarged on the screen so that we can really see if the cutting procedure is correct or not". Furthermore, Kyaia is associated to a company called ASPORTUGUESAS, that has developed an application using this technology. In this app the customer can choose a pair from the list of 3D models referenced either on the brand website or in the new application, by pointing the camera of their mobile phone or another electronic device at the feet, and the user will immediately be able to see how that model looks on their feet.

In addition to the technologies studied above, the CEO of AMF Safety shoes referred that they are the only company in the world that industrializes the 3D bonding technology for the footwear manufacturing. Making a shoe involves five processes: cutting, sewing, assembling, gluing or injecting and, in the end, finishing. However, with this technology it is possible to unite all the parts that make up a shoe with a single injection shot, without the need for sewing or assembly.

Furthermore, Kyaia developed a project called High Speed Shoe Factory with a new footwear factory model to provide agile answers in 24 hours. It was oriented to the unitary production, capable of answering without stocks to small online orders. This new production method is based on a single section logic, totally flexible and versatile, where production takes place in a single flow, replacing the traditional model divided into sections (cutting, sewing, assembly and finishing), with online systems for automatic distribution of the product flow (APICCAPS, 2020a).

5.5.2 3D Printing

From the interviews conducted, it was verified that six of the ten footwear companies have already implemented 3D printing machines. This technology is mostly implemented in the production of prototypes in order to help the visualization of how the final product would look like.

Luís Onofre has been using 3D printing to conceive rubber soles, heels and footwear applications for years. Firstly, they print a heel in 3D, followed by a 3D mockup, and the first samples use 3D printed heels. According to the commercial director of the company, "All of this is first created in 3D and after everything is done, if the stylist approves, it will be used for final molding, injection, etc".

In addition to the production of prototypes, AMF Safety Shoes is also doing experiments in order to produce molds using 3D printing. According to the CEO of the company, if these experiments are successful, it will be possible to reduce the cost of producing the molds and the whole process will be faster.

However, there were also some downsides and improvements regarding this technology that were suggested by the interviewees. There is still a lack of adequate materials in order to be able to print shoes or its components with good quality using 3D printing, especially for companies who produce leather shoes. According to the commercial director of Carité, "When talking about having a shoe in 3D it is more complex, as there are limitations in terms of materials that are used to do it. That is, we print the shoe in 3D, but it will never look the way you want". Procalçado in its turn recognizes that the type of materials they use for their shoes, such as rubber, gives them advantages in the use of 3D printing. According to the CEO of the Procalçado, "We have some advantages because of our materials. We now work with TPU, which is a type of material that is very close to an area of products that we have. We managed to recreate a little bit of reality, very close but it has a lot to do with our product typology".

5.5.3 Economic and Environmental Sustainability

The implementation of new technologies and equipment may create opportunities that allow a more environmentally and economically sustainable production, which is crucial in this type of industry that inevitably produces big amounts of waste.

From the interviews conducted, most of the footwear companies have already implemented or are planning to implement solar panels, are recycling, are environmentally certificated, are substituting the traditional glues into water-based glues, are using LED illumination, and are opting for electrical vehicles. Therefore, companies are making efforts to be more environmentally friendly. However, for this study it is important to analyze how some technologies improve sustainability.

The technology of 3D bonding mentioned above by AMF Safety Shoes has a tendency of zero wasting. Through this new technology, the company is able to reuse the various waste of shoes and incorporate it in the soles. Moreover, the cost of human labor in this process is insignificant and, therefore, they believe that producing shoes through this technology will have the same price anywhere. It is still in a development phase, but the company believes that this technology will consume much less energy, less raw material, less displacement of raw materials or products and, therefore, it will certainly improve sustainability. According to the CEO of the company, "Of course, with solar panels and more sustainable buildings in some way it is also helping us to reduce our carbon footprint, but I think the big change in the footwear industry in particular should be for the new technology".

Procalçado, through the digitalization of the whole product development process mentioned above, was able to become more sustainable and drastically decrease the amount of waste by avoiding the process of sampling development. They were able to reduce the costs, which are thousands of euros of investments, time, waste and everything that harms us. Moreover, the company is planning to invest 1 million euros in new production equipment that will allow the reduction of energy consumption and reduce their ecological footprint by 60%. According to the CEO of the company, "The equipment will make all the difference and, on a digitalization and industrial level, it is logical that all of this will help to reduce the negative impact we have on what we do. This is guaranteed".

Furthermore, most companies considered that the implementation of automatic leather cutting machines also allowed them to reduce the amount of leather wasting. The leather is digitalized first in order to detect any defects, and afterwards the automatic cutting machine will cut the leather avoiding the existent defects. According to the COO of Martiape, "The cutting machine fits the small pieces together to make the most of the leather, avoiding the defective areas. I think the fact that we have at this time 4 machines says it all, it is because we effectively know that we have more use and less waste".

5.6 Interoperability

The footwear production systems are characterized by advanced cutting, sewing and assembly equipment. In this sense, it was important to analyze the current state of interoperability of the Portuguese footwear companies and whether the integration is still performed manually. In table 11 it is possible to find the points of view of the interviewees from APICCAPS, CTCP and INESCTEC regarding this topic.

TABLE 11
Interoperability

Interviewee	Citation
APICCAPS	“The systems are completely integrated. The companies in these areas are very professional. It couldn't be any other way. Even when working with international brands or for top international customers, all these issues are thought out in detail”.
CTCP	“The industry is working in this area, for example, in accessing fast information. It really is an interesting technology to streamline the process, reduce the setup time, that is important”; “Nowadays it is important to have data and information. The vast majority of companies in the sector work with integrated management systems. The issue is not so much the capacity that these systems have to generate data, it is more the capacity to generate reliable data and the capacity to analyze it”.
INESCTEC	“If we are talking about IoT at the product level, I would say that there are many sectors that are still at an early stage. At the production process level, there is a greater advance because today practically all the systems that exist can already be connected to the network and in practice, are information systems”; “The other question is if companies are prepared to take advantage of this and use it to collect data and make artificial intelligence on top of that, to gain knowledge of the processes. And there, as I say, there is still a long way to go”.

From the interviews conducted with the footwear companies, it was possible to verify that there are two companies that already have integrated systems and recur to the IoT with RFID in order to be able to virtually monitor the production in real time.

Kyaia reported that the whole production is interconnected. The shoe enters the production line and until the end it has a RFID or code reading system that tells exactly in which phase of production the shoe is. According to the owner of the company, "If I am in China and turn on my phone, I know exactly the output of any production line, what is the production per hour, what products are being produced. So, there is this technology that informs me".

AMF Safety Shoes are also in the implementation process of this RFID system to make product traceability internally and follow-up in the production cycle. However, the CEO of the company considers that as the shoes in a series are all the same, it is not that important to know where one unit of the series is, but they are doing it for commercial support.

There are also four other companies that are able to monitor the production process in real time, however, by using different systems. Luis Onofre has a support software in which the first step is to create a database of all the footwear components, followed by the creation of a sampling. Next, after the sample is created, they pass on to sales from which a purchase order is generated with several manufacturing orders. Those manufacturing orders have bar codes or QR codes, and in each phase of production they read the codes. In this way, it is possible to monitor the production process and inform customers at what stage of production their order is.

Another example of production monitoring is Martiape. In each section the company has a checkpoint, which inserts the order that is in production on the computer and, as the pairs are produced, the information is inserted. With this type of system, not only are they able to know in which stage of product an order is, but also know whether all the materials necessary for an order are available or not to start producing.

In terms of recurring to the IoT to transform equipment into intelligent machines, there was one case reported in the interviews. AMF Safety Shoes is currently in the process of sensing their most expensive machine in order to integrate it with their system and be able to collect all the key performance indicators automatically. According to the CEO of the company, "This year the machine sensing will be done to interact with us, to interact between software. I imagine that this will evolve for other machines, but we are currently doing the first one".

Concerning the collection, analysis and visualization of information along the value chain in order to improve the business intelligence, six companies reported that they are already doing that. Procalçado, for example, reported that they have big amounts of data. In this sense, they work with support tools in order to obtain data and be able to analyze information and become more efficient at all levels. There is still space for improvement according to the CEO of the company, "There is an area at the business level, Business Intelligence that we do not have yet, but it is a super important tool that we still lack in the commercial area above all".

Furthermore, several companies reported that information regarding production defects, productivity, breakdowns, and information extracted from sales websites are very relevant and important to analyze.

5.7 Workforce Challenges

Through the interviews conducted it was intended to analyze if the implementation of new technologies create challenges for the footwear companies regarding their workforce and impacts on social sustainability.

5.7.1 Footwear Sector's Attractiveness

Firstly, there was an analysis of how companies overcome the lack of experience of some workers when facing new technologies and the possible difficulties in attracting new workers for the footwear sector. In table 12 the points of view of the interviewees from APICCAPS, CTCP and INESCTEC are represented.

TABLE 12
Footwear Sector's Attractiveness

Interviewee	Citation
APICCAPS	"The training given by companies is fundamental not only to attract talent, but to keep people in the structures of the companies themselves. Many times, when a company makes a significant investment in certain equipment, that is also a challenge for the company because the company has to adapt, and employees have to adapt to a new reality"; "It is difficult to attract new employees to the industry because when we talk about industry there is a negative connotation right away that makes it really difficult to attract new employees".
CTCP	"I would say that it is a challenge for all industrial sectors, one of the problems they report is precisely the loss of attractiveness of the industry to the younger workforce. Technology can help, which is much more socially accepted by young people to be an operator of a SNC cutting equipment than to be an operator of a hydraulic cutting machine".
INESCTEC	"One of the main barriers to this adoption is the lack of people with general knowledge in the field of engineering and in particular in the digital area and, therefore, if we do not make a big effort to train either the new ones or the people who are already in companies, we will have a serious problem with the difficulty of adopting and using digital technologies because we do not have people capable of using and exploiting them properly".

It was verified that most of the companies reported that attracting new workers for the footwear sector is a gigantic challenge, especially for the production area. This problem was mostly verified in companies that produce leather shoes and are more fashion oriented. Consequently, they consider that their main asset is the human component. In this sense, companies face the need to hire qualified people with experience in this sector or, otherwise, they provide them training in order to qualify them. Another reason for the lack of attractiveness of the footwear sector was the incapacity of companies to offer competitive salaries. According to the commercial director of Luis Onofre, "As good as Portuguese footwear is, it cannot sell. As he cannot sell, he cannot create income or margin to distribute to employees and he cannot attract many qualified people. The sector has to know how to sell our product in order to be able to pay better wages and be able to attract new, dynamic people with other ideas".

In order to be able to overcome this challenge, the CEO of Procalçado believes that the implementation of technologies will be very important for the company to continue to have people, but more than that to replace people who will not want to do the production operations in the future. One example was given by the manager of Klaveness that reported that it was much easier to recruit workers for the customized insoles line, which is based on industry 4.0, because they know they will work with computers and automatic machines than to recruit workers for manual production.

Furthermore, in general, the companies considered that the workers of the productive lines are receptive to learning how to deal with the new technologies. Even though in an initial moment some workers have greater difficulties, through training they are able to overcome the challenge.

However, contrary to the previous opinions, AMF Safety Shoes has a different point of view regarding this topic. The company faces a big challenge in attracting good new workers but, contrary to the other companies, for senior management positions and retain them. According to the CEO of the company, "I think they see it the other way around, the problem is not just working on the lines, the problem is good staff to manage the companies, recruiting good directors, good human resources, these are the ones who will take the company to different levels and positions". For the production lines, the company doesn't have the need to hire qualified people and stated that they have an average age of workers that is much lower than the industry average. In addition, they consider that offering good salaries is important to attract new people.

5.7.2 Social Sustainability

Concerning social sustainability, autonomous production systems can support workers, preserving their health and safety. However, it can bring some challenges with the reduction of employment. In this sense, it was important to analyze the opinions of the interviewees regarding this topic. In table 13 the points of view of the interviewees from APICCAPS, CTCP and INESCTEC are represented.

TABLE 13
Social Sustainability

Interviewee	Citation
APICCAPS	"I do not think that the adoption of new technologies can reduce the number of workers, because within the companies themselves there are several nuances. Therefore, there are very specific tasks, but there is an increasing number of professionals who are absolutely versatile and can perform various tasks within the company itself".
CTCP	"There are two perspectives. It is evident if I replace manual processes with capital intensive processes, that is to say that for me to produce the same, in theory, I need fewer people to produce, but perhaps I need more people to prepare. On the other hand, if a company becomes more competitive, in theory, it will get better and need more people. So, I would say that I don't see the issues as negative as that".

INESCTEC	"There is the idea that when you invest in technology you lose jobs. This is true if we keep production, that is, to produce the same quantity if I use technology, namely automation, I gain efficiency and need fewer workers. But something else was demonstrated, by investing in technology I became more competitive and captured more market. The amount of captured market gained was greater than my productivity gains. So, not only did I have productivity gains, but I had to create more jobs to be able to produce everything that I managed to capture resulting from my productivity gain".

Regarding the possibility of job reduction caused by the introduction of new technologies, AMF Safety Shoes stated that since the company has been continuously growing, they have been increasing the number of employees. However, they recognize that, nowadays, some operations require less people than they did in the past in some situations. Any investment in technology that the company is not able to amortize in five years' time they do not invest in it and, in this sense, according to the CEO of the company, "I could put robots on the lines, but for me to be able to monetize all the robots that I would put there, it would take me 10 years. It is not interesting, I mean, it is not very interesting and so it is better to keep people". However, they believe that with the implementation of the collaborative robots, which are more economical, easier to work with and occupy less space, and of the 3D bonding technology will be able to reduce a lot of workers. Moreover, the need of qualified people, i.e., people with experience in footwear, will decrease.

It was verified that Marisport also increased their number of employees in the areas of production support due to being more competitive and having increased the number of orders.

Companies such as Luís Onofre, Martiape, Carité and Savana, which are more fashion-oriented and produce mainly leather shoes, consider machines and technologies as a complement to help the workers and to increase production capacity. According to the commercial director of Carité, "In the footwear sector it is very difficult to reduce the number of elements needed to produce the shoe. In assembly, there are now new machines that are not about reducing, but more about increasing production capacity". Moreover, the administration assistant of Savana considered that the adoption of new technologies has created new workstations and in other cases it has freed people who were doing some things to help others, making the workflow a lot more fluid and interconnected.

The owner of Kyaia considers that the logic behind the implementation of new technologies and automatic production systems is to improve work conditions and, therefore, decrease the workload to produce any product. According to the owner of the company, "It is not a setback, it is an advance. The issue is social balance and society's view of the future".

Procalçado has been working in the area of social sustainability because they believe that the footwear is a hefty industry in terms of labor and physical effort in some areas, and more intelligent equipment may support people. The company has been developing some support equipment and performed a pilot test that was considered an innovation at the European level. However, the real implementation of this project requires big investments, and it is something that will be analyzed with time.

5.8 Chapter Summary

Generally speaking, it is possible to notice that the levels of industry's 4.0 technologies implementation throughout the value chain vary between companies depending on the type of business strategy and also the type of footwear produced.

Regarding the first parameter – Customer Experience Innovation and Product Development – the analysis must be divided into companies that produce business to consumer and the ones who produce business to business, which have different needs regarding the interaction with clients. Six of the interviewed companies work business to consumer, and in some cases, also business to business. Regarding the creative process of developing new models, it was verified that it is based on research, know-how and fashion trends, and little on technology. However, five of these companies have made big investments on their sales websites which provided them with big amounts of information regarding their clients such as the most and least searched models or their main clients' location. Klaveness uses an industry's 4.0 based technology to interact with their customers at a distance. They produce customized shoes using a 3D scanner to digitalize the customer's foot. Moreover, not only did AMF Safety Shoes develop insoles with sensing to measure working conditions, but also RFID introduced inside all the footwear to receive costumers' feedback regarding the shoes' durability and problems. On the other hand, companies who produce business to business do not go through the research phase since brands choose everything related to the footwear model and usually have their own designers.

In what concerns the product development process, the main software used is CAD/CAM. In this area, Procalçado stood out by having a fully integrated development process in 3D, in which the design is made through digitalization, and they also have 3D scanners to develop the molds. Moreover, they perform renderings and real visualization of the products to create digital catalogues, allowing them to decide collections before proceeding to physical prototypes.

Regarding the second parameter – Smart Manufacturing – it was verified that on a general basis companies are investing in new technologies in the production area. The most verified advanced production system was advanced production planning tools, which was verified in all the companies, however, at different technological levels. Moreover, seven of the ten interviewed companies have internal logistic systems, in which the conveyor belt is the most common. Regarding equipment failure prediction, only Kyaia has developed software in order to read the position of the equipment and predict future breakdowns. The remaining companies recur to preventive equipment maintenance and as a last resort recur to curative maintenance. Concerning the use of augmented reality, three companies reported using this technology in different areas. AMF Safety Shoes uses this technology in their showroom, with suppliers to make equipment rectifications, and with a German client using adequate glasses so they can see the same thing. Carité uses augmented reality in the cut line to see on a large screen if the cutting procedure is correct or not, and Kyaia developed an app using this technology in which the clients may see how a footwear model fits just by pointing their phone camera to their feet.

The use of 3D printing machines was also investigated. It was possible to verify that six of the interviewed companies have already implement this technology mainly for the production of prototypes and samples, and in some cases for the production of footwear components such as insoles.

In addition to the technologies studied above, AMF Safety Shoes is the only company in the world that industrializes the 3D bonding technology for the footwear manufacturing, which enable them to unite all the parts of a shoe with a single injection shot, without the need for sewing or assembly. Furthermore, Kyaia developed a project called High Speed Shoe Factory with a new footwear factory model to provide prompt responses in 24 hours. This new production method is based on a single section logic, totally flexible and versatile, where production takes place in a single flow.

Regarding economic and environmental sustainability, overall, companies considered that the implementation of some technologies allowed them to reduce waste and their carbon footprint, and also to become more competitive. Some examples are the automatic cutting machine, the 3D bonding technology of AMF Safety Shoes, and the digitalization of the product development process done by Procalçado.

Concerning the current state of interoperability of the interviewed companies, six companies are able to monitor the production process in real time. Two companies have more advanced systems for this process, Kyaia and AMF Safety Shoes, which have a RFID system to make product traceability internally and a follow-up in the production cycle. Regarding the transformation of equipment into intelligent machines using IoT, AMF Safety Shoes is currently in the process of sensing their most expensive machine in order to integrate it with their system and be able to collect all the key performance indicators automatically. Furthermore, six companies stated that they perform a collection, analysis and visualization of information along the value chain in order to improve decision making and business intelligence.

Regarding the third parameter – Workforce Challenges – two main topics were analyzed, namely the sector's attractiveness and social sustainability. Regarding the first topic, all the interviewees agreed that it is a big challenge nowadays. Eight interviewed companies reported to have difficulties in recruiting new workers mainly for the production lines, especially the companies focused on producing leather shoes that either need to hire qualified people in the footwear area or provide them with the necessary training. One of the main reasons for this challenge is the lack of attractiveness to work in any industry and the incapacity of companies to pay competitive salaries. Moreover, companies such as Procalçado and Klaveness believe that the implementation of new technologies will be important to replace people who will not want to do the production operations in the future. However, AMF Safety Shoes has a different point of view and stated that they do not have difficulties in recruiting people for the production lines but consider recruiting and retaining people for high position jobs a challenge.

Regarding social sustainability, in general, it was verified that companies consider machines and technologies as a complement to help the workers and to increase production capacity. It may reduce the number of workers in some specific tasks, but they will still need human labor. Moreover, it was considered that the implementation of intelligent equipment is a way of improving social sustainability in the sense that footwear is a heavy industry and workers must be supported by all of this equipment.

Chapter 6
Discussion and Conclusions

6.1 Introduction

The present chapter presents the discussion and main finding conclusions of the research. Firstly, the enquiry findings of each research objective will be discussed and related to the previous research and theory. Afterwards, the main conclusions drawn from the research findings and the limitations of this research will be presented. Finally, contribution to knowledge and recommendations for future research will be presented.

6.2 Discussion of the Research Objectives

The present investigation had the main purpose of analyzing how the implementation of industry's 4.0 technologies affects the Portuguese footwear manufacturers in all different stages of the value chain, creating opportunities to innovate client experience, smart production and employees' qualifications. In this sense, through the interviews conducted with three industry experts from APICCAPS, CTCP and INESCTED, and with ten Portuguese footwear companies, it was intended to achieve the following objectives:

- Analyze how the adoption of industry's 4.0 technologies create new ways of interaction with clients in a digital context;

- Analyze how smart manufacturing may improve flexibility, time of response and sustainability;
- Analyze the level of interoperability of the Portuguese footwear companies;
- Investigate the influence of industry 4.0 on workforce challenges regarding the footwear sector's attractiveness and social sustainability.

Regarding the first objective of this research - Analyze how the adoption of industry's 4.0 technologies create new ways of interaction with clients in a digital context - the literature considers that it is crucial for companies to be aware of the customers' constantly changing requirements and adapt their strategies in order to remain competitive (Bär et al., 2018). In this respect, the creation of new business models and the development of integrated systems solutions for products and services may help companies to identify new market segments (APICCAPS, 2020a). According to industry experts interviewed, companies are already investing in this area, however, still in a very incipient way. Moreover, these experts considered that companies' needs of investing in the area of customer experience innovation depend on their type of business. This was confirmed throughout the interviews. Companies which have their own brand and work business to consumer are the ones which implement more technologies in this area and have more integrated systems solutions for products. Five of the six companies who have their own brand have sales websites, which in addition to sales provide them with information regarding their clients. In addition, companies such as Klaveness and AMF Safety Shoes already develop solutions to interact with clients based on industry 4.0. It was possible to verify that companies who produce business to business do not have any major investments in this area because brands are the ones that choose everything related to the footwear model and usually have their own designers.

Moreover, regarding the product development process, companies recur to CAD/CAM software to design new models. In this area, Procalçado is the only company who reported to have a fully integrated development process in 3D through digitalization of the design, the use of 3D scanners to develop molds and the creation of digital catalogues.

The second objective of this research was to analyze how smart manufacturing may improve flexibility, time of response and sustainability. Within this objective, the analysis was divided in three topics, namely advanced production systems, 3D additive manufacturing, and economic and environmental sustainability.

Concerning the advanced production systems, the implementation of new technological advances may be important to enable very efficient and flexible manufacturing processes capable of handling demand changes in a low volume and high variety production environment such as the footwear industry (APICCAPS, 2020a). The industry experts consider that companies are particularly investing in terms of production to be more competitive and productive. However, once again, the need of implementation of new technologies depends on the type of shoes produced. Moreover, some technologies are still rigid and companies who produce small series face difficulties in implementing them and, therefore, are more adequate for the production of big series. According to the administrator of INESCTEC, Portugal has been mainly investing in the technologies that are more adequate for the production of small series and allow more flexibility. It was possible to verify that some companies feel reluctant in implementing some technologies because, since they produce small and variable series of shoes, they consider that it would require high efforts in terms of reprograming production systems.

Throughout the interviews conducted with the footwear companies' representatives, it was possible to verify that all companies plan their production in advance, guaranteeing that all materials necessary for production are available and, in some cases, group orders. Some companies are developing their own tools to support advanced production planning. AMF Safety Shoes has a great part of their production made to stock and, in this sense, they have been working with artificial intelligence to develop algorithms to forecast future sales for six months. Kyaia, through their technological company, also work with artificial intelligence and created an algorithm to manage the production system.

In regards to the use of internal logistic systems, it was verified that seven of the ten interviewed companies already have at least one type of these systems. The most used system in the footwear companies is the conveyor belt. The integration of CPS with production logistics has lots of potential to improve their manufacturing competitiveness and efficiency (Lee et al., 2013). (Lee et al., 2013). In this sense, Savana is an example of integrating CPS with logistic systems by having an automatic conveyor with sensors, which is connected to a computer to transport products from the sewing warehouse to workstations. Moreover, Kyaia has a wide variety of internal logistic systems from lifting straps to automatic conveyors.

The following topic analyzed regarding the second objective was the implementation of critical equipment failure prediction systems. It was possible to verify that nine of the ten interviewed companies do not have these systems and perform preventive maintenance and curative in cases of equipment breakdown. However, there already is one company, Kyaia, that created a process with the capability of reading the position of the equipment and prevent break downs or receive warnings about the equipment functioning.

Augmented reality is an industry 4.0 technology and, according to the literature, it can be applied, for example, in the integration of graphical assembly instructions into the workers' vision of their surroundings (Paelke, 2014). From the interviews conducted, there are three footwear companies that already use this technology with different applications. AMF Safety Shoes uses augmented reality in three different cases. Firstly, they use it in their showroom for commercial purposes, then, they use it with a supplier to be able to make equipment rectifications at distance and, finally, they use augmented reality glasses with a German client to see the same thing simultaneously. Carité implements augmented reality in the cut line to ensure that the cutting procedure is being well performed. Lastly, Kyaia implemented this technology on a mobile app in which the customers are able to observe how a footwear model fits by pointing the mobile phone camera at their feet.

In addition to the aforementioned systems, AMF Safety Shoes is the only company in the world to industrialize the 3D bonding technique in the footwear manufacturing to unite all the parts that make up a shoe with a single injection shot, without the need for sewing or assembly. Furthermore, Kyaia developed the project High Speed Shoe Factory with a new footwear factory model to provide prompt responses in 24 hours, based on a single section logic, totally flexible and versatile, where production takes place in a single flow.

The development of several methods and techniques of 3D printing was motivated by the need of producing prototypes quickly (Ngo et al., 2018). From the interviews conducted, it was verified that six companies already use 3D printing mainly for prototypes and samples production, and also for the production of footwear components. According to the literature, there are some challenges and improvements regarding this technology, namely the lack of materials available to reproduce the real quality of the products (Ngo et al., 2018). This was also a major concern regarding this technology reported by the interviewed companies, especially for companies that produce mainly leather shoes and for this reason only use this technology to get a first visualization of the product.

Regarding the last topic of the second objective, there was an analysis of how the implementation of new technologies created opportunities for the companies' economic and environmental sustainability. Manufacturing companies must create industrial value focusing on sustainability (Stock & Seliger, 2016). In this sense, the main innovation reported by the companies was the automatic cutting machine, which allowed companies to reduce leather waste and save money since leather is the most expensive raw material of a shoe. In addition to this technology, the 3D bonding technique used by AMF Safety Shoes and the digitalization of the product development process by Procalçado were reported to be very efficient in terms of economic and environmental sustainability.

The third objective of this research was to analyze the level of interoperability of the Portuguese footwear companies. According to the literature, organizations have the opportunity to integrate customers and suppliers, upgrading their value chain to networks with multidirectional information flows, and the digitization of all parts of the value chain will provide companies the opportunity to perform a deeper analysis of more diverse information (APICCAPS, 2020a). Six of the ten interviewed companies affirmed to being able to monitor the production process in real time. However, it was verified that in most cases this integration is done manually in each workstation. There are two companies, AMF Safety Shoes and Kyaia, which are able to monitor production in real time through a RFID system to make product traceability internally. Additionally, AMF Safety Shoes is currently transforming one equipment using IoT, by introducing sensors in order to integrate it with their systems. Regarding the collection of data throughout the value chain, six companies stated that they perform a collection, analysis and visualization of information along the value chain in order to improve decision making and business intelligence.

The last and fourth objective of this research was to investigate the influence of industry 4.0 on workforce challenges regarding the footwear sector's attractiveness and social sustainability. The literature suggested that there are some concerns regarding industry 4.0 and the workforce, and questions such as "Are we facing reduction of employment by automation rendering human work force uncompetitive with machines?" or "Can creation of new fields of employment, new types of jobs compensate for the loss of traditional labor market requirements?" arise (Rajnai & Kocsis, 2017). The industry experts interviewed considered that the implementation of new technologies may reduce jobs in some specific tasks, however, companies become more competitive and will need more workers. Therefore, there is a balance. With the exception of the CEO of AMF Safety Shoes, the remaining companies reported to have great difficulties in recruiting new workers for the production lines. Moreover, two of the interviewed companies considered that the implementation of new technologies in the production lines will make the job positions more attractive. On the other hand, CEO of AMF Safety Shoes stated that the major difficulty is in recruiting good workers for higher positioned jobs, which are the ones who will take the company to higher levels and retain them. Regarding social sustainability, companies consider machines and technologies as a complement to help the workers and to increase production capacity.

6.3 Research Conclusions

As mentioned before, throughout this investigation, the intention was to find answers for the research question, analyzing how the implementation of industry's 4.0 technologies affects the Portuguese footwear manufacturers in all different stages of the value chain.

In this study, the literature review tried to present the main concepts and technologies related to the concept of industry 4.0 as well as the opportunities for sustainability and workforce challenges. It was possible to conclude that the footwear industry may benefit from the implementation of this concept in several departments.

Regarding the first objective of this research - analyzing how the adoption of industry's 4.0 technologies create new ways of interaction with clients in a digital context – it was possible to conclude that some companies have already made big investments in this area and others are planning to do it. Companies that have their own brand, work business to consumer and sell online are at a certain level and, therefore, technologies for customer connection and digital process management are important for them to be prompt, fast and more flexible. On the other hand, industrial companies that work business to business for another industrial company have different technological needs. There are companies who work in co-creation with their customers and there are other cases that the manufacturer follows the instructions provided by the client, which was the most common. In the case of co-creation, the transference of CAD files, images and orders' communication platforms were considered relevant. For companies with clients that already did the whole product development process and simply need to follow their instructions do not require such a high level of technologies implementation.

Regarding the second objective - analyzing how smart manufacturing may improve flexibility, time of response and sustainability – technology and the industry 4.0 are relevant factors for the companies' competitiveness. However, once again, it should be taken into consideration the type of shoes that are being produced. In high-quality leather shoes the craftsmanship of the process is usually critical, and it still has not been possible to reach a level in which machines can replace some components of craftsmanship in terms of automatic processes, not only in terms of handling the product, but also because this type of product is normally associated to small series and some technologies are not flexible enough yet. Furthermore, it was possible to conclude that there is an investment in technology such as the 3D bonding that is more capital intensive and less labor intensive in order to reduce the costs, make the product more cost-competitive and allow for the production of products in more expensive areas such as Europe.

The implementation of industry 4.0 based technologies has created several opportunities for companies to be more economically and environmentally sustainable by the replacement of old equipment for newer and more efficient ones, technologies such as the automatic cutting machines that allow the reduction of waste and consequently a savings of money, the use of 3D printing machines, new production methods such as 3D bonding and the digitalization of processes.

Regarding the third objective of this investigation - analyzing the level of interoperability of the Portuguese footwear companies – it was concluded that most companies have their processes integrated, which are able to monitor the production processes in real time even at distance. However, this integration is performed on different technological levels. It should be noticed that there already are cases of using RFID systems and QR codes to perform product integration, and one company is currently sensing one machine to integrate it with the system. Also, in terms of collection and subsequent analysis of data to improve business intelligence, there already are some companies that acknowledge that it is a crucial area for the good functioning of companies. In terms of interoperability, it is possible to conclude that companies who produce big series are the ones with bigger advancements in this area and, in general, footwear companies have a lot of margin for improvement.

Regarding the last objective of this research - investigating the influence of industry 4.0 on workforce challenges regarding the footwear sector's attractiveness and social sustainability – it is possible to conclude that the loss of the footwear sector's attractiveness is a major challenge and, in the general cases, for the production lines. In this sense, both companies and the industry experts consider that the implementation of industry's 4.0 technologies may transform the current jobs into more attractive ones and help to recruit new workers easily. Furthermore, in what concerns social sustainability it is possible to conclude that the implementation of new technologies did not translate into a reduction in the number of workers. There are some specific tasks that may require less operators, however, there is a higher need of workers in areas such as design or computing. Also, companies reported that they have become more competitive and require more workers. However, it is possible to conclude that companies who produce big series are planning to invest in less labor-intensive technologies to reduce labor costs, which is the case of the 3D bonding. In general, companies look at technologies and machines as a way of supporting workers and recognize its potential to increase the well-being of workers in an industry where heavy loads are placed on workers. In this sense, it is concluded that the implementation of new technologies creates several opportunities for social sustainability, however, still with some challenges.

6.4 Limitations of the Research

As a result of the methodology chosen for this study – exploratory and qualitative – the present research presents some limitations that must be discussed.

Firstly, industry 4.0 is a broad subject with possible applications in several departments of a company. In this sense, through the interviews conducted it was intended to analyse the impacts of industry 4.0 along the value chain.

However, if the focus of the study was directed only at one of the departments, it would have been possible to carry out a more in-depth analysis.

The second limitation of this research was the sample size. In this sense, the investigation would be more complete if there were more companies involved. This constraint had to do with the fact that some companies were closed because of the pandemic context and also with some companies' lack of availability.

Moreover, there were some limitations regarding the qualitative nature of the study and the data collection method. In this type of study, even though the researcher intends to be impartial, the results analysis is inevitably influenced by the researcher's understanding. Furthermore, the answers provided by the interviewees are influenced by their experience and background. Finally, interviews and their subsequent transcription are very time-consuming processes, and the data quality is dependent on the interviewees availability and willingness to share information.

6.5 Recommendations for Future Research

The previously mentioned strategic plan, Footure 4.0, has the main goal to explore the opportunities created by industry 4.0 to make the Portuguese footwear cluster more competitive and reinforce its leadership. Throughout this research, the axis of customer experience innovation, smart manufacturing and qualification were explored and analysed. So, the first recommendation for a future research is to approach the fourth and final axis of the strategic plan, Sectorial Leadership and Plan Coordination, and explore how the smartization and digitization of footwear companies may help to improve the sector's intelligence and image.

One of the several industry's 4.0 technology is 3D printing, which is already being used by several companies to produce footwear components such as insoles and to produce prototypes or samples. One of the main disadvantages of this technology reported by the interviewed companies was the incapacity to reproduce the real quality of a shoe, especially fashion-oriented and leather footwear. In this sense, for a future research, this technology could be more deeply explored in order to find better solutions.

Finally, the digital transition of the Portuguese footwear sector and the promotion of Portuguese brands through social media and digital marketing could be explored since many companies face difficulties in successfully introducing their own brands to the market.

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