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Industry 4.0 in Portugal – the state of the art

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Abstract: The fourth industrial revolution aims to transform industrial units into more efficient and productive organisations, through the implementation of technologies based on digital and intelligent systems. This research assesses the level of implementation of the 'Industry 4.0' concept in Portugal, identifying its benefits and difficulties, and also seeking to identify the best tool to assess the level of I4.0. To this end, a qualitative approach was used, supported by 18 interviews with industrial managers. The research shows that there is no integrated view of the I4.0 concept, although the results demonstrate a concern of companies with the subject, with actions aiming to implement the concept in their organisations, where the main barriers are found at the level of investment needed and change management. As to the benefits, it is highlighted the increases in productivity and the reduction of errors in the process.

Keywords: Industry 4.0; innovation; industrial organisation; technological change; adaptation; technological impact.

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1 Introduction

The future in the industrial area is already a reality and is called Industry 4.0, being characterised by digital transformation and the introduction of cyber-physical systems. This fourth industrial revolution consists of the involvement of existing production methods with the latest developments in the area of information and communication technologies, following the digitalisation trend felt in all sectors of society (COTEC Portugal, 2017).

Through the integration of all players (people, machines, equipment, logistics systems and products) technologically supported by intelligent and connected cyber-physical systems, direct communication and cooperation with each other will be possible, with immediate impacts on the entire value chain, transforming the existing industrial paradigm of 'mass production' into 'mass customisation'.

Seen as an opportunity to increase global competitiveness in the industrial sector, this revolution allows for greater customisation of processes and adaptation of products to the particular needs and demands of each consumer. The three worlds that make up the industrial universe (the physical, digital and biological worlds) thus merge, supported by the growing use of the internet and increasing digital connectivity (Schwab, 2016).

The challenges arising from this revolution are obstacles to be considered by the sector, particularly in terms of implementation costs, organisational and procedural changes, human resources qualification and cybersecurity (Erol et al., 2016). However, benefits are also expected supported in the promotion of these technologies and consisting of an improvement in product quality, communications, time and costs savings, intensification of relationships between consumers and greater efficiency when developing customisable products (Oesterreich and Teuteberg, 2016).

The need to ensure a correct and successful implementation of the Industry 4.0 concept in Portuguese companies gives rise to the need, as a first step, to understand and clarify how Portuguese managers are preparing, in each of their organisations, the way for an effective adaptation of these organisations to this new paradigm, in order to then, and taking into account the final objectives, assess their level of digital maturity, thus allowing for the definition of the path to follow (strategy), using a generalist roadmap considering the identified stages.

Thus, the generic objective of this research is to understand the 'state of the art' of I4.0 in Portugal, characterising the Portuguese industry regarding the level of implementation of the 'Industry 4.0' concept, with other specific objectives consisting of:

1 understanding if the company's digitalisation strategy based on the Industry 4.0, is considered in the overall strategy of the organisation

2 identify the main barriers for a valid adoption of the intended technology

3 understand what impact can be expected by companies when implementing actions related to Industry 4.0

4 understand how Portuguese industrial companies can carry out a correct analysis of their 'state of the art'.

The structure of this article includes a literature review on the topic 'Industry 4.0', allowing a better understanding of the research, which addresses the historical evolution of the various Industrial Revolutions, the concept 'I4.0' itself, the tools to support the implementation, the expected impacts, and the forms of I4.0 assessment. Next, the methodology used in this work is explained, namely the qualitative approach based on a content analysis of 18 interviews. The next chapter is dedicated to the empirical study, where the results of the interviews with Portuguese industrial managers and directors are presented and discussed with reference authors. Finally, the conclusions of the study are presented, also referring to the research contributions, its limitations, and the suggestions for future work.

2 Literature review

2.1 The industrial revolutions

Throughout the history of humanity there have been significant moments that represent important stages in the development of society. Such was the case with the industrial sector, in which, from the 18th century to the present day, we can identify four major events that were named industrial revolutions, representing drastic and disruptive changes in the entire production process.

Originating in England at the end of the 18th century, the first industrial revolution resulted from the introduction of the steam engine in the production process (Jensen, 2005) and marked the transition from craft production methods to mechanised production processes. This innovation represented an increase in productivity levels and consequently an increase in the capital produced, transforming the UK into the world's first industrial power.

From the advent of electrification and the creation of assembly lines, the concept of mass production was born as the main characteristic of the second industrial revolution (1880–1950) that emerges as a development phase of the first revolution, where the optimisation of production times, the reduction of costs and the continuous increase of productivity rates are the engine of this change due to the adequacy of new methodologies based on recent technologies (Jensen, 2005).

The third industrial revolution represented the globalisation of industry worldwide (Stearns, 2018), being chronologically limited to the period between 1950 and 2000, and in which, new technological developments supported in electronics and automation enabled the use of robotic systems and the introduction of numerical and information systems, allowing for automated production.

From the introduction of cyber-physical systems originated in the fusion between the real world and the virtual world, the fourth industrial revolution is born, in which, people, products and equipment are connected through the internet, interacting with each other,

which allows these systems to analyse data, predict failures and their constant reconfiguration and adaptability according to customer needs (Huxtable and Shaefer, 2016).

2.2 Industry 4.0

Presented in 2011 at an event in Hannover and within the scope of a German government initiative, aiming at increasing the country's industrial competitiveness and based on an advanced technology strategy (Mosconi, 2015), the Industry 4.0 concept has spread to the rest of the world.

Regardless of the name used, the term 'Industry 4.0' embraces the latest technological advances, which lead to an organisational change supported by the automation and digitalisation of processes, as well as the development of new digital value chains (Oesterreich and Teuteberg, 2016) and the creation of their own ecosystems characterised by intelligent environments supported by communication between humans, equipment and products during the production process (Albers et al., 2016).

Having as main goals the increase of product quality, the reduction of delivery times, the development of innovative products and services and the modernisation of processes, thus making industry more efficient, Rüßmann et al. (2015) presented nine fundamental pillars for the support and proliferation of Industry 4.0:

1 Internet of Things (extension of network connectivity and computing power to objects, devices, sensors and other artifacts that are not normally considered computers, enhancing their self-management).

2 Big Data and data analysis (data and respective analysis that normally exceed the conventional capacity stipulated at the level of storage, processing and computing, transforming these same data into useful information – Najafabadi et al. (2015) and Oliveira (2019).

3 Autonomous robots (mechanisms capable of performing tasks with a high degree of autonomy, flexibility and cooperation).

4 Simulation (digital simulation of products and production processes).

5 Horizontal integration (collaboration between external partners, customers and suppliers) and vertical integration (transversal collaboration within the company, supported by intelligent production systems, with contact points between product development, production, logistics and commercial area).

6 *Cloud* services (data storage with accesses in external *cloud* services).

7 Cybersecurity (practice aimed at protecting all network-connected equipment – computers, servers, mobile devices, electronic systems, data, as well as the network itself - from malicious attacks, contemplating strategies such as: the use of a standard framework, the use of firewalls, blockchain and quantum cryptography (Schuh et al., 2017).

8 Additive manufacturing (also known as 3D Printing, is based on the construction of three-dimensional models through the successive overlapping of material.

9 Augmented reality (currently widely used in maintenance tasks, where through own equipment - usually, augmented reality glasses - operators receive work instructions according to the stipulated protocol).

Industry 4.0 is then characterised by the application of technology in all the integral elements of the processes, which leads to a more flexible and agile management with more efficient and differentiating control processes, compared to less technologically advanced management models.

However, the implementation and support of the concept and methodology of these systems involves much more than just the technological component, and the human component should also be considered (predisposition and adaptation to change by the company's human resources, appropriate training and management commitment), to which is added the organisational component (corporate culture understood and assumed by all stakeholders of the various processes and that considers the integration of innovative systems), thus leading to the creation of sustainable networks (Oks et al., 2018).

2.3 Expected impacts on i4.0 implementation

Kagermann et al. (2013) consider Industry 4.0 to have an extremely ambitious potential, promising greater operational efficiency, increased productivity, turnover growth, as well as improved competitiveness, also leading to the development of new business models, new services, and new products. According to Kagermann et al. (2013), the effective implementation of the concept and its technology involves the adoption of several types of integration: vertical integration – occurring internally and in the product design cycle, horizontal integration – related to the value chain, and finally digital integration – introduction of digital engineering mechanisms throughout the product life cycle and its value chain.

When embarking on a journey towards the adoption of Industry 4.0, organisations should start by analysing and assessing their capabilities, adapting strategies and seeking to implement them in the intended scenarios. In a study developed by the Centre for Strategy & Evaluation Services LLP (CSES) at the request of the European Parliament in 2016, the implementation of Industry 4.0 will only be successful if some key requirements are met: standardisation of ICT systems, their platforms and protocols; work organisation reflecting new business models; digital security and intellectual property protection; availability of skilled labour; innovation, development and investment; integration of SMEs and the existence of a common legal framework. From its correct implementation, productivity gains, increased revenue and greater industrial competitiveness can be expected.

To this end, the authors consider three dimensions of change: technological change, social change and change of business paradigm. In technological change, digitalisation presents itself with the greatest responsibility in driving changes throughout the value chain. The CSES lists several challenges in this area, highlighting cybersecurity issues related to the protection of intellectual property, data protection, and the structure and operation of information systems.

The need to equip employees with digital skills is one of the biggest concerns that social change brings. Given that, there is little awareness of the issue in the industry

(except for key stakeholders), the impact can be both positive and negative for human resources, depending on the response.

The change of business paradigm presents greater challenges for SMEs, since the risks, costs, little flexibility and reduced strategic capacity present themselves as barriers to the implementation of the Industry 4.0 concept.

Whereas there is general agreement among the academic community regarding the benefits of a proper I4.0 implementation, there is also a trend towards the same in terms of challenges or barriers.

De Carolis et al. (2017) present a list of obstacles to overcome when moving to Industry 4.0, where 11 barriers are identified and whose resolution is fundamental to ensure the success of the I4.0 transformation process: the uncertainty related to the size of the investment and its return, to which is added the lack of knowledge regarding the cost of implementation; the existing problematic in the communicational interconnection between the 'old' and the 'new' technology; the complexity vs. usability; the data issue (protection and privacy); interoperability and integration; structural difficulties in the transition to an industry based on cyber-physical systems; the immaturity of the systems used (no history of the operation); the protection and security of human resources; the transformation from previous technologies to recent technologies; the legal framework and regulations on work organisation; and finally the management of the complexity of the process.

According to the study conducted by Glass et al. (2018), where 253 German companies were surveyed regarding the difficulties experienced by them at the time of implementation, the following barriers to the process stand out: the poor external conditions (whether legal, structural,...); the lack of technological integration; the impossibility of standardisation; the lack of knowledge about the concept; the high investment risk; the difficulty in creating a strategy for Industry 4.0, also mentioned by Veile et al. (2020); the inherent risk of data loss and the possibility of malicious external intervention; the lack of a qualified workforce; inadequate customisation; the unwanted increase in flexibility on the part of the workforce; excessive complexity; the difficulty experienced in cooperation along the value chain; the low maturity of the technologies; the absence of a need to change the business model; and the lack of support from top management.

The referred impacts can then be globally categorised as human, technological or financial impacts (Santos et al., 2018).

2.4 Industry 4.0 in Portugal

In Portugal and similarly to the countries belonging to the European Union (EU), the implementation of Industry 4.0 is being boosted by the central government through programmes coordinated by the European Commission (EC) as part of the Industry Digitalisation Strategy launched in April 2016. Following this EC action, in January 2017, the Portuguese Government, through the Ministry of Economy, launched the 'Portugal i4.0' initiative, composed of 64 measures, whose mission is to accelerate the adoption of Industry 4.0 by the national business fabric, by promoting Portuguese technological suppliers as I4.0 experts, making Portugal an attractive hub for investment in Industry 4.0.

Nevertheless, Portugal has been placed on the sidelines of studies related to Industry 4.0, being that the first Portuguese participation in this scope was made in 2016 and by

the consulting firm PwC, and the results were presented in September of the same year in the report 'PwC Global Industry 4.0', from which the main conclusions, concerning the Portuguese case, are highlighted (Antunes et al., 2019): 34% of companies consider to be in an advanced level of digitalisation, aligned with the global results (33%); 86% of Portuguese industrial companies, aspire to achieve in the next 5 years high levels of digitalisation, revealing an expectation above the global result (72%); an average revenue increase up to 10% is expected by 57% of companies, a cost reduction above 10% in 55% of companies and an efficiency gain above 10% in about 70%; Big Data is used in 44% of Portuguese companies in improving their relationship with consumers; the lack of digital culture and training, is presented by 50% of the national business fabric observed as a barrier to digital operational development; 61% have concerns with cybersecurity, as well as the legal implications that a security failure may imply; data analysis is assumed as particularly relevant by 41% of respondents; 60% of companies expect a return on investment in 2 years; 7% consider to be in an advanced level of maturity, 59% in an intermediate state and 32% in a weak stage.

NovaSBE Center for Digital Business & Technology in partnership with EY, presented in October 2018 the "Digital Maturity Study of Portuguese companies", which sought to assess the levels of maturity and digital confidence of Portuguese companies, and from which some conclusions are drawn that highlight the Portuguese reality: there is a generalised optimism and confidence in digital transformation and the companies participating in the study believe that they are well positioned in their processes; digital transformation has already started, but it is still at an early stage and only a few companies believe that they are lagging behind their competitors; there seems to be evidence of ideas and leaders with the ability to think about digital transformation in their businesses and in their companies, but there is a significant *gap* between strategic formulation and its implementation; The investment and adoption of technology seems to follow first an imitation of other actors and only then the adaptation of technology to the context; the digital technologies most adopted by companies are Social Networks and Digital Marketing, Big Data and Analytics, Cloud Computing and IoT (Internet of Things), with sectoral differences in the level of implementation.

Already in 2019, a self-diagnostic tool – 'SHIFTo4.0' – was launched by the Institute of Welding and Quality (ISQ) with the support of IAPMEI, which aimed to assess the state of maturity of the Portuguese industrial organisations and, based on this survey, provide recommendations aimed at increasing the I4.0 level. With the participation of companies from various industrial sectors, they obtained an average score of 1.47, and the industries surveyed intend to reach an average maturity level of around 3.07 in five years. This survey, based on the IMPULS model, identifies the need to increase the number of awareness-raising actions on the subject, to reinforce training (both for top management and technical staff) and to increase the consultancy capacity to support companies in the process of implementing I4.0 technologies (Gouveia et al., 2019).

2.5 The assessment of Industry 4.0

The industrial paradigm shift does not occur instantaneously, and there is a consensus among the academic community that the adoption of new methodologies and innovative technologies, as well as the perception of their benefits by the stakeholders, is prolonged in the time horizon. This situation is related to the changes on the factory floor, with the

organisation, with the product/service and with the communication channels established among the *stakeholders* (Qin et al., 2016).

According to Oliveira and Kaminski (2012), it is important that in the selection process of tools and technologies for the development of a given productive process, models that evaluate the digital and technological maturity as well as the degree of innovation of an organisation for Industry 4.0 are used.

Models that assess the technological and innovation maturity of companies regarding Industry 4.0 have been adopted, seeking to support decision making when choosing the tools and technologies that best fit the interests of companies (Colli et al., 2018).

Table 1 Industry 4.0 maturity models

Model of maturity	*Stages of maturity*	*Dimensions*
I4.0MM Schumacher et al. (2016)	*Likert* Scale (1 to 5) (with '1' representing the lowest level of implementation and '5' the highest)	Nine dimensions, assessed at 65 points: 1 Strategy 2 Leadership 3 Products 4 Customers 5 Operations 6 Organisational culture 7 Human resources 8 Corporate governance 9 Technology
ACATECH Schuh et al. (2017)	Six stages: 1 Computerisation 2 Connectivity 3 Visibility 4 Transparency 5 Predictive capability 6 Adaptability	Four dimensions, subdivided into 27 capacities Industry 4.0: 1 Resources 2 Information systems 3 Organisational structure 4 Culture
IMPULS Lichtblau et al. (2015)	Six stages: 1 Outsider 2 Beginner 3 Intermediate 4 Experienced 5 Specialist 6 Top performer	Six dimensions developed in 18 fields: 1 Strategy and organisation 2 Smart factory 3 Smart operation 4 Smart product 5 *Data-driven* services 6 Staff

Source: Adapted by the author from Colli et al. (2018)

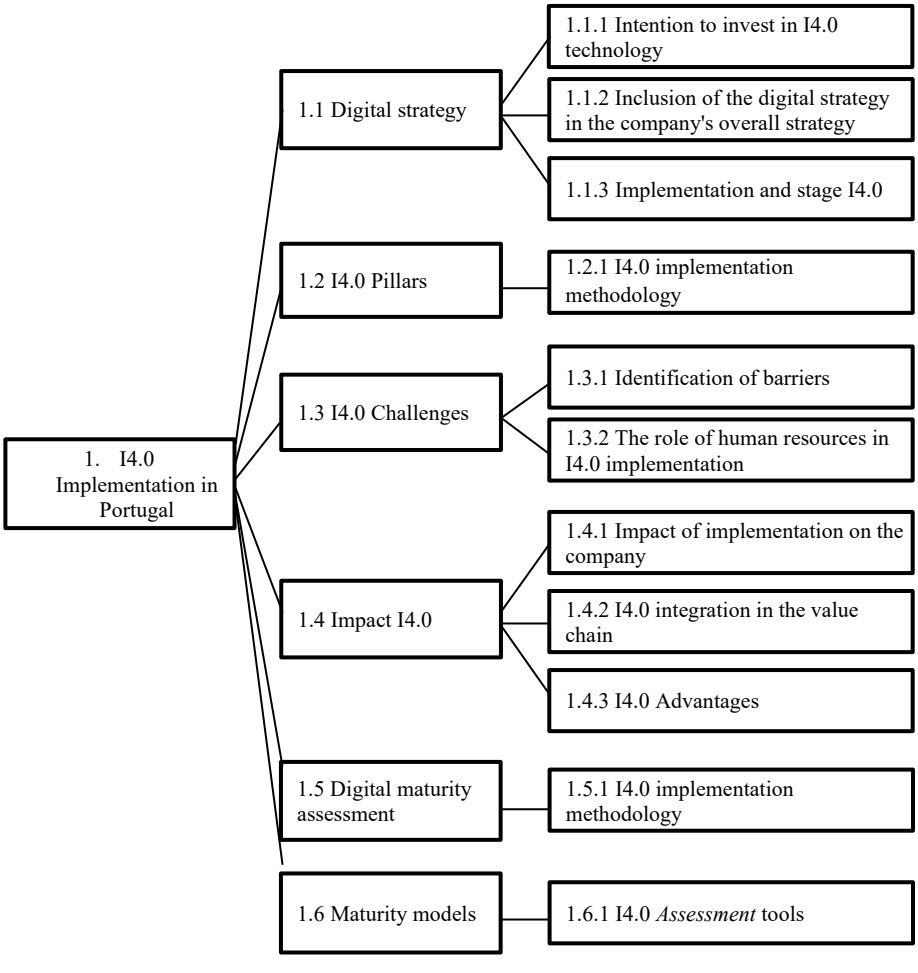
The countries considered at the forefront of the application of technological development have guided this maturity analysis through the application of three main models. Germany and Austria use the model proposed by Schumacher et al. (2016), composed of 9 dimensions and 62 maturity items; Sweden applies the IMPULS model by Lichtblau et al. (2015), where there are six dimensions detailed in 18 fields (Machado

et al., 2019); finally, Denmark presents the ACATECH model by Schuh et al. (2017), analysing 4 dimensions.

Digital transformation processes involve multidisciplinary activities, which require the existence of specialists in various areas, a scenario that does not occur in all companies (with particular focus on SMEs), a fact that highlights the importance of digital maturity assessment models.

The maturity models presented vary in 3 dimensions: number of digital stages/steps, number of dimensions that cover the various areas of the organisation and the implementation strategy, presenting, however, the same structure regarding the progression, development and concepts in each of the stages. With the data organised, the organisation can identify weaknesses and areas for improvement through pre-defined activities, according to the degree of digital maturity identified.

Figure 1 Categorisation and coding of the interview script



Source: Prepared by the author

3 Methodology

3.1 Research model

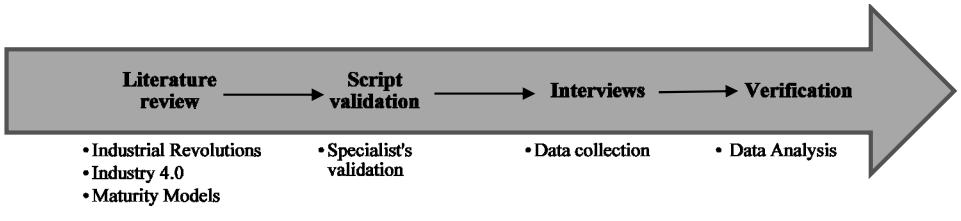
The research questions that support this article were answered by using a qualitative methodology, where a content analysis of 18 interviews that aimed to characterise the implementation of the concept 'Industry 4.0' in Portuguese industrial companies was carried out. Considering the research objectives, the interview was considered the most appropriate tool, despite the existence of a certain degree of subjectivity in the answers given, this fact being compensated with the possibility of additional inputs on the subject given by the interviewees (Carmo and Ferreira, 2008). The number of interviews conducted (18) ensures a good degree of confidence (Vilelas, 2009).

Since the qualitative analysis was based on the interview script, Figure 1 shows its categorisation and coding.

For content analysis, the program MAXQDA 2020 was used, which presents itself as specific software for qualitative analysis.

As for the sample, from the 18 interviewed companies, 10 (56%) are considered, regarding their size, as SME's and the remaining 8 (44%) as GE's. distributed by 12 different activity sectors (from which we highlight the metal-mechanic, furniture, energy and automobile industries). As for their location, 9 (50%) represent the centre of the country, 6 (33%) the south area, 2 (11%) the north region and 1 (6%) has its origin in one of the autonomous regions. 3 (17%) had been in business for less than 20 years and the remaining 15 (83%) had been in business for more than two decades. With regard to the positions held by the representatives of the organisations interviewed, 15 (83%) were Directors, 2 (11%) belonged to the administration and 1 (6%) is a coordinator.

Figure 2 Research model



Source: Prepared by the author

This research was developed in four stages. In the first stage, we worked on the literature review, where the industrial revolutions were presented in a more succinct and generalist way, and then developed more deeply the fourth industrial revolution with the description of its pillars and the expected impacts, addressing then the concept in a national perspective, sharing some studies on the digital 'state of the nation', ending this phase with *assessment* tools, namely with the description of 3 maturity models. The second stage consisted in transforming the basic theorisation of the dissertation to the field of observation, seeking to ensure results with the highest possible level of confidence, through the construction of an interview script that covered the research spectrum. The operationalisation of the script through the interviews corresponded to the third stage of this study, while the fourth stage consisted of the qualitative analysis of the data obtained in the interviews.

Table 2 allows for the analysis of the existing relationship between the research objectives and the research questions, as well as the connection with the literature review present in the initial chapters.

Table 2 Relationship between the objectives, the research questions and the literature review

Objectives	*Research questions*	*Review of literature*
OBJ1: To understand whether the company's digitalisation strategy, based on the pillars of Industry 4.0, is considered in the organisation's global strategy.	*QP1:* How is the I4.0 concept being internalised by the Portuguese Industry considering the existence of a clear and integrated strategy or, on the contrary, is the measures implemented loose and not very objective?	Correia et al. (2017), NovaSBE (2018), Glass et al. (2018), Gouveia et al. (2019), Veile et al. (2020)
	QP2: What are the most commonly used pillars for achieving this purpose and in what ways are they implemented by the units?	Rüßmann et al. (2015), Albers et al. (2016), Oks et al. (2018)
OBJ2: Identify the main barriers for a valid adoption of the intended technology.	*QP3:* What are the main challenges faced in implementing the I4.0 concept and are they human, technological or financial?	Santos et al. (2018), Glass et al. (2018), Machado et al. (2019), Veile et al. (2020)
OBJ3: Understand the impact expected by companies when implementing Industry 4.0-related actions.	*QP4:* On which aspects of the company will the effects of implementing I4.0 activities be felt and how will they be affected?	Correia et al. (2017), Oesterreich and Teuteberg (2016), Erol et al. (2016), Lucato et al. (2019)

Source: Prepared by the author

Table 2 Relationship between the objectives, the research questions and the literature review

Objectives	*Research questions*	*Review of literature*
OBJ4: Understand how Portuguese industrial companies can carry out a proper analysis of their 'state of the art'.	*QP5:* Are maturity models the right tools for a correct *assessment?*	Colli et al. (2018), Felch et al. (2019), Machado et al. (2019)
	QP6: Among the existing maturity models, which ones should organisations consider to carry out the purpose of measuring their digitalisation stage: will they use the approach suggested by the large consulting firms or should they follow a line supported by Academia?	Lichtblau et al. (2015), Schumacher et al. (2016), Schuh et al. (2017), Colli et al. (2018), Felch et al. (2019)

Source: Prepared by the author

4 Presentation and discussion of results

4.1 Digitalisation strategy in Portuguese companies

In order to answer the first two research questions and seeking to achieve the first objective of this research, which was, as previously explained, to understand whether the companies digitalisation strategy, supported by the I4.0 technology, was aligned with their overall strategy, the interviewees were presented with 4 questions aimed at

obtaining the framework, as shown in Table 3 that relates the objective with the research and interview questions.

Table 3 Relationship goal 1 – research questions – interview questions

Goal	***Research questions***	***Interview questions***
OBJ1: To understand whether the company's digitalisation strategy, based on the pillars of Industry 4.0, is considered in the organisation's global strategy.	*RQ1:* How is the I4.0 concept being internalised by the Portuguese industry, considering the existences of a clear and integrated strategy, or, on the contrary, are the measures implemented isolated and not very objective? *RQ2:* What are the most commonly used pillars for achieving this purpose and in what ways are they implemented by the units?	*IQ1:* Have investments already been made or is there the intention to invest in industry 4.0 technology? What percentage of the annual budget is dedicated to this purpose? *IQ2:* Is the digital strategy implemented in an integrated way with the company's overall strategy? How can vertical integration of the concept be ensured across the organisation? *IQ3:* How was the study for the implementation of an Industry 4.0 plan designed in your organisation? Did you use your own means or did you use external consultancy? *IQ10:* What do you consider to be the state of implementation of Industry 4.0 in your company, and what do you anticipate that same state to be in 3 years' time? Consider a scale of 1 to 5, where 1 indicates 'not at all implemented' and 5 'fully implemented'.

Source: Elaborated by the author

Figure 3 Intention to invest in I4.0 technology

Source: Prepared by the author

The first research question aims to understand how the implementation of the I4.0 concept is being developed within Portuguese organisations. Is it being assumed as a strategic commitment, or are the actions taking place only at an operational level?

The first step was to find out about the existence or intention of investments in this area, and then the integration of the digital strategy in the company's general strategy. From the answers obtained, we could see that today, the I4.0 concept is already effective in the Portuguese industry, with 72.22% of the company representatives attesting to investments actually made in this area, and this number rises to 88.89% in the intention to invest in the near future.

Regarding the alignment of the digital strategy with the general strategy and its integration throughout the company, the balance could not be better, with 50% of the interviewees responding that it was already a reality and the remaining 50% with answers to the contrary. With regard to how this integration is achieved, practically all respondents of the first group revealed a direct involvement of the company's management, together with the participation of all departments involved in the process, with the production, quality, maintenance and IT areas being mainly mentioned as those with the highest incidence in the conduction and implementation of I4.0 projects, factors that according to Glass et al. (2018) and Veile et al. (2020) are the most referred to in their study. Table 4 presents the generic answers and 2 examples of integration models.

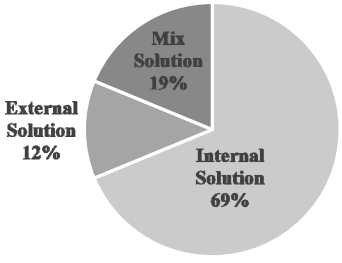
Table 4 Alignment of strategy and vertical integration models referred to

Text	*Generic category*	*Subcategory*	*No. times*	*Interviewee*
The digital strategy is not aligned with the company's overall strategy.	1.1	1.1.2	9	1, 2, 6, 9, 12, 13, 14, 16, 17
The digital strategy is aligned with the company's overall strategy.	1.1	1.1.2	9	3, 4, 5, 7, 8, 10, 11, 15, 18
Strategy with 3 major steps (connectivity, industrial engineering and maintenance).	1.1	1.1.2	1	5
4 phases:	1.1	1.1.2	1	3
1st Vision (what problems exist and can be solved through 4.0) – agility and efficiency)				
2nd Conceptualisation (find answers - several and measure them)				
3rd *MVP* (minimum value of the product)				
4th *Scale Up* (design and implementation on a large scale).				

Source: Prepared by the author

As for the second research question, it was intended to understand which I4.0 technologies are and how they are chosen for implementation and whether they would be the most suitable for the purpose proposed.

Figure 4 Distribution of resources for the I4.0 implementation



Source: Prepared by the author

In the present study, of the 16 companies that stated that they already have Industry 4.0 in the implementation process, 11 (68.75%) designed the implementation plan using internal means, 2 of them (12.50%) handed over the process to consulting partners and 3 organisations (18.75%) opted for a mixed solution, integrating internal means with other partners (suppliers and consulting companies).

It should be noted that as seen in the answers to the first question, the involvement of the human, technological and organisational component is fundamental to the successful implementation of the concept in companies, as suggested by Albers et al. (2016) and by Oks et al. (2018).

Regarding the tools that these means used in the design of the implementation, they can be observed in the following table.

Table 5 Tools used in the study to implement I4.0

Text	*Generic category*	*Subcategory*	*No. times*	*Interviewee*
Independent measures	1.1	1.1.3	7	1, 2, 4, 6, 9, 13, 14
Business cases	1.1	1.1.3	4	3, 5, 7, 17
Investment Plans	1.1	1.1.3	3	15, 16, 18
Business plans	1.1	1.1.3	3	10, 11, 12
Others (EAM)	1.1	1.1.3	1	8

Source: Prepared by the author

Table 6 I4.0 pillars mentioned

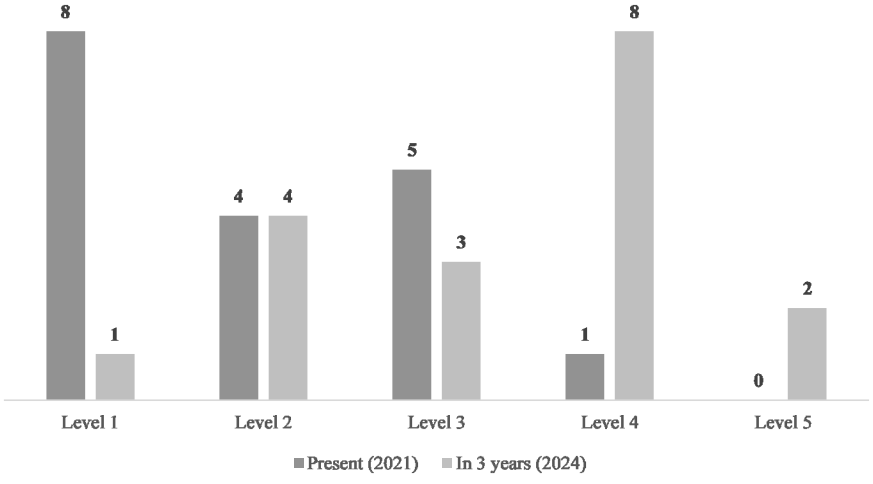
Text	*Generic category*	*Subcategory*	*No. times*	*Interviewee*
Internet of Things	1.1.	1.1.1.	16	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18
Big Data	1.1.	1.1.1.	14	2, 3, 4, 5, 7, 8, 10, 11, 12, 13, 14, 16, 17, 18
Cloud Computing	1.1.	1.1.1.	10	2, 3, 4, 5, 7, 8, 10, 13, 16, 17
Autonomous robots	1.1.	1.1.1.	7	3, 5, 10, 11, 12, 17, 18
Augmented Reality	1.1.	1.1.1.	4	3, 5, 8, 16
Simulation	1.1.	1.1.1.	3	3, 5, 10

Source: Prepared by the author

From the pillars presented by Rüßmann et al. (2015) and also within the scope of I4.0 technologies, corroborating the findings of the study of Correia et al. (2017) and NovaSBE (2018), the following pillars were identified as the most commonly used: Internet of Things, Big Data and Cloud Computing. There are also references to other pillars (autonomous robot*s*, augmented reality and simulation), as shown in Table 6.

In view of the above and comparing it with the study mentioned above, one can see an increase in the use of autonomous robots in the last three years, which raises questions related to the area of human resources, an issue which will be addressed in the following subchapter.

Figure 5 Expectation of evolution of the I4.0 implementation level at 3 years



Source: Prepared by the author

In the last question of the interview that supports this objective, managers were asked to quantify their current perception regarding the level of implementation of Industry 4.0 in their companies, and to do the same exercise in a time horizon of 3 years, using a scale from 1 to 5 (where 1 means 'not implemented at all' and 5 'fully implemented'). As can be seen in Figure 6.3 and Table 6.5, 66% of organisations consider that they are currently at levels 1 and 2, and in three years' time only 28% expect to remain at these levels.

Following on from the above, the positioning of the companies participating in the study regarding their level of implementation is presented below.

Table 7 Positioning regarding the level of implementation of the surveyed companies

	Level 1		***Level 2***		***Level 3***		***Level 4***		***Level 5***	
	Nº	*%*	*Nº*	*%*	*Nº*	*%*	*Nº*	*%*	*Nº*	*%*
Currently	8	44%	4	22%	5	28%	1	6%	0	0%
In 3 years	1	6%	4	22%	3	17%	8	44%	2	11%

Source: Prepared by the author

From this positioning, we obtain, through arithmetic mean calculation, an implementation level of 2.00, placing the Portuguese industry at the entrance of a new development level. Compared to the result obtained by Gouveia et al. (2019) of 1.44, we can, with the

necessary caveats, attest an increase in the implementation of I4.0 technology in Portuguese industrial companies.

4.2 Barriers in the implementation of the I4.0 concept

Considering the second research objective, which aimed to identify the barriers experienced by companies in the adoption of this technology, the interviewees were asked about the challenges experienced in the implementation phase, and more objectively, whether they considered that their organisations had the human competencies conducive to a proper development of the process.

Table 8 Relationship goal 2 – research questions – interview questions

Goal	***Research questions***	***Interview questions***
OBJ2: Identify the main barriers for a valid adoption of the intended technology.	*RQ3:* What are the main challenges faced in implementing the I4.0 concept and are they human, technological or financial?	*IQ4:* In your opinion and based on your experience, what are the main challenges/difficulties in adopting I4.0 technologies and how can they be overcome?
		IQ5: Do you consider that your company has the necessary human skills to meet the challenges of I4.0? Was it necessary to have a reskilling plan for the existing staff?

Source: Prepared by the author

In order to group the different answers to the interview questions, the typification of barriers suggested by Glass et al. (2018) was followed, structuring the results into 3 areas that include technological factors, financial factors and human or social factors. The technological factors (considered in subcategory 1.2.1.) include aspects related to the equipment, the possibility of integration in the I4.0 concept and the existing conditions for the suitability of the various I4.0 technologies (namely the internet of things, big data, cloud computing and cybersecurity). In subcategory 1.2.2, we have the financial factors that relate to issues associated with investments, forms of financing and other economic and financial concepts, as well as issues related to the legal framework. The human or social factors (subcategory 1.2.3.) include contents related to the work environment and the organisational structure, as well as aspects related to the requalification of employees and the need for greater labour flexibility.

Table 9 Technological factors

Text	*Generic category*	*Subcategory*	*No. times*	*Interviewee*
Obsolete industrial park	1.3	1.3.1	3	2, 4, 16
Vulnerability to cyber attacks	1.3	1.3.1	1	7
Network coverage	1.3	1.3.1	1	16

Source: Prepared by the author

Table 10 Financial factors

Text	*Generic category*	*Subcategory*	*No. times*	*Interviewee*
Volume of investment required	1.3	1.3.1	6	1, 2, 13, 14, 17, 18
Limited budget	1.3	1.3.1	1	4
Extended *ROI*	1.3	1.3.1	1	8

Source: Prepared by the author

Table 11 Human factors

Text	*Generic category*	*Subcategory*	*No. times*	*Interviewee*
Change management	1.3	1.3.1	6	3, 4, 10, 13, 15, 17
Top management involvement	1.3	1.3.1	3	1, 8, 12
Need for reskilling	1.3	1.3.1	2	7, 8
Lack of dedicated resources	1.3	1.3.1	1	5
Downsizing responsibility	1.3	1.3.1	1	8

Source: Prepared by the author

The tables show that the most mentioned barriers are those associated with the human and social aspects (mentioned 12 times), particularly the issue related to change management. On the other hand, the barrier related to the volume of investment, which receives the same mentions as the most mentioned human factor (6), is of no less importance.

In one of the interview questions, the respondents were asked whether they considered that the necessary human skills existed within their organisations to successfully carry out the challenges arising from the I4.0 implementation, and although about 56% of the respondents (10 companies) mentioned the absence of these resources and the consequent need for reskilling, only twice was this aspect mentioned as a barrier.

Analysing the answers of this study, we can state that the difficulties experienced by the Portuguese industry can, as listed by Santos et al. (2018), be categorised into 3 types: human, technological, and financial difficulties, being in line with the barriers perceived in other European countries, as evidenced by the results obtained by Machado et al. (2019) in Swedish companies, where human factors (organisational gap) and financial factors (investment capacity) were identified as the main causes of entropy in the process. Also in Germany, the conclusions of the studies of Glass et al. (2018) and Veile et al. (2020) reveal the investment risk and the issues related to the readjustment of functions as potential drivers of implementation failure.

4.3 Perceived impacts of implementing the I4.0 concept

Answering the fourth research question, in which it was gauged which areas of the companies would feel more the effects of the implementation of the I4.0 actions, thus achieving the objective number 3 of this study, 3 questions were asked concerning the theme.

Table 12 Relationship Goal 3 - Research Questions - Interview Questions

Goal	***Research Questions***	***Interview Questions***
OBJ3: Understand the impact expected by companies when implementing Industry 4.0-related actions.	*RQ4:* On which aspects of the company will the effects of implementing I4.0 activities be felt and how will they be affected?	*IQ6:* What methodology is used to calculate the impact of an I4.0 implementation? *IQ7:* In your value chain, are there units with I4.0 technology and how are they integrated in the process? *IQ8:* How has the implementation of I4.0 technology impacted the business, i.e. what are the main advantages you identify in Industry 4.0?

Source: Prepared by the author

Attesting to the purpose of greater operational effectiveness presented by Kagermann et al. (2013), the responses obtained in this research mostly direct the perceived impact of an I4.0 implementation to operational aspects, which corroborates the findings of Lucato et al. (2019).

To facilitate the reading of the data obtained, the answers were divided into 5 different areas: processes (where process control, resource optimisation and productivity increase are the most frequent responses); human resources (relating the impacts of providing new skills and also of reducing the number of employees); final product (the increase of the final quality of the product is one of the most addressed aspects); management (with decision support and cost reduction taking special emphasis); and finally, the equipment area (which includes aspects related to the improvement of maintenance indicators, such as availability and reliability).

Table 13 Impacts felt in the I4.0 implementation

Text	*Generic category*	*Subcategory*	*No. times*	*Interviewee*
Process	1.4	1.4.1	9	3, 5, 6, 7, 11, 13, 15, 16, 18
Human Resources	1.4	1.4.1	8	3, 5, 6, 7, 11, 15, 16, 18
Final product	1.4	1.4.1	3	2, 6, 17
Management	1.4	1.4.1	3	3, 5, 12
Equipment	1.4	1.4.1	2	8, 16

Source: Prepared by the author

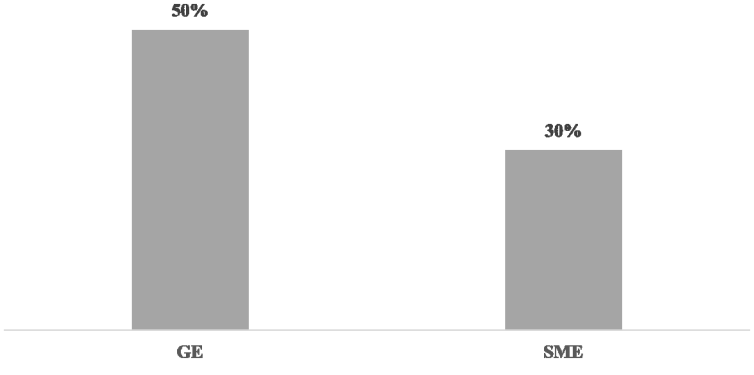
From the content analysis of Table 13, it can be concluded that the greatest impact is felt in the process and human resources areas, with the responses focusing on a greater transparency of the process – which allows real-time monitoring and consequent immediate corrective action with obvious gains in process control – and an increase in productivity leading to greater flexibility and agility of the employees, which is in line with what was presented by Erol et al. (2016), where these areas were presented as the most impacted during an implementation process. It should also be noted that, as Oesterreich et al. (2016) listed in their article, advantages were also perceived in terms of the final product, management and resources optimisation.

It should be noted that 4 organisations (22.22%) reported that there were no relevant impacts on the implementation process, as they considered that they were at an early stage of the process.

We also sought to understand if the impact of the implementation is subject to prior calculation and also if, along the value chain, the different units manage to achieve horizontal integration, resulting in greater process optimisation and overall gains.

From the obtained answers, it is possible to perceive a lack of associativism and partnership spirit with the organisations integrating the value chain, being the openness to the partners still felt with mistrust and fear, not denoting in this case, an improvement when compared to the same conclusion presented by Correia et al. (2017). In this section, it is important to consider the integration differences between SMEs and EGs, as SMEs show greater difficulty in integration (30%) compared to large companies that have an integration rate of 50%, as shown in Figure 6.

Figure 6 I4.0 technology integration level in the value chain



Source: Prepared by the author

Regarding the methodology used to calculate the impact of the I.40 implementation on the companies, the conclusions obtained refer to a not very optimistic scenario, in which more than 60% of the companies reveal not having prepared a plan that would allow them to establish a comparison metric between previous results and those arising from the new paradigm. In this aspect, the differences between the EGs and the SMEs are not so relevant when compared to the previous scope, presenting the lack of a plan in the EGs a total of 62.50%, while in the SMEs, the same phenomenon occurs in 60% of the companies. From the positive answers, it can be identified that the most common approach at SMEs is inserted within an investment project, and that at EGs the methodology followed is integrated in the *business cases*, which present several lines of resolution for the same problem.

4.4 The maturity model as an assessment tool

The last proposed objective aims to understand how the Portuguese Industry can assess its state of the art regarding its level of digitalisation. To this end, two other questions were asked to the companies participating in this study, as shown in Table 14.

Table 14 Relationship Goal 4 - Research Questions - Interview Questions

Goal	***Research questions***	***Interview questions***
OBJ4: Understand how Portuguese industrial companies can carry out a proper analysis of their 'state of the art'.	RQ5: Are maturity models the right tools for a correct assessment? RQ6: Among the existing maturity models, which ones should organisations consider to carry out the purpose of measuring their digitalisation stage: will they use the approach suggested by the large consulting firms or should they follow a line supported by Academia?	IQ3: How was the study for the implementation of an Industry 4.0 plan designed in your organisation? Did you use your own means or did you use external consultancy? IQ9: How did the company set out to find the right I4.0 tool(s) to achieve the intended results?

Source: Prepared by the author

During the interviews, it was detected that most organisations were unaware of the existence of tools that could assess their level of digital maturity, and more specifically, the use of maturity models as a starting point for a correct assessment of their technological positioning in the Industry 4.0 area (Machado et al., 2019) and subsequent construction of an implementation roadmap. After the explanation on how maturity models work, based on the analysis developed by Colli et al. (2018) and Felch et al. (2019), all interviewees considered them to be an asset to be taken into account, although they pointed out that, since it is a tool of strategic application, the decision to use it should be made by boards of directors (in the case of large companies) and general management (in SMEs).

Table 15 Description of methodologies for designing the I4.0 implementation

Text	*Interviewee*
The most critical points of the whole process and vulnerability in terms of human error (...) were identified, and investments were made in order to automate the stages of the process seeking to ensure reliability, systematisation, replicability (...) in order to ensure a product with quality and uniform over time without large oscillations between different orders of the same product by a customer.	2
4 phases: 1st Vision (what problems exist and can be solved through 4.0) - agility and efficiency) 2nd Conceptualisation (find answers - several and measure them) 3rd *MVP* (minimum value of the product) 4th *Scale Up* (design and implementation on a large scale).	3
Brainstorming and *business cases* (project by project) with 4 focus areas: machinery (MTBF and MTTR), people (access to knowledge and quality data), management (HR optimisation, temporary operations and training), logistics (autonomous vehicles).	5
Through the indication of priority equipments and susceptible to a faster productivity gain.	15
(...) the help of national suppliers who created a totally new process, adjusted to the need we had. All the follow-up was then done together with very positive results.	18

Source: Elaborated by the author

It can then be assumed that, as observed in subchapter 3.1 (Table 5), Portuguese industrial companies immediately develop actions of operational nature, not seeking first the identification of the dimensions that most need intervention, thus sustaining the I4.0 implementation. Table 15 presents some of the *feedback* provided by the interviewees regarding the approach that their organisations followed when designing the implementation, where it can be seen that the implementation design of I4.0 technologies does not follow any previously established protocol.

It was also observed that the use of consulting firms occurs mostly in large enterprises, even if they do it in a mixed context, that is, in a partnership perspective with the creation of teams composed by internal and external elements. As for SMEs, the use of consultancy firms is practically inexistent, and from the 8 small and medium enterprises with implementation process underway, only 1 (and in a mixed regime) admitted to use consultancy.

The partnership with academic institutions was mentioned by 14 organisations (77.78%), and all SMEs (10) expressed interest in participating in studies aimed at analysing their digital maturity. About cooperation between academia and large enterprises, it can be concluded that this is a fairly sustained reality, with only one organisation referring to this cooperation as occasional.

From this last observation, we can conclude that the model of academic origin proposed by Schumacher et al. (2016), is the most suitable for gauging the state of digital maturity of the Portuguese Industry, since it ensures a greater universality of use than the corporate models such as those originated in Lichtblau et al. (2015) and Schuh et al. (2017).

5 Conclusions

5.1 Final considerations

The fourth industrial revolution has created a new world, in which virtual and physical production systems cooperate with each other globally, bringing to companies an improvement in productivity, a gain in process efficiency and an increase in quality to the final product, making organisations more competitive, raising global income levels and representing an increase in people's quality of life (Schwab, 2016).

Thus and given the benefits mentioned above, this research had as main objective the presentation of the state of the nation, regarding the implementation of the concept Industry 4.0, listing the advantages identified during the process, presenting the barriers experienced and seeking to identify the best tool for measuring the I4.0 maturity level, quantifying the level of I4.0 implementation in Portugal. After an extensive literature review on the subject and following the content analysis of the 18 interviews conducted with representatives of Portuguese industrial companies, the purpose of this research is considered to have been achieved, through a set of conclusions that are presented below.

As can be seen from the interviews, Industry 4.0 is already a concept assimilated by Portuguese companies and its implementation is perceived by all as inevitable. This conclusion is proven by the fact that almost 90% (88.89%) of organisations already include initiatives in this area in their action plan.

Regarding the integration of the digital strategy in the company's overall strategy, it is clear that many companies focus on the technology itself, 'jumping' immediately to the

technical and operational aspects of the solution, disregarding the necessary research regarding the company's higher purpose, its objectives, the impact on competitive advantages and gains in the value chain, thus missing the integrated vision considered important for the success of the implementation. This conclusion is confirmed by the percentage of companies that state that the digital strategy is not included in their overall strategy (where 50% of the companies responded in this sense). The tools used in the implementation study also corroborate this idea, being the independent measures or the *business cases* those to which companies resorted the most.

Considering the pillars that support Industry 4.0, the most mentioned by respondents are in line with previous studies on the subject in Portugal, with technologies related to connectivity, data registration, organisation and storage standing out from other less used pillars. However, it should be noted that in comparison with past research, there are technologies that have seen an increase in use, namely: autonomous robots (in production lines and logistics processes), augmented reality (mostly in maintenance and training actions) and simulation (in the design of new production processes).

As in any new process or procedure, there are barriers that arise along the implementation path, and in the Portuguese case and during the introduction of the concept under study, human factors were observed in greater number, where resistance to change, the need for greater involvement by top management, the reference to the readjustment of functions and the acquisition of digital skills are the most frequently reported. The analysis of the interviews also reveals that the size of the initial investment required, as well as some difficulty in accessing finance and the uncertainty about the economic viability of this process are also barriers to the implementation of Industry 4.0. Other barriers were mentioned in the interviews, albeit separately, and of which the following stand out as being considered relevant: the lack of knowledge on the topic, the difficulty in associating between partners (whether suppliers, customers, universities or the government itself) and the absence of a strong business culture.

Kagermann et al. (2013) presented the improvement of operational indicators as one of the impacts arising from the adoption of the I4.0 technology. This was also observed in this study, as Portuguese companies felt the impact in terms of process control and increased productivity. The availability of information in a permanent and immediate way, which results in faster and more accurate decision making, as well as the optimisation of resources through the flexibility and agility of employees, reveals themselves as advantages to be considered. However, it is concluded that the impacts of the implementation are not immediately perceived by organisations, having been transmitted by 4 of the surveyed companies, an inability to enumerate these impacts, due to the embryonic phase in which the process is.

Regarding the last proposed objective, it can be concluded that the Portuguese industry (similarly to its European counterparts), does not start the process in the 'starting point', in which it should first make an analysis of its digital maturity level, in order to start from a more grounded basis, developing one or more action plans to solve the identified shortcomings and establish a solid implementation plan. On the contrary, it can be observed in the implementation process in Portugal, a concern to immediately solve situations that can be operationally improved, even if isolated and not considering the whole industrial environment. A note for the fact that all the surveyed companies expressed their willingness to participate in studies aimed at improving their digital skills and consequent increase in their digital maturity.

In conclusion, it is clear from this study that the Portuguese industry has a clear notion of the advantages arising from the introduction of I4.0 technology in their business models, perceiving benefits that include faster and more direct communication channels, increased agility in the production process, an increase in their competitive advantages over their competitors, business growth and increased business profitability, by reducing waste and costs. Barriers are also understood in an assertive way, and industrialists seek ways to minimise their impacts.

As the Industry in Portugal is positioned at an early stage of the implementation process, and as in any transformation process, it must, without further delay, analyse the starting point, decide the goal it sets itself and define the route adjusted to the achievement of that purpose, not forgetting that Industry 4.0 is based on the methodological and technological transformation of the processes.

5.2 Contribution to the implementation of the I4.0 concept

As the 'Industry 4.0' phenomenon is relatively recent, the topic is on the agenda of numerous organisations, governments and universities, all of which are willing to contribute to making this digital transformation an effective reality.

The study presented herein aims to contribute to the clarification of the implementation process of Industry 4.0 in Portugal, seeking to draw a faithful and realistic scenario of the panorama related to the fourth industrial revolution, insofar as issues related to the digital strategy followed by companies are presented, discussed and analysed, issues that consider the existing barriers at the time of implementation and the impacts arising therefrom, as well as points that help organisations to attest their level of digital maturity.

Therefore, considering the importance of the mentioned problematic and in order to assure the purpose of contribution that this research proposes, there are three aspects to take into account: firstly, to lead companies to reflect on the way they are conducting the implementation process of Industry 4.0, and what are the impacts (positive or not) that come from their decisions; next, to make known other implementation examples (national and/or international) that allow the demonstration of different solutions, benefiting the Portuguese industry in its role of *fast follower*, through the study of implementation experiences occurred in other countries with more advanced digital maturity stages; and finally, presenting and encouraging the use of implementation roadmaps that can be progressive or more direct, supported by the introduction and application of digital maturity models in organisations, identifying through this tool, the dimensions where a more pressing and incisive intervention is required.

5.3 Limitations of the research

Having used a qualitative approach, based on the content analysis of 18 interviews with middle and senior managers of Portuguese industry, it is important to mention that the conclusions reached in this study cannot be generalised or considered representative of the Portuguese's industry, due to the small sample size, and the fact that it reproduces observations concerning a specific experience (I4.0 implementation) in a particular country (Portugal).

Notwithstanding the above, it should be noted that this study corroborates the conclusions obtained in the existing literature on the topic.

5.4 Suggestions for future research

It would be interesting to use this research as a starting point for a deeper analysis of the implementation of the I4.0 concept in Portugal, in which, in a first stage, by increasing the sample size, the conclusions presented in this study would be confirmed, using the same qualitative approach.

Following this content analysis, and after the selection of a maturity model considered to be the most appropriate to the Portuguese reality, the digital maturity level of national industries would be characterised, following a quantitative methodology.

From the result of this suggestion for future research, it will then be possible to characterise Portuguese industry in more detail, establishing comparisons between the different regions, or characterising the various industrial sectors separately, as an example.

As a final suggestion, it is possible to build a roadmap for the implementation of the I4.0 strategy, based on the conclusions obtained in this research, typifying the Portuguese companies according to the suggested model, and proposing action plans targeted for each stage of development.

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