UNIVERSIDADE CATÓLICA PORTUGUESA

# Digital Transformation of the Portuguese Footwear Industry

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# Digital Transformation of the Portuguese Footwear Industry

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# Resumo

A tecnologia está a evoluir mais rápido do que nunca, e não acompanhar a inovação pode ser um risco de vida para qualquer empresa. A Quarta Revolução Industrial baseia-se na interconexão, transparência e descentralização com o objetivo de alcançar fábricas inteligentes. A utilização dos pilares tecnológicos da Indústria 4.0 é essencial para transformar a produção industrial, aumentando a produtividade, a eficiência e a qualidade, reduzindo custos e desperdícios.

A indústria do calçado tem uma importância significativa na economia portuguesa. Como parte da indústria da moda, espera-se que inove e crie tendências, mantendo a classe e a intemporalidade, tornando-a única e complexa. Além disso, sendo a Indústria 4.0 um tema atualmente muito estudado e falado, faz sentido perceber o estado de adoção da tecnologia da Indústria 4.0 numa indústria tão complexa como a indústria portuguesa de calçado.

O estudo recorreu a uma investigação qualitativa exploratória, recolhendo informação junto das empresas de calçado e das associações do setor, através de observações diretas, via visitas ao chão de fábrica, e entrevistas semiestruturadas, onde os participantes foram questionados sobre Indústria 4.0.

Apesar da motivação, há um longo caminho a percorrer. Embora algumas tecnologias da Indústria 4.0 sejam fortemente utilizadas, como simulação e integração horizontal e vertical, as empresas precisam de mais conhecimento de Indústria 4.0, para uma implementação integral e eficaz. Um cluster composto principalmente por microempresas, aliado a uma forte resistência à mudança e onde o aspecto artesanal é valorizado, dificulta a adoção da Indústria 4.0. Apesar da lenta mudança, é uma indústria com potencial para participar na Indústria 4.0.

**Palavras-chave:** Indústria 4.0; Indústria Portuguesa do calçado; Gestão de Operações; Transformação Digital; Fábrica Inteligente; Maturidade Digital

# Abstract

Technology is evolving the fastest it has ever been, and not following innovation can be life-threatening for any company. The Fourth Industrial Revolution is based on interconnection, transparency, and decentralization to achieve smart factories. Using Industry 4.0 technological pillars is essential to transforming industrial production, increasing productivity, efficiency, and quality while reducing costs and waste.

The footwear industry has significant importance in the Portuguese economy. As part of the fashion industry, it is expected to innovate and create trends while maintaining classiness and timelessness, making it unique and complex. Furthermore, since Industry 4.0 is a currently highly studied and talked-about topic, it only makes sense to understand the adoption state of Industry 4.0 technology in such a complex industry as the Portuguese footwear industry.

The study used qualitative exploratory research, collecting insight from footwear companies and the sector associations, through direct observations, via shopfloor visits, and semi-structured interviews, where key participants discussed the level of Industry 4.0 implementation.

Despite having motivation, there is a long way to go. Although some of the technologies of Industry 4.0 are heavily utilized, such as simulation and horizontal and vertical integration, companies need more Industry 4.0 literacy to move towards an integral and effective implementation. A cluster composed mainly of microenterprises, paired with strong resistance to change and where the handmade aspect is valued, hinders the adoption of Industry 4.0. Although changing slowly, it is an industry with the potential to participate in Industry 4.0.

**Keywords:** Industry 4.0; Portuguese footwear industry; Operations Management; Digital Transformation; Smart Factory; Digital Maturity

**Word count:** 9994

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# List of Abbreviations

2D – Bidimensional

3D – Three Dimensional

AGVs - Autonomous Guided Vehicles

AI – Artificial Intelligence

AM – Additive Manufacturing

AMRs – Autonomous Mobile Robots

APICCAPS – Associação Portuguesa dos Industriais de Calçado, Componentes, Artigos de Pele e seus Sucedâneos

AR – Augmented Reality

BCG – Boston Consulting Group

CAD – Computer-Aided Design

CAE – Código Atividade Económica

CPS – Cyber-Physical Systems

CRM – Customer Relationship Management

CTCP – Centro Tecnológico do Calçado Português

DAI – Digital Acceleration Index

ERP – Enterprise Resource Planning

GTAI – Germany Trade & Invest

HR – Human Resources

I4.0 – Industry 4.0

I5.0 – Industry 5.0

ICT – Information and Communications technology

IoE – Internet of Everything

IoT – Internet of Things

IT – Information Technology

MM – Maturity Model

NUTS - Nomenclatura das Unidades Territoriais para Fins Estatísticos

PLC – Programmable Logic Controllers

RFID – Radio Frequency Identification

SMEs – Small and Medium Enterprises

UK – United Kingdom

VR – Virtual Reality

# 1. Introduction

## 1.1 Problem Situation

Industrial Revolutions changed how goods and services were produced and delivered to consumers, and the 4th is no different. According to Lasi et al. (2014), the need for I4.0 was the conversion of regular machinery into self-aware and self-learning machines, improving overall performance for the creation of smart manufacturing platforms. I4.0 fosters a network of people, processes, and products, reducing the complexity of operations and increasing efficiency and effectiveness, reducing costs and improving processes (Gaspar & Juliao, 2021).

Portuguese footwear is recognized for high-quality craftsmanship and innovation, focusing on high-quality products (Abrunhosa & Moura E Sá, 2008; Diniz et al., 2015). APICCAPS's president aims to *"become an international benchmark and strengthen its exports, combining sophistication and creativity with productive efficiency, based on the technological development*" (Onofre, 2023).

However, despite the benefits and initiatives to implement I4.0, the digital transformation process of Portuguese footwear companies remain relatively unexplored and understudied, arising a gap in the literature regarding the current status of I4.0 in the Portuguese footwear industry.

## 1.2 Research Definition

This study aims to answer the question: *"What is the current I4.0 maturity in the Portuguese footwear industry?"* The main objectives are understanding the I4.0 implementation status among the Portuguese footwear industry, its benefits/challenges, and discovering future I4.0 trends. This study will add to the current literature on I4.0 and give insights for enterprises in the Portuguese footwear sector to make educated decisions on I4.0 adoption.

## 1.3 Methodology

This dissertation will follow qualitative exploratory research to understand the Portuguese footwear industry stakeholders' perspectives on adopting I4.0. The data collection methods were direct observations and semi-structured interviews with top industry companies and the cluster’s associations, APICCAPS and CTCP. Finally, NVivo was used for data analysis to aid each interview's insight gathering and comprehension.

## 1.4 Dissertation Outline

In the first chapter, the introduction summarizes the context of the theme and the study’s motivation and research question. Chapter 2 presents an overview of the current literature regarding I4.0 and the Portuguese footwear industry. The methodology used is described in Chapter 3. In Chapter 4, the results of this dissertation are addressed and analyzed, and in Chapter 5, the conclusions are unveiled. The bibliography and appendixes can be consulted on the last pages.

# 2. Literature Review

The literature review provides an overview of the current research on I4.0 and its impact on the Portuguese footwear industry. This review will form the research study's foundation and the research question and objectives.

## 2.1 Industry 4.0

### 2.1.1 Overview

Four major disruptive events occurred in the industrial sector and influenced developing societies. Technological advancements of the past centuries led to the emergence of new paradigms known as Industrial Revolutions (Lasi et al., 2014). Figure 1 presents the factors that contributed to each Industrial Revolution.

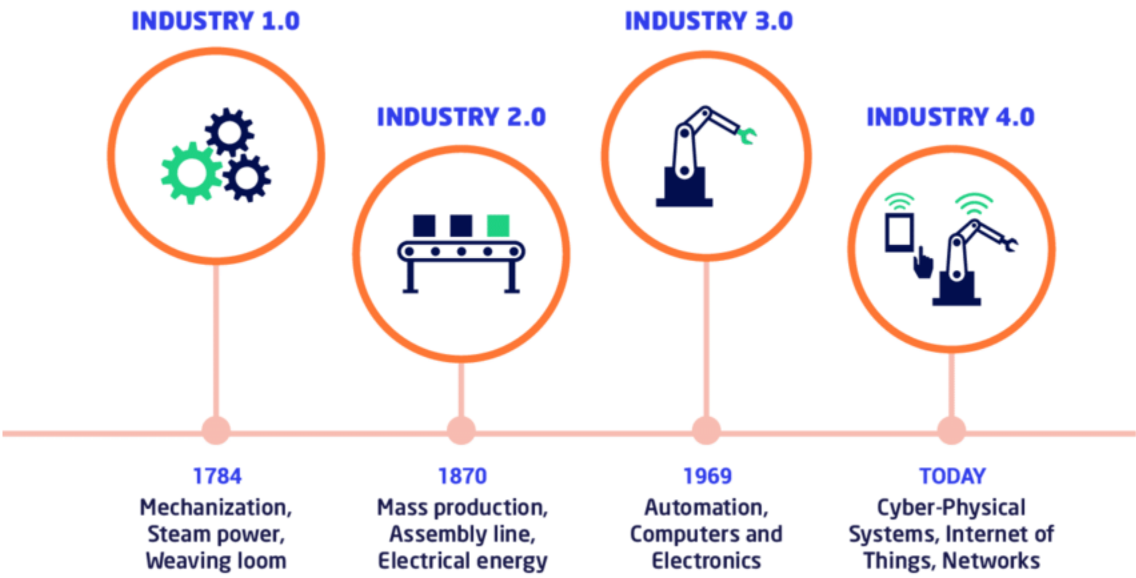


**Figure 1: The four Industrial Revolutions**

**SOURCE:** Kadir (2020)

In 2011, I4.0 was introduced. The GTAI first addressed the term I4.0 to describe the technological advancements that drove the most recent industrial revolution, connecting in real-time the physical and digital worlds (Olsen & Tomlin, 2020). The idea was to explore emerging technologies, digitalize the real world, integrate processes in companies, and install a smart factory (Rojko, 2017), strengthening manufacturing industries' competitiveness by converting ICT into industrial production (Hermann et al., 2016).

The principles identified by Hermann et al. (2016) demonstrate the motivation to adopt I4.0:

- **Interconnection:** I4.0 connects people and objects through IoE to achieve common goals. Within I4.0, collaboration and communication between machines and humans are crucial for integrating into a unique smart factory system.
- **Information Transparency:** With CPS, the connection between physical and virtual paradigms allows a transparent value chain overview. Factories can create a virtual copy of their physical world through digital models. It allows systems to perform tasks based on real-time data captured from the physical and virtual worlds.
- **Decentralized decisions:** Because of interconnection and information transparency, IoE participants can perform their roles autonomously, accessing all real-time information for better decision-making.
- **Technical assistance:** Humans become strategic decision-makers and problem-solvers rather than machine operators, and assistance systems aid humans in better-informed decisions. Objects and machines have reliable and intuitive interactions with humans to achieve better collaboration.

### 2.1.2 Smart Factory

According to Kagermann et al. (2013), there are three components to understanding I4.0:

- Through **IoT**, *"things and objects"* are connected, interact with each other and cooperate to perform tasks and achieve final goals.
- Industrial processes are controlled using **CPS**, integrating digital and physical processes. Information is shared via human-human, human-machine, and machine-machine collaborations (Schuh et al., 2013).
- **Smart factory** integrates the concepts of CPS and IoT. It enables people and machines to perform tasks more efficiently, being aware of the context and continuously receiving inputs from the physical and virtual realms.

Smart factories are crucial in integrating management and production's informational and physical subsystems. By implementing these factories, I4.0 technologies can integrate production, transforming into a *"highly flexible and reconfigurable manufacturing system."* The goal of applying I4.0 is to implement a Smart Factory (Kagermann et al., 2013). Since I4.0 manufacturing makes use of CPS to make autonomous decisions based on real-time data (Rojko, 2017), smart factories use *"smart systems that included smart machines, smart devices, smart manufacturing processes, smart engineering, smart logistics, smart suppliers and smart products"* to achieve greater digitalization and automation (Abdirad & Krishnan, 2020). The development of smart factories allows workers, machines, and resources to communicate with each other as if they were in a social network (Kagermann et al., 2013). This communication enables continuous feedback loops between the physical and virtual elements based on extensive data analysis, optimizing manufacturing performance (S. Wang et al., 2016).

## 2.1.3 Industry 4.0 Pillars and Technologies

I4.0 is enabled by technological improvements that help transform the production process by integrating isolated cells *"into a fully integrated, automated, and optimized production flow,"* allowing it to perform more efficiently and providing a network for relationships between suppliers, producers, and customers (Rüßmann et al., 2015). The same authors state that are nine I4.0 pillars that transformed industrial production.


**Figure 2: I4.0 Pillars**

**SOURCE:** Kadir (2020)

### 2.1.3.1 Internet of Things

Cost reductions in sensors and increasing processing power, paired with the evolution of ICT, enabled the creation of IoT, consisting of *"interconnected sensors on machines, people, and products coupled with intelligent controllers, broadly defined, that can take actions based on real-time sensor readings"* (Olsen & Tomlin, 2020). By assigning a digital identity to objects, IoT allows the internet to be everywhere and assures unrestricted interaction between things and people (Gomes & Bergamo, 2018), improving processes and information processing procedures (Qu et al., 2017).

One of those *"things"* are RFIDs, which enable real-time tracking and monitoring of all products (Gubbi et al., 2013), allowing the digitalization of the production process (Abdirad & Krishnan, 2020), making the information more transparent and less error-prone.

#### 2.1.3.2 Big Data

Big data is the acquisition, storage, and processing captured from *"production equipment and systems as well as enterprise and customer management systems"* (Rüßmann et al., 2015). The expected outcomes of using it are customer-centricity, operational optimization, risk and financial management, and the insurgence of new business models. According to Wang (2015), it is categorized by the *"3V."*

- Volume – Capturing massive amounts of data generated from numerous sources
- Velocity – High speed of data that is captured, stored, and proliferated
- Variety – Emergence of new data types from *"social networks, machine devices, and mobile sources integrated into traditional transactional data types."*

Nevertheless, because it is unstructured and heterogenous, traditional software database approaches of capturing, storing, management, and analysis fail due to its size and need to be treated differently (Yin & Kaynak, 2015). If adequately leveraged, big data can drive informed decisions. Since *"big data are worthless in a vacuum,"* companies must be able to transform vast amounts of raw data into relevant information. Big data analytics plays a crucial role, as intelligence is acquired and analyzed from data sources (Gandomi & Haider, 2015).

### 2.1.3.3 Simulation

Simulation allows replicating the real world into a virtual model, using real-time data from machines, products, and humans. By testing and adjusting machines' settings in the virtual realm, engineers can optimize machine setups and testing times, minimize costs and increase the quality to implement during the physical changeover (Rüßmann et al., 2015).

The digital twin refers to the virtual copy of real-world physical systems that *"allows for process simulation and optimization, as well as system monitoring and control"* (Gaspar & Juliao, 2021). Combining real-world data with simulation models provides high fidelity in manufacturing process predictions (Goossens, 2017).

CAD is a simulation technology for visualizing products and production processes (Ramírez-Durán et al., 2021). Creating a simulation of real-world products in 2D or 3D allows workers to optimize their design with scale, precision, and physics properties before manufacturing (BasuMallick, 2022).

### 2.1.3.4 Augmented Reality

Azuma (1997) defines AR as a combination of real and virtual, real-time interactivity, and 3D registering. AR enhances human-machine interaction by enabling workers to *"access the digital world through a layer of information positioned on top of the physical world,"* expanding the real world without replacing it. AR-enabling devices can provide workers with real-time information, facilitating decision-making and manufacturing (Vaidya et al., 2018). AR has great applicability in design and manufacturing, training, or maintenance processes (Masood & Egger, 2019).

### 2.1.3.5 Cybersecurity

The growing number of connected devices associated with the emergence of I4.0 increased the need for companies to protect their operations from cybersecurity threats (Rüßmann et al., 2015). Organizations should adopt a comprehensive strategy to address cyber-attack threats, including developing secure operations, by incorporating cybersecurity policies into organizational and IT strategies (Waslo et al., 2017). External pressures, such as political and monetary interests, will demand cybersecurity to protect production facilities (Hermann et al., 2016).

### 2.1.3.6 Cloud

Companies must make decisions based on large amounts of information during manufacturing, relying on intense computation. For efficient data exchanging and sharing, cloud computing services aid in complex decision-making operations, storing data in public or private cloud servers and facilitating IT transmission through an internet network (Xu et al., 2018).

The cloud provides a pivotal structure for integrating elements of I4.0 smart factories (Landherr et al., 2016). Cloud manufacturing uses a virtual network, organized and controlled by cloud services, which allows the interaction of suppliers and clients *"for trading and usage of configurable resources/services, as well as dynamic and flexible cooperation and collaboration in multi-partner manufacturing missions"* (Adamson et al., 2017).

### 2.1.3.7 Autonomous Robots

According to Bahrin et al. (2016), production methods can become autonomous because robots work in environments and time frames where human workers are usually restricted. This implementation allows mass customization, increase in productivity, flexibility, production speed, cost reduction, and quality improvement. They can now work without supervision and develop and coordinate various tasks, having the ability to communicate with each other and with humans (Rüßmann et al., 2015). Manufacturing processes are aided by control devices based on machine learning algorithms that can uncover complex and individual features (Ellefsen et al., 2019).

#### 2.1.3.8 Additive Manufacturing

Until today, most manufacturing methods in the industry were subtractive, which involved cutting/grinding away solid materials to create new parts. However, with I4.0, AM, also known as 3D printing, encompasses manufacturing technologies that produce objects by addition rather than subtraction (Beyca et al., 2018). AM facilitates the production of prototypes and small batches of various customized products (Rüßmann et al., 2015) and reduces waste (Beyca et al., 2018).

#### 2.1.3.9 Horizontal and Vertical Integration

Vertical integration refers to incorporating the company's activities at various hierarchical levels, such as *"the organizational structure, human factor, departments relationships, technological and management level."*. On the other hand, horizontal integration constitutes networks composed of companies, suppliers, customers, and competitors (Pérez-Lara et al., 2020). In pursuing a smart factory, horizontal and vertical systems must be integrated, with transversal collaboration supported by intelligent I4.0 production systems (Rüßmann et al., 2015).

ERP is a tool that allows all procedures, such as finances and accounting, sales and marketing, production, and HR, to be integrated in real-time, supported by software of interconnected modules with a shared central database (Laudon & Laudon, 2019). It enables effective decision-making, planning, and controlling of the company's resources, as ERPs allow the visualization of operations as a whole (Briffaut, 2015).

### 2.1.4 Benefits of Industry 4.0 Implementation

The emergence of I4.0 has created new opportunities for companies. Several data sources provide added-valued information for the decision-making process (CTCP, 2019) and, thus, contribute to the emergence of new value chains and the development of innovative business models (Mohamed, 2018), where integration between different actors is vital (Dalenogare et al., 2018).

Kagermann et al. (2013) identify the potential to meet individual customer requirements with the availability of incorporating customer-specific criteria *"in the design, configuration, ordering, planning, manufacture and operation phases,"* granting more customization and the possibility of batch sizes reduction or personalized one-off items, still being profitable. Customer co-creation is possible *"through digital channels and smart products that integrate the firm with the customers, allowing the delivery of higher value"* to the clients (Dalenogare et al., 2018). Also, reducing lead times and improving time-to-market is beneficial for manufacturing companies by allowing them to respond faster and more effectively to customer demands (Oesterreich & Teuteberg, 2016).

CPS provides a dynamic configuration of various business processes such as quality, time, risk, robustness, price, and eco-friendliness. This technology can support companies in continuously improving their supply chain efficiency. It can make processes more agile and provide them with the necessary flexibility to respond to variable supply conditions. End-to-end transparency is a critical component of innovation that enables companies to improve their design and engineering processes. It allows them to quickly identify and respond to changes in their operations (Kagermann et al. 2013). Quality will be higher, and the error rate will be reduced as sampling methods for error detection will be replaced by real-time sensor information leading to increased productivity, efficiency, and decision-making optimization (CTCP, 2019).

The goal of the I4.0 implementation is to maximize resource productivity and efficiency as processes become increasingly flexible and less complex, resulting in the *"reduction of labor costs, the simplification of business processes and the reduction of inventory inaccuracies, as well as more transparency in logistics processes"* (Kagermann et al. 2013). These factors increase productivity and revenue, translating into company growth (Mohamed, 2018), being the foundation for their strategic differentiation and competitive advantage (Kiel et al., 2017). I4.0 aims to create an intelligent network of products and processes to help companies reduce complexity and improve efficiency with long-term cost reduction and process improvement (Santos et al., 2017).

### 2.1.5 Challenges of Industry 4.0 Implementation

Despite the benefits of I4.0, there are also difficulties that companies may face. Cybersecurity concerns constitute an essential topic in I4.0 adoption, as the business' infrastructure and data stored in the systems must be protected from exploitation and unwanted access (Pereira et al., 2017). The appearance of I4.0's highly sophisticated technologies will demand specialized workers with digital skills, which are scarce in the current labor market, making it difficult for companies to implement I4.0. Education is essential to prepare workers for this new technological paradigm (Kagermann et al., 2013). I4.0 promotes the emergence of new jobs like *"robot coordinator"* and *"data scientist,"* while routine and physically demanding jobs will disappear, replaced by new technologies like autonomous robots. This scenario generates a significant obstacle: resistance to change (CGI, 2016). Additionally, adopting I4.0 requires substantial investment in new equipment, software, and training, and this cost can be a barrier for some companies, especially micro and small enterprises (Correia et al., 2016).

## 2.2 Industry 4.0 in Portugal

Initiatives have been made to implement I4.0 in Portuguese companies. In 2017, the creation of the government-funded *"Programa Indústria 4.0"* aims to accelerate the adoption of I4.0, promote Portuguese technological suppliers as I4.0 players and make Portugal an attractive pole for I4.0 investment.

The 2021 *"O caminho para um Portugal biónico: A maturidade digital do tecido empresarial em Portugal"* BCG study evaluates the digital maturity of companies through DAI, a BCG metric, characterized by four levels: starter, literate, performer, and leader. The digital maturity of Portuguese companies is only at level 2 with 31/100 DAI points, far from the European average of 52 DAI. BCG characterizes Portugal as digitally literate, where *"there is recognition of the need for digital and a defined roadmap to bridge existing gaps. Processes are being digitized, and business units and functions are already implementing digital initiatives, although they are still compartmentalized"* (Abecasis et al., 2021). Medium and large companies are already more mature than small companies, making them more productive (Abecasis et al., 2021). This scenario hinders the adoption of I4.0 technologies since most companies are micro or small (Correia et al., 2016).

### 2.2.1 Portuguese Footwear Industry and Industry 4.0

*"The Sexiest Industry in Europe,"* also known as the Portuguese footwear industry, is characterized by innovation, modernization, and competitiveness. Since the cluster's foundation, the factors contributing to the growth of the footwear industry in Portugal have changed. In the 1970s and 1980s, *"the industry grew based on the low labor costs and economies of scale based on large volume."* However, in the 1990s, the competitive intensity led companies to modify their business model. Many global footwear buyers shifted their operations from Portugal to cheaper Eastern Europe and Asia. So, for Portuguese companies to

survive and prosper, a differentiation strategy was pursued, supported by innovation (Abrunhosa & Moura E Sá, 2008). Instead of focusing on economies of scale and cost reductions, the Portuguese industry focuses on quality and redirection to added-value market niches (Diniz et al., 2015). With this decision, Portuguese companies could penetrate the external markets, distinguishing themselves with high-quality products, mainly in the leather sector, focusing on exports and allowing the cluster to reinforce its importance in the Portuguese economy. 66% of sales are through exports (Banco Portugal, 2021), and Portugal is in the top 20 World's biggest shoe exporters (APICCAPS, 2022).

In 1975, APICCAPS was founded. The association institutionally represents the footwear, components, leather goods, and substitutes industries. Also, it has interventions in innovation, business competitiveness, internationalization, and improvement of employability conditions in the sector (APICCAPS, 2022). CTCP, founded in 1986, aims to provide technical support to the cluster's companies, promoting investment in product quality and industrial processes through research and development, endorsing specialized training among workers, and disseminating information (CTCP, 2022).

The latest data from Banco Portugal (2021) shows that, of the 1 869 companies, the Portuguese footwear industry is characterized by microenterprises (56,44%) and SMEs (31,87%), with only nine large enterprises, hindering I4.0 adoption (Correia et al., 2016). Nonetheless, the top 20% of companies in the sector represent 86% of turnover. A comprehensive overview of the Portuguese footwear industry is available in Appendix I.

The 2022 *"Plano Estratégico do Cluster do Calçado"* vision is *"to be an international reference of the footwear industry."* The cluster recognizes the strengths to position itself favorably against international competition, being its high standards of quality, design, and sustainability, the capability of responding quickly and flexibly to customers, the recognition in the international professional market, and the collective culture shared by companies and sectorial institutions to develop projects of common interest. However, some weaknesses were acknowledged, namely the sector's high production costs and labor shortage, hampering the ability to compete in the most massified segments of the market and limited skills in digital processes (APICCAPS, 2022). With this in mind, the newest strategic plan is based on four axes:

1. **Qualification of People and Companies**: The productivity levels are still below those of other European competitors, as the qualifications of the cluster are still subpar. To improve its competitiveness, considering new technological landscapes, it plans to establish a comprehensive framework for the industry's requalification and rejuvenation by 2030.

2. **Sustainable Products and Processes**: The planned interventions aim to reinforce the industry's circularity and reduce waste in the production process.

3. **Flexibility and Speed of Response:** The efficiency of the product development process is significant in an industry that is constantly looking for ways to innovate and distance itself from traditional footwear manufacturing, which is time-consuming and costly, requiring the construction of prototypes and multiple ineffective interactions with clients. It aims to implement intelligent logistics solutions, improve the speed and flexibility of response, and reduce the number of steps required for production. Reinforced automation is an objective for crucial areas of footwear production, such as cutting, sewing, carding, or assembly, reducing human intervention in the process. Another objective is to digitalize the factory floor to allow workers to acquire, store, and manipulate data at the factory's level more efficiently, reinforce the management and planning functions, and integrate the entire process. Investing in I4.0 is imperative to achieve the goals set for the cluster.

4. **Cluster's Active Presence in the Markets**: Ensuring the presence of Portuguese companies in the leading international markets continues to be

relevant in the sector's strategy, betting on the strength of the Portuguese offer, the *"Made in Portugal"* trademark, and the definition of digital strategies to solidify the presence in current external markets and to penetrate new ones.

Using I4.0 technologies in the Footwear Industry has brought added efficiency in responding to market needs. Nonetheless, many tasks still involve manual labor due to the specificity of the footwear production process (CTCP, 2019). In the segment of high-added value shoes, most of the production is still a handicraft process (Oliver et al., 2021), impeding the adoption of I4.0 technologies. The creation of fashionable footwear is partially manual, with some production steps like cutting aided by specialized robots. It is challenging for fashion shoe companies to adopt automated technologies like robotics since there is a wide range of heterogeneous products with different specialties (design, application, and fashion trends), materials, and components, increasing the complexity of the production and assembling process. Finding the right balance between knowledge, craft skills, and automation in new production configurations is necessary. The use of robotics is prevalent in producing technical footwear, where the products are homogenous and less complex (CTCP, 2019).

With the increasing attention of the Portuguese footwear market and industry strategies having the I4.0 as a focus, and the will to digitalize processes reflected in the APICCAPS' strategic plan, mainly in axis 3, arose a need to study and understand what is the current I4.0 maturity of the Portuguese footwear industry.

# 3. Research Methodology

This chapter focuses on the research methodology used in this study. The research question and objectives and the selected research strategy are presented. The research design is discussed, including the selection of interviews, question design, sampling, data collection, and analysis techniques.

## 3.1 Research Question and Objectives

This dissertation aims to study the research question: *"What is the current I4.0 maturity in the Portuguese footwear industry?"* It will address the impact of I4.0 technologies on the Portuguese footwear industry and assess the level of I4.0 implementation in Portuguese companies, diving into the main changes in several dimensions, the benefits/challenges of this implementation, and future trends.

## 3.2 Research Strategy

Despite having different strengths and logic, quantitative and qualitative research are tools for achieving the same goal (Maxwell, 2004). Cleland (2015) summarizes the main differences between both methodologies in Appendix II.

Since the existing literature regarding this topic is scarce, the study will utilize an exploratory nature, following a qualitative strategy with an interpretative paradigm. Qualitative research is well-suited to understand complex experiences, providing insight into stakeholders' perceptions regarding the adoption of I4.0 in the footwear industry, capturing nuanced perspectives to understand the phenomenon (Hillebrand & Berg, 2000). The size of the sample is not essential in this approach. The goal is to understand the participants' views instead of testing hypotheses on a large sample (Hellström, 2008). It is critical to understand the subjective interpretations of each participant as multiple realities are created according to one's interpretation or construction (Smith, 1983).

## 3.3 Research Design

### 3.3.1 Data Collection

According to Johnson & Stake (1996), six methods are used to collect data in qualitative research: direct observations, interviews, documents and artifacts, surveys and questionnaires, tests and assessments, and physical traces. The most common method used is interviews, which will be the primary source for data collection. Structured, unstructured, and semi-structured interviews are different interview approaches. Semi-structured interviews were considered the most suitable option for this investigation. It is a hybrid type of interview that combines the elements of structured (standard predetermined questions) and unstructured (open-ended questions to allow the participants to make decisions regarding the topics) methods. It usually follows a set of questions with follow-up questions designed to elicit further information from the participants. This type of interview is for a deeper understanding of complex subjects (Flinders, 1997), using interrogative words such as why and how, allowing the researcher to capture the full range of the participant's responses and improve the quality of the conversation (Adams, 2015). Direct observations were also employed as they capture real-time data and nonverbal communication, making identifying discrepancies between reported and actual behavior easier, enriching data analysis (Creswell, 2015).

### 3.3.2 Question Design

Two types of interviews were prepared: one for the associations, with more transversal questions to capture the footwear industry as a whole, and one for the footwear companies. For the second group, the design of the question was based on the Schumacher et al. (2016) I4.0 Maturity Model. The goal of the I4.0MM is to provide a framework for companies to identify their current state of I4.0. It consists of a maturity assessment model considering nine organizational dimensions, broken down into a questionnaire, measured using a five-point Likert scale. However, since this investigation follows a qualitative methodology, recurring to semi-structured interviews, this I4.0MM was adapted to better respond to the research question. The most relevant of the nine organizational dimensions were chosen, and the questionnaire-type questions were transformed into open-ended ones. These include strategy, products, customers, operations, and technology. A final assessment topic is addressed as well. It should be noted that the last question seeks to quantify, albeit subjectively, the level of digital maturity at which the company/industry is. The interview questions are presented in Appendix III.

### 3.3.3 Sampling

Interviews with APICCAPS and CTCP were done, as they can give their transversal overview of the industry's status.

| Interview Code | Association | Interviewee's Position |
|---|---|---|
| **I1** | APICCAPS | Project Analyst |
| **I2** | CTCP | Researcher in Innovation and Digital Manufacturing |

**Table 1: Associations' interviewees**

**SOURCE:** Own made

The criteria used to assess individual enterprises is interviewing companies within CAE 152: Footwear Industry. As most Portuguese footwear companies are microenterprises, it multiplies the difficulties in adopting I4.0, as these technologies require digital literacy and investment. The focus of these interviews is on companies able to carry out these sorts of investments. Using SABI (2023), it was possible to gather companies with the most turnover and their contacts. Also, companies recommended by CTCP were taken into consideration.

The following companies agreed to participate in this study. The companies were coded for confidentiality and ease of identification throughout the work.

| Interview Code | Company Code | Size[1] | Field of Activity | Interviewee's Position |
|---|---|---|---|---|
| **I3** | CompanyA | Large | Fashion Shoes | Brand Marketing Manager |
| **I4** | CompanyB | Large | Fashion Shoes | CEO |

[1] According to the European Comission Recommendation 2003/361/CE

| | | | | |
|---|---|---|---|---|
| **I5** | CompanyC | Medium | Safety Shoes | CEO |
| **I6** | CompanyD | Medium | Fashion Shoes | Commercial Director |
| **I7** | CompanyE | Medium | Shoe Components | CEO |
| **I8** | CompanyF | Large | Fashion Shoes | Operations Director |

**Table 2: Companies' characterization and interviewees**

**SOURCE:** Own made

### 3.3.4 Data Collection and Analysis

Most interviews were conducted online via MTeams. However, interviews with CompanyA and CompanyB were held at their facilities, with the addition of a shopfloor tour. The interviews were held from March 1st to May 2nd, with an average of thirty-nine minutes. Based on the participants' homogeneity and the study's exploratory nature, final interviews yielded no new perceptions. Eight interviews were considered sufficient (Braun & Clarke, 2006; Guest et al., 2006).

The analysis began with thoroughly reading and re-reading the transcripts to acquire complete data comprehension. NVivo was then used to generate and apply codes to the data to detect and group text segments related to similar topics. This procedure entailed discovering patterns and linkages in the data, which aided in generating insights and comprehension of the study phenomena (Charmaz, 2006; Saldaña, 2016).

# 4. Results and Analysis

This chapter presents the interviews' findings. The results of this investigation take into account perspectives of APICCAPS and CTCP and standpoints from companies' relevant stakeholders. The analyzed results will be compared with the literature review.

## 4.1 Strategy

APICCAPS (I1) and CTCP (I2) actively promote companies' strategy of adopting I4.0, diagnosing their degree of digital maturity and explaining the concepts of I4.0: *"There are companies that still do not understand what I4.0 is, which does not mean that they do not implement it"*(I2). They aim to increase digital literacy and demystify the concepts of I4.0, coordinating efforts between footwear manufacturing companies, knowledge producers (universities and research institutes), and technology companies. They also pay attention to major technological innovations and assess how they can be applied to the cluster.

The strategic plans of APICCAPS were mentioned in I1 as critical to driving innovation. Also, several programs like Footure4.0, FEETIN4.0, and FAMEST were cited in I2, as they sought to explore the opportunities created by I4.0 to cement their international presence further, as footwear companies need to be constantly innovating. The objectives were to create new forms of interaction in a digitally connected network and develop new business models in an omnichannel environment, involving clients in the co-creation process. The goal was that I4.0 played a significant role in developing fast and flexible value chains, efficient product development and prototyping, and using intelligent technologies to digitalize the methods (Kagermann et al., 2013). Also, it emphasized the importance of the qualification of the sector, preparing it to adopt I4.0 practices, which aligns with the strategic plan.

Most companies interviewed understood the importance of the cluster's associations in adopting these technologies:

*"APICAPS and CTCP are always in support. They are partners we consult for adopting new technologies"*(I3).

*"Not having the liquidity to acquire tools in this area, they often point out which programs, national or European, we can apply for and help us in the application"*(I7).

CompanyF belongs to an international group and follows headquarters guidelines, and does not see any value in the associations' support.

The primary motivation for companies to adopt I4.0 practices and technologies is economic efficiency and productivity gains. All interviewees shared this opinion, as companies want to produce more, better, faster, and reach customers quickly: *"We have a vision of getting closer to our customers, and if we can use I4.0, we can get a better understanding of the market"*(I5). Furthermore, companies want to make gains at the organizational level by better organizing their processes and workflows with I4.0, which can help streamline operations and improve communication and collaboration among different departments. CompanyE reinforced the need for process transparency and decision-making decentralization. Moreover, concerned about their workers, implementing robotics and automation provides them with better working conditions: *"Workers end up having a lot of physical wear and tear due to intensive labor. We started thinking about ways not to wear out the worker"*(I4).

## 4.2 Operations

The first I4.0-sponsored change is in the organization of the production process, which has moved away from paper-based systems and towards using ERPs to help with management, monitoring, and support decision-making. CTCP and APICCAPS have facilitated this change by integrating technology producers into the cluster companies (I2). ERPs have enabled companies to become more efficient, collaborate better with suppliers and be responsive to customers. I4.0 brought automation to repetitive processes and logistics, with a large part of manufacturing orders already being digital. This implies a high integration between various processes, resulting in high levels of organization, less waste, and improved overall efficiency.

However, the level of change in operations was most prevalent in CompanyA, CompanyC, CompanyE, and CompanyF. CompanyA has an I4.0 system that helps manage the production lines and increases flexibility. Their smart factory allows real-time information collection from production systems and determines the best production sequence, facilitating small series production with shorter response times, less human intervention, and increased productivity. CompanyC bets on increasing efficiency by abolishing manual inventory records, developing robots where the *"machine can communicate with the shoe,"* and machine gamification to help machine programming for younger workers. CompanyE and CompanyF have significant process automatization and data processing, with CompanyE starting to integrate this with AI.

I4.0 aided some cluster companies in developing smart factories. Entreprises are integrating the IoT and CPS concepts identified by Kagermann et al. (2013) to achieve greater digitalization (Abdirad & Krishnan, 2020), reducing lead times and enhancing quality and supply chain management. One great example is CPS Cutting Equipment and RFID tags used by some interviewed companies, which collect information from productive equipment in real-time, for example, speed, energy consumption, or equipment status. The integration between things and humans, physical and virtual, allows the optimization of manufacturing performance identified by Wang et al. (2016). Also, these changes in operations reflect the third axis of the strategic plan (APICCAPS, 2022).

## 4.3 Technology

### 4.3.1 Internet of Things

APICCAPS and CTCP state that IoT in the footwear industry is not widespread. However, companies A, B, C, and E, to increase factory automation, use intelligent sensors and RFIDs to track production and count the number of pairs produced: *"We can count almost automatically, so it is an advantage of reducing time and effective control. We no longer have to do sample control, we can do it 100%"*(I5). CompanyD and CompanyF do not use RFID technology.

Using RFID to track production (Gubbi et al., 2013) improves processes and interactions between things and objects (Gomes & Bergamo, 2018; Qu et al., 2017). Nonetheless, the Portuguese footwear industry appears to be in the early stages of exploring and adopting IoT. RFID reduces lead times, improves quality control, and better management of production phases, so companies must adopt such practices.

### 4.3.2 Big Data

In I1 and I2, big data in the footwear industry is seen as not prevalent. Other companies corroborated that this pillar is poorly developed, mainly using data collection systems from the production process to aid management decisions. However, one promising use of big data is CompanyC developing the possibility of predicting upcoming shoe trends to create an offer that responds to the needs of specific market segments, transforming raw data into useful information to aid their production strategy (Gandomi & Haider, 2015): *"If we anticipate, we will have a much more efficient service"*(I5).

In contrast, CompanyE is starting to pilot the use of data with AI to automate production decisions:

*"We have already extracted many data from all the machines. These data will fall into a database, and through statistical analysis, you can infer macro-trends and root causes of problems and (…) with the help of AI, I would like the data to almost magically self-organize."*

Nonetheless, the lack of big data implementation appears to be due to a poor understanding of its potential benefits and expertise to implement it, creating disinterest from companies in the industry.

### 4.3.3 Simulation

CAD appears to be used transversally by all the companies interviewed. Also, APICCAPS and CTCP developed the company Mind Technology. Their product, MINDCAD3D, uses CAD, where designers can create virtual 3D models of shoes, simulating their appearance and structure efficiently without physical prototyping, which can be time-consuming and expensive.

This technology enables the development of footwear models that can be sent to customers for virtual customization, making it a highly personalized experience. Customers can choose from various parameters to customize multiple aspects of the shoe, such as leather, color, sole type, and eyelets. This co-creation process allows the integration of the client into the value chain (I2).

Simulation is fundamental to the Portuguese footwear industry, allowing for more efficient prototyping and new customization opportunities. The results of this study support the conclusion of prior simulation research done by Rüßmann et al. (2015), where processes are optimized during prototyping. The use of CAD to design footwear with precision (BasuMallick, 2022) is prevalent.

### 4.3.4 Augmented Reality

AR is still very underdeveloped. Most companies disregarded using AR wearables as an added value. However, CompanyE uses AR to collaborate in real-time with partners using glasses to conduct tests and production of molds for better results, avoiding back and forth of defective material. CompanyC has virtual showrooms, an interactive experience: *"We demonstrate the details of each shoe in our collection in a virtual way, with 360º AR glasses"*(I5). Nonetheless, CompanyC plans to implement injection tools with AR, where it will be possible to understand the injection channels, how the material will behave, and if there is any error. As AR develops and becomes widely used, it is feasible that its use in the footwear sector may grow because, according to Vaidya et al. (2018), workers can be provided with real-time information facilitating decision-making.

### 4.3.5 Cybersecurity

As in the findings of Rüßmann et al. (2015), cybersecurity was mentioned as a significant concern for companies undergoing digital transformation, namely the risk of cyberattacks and the potential theft of processes and know-how from non-Portuguese companies. The lack of cybersecurity literacy was also highlighted as an issue (I2). It is positive to note that the companies are aware of these risks and are working with IT companies to address them: *"It is a cluster that works very well in cooperation with the companies that provide services and that grow together"* (I2) suggesting a collaborative approach to tackling cybersecurity concerns.

### 4.3.6 Cloud

The use of cloud technology is already widespread in the footwear industry. Companies store their data in the cloud or through third-party cloud services. Additionally, the mention of having data safeguarded indicates that the industry is taking measures to ensure its data security in the cloud.

The findings imply that the companies have recognized the benefits of cloud technology in terms of easy access to data and cost-effectiveness (Xu et al., 2018) and that cloud technology is essential to the industry's digital transformation efforts.

### 4.3.7 Autonomous Robots

Robotics is not very widespread throughout the cluster (I2). The high initial costs involved in implementing it and the fact that the footwear industry does not have as many opportunities for automation compared to other industrial sectors (CTCP, 2019) make the adoption of robotics less attractive. There are several shoe collections, and for each collection, there are numerous sizes, in which it is also necessary to produce a shoe for each foot, increasing the complexity of robot programming and difficulting automation processes. It was clear from the interviews and the shopfloor tours that many tasks are manual because the Portuguese footwear industry requires these manual procedures (CTCP, 2019; Oliver et al., 2021).

*"The problem with shoes is that they have many operations, and unfortunately, most still have to be manual. There is no production line where you put the leather on one side and the shoe comes out on the other"*(I4).

CompanyB failed to implement a fully robotic production line: *"We were among the first to have a robotic line, but it was not worth the investment. The robotics maintenance itself had many issues, quickly becoming obsolete. Our business model also does not help to automate and robotize"*(I4).

However, robotics is used for specific operations, such as cutting. This process used to be done manually, but now it is being automated. Automatic Cutting Machines, present in all interviewed companies, are computer-controlled devices that employ specialized software to cut various materials, even in small batches. They are much faster and less wasteful than traditional manual and mechanical cutting by presses (*"balancé"*). These machines integrate sensors in the cutting systems for data collection and decision-making, and the new waterjet or knife-cutting systems guarantee greater productivity. Robots for the automation of component abrasion tests are also utilized. CompanyA employs AGVs to transport materials between production and warehouses, implementing intelligent logistics: *"As we produce many things in small quantities, the company was forced to build a dynamic automatic warehouse* "(I3). AGVs are robots with conveyor belts or forks for material movement and handling without a human operator (CTCP, 2019). Using AGVs is efficient as it automates logistics movements and reduces materials' manual handling and transportation (De Ryck et al., 2020). CompanyC and CompanyF use robots to do the direct injection process, where the sole is formed directly on the upper. CompanyF also uses robotics in the majority of its production processes:

> *"It is not very usual to have a lot of robotization and automation in this industry. However, robotization and programming of production processes are already very common and have existed in the group for quite some time, resulting in a high level of automation."*

CompanyE finds it more manageable, in comparison with the other companies, to mass-produce components using robots throughout the whole production line.

Implementing 100% robotics in shoe production is complex since artisanal work still adds much value to the product.

### 4.3.8 Additive Manufacturing

AM is mainly used by component companies in the footwear industry to produce soles, insoles, and heels. It is also highlighted that 3D printing plays a crucial role in the orthopedics sector, where it is used to make shoes tailored to individual customers' health needs (I2), allowing the customization that Rüßmann et al. (2015) identified. The production process is more efficient with 3D printing by minimizing waste and manual labor, as Beyca et al. (2018) suggested. New technological advancements in AM can aid the strategic plan objectives of improved prototyping and sustainability (APICCAPS, 2022).

For footwear companies, *"3D printing does not have much use in production"*(I6). CompanyA and CompanyC are working to implement it in the design and development part. CompanyF uses 3D technology for component testing and product development.

However, footwear companies should learn from component companies about the use of AM, with the example of CompanyE, which considers it *"old news"* and has been using the technology for years. Although it is impossible to produce shoes only through 3D printing, this technology would bring significant benefits for prototyping, adding the possibility for customization and testing of innovative designs.

### 4.3.9 Horizontal and Vertical Integration

The interviews suggest a high level of integration within the industry. Vertically, there is integration within the company with ERP systems connected with the production process. CompanyB uses SAP, while others develop their ERPs tailored to their own needs, as stated in I5:

*"We have not had much success with tools like SAP because they are costly. We tried to approach, but the values we spoke and the complexity did not seem very interesting to us."*

CompanyA's ERP integrates and manages various business processes and operations, enhancing visibility and control and improving overall efficiency. This software enabled the digitalization of the production orders:

*"Our international agents place customer orders on the platform, which enters the company's system for production, making the job much easier because it was done on paper in the past. After filling it out, it arrived here and had to be manually inserted into the system, or it could get lost. The new method saves time, and there are no errors."*

Horizontally, CompanyF integrates its suppliers and other companies of their international group:

*"We have the ERP integrated with the other factories, so horizontal integration exists. We are also integrated with our leather and sole suppliers, which are part of our group. We integrate much of the value chain."*

Overall, using ERP enables greater monitoring of relationships in the collaborative network (Briffaut, 2015).

Also, as stated before, in the footwear cluster, there is a high level of integration between various entities, including associations like APICCAPS and CTCP, footwear companies, technology companies, and research centers like universities. These entities work together closely, fostering communication, collaboration, and knowledge sharing between all these entities to drive innovation and efficiency in the industry and become more competitive worldwide (Pérez-Lara et al., 2020).

Additionally, these pillars are permanently interconnected. An example from I2 is:

*"In some companies, there is a large part of prototyping simulation of shoe production with CAD. Then automatic cutting machines are used to cut the materials. RFID sensors can track production. ERP systems are integrated with production orders and big data to predict the following collections"*.

## 4.4 Products

I4.0 technologies allowed more complex and premium products with fewer errors, betting on quality, where Portuguese footwear is recognized internationally (Diniz et al., 2015). Nonetheless, developing new products is still primarily manual despite the introduction of CAD and 3D printing in the components sector.

While some companies are still very conservative in the shoemaking process, most are starting to use digital tools to innovate their products. On I7, the use of shopfloor data was stated as crucial to detect flaws in products. With this transparency, CompanyE can identify the causes and eliminate the root problem. CompanyC has better market understanding through data collection and analysis that made it possible for them to not only innovate on their product but to work on their sales prediction and market behavior to support the production process. CompanyF uses prototyping technology to test new designs and present them digitally to the customer in all possible variations, reducing physical prototyping waste.

One common ground when talking about products is the usage of digital platforms for sales and marketing and internal systems to control processes such as delivery and order processing.

Using data from retail sales, online websites, and social media engagement assists management concerning detailed statistics for new product launches: *"The information turns out to be there, all together, and we can obtain it much faster"*(I6).

There is still a considerable gap in the footwear industry when discussing data analysis for product creation, production, and sales forecast. There is a common difficulty in working on raw data, so companies have access to data but do not know how to benefit from it.

## 4.5 Customers

I4.0 has provided benefits to footwear industry clients. CAD and AM allow greater customization. CompanyC's 3D bonding technology allows the end user full customization of their safety shoe. Integrating customers via digital channels such as e-commerce platforms or CRM into the ERP (I4) allows companies to have consolidated client data. CompanyD and CompanyE use social media platforms to tag the products into analysis tools and access customers' evaluation data for product improvement. Also, using I4.0 led to efficient supply chain management with better traceability of products and reduced time-to-market, improving customer satisfaction. Finally, for CompanyC, I4.0 enhanced after-sales services:

*"We are sensitizing customers to register the guarantee of shoes, and with that, we are collecting more information from customers. Therefore, we are creating a customer profile database to help us make decisions based on the customer profile or in the criticisms for improving some production processes here."*

CompanyE engages the clients using simulation technology:

*"We had much recognition for being the first to go to footwear fairs with VR tools, where our customers could experience not only what our factory was like, but they could manipulate patterns."*

In contrast, CompanyF does not see I4.0 as a way to improve customer relationships by offering customized solutions since they take a more conservative approach of standardizing their collections, avoiding more complexity, but increasing automation in their value chain.

However, the gap mentioned in the previous section can be seen here. There is still difficulty in working with the data the company receives when predicting customer behavior. Nonetheless, the data received for customer feedback is heavily used by all companies.

## 4.6 General Assessment

### 4.6.1 Perceived Benefits

This initial I4.0 implementation has significantly impacted the Portuguese footwear industry, although being very premature. The main benefits highlighted are:

- **Efficiency and efficacy**, I4.0 optimized production, increased product quality, increased processes transparency, reduced errors, and diminished lead times and waste;
- **Quicker response to customers**, enabling faster and more accurate production to meet customer demands, as well as digital channels for overall communication;
- **Faster handling of information**, improving data management and control and decision-making processes;

- **Development of new business models/products and better customization**, having the possibility of adding more value to customers;
- **Improvement in the organization** by integrating the company and upgrading the production process.

The perceived benefits of I4.0 in Portuguese footwear corroborate the existing literature. The development of innovative business models (Mohamed, 2018), the integration of the companies (Dalenogare et al., 2018), the potential to meet individual customer and co-creation requirements (Kagermann et al., 2013), the reduced lead times and improved time-to-market (Oesterreich & Teuteberg, 2016), the improved resource productivity and efficiency, as well as the increased revenue and competitive advantage (Kiel et al., 2017) are well documented in the current literature and stated as I4.0 benefits perceived by the interviewees. Using I4.0 technologies supports the Portuguese footwear cluster differentiation strategy of innovation (Abrunhosa & Moura E Sá, 2008), allowing the penetration in niche markets (Diniz et al., 2015), with the focus on quality and customization that I4.0 provides.

### 4.6.2 Perceived Challenges

The main challenge in adopting I4.0 technologies was the lack of digital literacy from the companies. From I1 and I2, it was stated that most companies do not know how to apply I4.0, do not understand the benefits of I4.0, and some do not recognize the concept at all. Also, in some interviews, I4.0 was unclear to the interviewees, which is in line with the relevant literature, that states difficulty in hiring digital literature workers (Kagermann et al., 2013), a low level of digital literacy among Portuguese companies (Abecasis et al., 2021), and limited skills in digital processes from the footwear companies (APICCAPS, 2022).

Another difficulty is that the Portuguese footwear Industry business is composed mainly of micro and small enterprises, and they cannot invest in I4.0, as it is costly. To overcome this, the projects from the cluster's association aid in the technology implementation, development, individual projects, to productive innovation: *"We do a lot of this type of thing that helps companies, which often have economic difficulties, to have great support in their execution"*(I1). Even bigger enterprises like CompanyB, CompanyC, and CompanyE stated financing problems.

Another challenge identified is resistance to change from some workers, who have been accustomed to performing tasks in a particular manner for many years and have difficulties adapting to the new paradigms, as mentioned in the literature review by CGI (2016). It is crucial to demonstrate that these changes improve overall outcomes. However, as these new changes are very complex, prioritizing training for the teams and equipping them with the necessary skills and knowledge for effective I4.0 implementation is necessary and is present in the strategic plan (APICCAPS, 2022).

Also, the incompatibility between the Portuguese high-end shoe fashion, where many processes are still manual with the automation of processes, corroborates with the existing literature. It is difficult to automate in the footwear industry because *"footwear requires knowledge of the material, which is not that easy to pass on to something automatic"*(I3), and *"it is still a very manual Industry"*(I6). Also, the heterogeneity of products does not allow automation: *"We have many different models and specific niches"*(I4); *"Right now I am producing 30 or 40 different models at the same time (...) it adds complexity to automate"*(I8). Craftmanship in the Portuguese footwear industry is valued. Finding the right balance between the automation of processes and craft work is essential (CTCP, 2019).

### 4.6.3 Next Steps

For APICCAPS and CTCP, the next step for a consolidated implementation of I4.0 is integrating more companies, universities, and technological centers to incite innovation. Also, it is necessary to make companies realize why I4.0 is helpful and increase the digital literacy of the cluster:

*"Why does I4.0 matter? It is imperative to answer this and continue training and pilot projects for companies on I4.0 to reach the cluster more quickly and show the improvements"*(I2).

They currently have two big flagship projects: BioShoes4all (sustainability) and Feist (productive technologies), which will aid the implementation of innovations on the factory floor and bring technological capacity to the cluster companies.

The following steps for companies in I4.0 involve continuous improvement and innovation, including updating ERPs for companies like CompanyB and CompanyA, implementing RFID technology for CompanyD, utilizing Big Data for market forecasting, and automating warehouse processes for CompanyC. CompanyE aims to take advantage of AI tools for data analysis and decision-making, use collaborative robotics in the production line and have the possibility to achieve better workers' salaries since *"to pay people better, you need to have much more efficient processes. To have the most efficient processes you must have I4.0 solutions."* CompanyF aims to continue to invest in I4.0 to grant them even more flexibility.

### 4.6.4 Quantitative Grade

The following table presents the grades given by APICCAPS and CTCP for the implementation state and maturity of I4.0 in the Portuguese Footwear industry as a whole, as well as the self-assessment grades provided by the interviewed companies. The scale ranges from 1 to 5, where 1 indicates *"not implemented at all"* and 5 *"fully implemented."*

| Association/Company | Grade |
|---|---|
| **APICCAPS** | 3 |
| **CTCP** | 3 |
| **CompanyA** | 4 |
| **CompanyB** | 3 |
| **CompanyC** | 3 |
| **CompanyD** | 4 |
| **CompanyE** | 1 |
| **CompanyF** | 3 |

**Table 3: Implementation Grade**

**SOURCE:** Own made

It is possible to create almost a correlation between literacy and the perception of the implementation stage of I4.0. Companies with more I4.0 literacy tend to undervalue themselves, being more rigid and conservative with the evaluation because they understand the complexity and time that digital transformation takes. In contrast, companies that are less knowledgeable of the topic tend to see themselves as more advanced than what can be perceived from the interviews.

# 5. Conclusions

## 5.1 Theoretical Contributions

Extensive literature research, namely in I4.0 smart factory, the nine technological pillars of I4.0, and the Portuguese footwear industry, paired with the interviews' findings, allowed this study's proposed objectives to be achieved. Using empirical evidence from the associations and companies provides a practical foundation for this dissertation. The insights from relevant footwear stakeholders give valuable perspectives on the impact of I4.0 technologies on the Portuguese footwear industry and the current state of this implementation. Overall, the study enriches the current literature as it provides valuable insights into the digital transformation of the Portuguese footwear industry and its journey toward I4.0 maturity.

The cluster desires to innovate and gain a competitive advantage by adopting I4.0 technologies. Hermann et al. (2016) principles have been identified in the Portuguese footwear industry. The interconnection of machines and people, the transparency and availability of information, the possibility for each stakeholder to make autonomous decisions, and the use of intelligent technologies for efficient decision-making enabled several Portuguese footwear companies to create smart factories by leveraging IoT and CPS (Kagermann et al., 2013). The support from APICCAPS and CTCP in transitioning companies to I4.0 has resulted in implementing various innovations. Companies in safety footwear, like CompanyC, and in the components sector, like CompanyE, find it relatively easier to adopt I4.0 due to their less complex business models with fewer variables than fashion footwear companies (CTCP, 2019).

When discussing the implementation of I4.0 through the pillars of Rüßmann et al. (2015), it is possible to see extensive development in simulation, cloud, and horizontal and vertical integration, as they were implemented in all the interviewed companies and noted by the associations. Some pillars with smaller gaps, such as cybersecurity, IoT, and robotics, are more commonly known and talked about but not heavily implemented. Moreover, bigger gaps in AM, big data, and AR, as they are not only not known but perceived as not so necessary to implement or even as a lower priority to do so.

On another note, the topics of products and customers show that although there are advances with the use of I4.0, there is still a lack of knowledge on the topic, especially on data analysis. While the companies and associations understand the benefits and challenges of adopting I4.0, there is room for growth in this traditional industry.

The perceived benefits of increased efficiency and efficacy were identified in all enterprises. However, the mentioned challenges need to be addressed in depth, such as the issue of digital literacy among companies. Many firms still struggle with understanding and implementing I4.0 due to a lack of knowledge. Additionally, only standpoints from enterprises that can invest in I4.0 were obtained. However, micro and smaller enterprises' viewpoints were missing, suggesting that there may be an even more significant digital transformation gap among these smaller businesses that do not have the same capacities to invest in I4.0. Also, adopting specific I4.0 technologies is hindered since this industry still requires much handcrafting, and the producers and customers still value this characteristic.

It is intriguing to draw comparisons between the findings of this study and a similar dissertation from 2019. The author arrived at six key conclusions:

- Silva (2019) claimed that this industry is knowledgeable, with manufacturers aware of existing and emerging technologies. This is in contrast to the findings of our study, which identified a lack of I4.0 literacy among some of the interviewed companies and in the Portuguese footwear industry as a whole. This study, however, confirms Silva's claim that APICCAPS and CTCP are crucial in aiding the industry's transformation to the new technological paradigm.

- Silva (2019) reported a self-assessment score for I4.0 deployment in the Portuguese footwear industry of 3 out of 5, which concurs with current findings. This shows that, despite the industry's acknowledgment of some technology breakthroughs, it *"is still very much dependent on human labor and skills."*
- It was highlighted that automatic cutting machines were one of the most commonly implemented technologies in the Portuguese Footwear Industry, consistent with the findings of this study.
- The fourth conclusion refers to the benefits of I4.0 implementation. *"Increasing flexibility, quicker production, better efficiency, better client interaction and also, the fact that, by automating the processes"* (Silva, 2019) are benefits aligned with this study.
- The challenges of high implementation costs and the shortage of digitally literate workers were also identified by Silva (2019) and are consistent with the established facts.
- The research for the motivation for adopting I4.0 parallels both conclusions, as companies want to innovate and are supported by association and national incentives.
- Silva's (2019) study evaluated the impacts of I4.0 on the company's workforce, which was not the main focus of this dissertation. However, both studies emphasize the criticality of education for workers in adopting I4.0 technologies.

## 5.2 Managerial Implications

As discussions about I5.0 gain momentum, the Portuguese footwear industry still faces challenges in adopting I4.0. With the right approach, the Portuguese footwear industry can embrace I4.0 and pave the way for future advancements in the manufacturing sector. The study's findings and recommendations can be used by footwear companies, policymakers, and researchers to develop initiatives to accelerate the adoption of I4.0 in the industry and unlock its full potential.

To overcome the digital literacy issue, developing a well-formalized digital strategy is imperative, promoting knowledge of I4.0 concepts from top management to factory workers and providing adequate upskilling and reskilling. To support micro and small enterprises, policymakers should provide financial incentives and other support mechanisms to enable them to invest in I4.0. Industry associations should continue access to knowledge-sharing platforms and facilitate collaborations with other companies in the cluster. Finally, despite the industry's reliance on manual labor, enterprises should try to implement I4.0 technologies. While continuing to use other technologies, underutilized AM, Big Data, and AR must be considered, as they significantly improve productivity, quality, and cost-effectiveness.

## 5.3 Limitations and Further Research

Despite the work's sound conclusions, some limitations should be mentioned. The lack of I4.0 knowledge among some interviewees hindered the flow of conversation. As a result, in-depth insights and perspectives on the topic may have been missed or not fully captured. This limitation underscores the importance of addressing the digital literacy gap in the industry. As this study used a qualitative nature, it did not allow generalizability, despite having the perspective of transversal players like APICCAPS and CTCP and overall adequate sample size.

Future studies in this area may undergo a quantitative analysis, reaching a large number of companies and using questionnaires to gather information. In this way, having a complete view of the footwear industry, with even inputs from micro and small companies, would be possible since each company would contribute with their experiences with I4.0. The questionnaire could follow the I4.0 MM, addressing the nine organizational dimensions.

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# Appendixes

## Appendix I - Portuguese Footwear Industry Characterization and Trade Balance

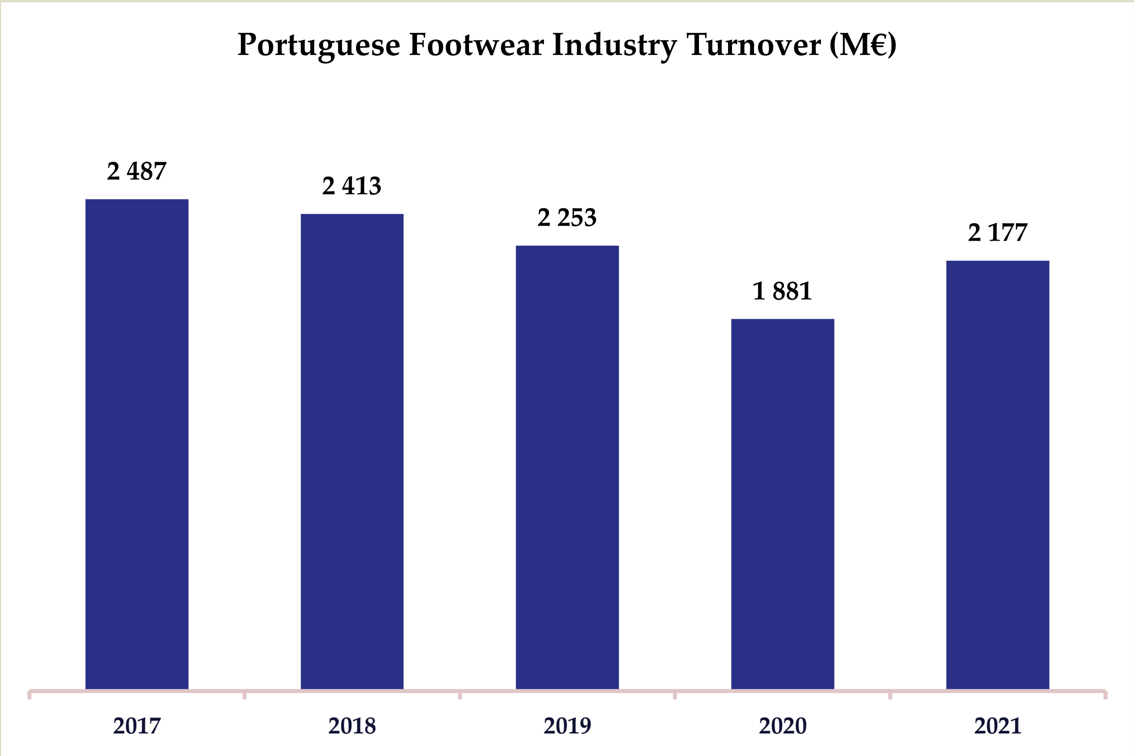


**Figure 3: Portuguese Footwear Industry Turnover (M€)**

**SOURCE:** Banco Portugal (2021)

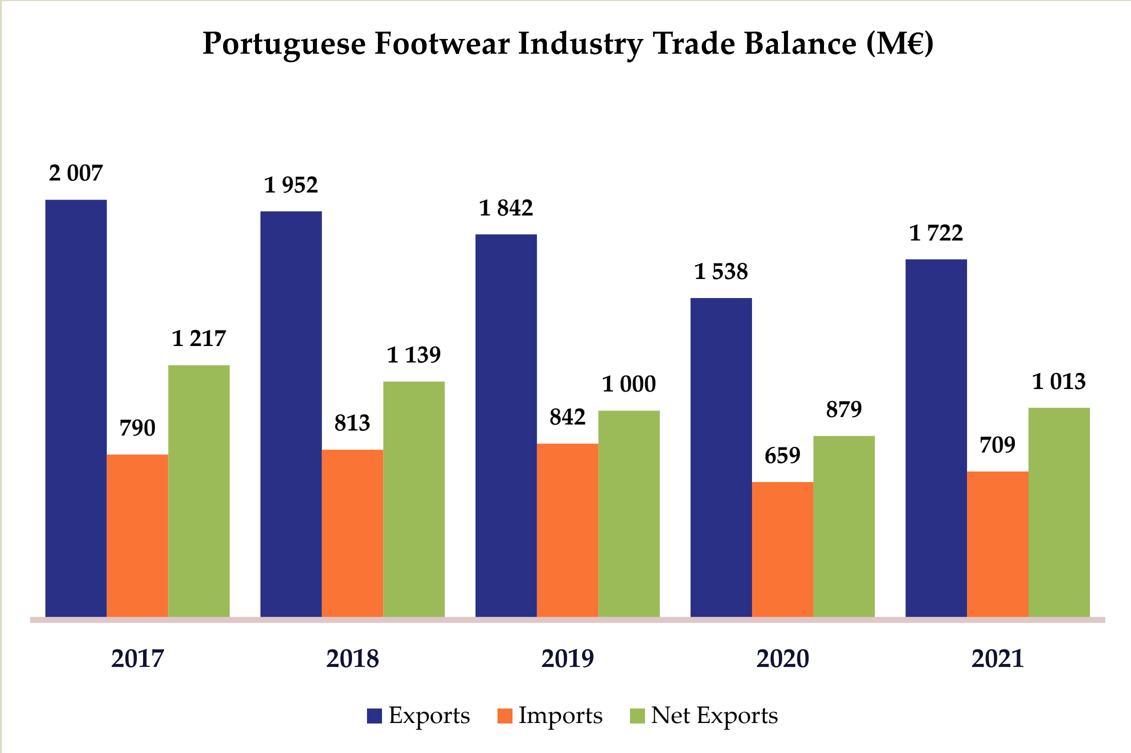


**Figure 4: Portuguese Footwear Industry Trade Balance (M€)**

**SOURCE:** Marques (2022)

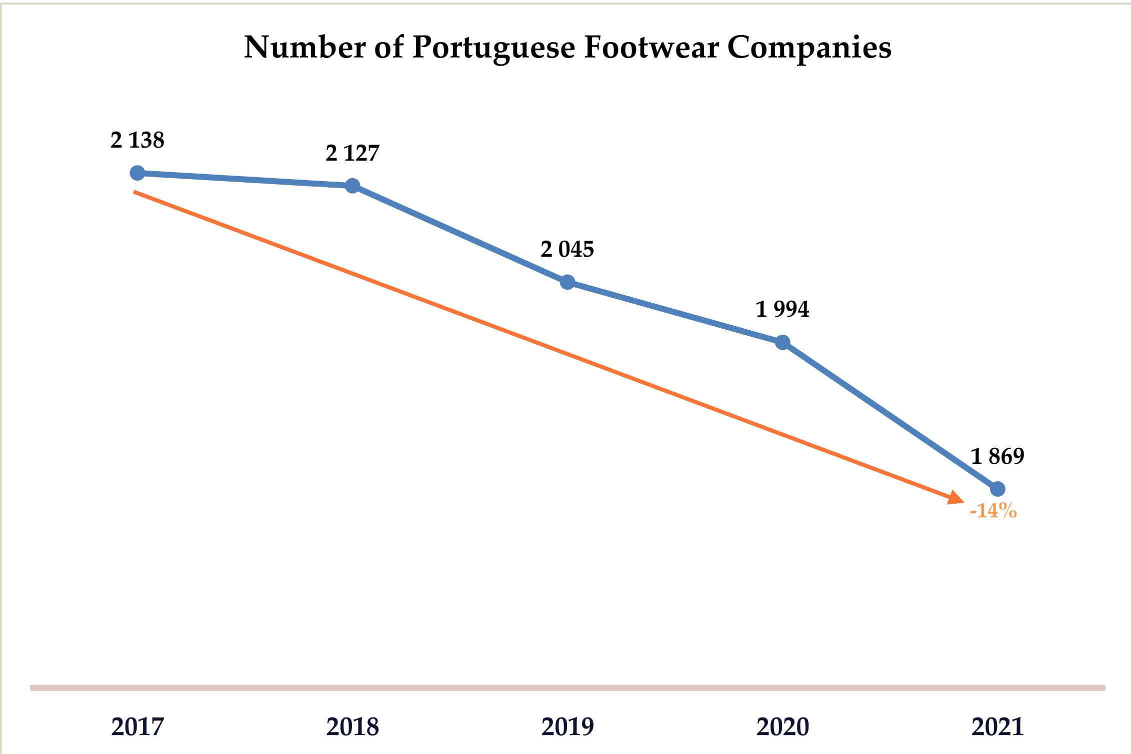


**Figure 5: Number of Portuguese Footwear Companies**

**SOURCE:** Banco Portugal (2021)

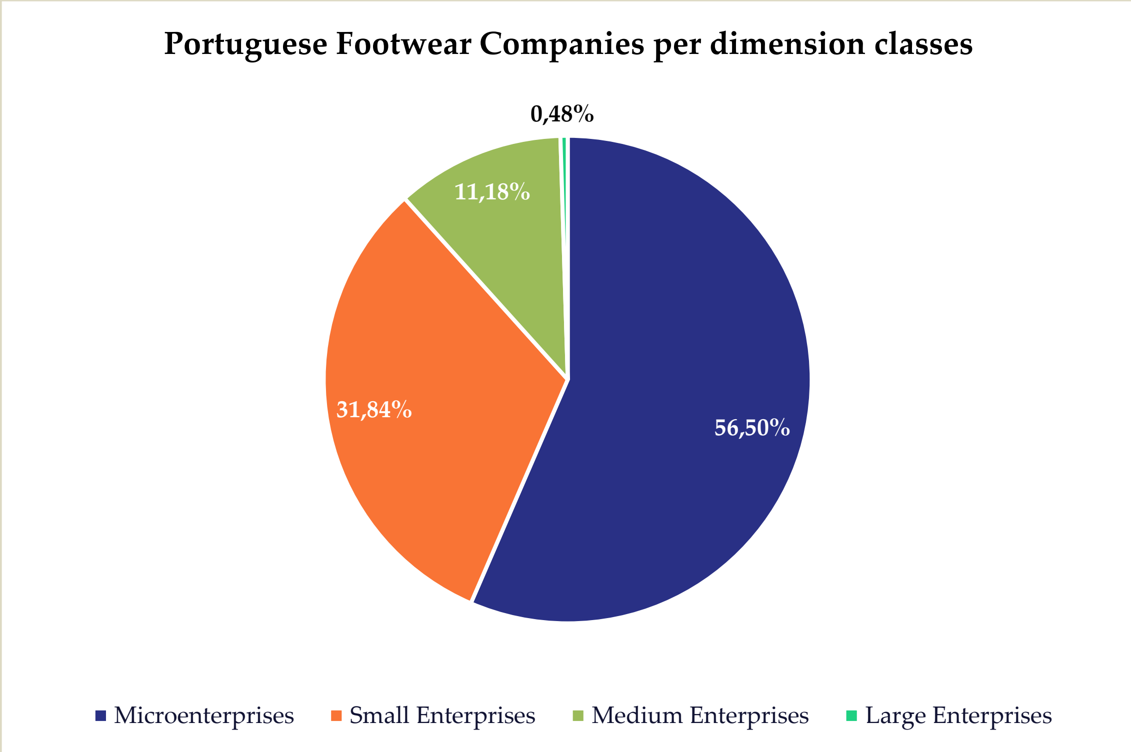


**Figure 6: Portuguese Footwear Companies per dimension classes**

**SOURCE:** Banco Portugal (2021)

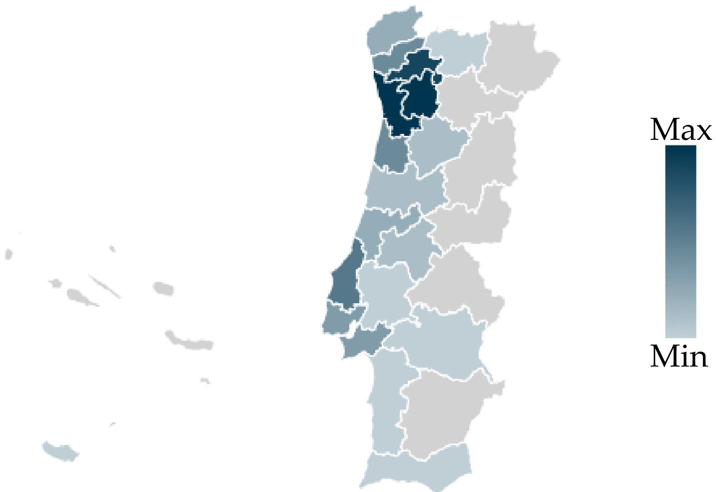


**Figure 7: Geographical distribution by location of headquarters (NUTS II)**

**SOURCE:** Banco Portugal (2021)

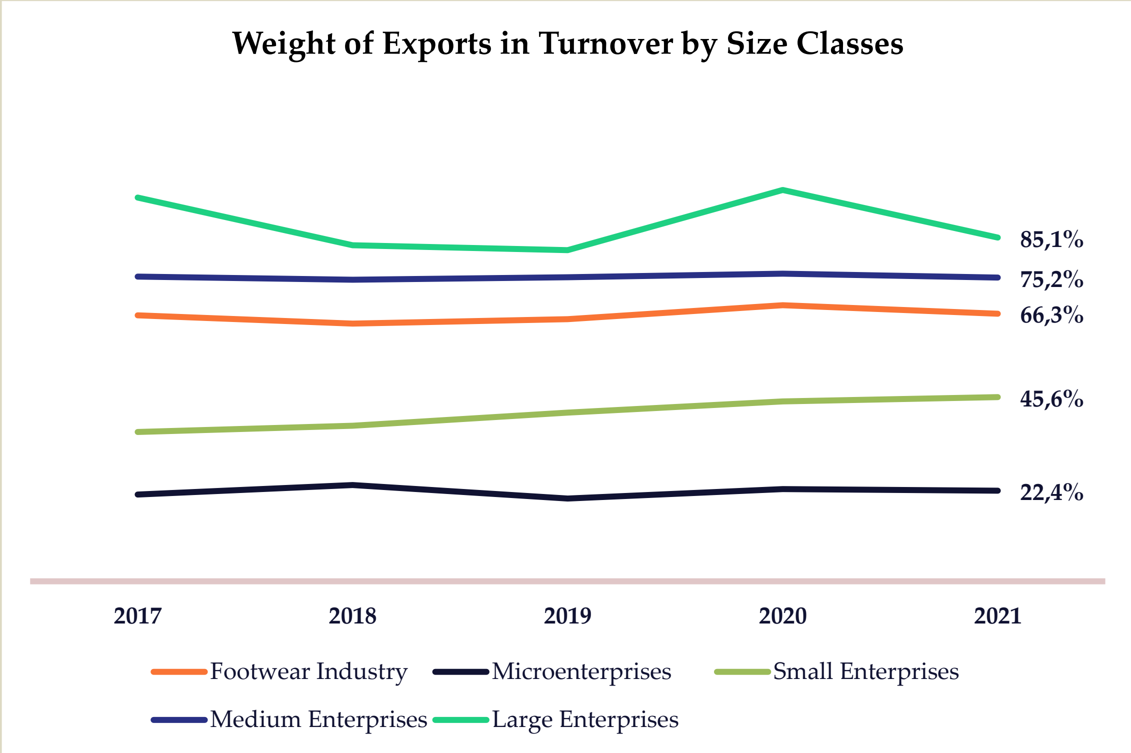


**Figure 8: Weight of Exports in Turnover by Size Classes**

**SOURCE:** Banco Portugal (2021)

| Export Markets | Millions EUR | Value Quota | Millions of Pairs | Quantity Quota |
|---|---|---|---|---|
| France | 333 | 21% | 11.4 | 19% |
| Germany | 317 | 20% | 12.5 | 20% |
| Netherlands | 220 | 14% | 7.6 | 12% |
| Spain | 126 | 8% | 9.3 | 15% |
| UK | 96 | 6% | 3.9 | 6% |

**Table 4: Main Trade Partners**

**SOURCE:** APICCAPS (2021)

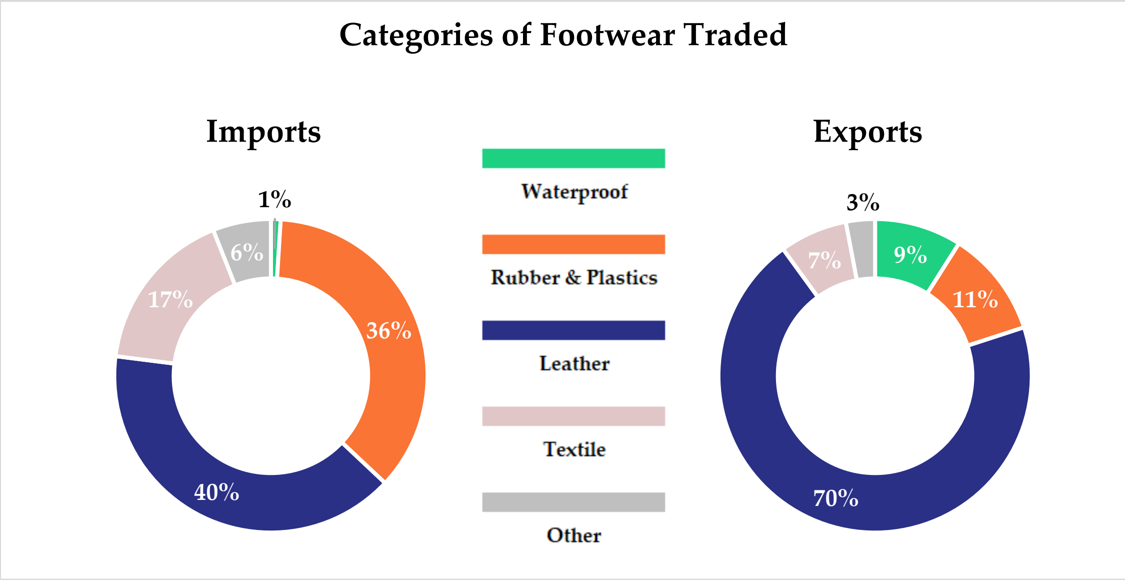


**Figure 9: Categories of Footwear Traded**

**SOURCE:** APICCAPS (2021)

# Appendix II – Main Differences between Quantitative and Qualitative Research

| | Quantitative research | Qualitative Research |
|---|---|---|
| **Assumptions** | • Positivism/post-positivism<br>• Social phenomena and events have an objective reality<br>• Variables can be identified and measured | • Constructivism/interpretivism<br>• Reality is socially constructive<br>• Variables are complex and intertwined |
| **Purpose** | • Generalizability<br>• Prediction<br>• Explanation | • Contextualization<br>• Interpretation<br>• Understanding |
| **Approach** | • Hypothesis testing<br>• Deductive, confirmatory, inferential — from theory to data<br>• Manipulation and control of variables<br>• Sample represents the whole population, so results can be generalized<br>• Data is numerical or transformed into numbers<br>• Counting/reductionist<br>• Statistical analysis | • Hypothesis generation<br>• Inductive and exploratory — from data to theory<br>• Emergence and portrayal of data<br>• The focus of interest is the sample (uniqueness)<br>• Data is words or language, with minimal use of numbers<br>• Probing/holistic<br>• Analysis draws out patterns and meaning |
| **Researcher Role** | • The researcher is objective and 'outside' the research | • The researcher is part of the process |

**Table 5: Main Differences between Quantitative and Qualitative Research**

**SOURCE:** (Cleland, 2015)

# Appendix III – Interview Script

**For APICCAPS and CTCP**

Let me begin by thanking you for agreeing to take part in this study. This study aims to understand the impact of I4.0 technologies on a number of Portuguese Footwear companies, assessing their degree of I4.0 maturity and digital transformation as well as the main benefits/challenges of this implementation and future trends, among other topics.

Industry 4.0 refers to the fourth industrial revolution, characterized by the integration of advanced technologies such Internet of Things (IoT) and robotics into manufacturing and other industrial processes. The aim of Industry 4.0 is to create highly automated and connected smart factories, resulting in greater efficiency, agility and customization (Rüßmann et al., 2015).

The interview will be recorded for transcription purposes, and the recording will be destroyed afterward.

**Part 1: Interviewee's General Description**

1. I will ask you to give a general description of your position in APICCAPS/CTCP.

  1.1 What is the position you hold in APICCAPS/CTCP?

  1.2 What are the main functions that this position entails?

**Part 2: Assessment of organizational dimensions**

Regarding the implementation of I4.0 practices and technologies, I propose that we address the impact on the industry as a whole:

1. How did it come about, and what motivated the footwear industry to adopt I4.0 practices and technologies?

2. Did APICCAPS/CTCP initiatives have an impact on the adoption of I4.0 measures by companies? If so, in what way?

3. What were the main changes made in operations/productive processes sponsored by I4.0 technologies?

4. Which I4.0 pillars, shown below, are most used by organizations in the production process? In what way?

1. Internet of Things
2. Big Data
3. Simulation
4. Augmented Reality
5. Cybersecurity
6. Cloud
7. Autonomous Robots
8. Additive Manufacturing
9. Horizontal and Vertical Integration

5. In your opinion, what are the main benefits of implementing I4.0 for the industry?

6. What are the main challenges/difficulties that arose in the adoption of I4.0 technologies and how can they be overcome?

7. What are the next goals, related to I4.0, for the companies and APICCAPS/CTCP?

8. What do you consider to be the status of Industry 4.0 implementation in the sector. Consider a scale of 1 to 5, where 1 indicates "not implemented at all" and 5 "fully implemented".

## For Portuguese footwear companies

Let me begin by thanking you for agreeing to take part in this study. This study aims to understand the impact of I4.0 technologies on a number of Portuguese Footwear companies, assessing their degree of I4.0 maturity and digital transformation as well as the main benefits/challenges of this implementation and future trends, among other topics.

Industry 4.0 refers to the fourth industrial revolution, characterized by the integration of advanced technologies such Internet of Things (IoT) and robotics into manufacturing and other industrial processes. The aim of Industry 4.0 is to create highly automated and connected smart factories, resulting in greater efficiency, agility and customization (Rüßmann et al., 2015).

The interview will be recorded for transcription purposes, and the recording will be destroyed afterward.

**Part 1: Interviewee's General Description**

1. I will ask you to give a general description of your position in the company.

   1.1 What is the position you hold in the company?

   1.2 What are the main functions that this position entails?

**Part 2: Evaluation of Organizational Dimensions**

Regarding the implementation of I4.0 practices and technologies, I propose that we address the impact caused in 5 business dimensions:

<u>1. Strategy</u>

   1.1 How did it come about, and what motivated the adoption of I4.0 practices and technologies? Are these practices integrated with the company's overall strategy?

   1.2 Did initiatives from APICCAPS, CTCP or other entities influence the adoption of I4.0 measures? If yes, in what way?

2. Operations

2.1 What main changes were made in operations/production processes sponsored by I4.0 technologies?

2.2 What is the level of digital transformation and automation of operations?

3. Technology

3.1 Which of these I4.0 technology pillars does the organization use in production? In what way?

1. Internet of Things
2. Big Data
3. Simulation
4. Augmented Reality
5. Cybersecurity
6. Cloud
7. Autonomous Robots
8. Additive Manufacturing
9. Horizontal and Vertical Integration

4. Products

4.1 How does the organization leverage I4.0 technology to improve existing products and/or innovate new products? In what ways is product development different?

4.2 How has I4.0 allowed the organization to differentiate itself from its competitors through its products? Has I4.0 enabled the company to enter and/or consolidate its market positioning?

5. Customers

5.1 How are customer usage inputs used for product/service innovation? What digital channels does the company use to keep in touch with customers?

5.2 How does I4.0 help the company to offer customized solutions according to customer requirements? Are customers satisfied with these technological advances reflected in the products?

**Part 3: General Assessment**

We now turn to an overview of the I4.0 implementation.

1. What are the main benefits of implementing I4.0?

2. What are the main challenges/difficulties faced in adopting I4.0 technologies, and how are they overcome?

3. What are the next goals related to I4.0?

4. What do you consider to be the state of implementation of Industry 4.0 in your company? Consider a scale of 1 to 5, where 1 indicates "not implemented at all" and 5 "fully implemented".