

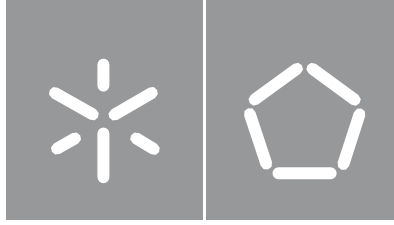


**From Concept to Application:
Implementation of a Capability
Roadmap towards Quality 4.0**

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From concept to application: Implementation of a Capability Roadmap towards Quality 4.0

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DO CONCEITO À APLICAÇÃO: IMPLEMENTAÇÃO DE UM *CAPABILITY ROADMAP* PARA A QUALIDADE 4.0

RESUMO

A ligação entre os domínios físicos e digitais surgiu com a Quarta Revolução Industrial, com o aumento da automação, da realidade aumentada e a integração de pessoas, máquinas e processos. Com o foco na Transformação Digital emerge também o conceito de Qualidade 4.0. A Qualidade 4.0 não substitui os métodos tradicionais, mas adapta-os para que o conceito de Qualidade inclua a nova tecnologia como forma de maximizar valor. A combinação das práticas de gestão da qualidade com as ferramentas tecnológicas pode tornar-se um fator crítico para o sucesso organizacional, permitindo às organizações tirar partido de dados em tempo real e análise de *Big Data*, implementar produtos e processos inovadores e identificar de forma eficiente como corresponder às necessidades e requisitos dos seus *stakeholders* e redefini-las. A gestão da qualidade também beneficia de processos de produção mais digitais e automatizados pois tornam a inspeção da qualidade mais fácil e mais fiável. Ao utilizar as novas tecnologias disponíveis torna-se possível antecipar e eliminar não-conformidades, e os trabalhadores ou até mesmo as próprias máquinas, poderão ter a capacidade de realizar quaisquer ações preventivas ou corretivas que possam ser necessárias.

Face a esta transição, o desenvolvimento e implementação de *capability roadmaps* tem gerado interesse. Ao providenciar uma avaliação da maturidade para a Qualidade 4.0, através da análise de cada dimensão ou campo estrutural do modelo em profundidade, estes modelos mostram às organizações qual o seu estado atual de preparação, permitindo-lhes também perceber o que lhes falta para atingirem o nível de maturidade que desejam. Como resultado, as organizações podem acabar por ter um *roadmap* personalizado para as ajudar a atingir os seus objetivos estratégicos. No entanto, como o desenvolvimento de *roadmaps* para a implementação da Qualidade 4.0 ainda é um esforço relativamente recente, faltam evidências empíricas consistentes e casos de estudo suficientes.

Este trabalho apresenta a implementação e validação empírica do modelo proposto por Dias (2021). Este modelo é constituído por 3 dimensões – “Value Chain and Operations”, “Strategy and Organization” e “People and Culture” – cada uma com 3 subdimensões. Os níveis estão divididos em níveis de preparação, de 1 a 3, e de maturidade, de 4 a 6, onde as metodologias e ferramentas tradicionais da qualidade são integradas com a utilização de tecnologia.

PALAVRAS-CHAVE: *Capability Roadmap*, Gestão da Qualidade, Qualidade 4.0, Maturidade

FROM CONCEPT TO APPLICATION: IMPLEMENTATION OF A CAPABILITY ROADMAP TOWARDS QUALITY 4.0

ABSTRACT

The connection between the digital and physical domains was brought to the forefront with the Fourth Industrial Revolution, with increased automation, augmentation, and the integration of people, devices, and processes. With the focus on the Digital Transformation, the concept of Quality 4.0 also emerges. While Quality 4.0 does not replace traditional quality methods, it adapts them so that the concept of quality embraces new technology to maximize value. The combination of quality management practices with technological tools can become a critical factor for organizational success, allowing organizations to take advantage of real-time data and Big Data analytics, implement innovative products and processes, and efficiently identify how to fulfil the needs and requirements of stakeholders and redefine them. Quality management also benefits from automated and digital production processes that make quality inspection easier and more reliable. By using new and emerging technologies it becomes possible to anticipate and eliminate non-conformances, and the workers, or even the machines themselves, could have the capacity to perform any corrective or preventive measures that may be needed.

In the face of this transition, the development and implementation of capability roadmaps have gained interest. By providing an assessment of maturity for Quality 4.0, models show organizations their current state of readiness for the digital transition allowing them to see what they lack to meet the desired level of maturity through an analysis of each dimension or structural field of the model in depth. As a result, organizations can end up with a customized roadmap to help them achieve their strategic goals. However, since the development of Quality 4.0 implementation roadmaps is still a relatively recent effort, it lacks validation through sufficient case studies and consistent empirical evidence. This work presents the efforts to implement and empirically validate the model proposed by Dias (2021). This capability roadmap looks at 3 dimensions – “value chain and operations”, “strategy and organization” and “people and culture” – each with 3 sub-dimensions. The capability levels are divided into readiness, for levels 1 to 3, and maturity, for levels 4 to 6, where traditional quality tools and approaches are integrated with the use of technology.

KEYWORDS: Capability Roadmap, Quality 4.0, Quality management, Maturity,

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LIST OF ABBREVIATIONS

AI Artificial Intelligence

AQMS Autonomous Quality Management System

AR Augmented Reality

CI Continuous Improvement

CPS Cyber-Physical Systems

DT Digital Twin

EQMS Enterprise Quality Management System

ERP Enterprise Resource Planning

I4.0 Industry 4.0

ICT Information and Communication Technology

IT Information Technologies

IOT Internet of Things

KPIs Key Performance Indicators

ML Machine Learning

OEE Overall Equipment Efficiency

PPM Parts per Million

Q4.0 Quality 4.0

QMS Quality Management System

UPS Uninterruptible Power Supply

VM Virtual Machine

VR Virtual Reality

1 | INTRODUCTION

Quality 4.0 can be considered as an approach that prioritizes quality and performance goals, focusing on how individuals, systems and emerging technologies interact to improve connectedness, intelligence, and automation (Radziwill, 2018). Q4.0 can also be defined as a product's adaptative capacity to meet the needs of customers, at any stage of its life cycle, while also considering the interests of other stakeholders (Salimova et al., 2020) or seen as a new method where digital tools are used to drive improvements across the value chain (Sony et al., 2020). Q4.0 is a large-scale transformation with implications on culture, leadership, collaboration, and compliance where new-era technologies are used as catalysts of people, products and processes efficiency, performance, and innovation. To achieve a successful transition to Q4.0, organizations must understand the concept and its importance in a clear and structured way (Dias et al., 2022).

The combination of quality management practices with technological tools can become a critical factor for organizational success, allowing organizations to take advantage of real-time data and Big Data analytics, implement innovative products and processes successfully by incorporating emerging technologies and materials and, efficiently identify how to fulfil the needs and requirements of stakeholders and redefine them as needed (Carvalho et al., 2021).

Quality management also benefits from automated and digital production processes that make quality inspection easier and more reliable, allowing the shift from control by sampling to total control. Furthermore, by using new and emerging technologies it becomes possible to anticipate and eliminate non-conformances and the workers, or even the machines themselves, could have the capacity to perform any corrective or preventive measures that may be needed (Dias, 2021).

However, Q4.0 is still a relatively new concept, still lacking an agreed-upon definition, sufficient case studies or even a framework to guide organizations that wish to make the transition.

Maturity models are often used as an evaluative and comparative tool, designed to assess the maturity – or competency, capability – of an organization in a selected domain based on a set of criteria. They can serve as the basis for improvement and to derive an informed approach to increase the capability of a specific area within an organization (de Bruin et al., 2005). In addition, these models can also provide a roadmap and detailed guidelines to assist organizations, with increased relevance to management practices (Santos & Martinho, 2020). Since these models help define the capabilities that should be developed to meet future needs and how those capabilities should be developed, capability

roadmaps are more often being used with technology roadmaps, or even substituting them, in a market environment where organizations need to be more flexible and adaptable to fast changes and disruptions (Dias, 2021). These kinds of models can also allow organizations to assess antecedents and precedents in the digital transformation phase thus contributing to organizational transformation and enabling the decisions of when and how to intervene and how can the success of the implementation of the selected domain be measured (Hizam-Hanafiah et al., 2020).

Most published models are oriented towards I4.0 maturity or readiness assessment and review, with few models focusing primarily on Q4.0 assessment, however, some principles and fundamentals of these models can be adapted to Q4.0 maturity assessment methodology (Nenadál et al., 2022). By providing an assessment of maturity for I4.0 or Q4.0, models show organizations their current state of readiness for the digital transition allowing them to see what they lack to meet the desired level of readiness or maturity through an analysis of each dimension or structural field of the model in depth. As a result, organizations can end up with a customized roadmap to help them achieve their strategic goals (Dias, 2021).

Furthermore, most published models include a technology dimension, either specifically or extended through other dimensions like operations or product lifecycle. Dimensions related to people and organizational management also appear often, as well as ones related to organizational culture and strategy. Customer focus and leadership-related dimensions also seem to have gained importance in the most recent models (Dias, 2021; Hizam-Hanafiah et al., 2020). However, these models differ in terms of content, quantity, definition and in the methods of assessing maturity (e.g., Dias, 2021; Hizam-Hanafiah et al., 2020; Lichtblau et al., 2015; Nenadál et al., 2022; Santos & Martinho, 2020).

The capability roadmap that is intended to be implemented and tested was developed by Dias (2021) and is constituted of 3 dimensions – “value chain and operations”, “strategy and organization” and “people and culture” – each with 3 sub-dimensions – “customers”, “products and services”, “processes”, “strategy”, “integration”, “innovation and improvement”, “role transition”, “organizational culture” and “leadership”. The capability levels are divided into readiness, for levels 1 to 3, and maturity, for levels 4 to 6, where traditional quality tools and approaches are integrated with the use of technology. These levels were designed to provide Quality 4.0 a sense of progression with the order of levels intended to be followed to get a sense of what is missing. This model guides the users from their initial interaction with Q4.0 through the development of company-specific fields of action utilizing state-of-the-art

technologies. By being aimed at organizations already embedded in a culture of quality, the model makes it easier to understand its importance and applicability (Dias, 2021).

2 | METHODOLOGY

The purpose of this study is to apply and the capability roadmap towards Quality 4.0 developed by Dias (2021) and assisted by these results, develop some strategic guidelines for the implementation of Quality 4.0 projects in three different organizations. Considering the research questions, a research protocol was created (Figure 1).

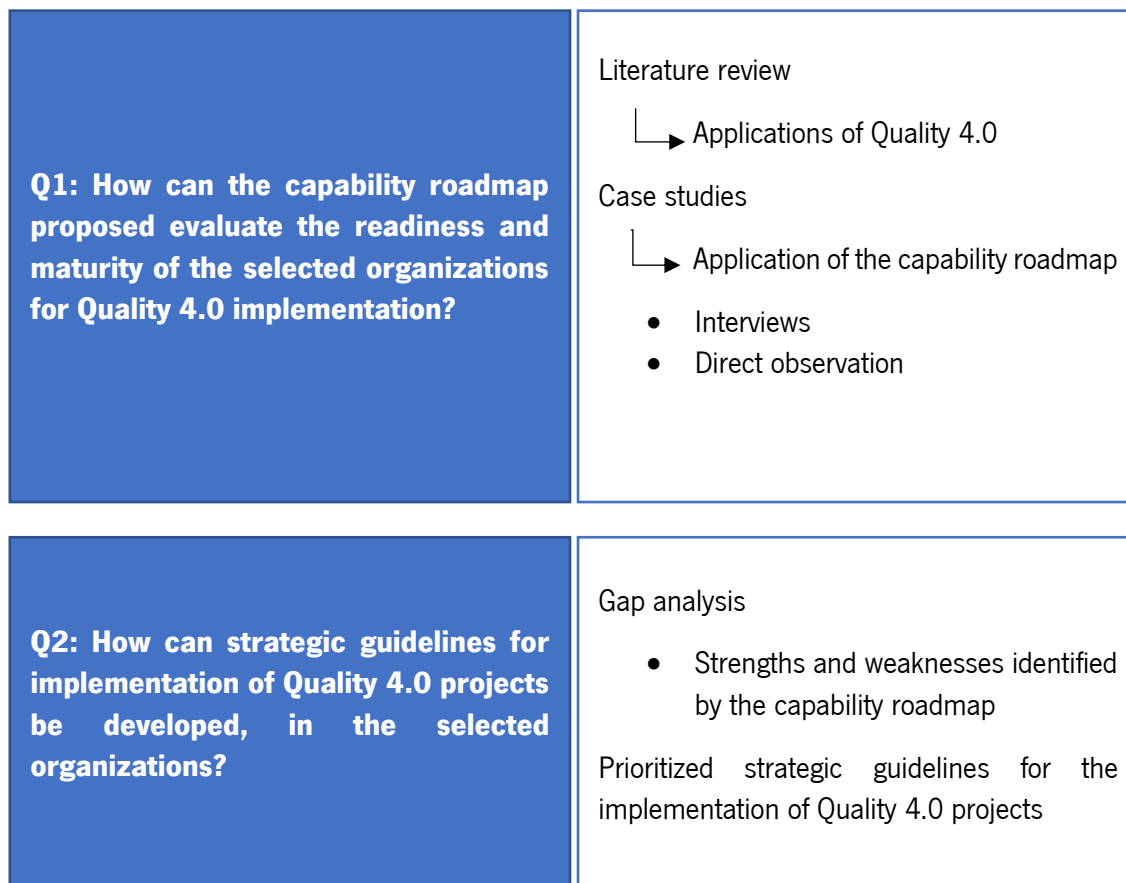


Figure 1 | Schematic of the adopted research protocol.

2.1 | ORGANIZATION SELECTION

For testing the capability roadmap and developing the strategic guidelines for the implementation of Quality 4.0 projects, a case study approach was selected since it is suitable not only for answering how and why questions but also for theory development, testing and refinement (Voss et al., 2002). The organizations BDO Portugal, Becri and SNA Europe were selected by intentional sampling, each representing a different business model – two for product manufacturing and another for services. Only three organizations were chosen due to constraints of time and access and to allow each case to be analysed more in-depth.

BDO is one of the five biggest global networks of auditing and consulting services, working in 164 countries through more than 111000 professionals distributed over more than 1800 offices worldwide. In Portugal, BDO has seven offices and more than 300 professionals and 18 partners. BDO Portugal offers auditing and consulting services, with the office located in Braga, which constitutes our case study, focusing mainly on financial and IT advisory services, including business analytics.

Becri was founded in 1983 and currently, the Becri Group has 10 units, encompassing several commercial identities, spread across Portugal with close to 800 employees, being a textile company focussed on international markets. Becri, specifically, is the central company of the group and offers services focused on the textile cutting process and sample manufacturing.

SNA Europe, with its 170 years of history, is part of the larger industrial group Snap-on, present in 130 countries and counting with 128000 employees. SNA Europe is constituted by 10 production facilities, 2 distribution centres and 30 sales units, employing more than 2000 people. Its main activity is the manufacture of tools like wrenches, cutting tools and others, having invented the adjustable wrench in 1892. The case study was applied to the branch SNA Europe Vila do Conde, which is mainly a production facility that does not deal with sales to the final customer.

Confidentiality and anonymity were maintained by adapting the data collection protocol to not include any confidential information, with a signed informative leaflet being delivered to all participating organizations, and authorization from the participants was obtained to proceed with the data collection whereas one participant in each organization signed a collaboration agreement (Appendix I). There were no major confidentiality concerns with the information collected during the whole process and so, the information presented here has not been censored or doctored besides the elimination of personal information of the people participating.

2.2 | DATA COLLECTION

2.2.1 | LITERATURE REVIEW

For a better understanding of the subject of Quality 4.0, a review of recent and available articles was conducted. This review was based, mainly on the literature review by Dias et al. (2022) and supplemented with a search in the Scopus database where articles, conference proceedings, books and reports were considered for review, but limited to those published after 2019. The main focus was on documents related to the practical application of Quality 4.0 tools and techniques, with documents pertaining mainly to the definition of Quality 4.0 being excluded. This literature review consisted of three

basic steps: screening, analysis, and writing. In the first step, the output from the Scopus database consisted of 131 documents, whose titles, keywords, and abstracts were screened to determine relevance for our literature review. The first screening resulted in 78 documents that were then analysed in full. The final selection consisted of 51 documents, obtained both by the database search and by analysing the references of selected papers. This search allowed a deeper understanding of how Quality 4.0 can be applied to the organizations selected for this study and what benefits and challenges they might face.

2.2.2 | INTERVIEWS

The main source of data was semi-structured interviews, while having a set of questions prepared and reviewed, follow-up questions can come up organically during the interview both for clarification and to cover possible gaps in the data needed. At least two people, within the selected organizations who had the necessary knowledge and experience to answer the questions, were the main participants in the interviews, with the option of being accompanied by a coworker who had more specialized knowledge and could share specific inputs. The interviews were conducted in the organizations' facilities, having a duration of approximately 30 to 150 minutes. The questions were asked in Portuguese since that was the native language of all the participants and to ensure that there was no misinterpretation of information or miscommunication due to the language barrier. All the interviews were recorded and then transcribed word for word in the following days.

2.2.3 | DIRECT OBSERVATION

In order to adhere to the underlying principle of triangulation, and in an effort to increase the validity and reliability of the data collected, the interviews will be backed up by direct observation of processes and/or technologies chosen by the organizations to share. During this observation process, we verified if the statements of the interview were translated into the organizations' reality and took written notes of new information.

2.3 | DATA ANALYSIS

2.3.1 | ANALYSING THE INTERVIEW TRANSCRIPTS AND OBSERVATION NOTES

The interview transcripts were analysed according to the methodology described in Sheppard (2020), with a deductive coding approach since we had a specific set of interest categories from the beginning. Since the main purpose of the interviews and observation was to support the application of the Capability Roadmap towards Q4.0 (Dias, 2021) the categories created reflected a combination of its

dimensions and levels. Finally, a data table was created reflecting the model that allowed us to sort through affirmations/sentences from the transcript of the interviews and place them in the corresponding category.

2.3.2 | APPLICATION OF THE CAPABILITY ROADMAP

Following the information collected from the interviews and direct observation, a score from 1 to 6 is attributed to each dimension of the capability roadmap, with the first three levels representing the organization's readiness and the last three representing its maturity towards Quality 4.0. The attribution of a level in each dimension was supported with specific affirmations of the interview transcripts that showed the necessary conditions were applicable in the organization. Since the model has a strong emphasis on progression, the next level was only attributed once all the conditions of each dimension were present.

2.3.3 | STRATEGIC GUIDELINES DEVELOPMENT

The strategic guidelines for the implementation of Q4.0 projects were developed based on a gap analysis, considering the results obtained by the application of the Capability Roadmap. Taking into account the levels of readiness or maturity achieved by each organization where the roadmap was tested, we evaluated the current state, the strengths – where the scores were higher – and weaknesses – where the scores were lower – of each organization. A priority list of strategic guidelines was then created based on those strengths and weaknesses, aiming to help the participating organizations increase their scores and achieve the readiness or maturity level they desire.

3 | LITERATURE REVIEW

Traditional quality methods and tools need to be improved so the connection between quality excellence and new-era technologies can be made, new business approaches are necessary to deal with new economic, human, and technological aspects, so reshaping risk and overall business management is essential.

Industry 4.0 (I4.0), based on connected and intelligent ecosystems at both intra and inter-organizational levels, was proposed as a large-scale industrial revolution that blurred the boundaries between physical and digital systems. The term digital transformation was proposed to refer to the use of disruptive and digital technology to alter the entire value chain, business model, management, and organizational methods to meet the organization's strategic objectives, build capabilities and enhance its agility (Cots, 2018; Herceg et al., 2020).

A core concept of I4.0 is the smart factory consisting of a highly digitalized, connected, autonomous, intelligent, and dynamic environment where machinery and equipment are data-driven, incorporate smart technology, and thus are able to improve processes through automation and self-optimization, converging information technologies with operational ones (Pollak et al., 2020).

The connectivity and communication between people, machines, and objects, allows for customer-specific production, creating a dynamic distribution of value chain activities and achieving higher efficiency and productivity levels at a lower cost (Armani et al., 2021; Sanchez et al., 2020; Xu et al., 2018). I4.0 systems can self-plan and self-adapt, which increases operational efficiency, providing greater flexibility and adaptability, allowing the fulfilment of customer's requirements along with the development of new business models, products, and services (Pollak et al., 2020; Salkin et al., 2018).

Industry 4.0 brought forth the production of increasingly sophisticated and complex products which, in turn, required more complex quality control and assurance systems, including more sophisticated and accurate measurement and correction tools (Sader et al., 2022). To make the connection between quality excellence and new-era technologies, the traditional quality tools and methods need to be improved and adapted and to achieve a successful transition to Q4.0 organizations must understand the concept and its importance (Dias, 2021).

3.1 | QUALITY 4.0

Quality 4.0 (Q4.0) combines the use of traditional quality methods with digital tools to accomplish quality objectives and pursue performance excellence. According to Radziwill (2020), Q4.0 can be

considered an approach that prioritizes quality and performance goals, focusing on how individuals, systems, and emerging technologies interact to improve connectedness, intelligence, and automation. Salimova et al. (2020) define Q4.0 as a product's adaptative capacity to meet the needs of customers, at any stage of its life cycle, while also considering the interests of other stakeholders along the value chain. Sony et al. (2020) add that Q4.0 can be seen as a new method for digital tools to drive improvements across the value chain. Q4.0 is a large-scale transformation with implications on culture, leadership, collaboration, and compliance (Jacob, 2017) where new-era technologies are used as catalysts of people, products, and processes efficiency, performance, and innovation (Radziwill, 2018). Antony et al. (2022) define Quality 4.0 as "the use of advanced technologies – such as Internet of things (IOT), Cyber-physical Systems (CPS), and cloud computing – to design, operate, and maintain adaptive, predictive, self-corrective, automated quality systems along with improved human interaction through quality planning, assurance, control, and improvement to achieve new optimums in performance and operational excellence", while Dias et al. (2022) see Quality 4.0 as the "delivery of superior quality, using modern technology to augment the capabilities of both people and quality tools and methods".

Since Quality 4.0 is still a relatively new concept there is not a single universal agreed-upon definition, but all the proposed definitions seem to refer to the synergy between people and emerging technology – with a focus on its predictive and auto-corrective capacities - to achieve quality and performance goals and pursue organizational excellence. Some authors also highlight similarities between Q4.0 and Lean Six Sigma, including the fact that both bring breakdown improvement in performance but require investment, management commitment, training, system integration, need for project management and culture change while also being oriented towards data and analytics (Yadav et al., 2021).

Q4.0 will shift focus from the operationally oriented task of creating and executing a quality strategy to holistically applying quality as a strategy across the entire organization (Antony & Sony, 2023), not by replacing the traditional quality methods, but by adapting them so that the concept of quality embraces the new technology and its users and processes to maximize value (Armani et al., 2020). We can go further and say that the basic premise remains the same – how can organizations meet the needs of their customers and surpass their expectations (Antony, Sony, et al., 2022). The combination of quality management practices with technological tools can become a critical factor for organizational success, allowing organizations to take advantage of real-time data and Big Data analytics, implement innovative products and processes successfully by incorporating emerging technologies and materials and,

efficiently identify how to fulfil the needs and requirements of stakeholders and redefine them as needed (Carvalho et al., 2021), while, due to the resulting products' and services' adaptive capacity, ensuring superior quality and performance and, consequently, increasing customer satisfaction and stakeholder interest along the value network (Dias et al., 2022; Salimova et al., 2020).

Antony, McDermott, Sony, et al. (2022) surveyed a global panel of quality management, and operational excellence professionals from leading companies deploying Q4.0 on their views of Q4.0 and their organizations' transition. Based on respondents' definitions and inputs Q4.0 was defined as “the systematic integration of I4.0 technologies with existing quality tools and methods using a meaningful framework and also incorporating human factors, to achieve superior quality performance and higher levels of operational excellence”. To achieve a successful transition, organizations must acquire some essential technical and soft skills – like data science, analytics, teamwork, communication, decision-making, problem-solving and enhanced management skills – potentially by investing in the reskilling and upskilling of their employees (Antony, McDermott, Sony, et al., 2022), since shortages of digital skills and challenges with technology and data are significant barriers to Q4.0 implementation (Santos et al., 2021; Sony et al., 2021). It's important for an organization to determine their readiness state for Q4.0 implementation and their ability to take effective advantage of I4.0 technologies is an essential factor (Antony, McDermott, Sony, et al., 2022). There are 8 factors described as critical for the effective implementation of Q4.0 (Antony, Sony, et al., 2022):

1. The organization's capacity to handle Big Data
2. Their improvement of prescriptive analysis
3. The effective vertical, horizontal, and end-to-end integration of Q4.0
4. How the organization uses Q4.0 for strategic advantage
5. Leadership
6. Training
7. Organizational culture
8. Top management support

Quality is much more than technology; it is characterized by the synergies established between humans and technology in a goal-oriented manner to meet the quality strategy and objectives of the organization (Sony et al., 2020). Previously, Quality Management was focused on the detection and diagnosis of processes, and failures and anomalies were dominated by in-process controls. However, because of advanced sensing technologies and analytical capabilities, the paradigm shifted to the

prediction and diagnosis of process conditions and understanding of the performance of quality characteristics, which are critical to both customers and organizations (Antony, Sony, et al., 2022). This shift allows organizations to measure and predict the quality of systems and products much sooner than what was possible by traditional preventive approaches and is possible by utilizing technologies like Big Data, automation, and data analytics (Zonnenshain & Kenett, 2020).

3.2| POTENTIAL BENEFITS

A sustainable environment is key for continuous development. A sustainable development based on Q4.0 is aided by a connected, transparent, preventive, and innovative environment. Connecting allows a holistic view of the organization, transparency enables one to easily understand the organization's activities and responsibilities, and preventive activities show an understanding of the future. One of the foundations of organizational development in today's environment must be innovation (Dias, 2021).

Q4.0, incorporating the principle of customer focus, can utilize technology to create new communication channels and incorporate the customer through the value chain. Technologies that support 24/7 Voice of the Customer services present an interaction pathway, including but not limited to call centres, automated online assistants or chatbots, and sensors built into the product (Dias, 2021), whereas interaction is not limited to after-sales but also allows for a new concept of industry customer experience including participation in the design and development of the products and services (N. Radziwill, 2018). Virtual Customer Integration, for example, is a collaborative system that allows customers to provide insights on new product design. The customer feedback obtained in the design phase reduces the risks associated with the launch of a new product as it helps their needs to be recognized more precisely (Bartl et al., 2012; Dias, 2021).

Additional reported benefits of emerging technologies for quality management in general, include a much smaller margin of error, and the capability to transmit, process and analyse a large amount of data in no time, reducing the dependence on human intervention, among others (Yadav et al., 2021). Utilizing these emerging technologies means that most products, services, and processes can be controlled in an automated way and throughout the value chain (Sader et al., 2019). Considering the increasingly customized products and processes, it becomes extremely important to maintain a high process quality. This complexity of products and processes entails an equally complex analysis, particularly when aligning causal relationships between problems and their unseen root causes (Sader et al., 2022). Automation of inspection facilitates lean quality methods where the ultimate goal is to identify future problems instead of reaching process stability. Smart machines, factories, and operators armed

with augmented reality technologies can communicate and collaborate to identify and remove the root causes of production defects, take immediate measures to prevent defects and avoid production and product failures. Furthermore, predictive analysis of mass data can provide early insights into the expected defects, enabling organizations to avoid them before they occur (Sader et al., 2019, 2022).

These links between people, machines, and data offer new opportunities to support quality operations, eliminate rework and scraping, increase productivity, and reduce the time and effort required to address quality issues (Sader et al., 2019). Quality 4.0, supporting dynamic data-based decisions, can reduce the turnaround time to launch a product or service, leading to similarly reduced costs of redesign and rework, empowering internal and external customers with effective collaboration, connectivity, and co-creation (Dias et al., 2022).

Quality management also benefits from digital and automated production processes where the work becomes automatic, capable, safe, and error-free, enabling organizations to increase conformance, whereas corrective and preventive measures may be done by the workers or by the machines themselves (Antony, Sony, et al., 2022; Dias, 2021). By automating inspection, the time between detecting a defect and the response to adjust the process is minimized. This automation can be done by employing sensors and IOT devices that control quality gates preventing defective elements from passing through in production, and providing accurate information aligned with operational instructions to production operators and supervisors, possibly resulting in zero defects in that production station (Sader et al., 2022). Because of the improved information flow, organizations can monitor a product throughout all the stages of the process and adjust the process when needed according to the quality analysis results. Information sharing is one of the main challenges in supply chain design and the use of technology such as digital twins or CPS can help information dissemination in all elements across the supply chain, enabling the product value chain to adjust immediately responding to quality issues detected during inspection (Chen & Huang, 2021; Sader et al., 2022). Moreover, Big Data generated in real-time within the organization and across the value chain can be streamed back to involve all parties allowing efficient resource utilization, to track and resolve quality issues, standardize quality practices, and improve performance throughout. Big Data can also provide the flexibility to reduce non-value-added activities and will enable dynamic resource scheduling in product manufacturing (Antony, Sony, et al., 2022; Sader et al., 2022). Information accessibility also allows for a real-time perspective of the entire process which, in turn, allows for more flexibility in product and service development, and real-time process data collection assists in the early identification of failures and hazards, allowing for appropriate corrective and preventive actions (Dias, 2021). Besides, accurate customer needs assessment and improved responsiveness to customer

needs are also possible because of increased automation of all production-related activities and through the utilization of Big Data analytics. The improved quality of products and services will improve customer satisfaction, and this will result in enhanced revenue and competitive advantage (Antony, Sony, et al., 2022).

With the ever-changing customer preferences, volatile markets and high stakeholder expectations, the potential benefits of Quality 4.0 become even more attractive. Besides, associated with these, there are also other possible organizational motivators, like the current society's focus on circular economy and sustainability, and the expectation's shift from continuous quality improvement and sustainment to dynamic product and service development (Antony, McDermott, Sony, et al., 2022; Sony et al., 2021).

3.3| POSSIBLE CHALLENGES

Despite its many potential benefits, the implementation of Quality 4.0 also has its challenges.

The lack of resources but also a lack of awareness of the potential benefits were reported in a survey of managers across several industries (Antony, McDermott, Sony, et al., 2022). The high initial investment required and the mismatch of Quality 4.0 with the existing corporate strategy were also mentioned. The implementation of Q4.0 requires substantial investment in the deployment, provisioning, operation, and management of a network of interconnected technologies (Hanifa et al., 2018; Saihi et al., 2023). In addition to this, organizations need to have effective change management so that new technologies and ways of work are accepted but also need to be careful with the interoperability of all different systems or software they intend to implement (Sony et al., 2020).

Data is essential in Q4.0. Through technology, organizations can collect massive amounts of data but the lack of processing capacity, delays in feeding real-time data, and effective management of massive amounts of data that need to be analysed to obtain useful insights, can be a challenge (Godina & Matias, 2019; Saihi et al., 2023). Also, with these massive amounts of digital data emerge concerns about cybersecurity and data protection (Sader et al., 2019).

Moreover, the already effective continual improvement strategies implemented by organizations limited the adoption of Quality 4.0 (Antony, McDermott, Sony, et al., 2022). Since digital empowerment, digitalisation, and dynamic quality enhancement seem to be essential for Quality 4.0 implementation along with the need for cultural transformation, the people involved could become the greatest challenge - either due to the lack of specific skills or due to their resistance to change- along with the need and

capacity to acquire the experience of Q4.0 in action at the factory level (Balouei et al., 2022; Ramezani & Jassbi, 2020).

3.4 | APPLICATION EXAMPLES

The overarching consensus amongst participants in a survey conducted by Antony, McDermott, Sony, et al. (2022) was that the Q4.0 projects they were involved in were considerably advantageous to their organisations and brought numerous benefits. For example, in one of the participant's organizations, using automated inspection with enhanced vision systems led to an increase in the accuracy of the inspection process, and the elimination of non-value human inspection and the associated costs. In another, going paperless with centralized documentation systems led to a reduction in document signoffs from an average of 30 days to an average of 3 days on the electronic system. Data visualization of key process data and KPIs allowed the prioritization of quality issues and tracking of root causes and corrective actions in real-time all in the same place at another organization. One organization used technology to replace manual and repetitive interventions in processes by introducing autonomous mobile robots into single lines to reduce handling, increase floor space and improve quality (Antony, McDermott, Sony, et al., 2022).

Improvement programs and digital technologies seem to be most often linked through continuous improvement (CI) tools like Lean Six Sigma and technologies like Big Data, IoT and Machine Learning (ML) (Santos & Martins, 2020). An empirical study, with data collected from organizations like Accenture, Capgemini, McKinsey, BBC, BDO, and PwC, evaluated process monitoring and estimated that through intelligence and automation, achieved with technologies like IOT and CPS, increased adjustability which in turn enhanced the products' quality facilitated by the superior and real-time process monitoring in I4.0 systems (Gray-Hawkins et al., 2019). Automated ML has been used for predicting quality in production and, when compared to a manual implementation, has been useful to predict earlier whether a final product will meet the specifications, especially for cases where the process chain takes several days (Krauß et al., 2020). These predictions of machine failure or product defects allow organizations to make the necessary corrections and instantly analyse possible root causes and their recommended solutions which, in turn, enhances their ability to anticipate risks (Krauß et al., 2020; Sader et al., 2019).

A case study in a food packaging business that supplies fruit to major UK retailers optimized quality control checks to reduce physical waste and resource usage through business process engineering where the paper-based quality checks were replaced by tablet-based checks with specific software. This led to a reduction in the time needed to conduct the checks, an increase in the time the quality team

spent on the production lines with the packers and facilitated the identification of defects. While ensuring that the product met the customers' requirements and consequently reducing the likelihood of rejection, the new system also enabled monitoring each production line in real-time and gathering accurate information faster (Garcia-Garcia et al., 2021).

An Autonomous Quality Management System (AQMS) was developed to achieve automatic gauging, auto-detection, auto-correction, smart segregation, and quality data recording and applied in an automotive component manufacturing industry founded in India. This system enabled the organization to reduce costs and defects and increase process yields - production and inspection costs were reduced by approximately 52% and 78%, respectively, whereas the process yield increased from nearly 87% to more than 99% and the component rejection rate decreased by more than 93%. Where the previous process had a sigma level of 1.5 and a PPM between 70 and 80 thousand, with the AQMS the sigma level increased to 5.5 (Singh et al., 2022).

To address the challenges of integrating multiple fragmented data sources, applying advanced ML techniques for multi-objective optimizations, and implementing configurable Digital Twins (DT) that can flexibly adapt to changing industrial configurations, Christou et al. (2022) propose an end-to-end IoT platform that has been tested in several pilot cases across industries. In one of the pilot cases, a quality management and predictive maintenance instance was deployed on a Virtual Machine (VM) on the shop floor, addressing data integrations and management challenges while providing tangible benefits for the organization, like dynamic analytics – which are key for implementing and testing alternative DT with minimal implementation effort -, configurable data management and analytics – which meant that changes in data sources and in the ML algorithms did not require additional programming effort -, and streaming data management – important for supporting high-performance near real-time functionalities for defect detection or asset performance degradation. Other observed benefits of implementing this platform included its ability to accelerate application development, reduce unscheduled downtimes, provide increased Overall Equipment Efficiency (OEE) and lower the percentage of product defects by computing production parameter configurations, and its capacity to predict product defects before they occur (Christou et al., 2022).

Another example of the application of I4.0 technology and tools for quality control is the tool developed by Ramezani & Jassbi (2020) which consists of a neural expert system in intelligent real-time monitoring and predictive, corrective, and remedial diagnosis of process control in plaster production. This hybrid model is based on a neural network and a rule-based expert system for dealing with control

chart patterns, helping quality personnel recognize the roots of deviations and taking the needed corrective or preventive actions. By introducing a neural expert system-based pattern identifier, the operator can be warned if an abnormal pattern occurs in the process. Replacing human skills with a detection algorithm leads to reduced human intervention and an intelligent manufacturing environment. The results of this case study show improvements in the process capability, with control charts not showing any out-of-control modes after following the suggested corrective actions. The proposed model was found to be a reliable decision support system (Ramezani & Jassbi, 2020).

3.5 | THE CAPABILITY ROADMAP TOWARDS QUALITY 4.0

This dissertation describes the application of the Capability Roadmap towards Q4.0 developed by Dias (2021) and it's intended to be both a diagnostics and descriptive tool for organizations to understand where they are on their transition journey and what they are missing, thus allowing for a sustainable progression towards a fully mature Q4.o organization (Dias, 2021).

The Capability Roadmap has a table format to allow for easy reading and highlighting of the intersection between each level, dimension and subdimension. It is constituted by two layers, whereas the second layer was created to further develop the concepts and conditions presented in the first layer reducing the complexity of the model and, thus, allowing for the creation of an easier tool to use for an organization's self-assessment of Q4.0 readiness, enabling them to position themselves on this maturity scale and to develop a strategy for moving up those stages (Dias, 2021).

It encompasses three dimensions – “Value Chain and Operations”, “Strategy and Organization”, and “People and Culture” – that are further divided into three subdimensions each – “Customers”, “Products and Services”, “Processes”, “Strategy”, “Integration”, “Innovation and Improvement”, “Role transition”, “Organizational Culture” and “Leadership”. The “Value Chain and Operations” dimension shows that quality should be the basis of an organization's processes, even if the transformation is driven by technology that should be integrated with “Customers”, leading to the development of new “Products and Services” and the need to adapt the “Processes” to new ways of work. The “Strategy and Organization” dimension represents the overall organizational growth, through the creation, development and monitoring of a “Strategy” for the Q4.0 transition, the “Integration” of new technologies, new ways of work, and new ways of learning and communicating, creating an underlying premise for “Innovation and Improvement”. The human and social aspects of an organization are mirrored in the “People and Culture” dimension. People are the foundation of any organization, and they should invest in the reskilling and upskilling of their professionals to prepare for necessary “Role transitions”, with “Organizational

Culture” and everyone’s awareness of it working as a facilitator in the transition process, which is led by the organization’s “Leadership” (Dias, 2021).

The Capability Roadmap has six levels – “Stakeholder Interaction”, “Process Integration”, “Digitization”, “Automation”, “Connectivity” and “Intelligence” - ranging from readiness stages for levels 1 to 3 and maturity stages for levels 4 to 6. The levels progress from the physical to the digital and cyber-physical domains and from a reactive approach to a predictive and prescriptive one in the advanced maturity levels. Since the model is aimed at organizations with an already well-established culture for quality, the first level “Stakeholder Interaction” means to act as the base state of such organizations. “Process Integration” means the integration of Q4.0 concepts, approaches and tools in an organization’s processes and “Digitization” refers to the transition of organizational data to a digital format and the consequential creation of improved communication channels. “Automation” is the first maturity stage and encapsulates the automation of certain points in organizational processes, reducing human intervention and augmenting capabilities and decision-making. “Connectivity” means effective communication among people, technology and systems across the value network and “Intelligence” represents the use of emerging state-of-the-art technologies to shift the organization to a predictive approach, including, for example, the prediction of process parameters or market changes. This highest level of maturity also functions as a possible connection towards an organization's continued transition to Q5.0, where the human and social elements take centre stage (Dias, 2021).

4| RESULTS

Two interviews with knowledgeable personnel were conducted in each of the selected organizations in order to obtain information to apply the Capability Roadmap towards Q4.0 (Appendix II - Table 2). The transcripts of these interviews were then analysed, and the data was used to fill each applicable section of the Capability Roadmap. Table 1 shows a partial example of this analysis for BDO, with excerpts from the interviews being used to demonstrate the applicability of each of the models' dimensions, in this case, for level 2 readiness – Process Integration. The first coloured line represents the dimensions of the model followed by the sub-dimensions, the conditions present in the first layer of the model, then the conditions of the second layer, lastly are excerpts of both the interviews conducted in BDO Braga that illustrate the applicability of those conditions.

4.1 | VALUE CHAIN AND OPERATIONS

4.1.1 | BDO

In this model dimension, BDO is placed on maturity level 4 – Automation – since it has invested in digital solutions and adopted new ways of work that allowed the automation of several repetitive processes. In the case of BDO's office in Braga, there is a team focused on "Incentives", meaning they provide services to help clients apply for financial incentives and the consequent project follow-up and a team of "Control and Corporate Finance" which provides services related more to corporate data analytics and finances. Both services encompass processes with a lot of documentation and periodical reporting as well as gathering data from external sources for compilation and analysis. In their transition towards Q4.0, BDO has invested in the acquisition and even internal creation of digital applications and tools that would allow for the partial or total automation of these time-consuming and error-prone processes. In the case of Braga's office, Microsoft software is prevalent, predominantly the 365 universe, where Sharepoint is used as an information repository and through shared folders, in the cloud, both the internal BDO teams and their clients can instantly deposit, share and have access to information and documentation related to their specific project according to profile based permissions built into the software. Through tools like Power Automate and Power Query – both tools from the Microsoft 365 universe – they have managed to automate the reporting process. The data collection and validation, because of ERP limitations, is still manual but after the client deposits the information into the respective shared folder, the software recognizes that something was added or modified, and it triggers the automatic process for the creation or even updating of the corresponding reports. In the Lisbon office, for example, since they use a different ERP, they managed to automate the whole process, from data extraction to reporting. In

Table 1 | Example of model application on BDO, readiness level 2 - Process Integration.

2	Value Chain and Operations			Strategy and Organization			People and Culture		
	Customers	Products and services	Processes	Strategy	Integration	Innovation and Improvement	Role transition	Organizational culture	Leadership
	Customer integration in product/service lifecycle, specifications are discussed and reviewed at gates	Stakeholders' integration along product/service lifecycle, specifications are discussed and reviewed at gates	Operational processes integrated within organizational processes	Integration of Q4.0 dimensions with the organization's Digital Transformation strategy	Integration of Q4.0 dimensions with the organization's Quality Management System	Innovation and improvement integration in organizational processes	Training plan towards digital competencies and new ways of work	Cross-functional cultural development initiatives focused on Q4.0	Leadership driving company-wide effort for the recognition and understanding of Q4.0
	Customers' needs and/or preferences are taken into account during the product/service development and production processes	Stakeholders' needs and/or preferences are taken into account during the product/service development and production processes	Data sharing between operational processes and other organizational processes	Perception of organizational readiness for the introduction of new technologies and ways of work; Metrics and development plans are focused around Q4.0 objectives including resource allocation and risk assessment of investment in technology and IT infrastructure	Development of quality management programs and tools based on digital technologies; Policy and procedures suitability for Q4.0	The organization's practices include encouraging innovation and pursuing continuous improvement approaches	Openness of associates to new technology; Time to explore and adopt new ways of work	Personal development plans are focused around Q4.0 objectives; Associates' involvement and empowerment in Q4.0 initiatives; Existence of a company's continuous improvement culture to adopt Q4.0	Leadership takes the opportunity in acquiring the skills required to handle the transition to Q4.0 and is in charge of fostering in the organization a culture of openness for progress
	"essa área em particular aquilo que nós sentimos muitas vezes é que o cliente, alguns clientes por um lado têm vários projetos e estavam, era difícil acompanharem o estado de cada um, (...) e aquilo que nós fizemos foi um dashboard (...) em PowerBI que o cliente tem acesso em tempo real a essa informação"	"E depois na área financeira temos quer soluções desenvolvidas à medida e aí são soluções que ligam diretamente ao ERP da empresa e que, portanto, precisam ali de algum desenvolvimento e que têm mapas próprios, como também temos algumas soluções plug-and-play (...) para alguns clientes é uma solução interessante, é uma solução fácil e barata de implementar"	"(...) é uma partilha enquanto reunião, (...), uma vertente mais estratégica e que vão sendo partilhadas ideias entre líderes de grupo, (...), o líder da Service Line conseguir reunir ali, ter uma visão de helicóptero para com todos os restantes responsáveis das suas equipas (...)"	"temos um ano para medição de resultados que vai desde Maio a Abril e o lema para esta época de 23/24 é precisamente a questão da qualidade e da digitalização também, portanto, acabamos por ver também nos próximos tempos maior aposta nisso"	"temos apostado bastante em ferramentas digitais quer internas quer externas, para a gestão mais operacional do nosso trabalho, para aquilo que é também comunicação, alguns elementos mais de marketing e depois também para controlo interno em termos daquilo que é qualidade"	"(...) há uma aposta muito clara nesta parte digital e todas as reuniões gerais isto é abordado, até há um espaço específico, (...) para apresentar aquelas ferramentas digitais que foram implementadas naquele período, quais é que estão neste momento a ser implementadas e a perspetiva para o futuro."	"E depois também para a equipa interna, portanto, sensibilizar a equipa para a importância da utilização dessas ferramentas, e a recetividade também tem sido boa nisso e as pessoas têm contribuído ativamente para esse processo"	"E existe um plano estratégico para a transição digital, onde, por exemplo, aquela ferramenta que falamos à pouco de registo automático de faturas, estava no roadmap, já foi executada, mas, pronto, existem outras também que estão em desenvolvimento"	"têm vindo a ser criados departamentos internamente na BDO nesta área tecnológica, portanto, têm sido também contratadas pessoas para essa área."

another process that included the analysis and reporting of salary information and processing where each file needed to be manually analysed, they identified a pattern related to the ERP the clients used and through this managed to automate this process according to the most often used ERPs by their clients.

4.1.2 | Becri

Becri achieved a level 2 – Process Integration – in the “Value Chain and Operations” dimension. This level entails the customer and stakeholders’ integration in the product lifecycle, taking their preferences into account during product development and production processes and the integration of operational and other organizational processes. Becri has started their Quality 4.0 transition journey, having a strategy currently focused on the digitization and centralization of information and data while also taking great strides in the sustainability of the production process. Automation, while a future goal, is not the focus of their strategy because Becri’s production processes are very specific and still heavily reliant on manual labour, with the available technology not being able to correspond to the challenge, representing a significant investment for not enough benefits. However, they have invested in a platform that allows the clients and stakeholders to see the product’s fit during the design and development stages, before going into production, through 3D design technology. By permitting product customization right at the design phase, Becri has managed to accelerate customer interaction and increase customer satisfaction. The ERP centralizes the available organizational and production data, where everyone with a computer can have access to the information they need, although most of this data is still obtained through manual input. In an effort to avoid having a great number of software that might not have the necessary interoperability in the future, Becri has been collaborating with a consortium of other textile companies and a partner responsible for software design to integrate and personalize the specific functions needed into the ERP already in use. This means that different companies might invest in the same features making the final software cheaper and that testing doesn’t need to be concentrated in a single organization, being diluted through several instead.

4.1.3 | SNA Europe

In the “Value Chain and Operations” dimension, SNA Europe is at readiness level 1 – Stakeholders Interaction. SNA’s product is fully mature and without any incorporated technology, so there is no evolution in this regard with the transition towards Q4.0. What they expect is that this transition will bring a marked evolution in their processes that will allow them to increase efficiency and efficacy. So, their strategy, at the moment, is focused on data. They are in the initial testing phase of the introduction

of tablets at the production cells for data collection and analysis through Power BI. By digitizing data collection and centralizing data, they want to reduce the time it takes to detect and react to any fluctuation in the process, leading to optimized processes and a decrease in defects, at the point of fluctuation and those that continue in the production process. The operators at this phase will introduce the data they already collect on paper in the tablets and through Power BI will receive a report of what is happening in real-time, predominantly through graphics. More strategic and management data are collected, centralized, and analysed in their ERP, with some data collection being made through barcode pistols. Nonetheless, in their experience these two data streams rarely intersect.

SNA does not deal with the final customer in the Vila do Conde facility, shipping to distribution centres in great quantities. This allied to the fact that the product that reaches the final customer is relatively cheap and so not worth the trouble of issuing a formal complaint, which means that they tend not to receive feedback from the final customer. The feedback they get is from the distribution centres and only if an order of several thousand products is all defective or has any problems with the packing or transport, which, by their accounts, rarely happens. Therefore, their “customer interaction” happens inside the SNA group, and the evolution, not in the product but in the processes, is due to the need to continuously improve to survive in a very competitive market and not necessarily due to customer feedback.

4.2 | STRATEGY AND ORGANIZATION

4.2.1 | BDO

In the strategy and organization dimension, BDO also achieves the maturity level 4 – Automation – where the appropriate levels of automation are defined, the information flow is also automated, and the human interaction and autonomous improvement level in the organization's processes are defined. BDO has a defined strategy for the transition even if they don't have specific Key Process Indicators (KPIs). A platform was created to function like a suggestion box where employees can suggest improvement opportunities, there are periodical meetings, not only for each team but also for the Business Unit and Service Line where managers are invited to provide feedback and participate in the strategy definition. BDO understands that their clients value an individualized approach and that projects differ from each other not allowing full automation of processes, having created a team focused specifically on this transition to Quality 4.0, identifying opportunities for digitization and automation, and identifying where human intervention is essential, and either procuring or creating the technological tools needed to achieve it. Their systems belong to a network with employees having access to their digital workspace anywhere

– as long as there is internet access. This digitization of the workspace facilitates remote work – vital during the COVID-19 pandemic – and allows for several people working on the same document simultaneously as well as allowing clients immediate access to their project documentation without the need for back-and-forth communication. This led to great time savings, minimization of human error, facilitated the standardization of the services provided and increased the unity and synergies in and between teams.

4.2.2| Becri

In the “Strategy and Organization” dimension, Becri also reaches level 2 – Process Integration – although in its very early stages in all subdimensions. The organization has a perception of their readiness for the introduction of new technologies and ways of work since management has taken some time to attend events focused on Q4.0 initiatives, like colloquiums and presentations which gave them a perception of what the future of the textile industry might look like and ideas on how Becri might achieve it. This allowed them to develop a strategy and consider several investments. Some, due to the cost-benefit ratio or the available technology being considered inadequate, were put on hold or rejected until new developments arise. Nonetheless, there has been significant investment in IT infrastructure, like new servers, dedicated Wi-Fi, UPS systems and other failsafes to prevent the complete stop of the whole infrastructure in case of, for example, an energy cut or network failure. They have adapted procedures for Q4.0, namely, in the cutting process, which was the first process they decided to start the digitization and possibly automation. Becri and its leadership seem open to innovation and continuous improvement, seeking new knowledge and experiences when it is possible, pioneering some projects and coordinating some developments with the consortium they integrate. This partnership with the consortium also allows Becri to exchange experiences with other similar organizations and somewhat benchmark their own Quality 4.0 transition.

4.2.3| SNA Europe

SNA is also at readiness level 1 – Stakeholders Interaction – in the “Strategy and Organization” dimension. SNA's management is aware of I4.0 and Q4.0 concepts and the potential benefits of their application, being at an embryonic stage of its implementation, as mentioned in the previous section, with the testing of the use of tablets in the production cells for data collection and automatic data analysis, in real-time. There is some interaction for defining and implementing quality initiatives, but it happens mainly between organizational branches of Snap-on, the group SNA Europe integrates, where different initiatives might be tested in each facility, the results are shared among the group and, if the

implementation is considered successful and beneficial, these initiatives are replicated at other locations with similar operational processes. Rapid continuous improvement is one of the values of Snap-on, mirrored in SNA and visible to all throughout their facilities. At present, they are focused on the Quality and Security dimensions of their operations, investing in training their workforce to improve these areas. Since they lack the customer interaction that would enable them to receive feedback, SNA's improvements and innovation initiatives are not so much a result of corrective actions due to customers' feedback but preventive ones and the ever-present need to accompany a ferociously competitive market in order to survive.

4.3| PEOPLE AND CULTURE

4.3.1| BDO

Like in the previous dimensions, BDO achieves a maturity level 4 in the People and Culture dimension with the sub-dimensions "Role Transition" and "Leadership" scoring above at a maturity level 5 – Connectivity. This dimension's level 4 conditions include the use of technology to augment people's capabilities while adapting to new technologies and ways of work and supporting the decision-making process with automation and reliable information. The "Role Transition" and "Leadership" sub-dimensions go a little further by having an active value network connected for knowledge sharing, decentralizing leadership and creating a sense of shared ownership of Quality. BDO corresponds by investing in technological solutions, some already described in the previous sections, that automate repetitive processes allowing for reduced human intervention and leading to significant time savings and reduced human errors. This means that employees complete the same amount of work in less time, reducing overtime, delays and increasing compliance to set deadlines and employee satisfaction. There has been a marked investment in the upskilling and reskilling of the employees with frequent training sessions when a new technology is adopted. This training needs can be a result of performance evaluations and suggested by the organization but also can result from a request from the employee, with training being financed by BDO, which is an additional incentive to pursue further education that brings added value to their work. A shared knowledge repository has also been created where training and education materials are shared and can be accessed by anyone who wishes to do so, whereas the use of manuals with process instructions is also encouraged. Policies and procedures have also been updated to reflect the growing concern with cybersecurity and data protection, with the acquisition of technology that allows sharing of digital data in a safer manner. BDO leadership seems to be a big driver of this transition towards Quality 4.0. They have established a strategy, created space for employees to

participate in the innovation and improvement processes and adapt to new ways of work, invested in technological solutions that brought numerous benefits to the organization and, due to the way the company is structured, decentralized leadership – with each team, business unit and service line having a leader as well as an executive council – and created a culture where Quality is everyone's concern.

4.3.2 | Becri

Becri, once again, achieves a tentative level 2 – Process Integration – in the “People and Culture” dimension. “Leadership” in particular seems to be the most advanced subdimension because, according to the participants, Becri’s leaders are participative and involved not only in the day-to-day activities of the organization but also in any new initiatives and approaches that might appear, giving room and encouraging all employees to bring forth their improvement ideas and potential learning needs. Training and learning happen mainly inside the organization, since, when recruiting, it is hard to find candidates that already have all the necessary skills to perform the job. Due to this, Becri has an extensive onboarding training plan where new employees learn by doing and are introduced to the new procedures. Even so, Becri is part of a larger group, and the work is still heavily reliant on manual work, so this training is still very focused on the manual skills needed and not so much on the digital skills that might potentially be needed as they advance in their transition towards Q4.0. Furthermore, with the adoption of new ways of work and technologies, like tablets on the shopfloor, management felt resistance to the changes from employees, but, with the involvement of leadership and middle management in the process, as well as some time to adapt, this resistance seems to have lessened if not disappeared. With this decrease in resistance and adoption of new ways of work, employees were also described to have become more participative in the organization’s meetings, offering their improvement ideas, either in those meetings or by email or suggestion box, more readily and showing enthusiasm for the evolution of Q4.0.

4.3.3 | SNA Europe

In the “People and Culture” dimension, SNA is also at a readiness level 1 – Stakeholders Interaction. The conditions for this level include the analysis of competencies and skills in order to understand which are needed, the associates’ engagement and empowerment whose fostering is a responsibility of the leadership. At SNA, a recurring practice is the use of proficiency matrixes, where employee skills, knowledge and experience are recorded. These matrixes are also used to determine training plans and to assign workers in another position to cover for an absentee, for example, or to teach more junior personnel. Their training is mainly offered internally due to the specificity of both the product and processes.

Through, regular meetings and assemblies, including the daily meetings to discuss the previous day, there is space for employees to come forward with their ideas and to discuss improvement opportunities and solutions. Leadership is almost always present at these meetings as well as at least one-third of the employees of the intervened area. Leadership has noticed some resistance to the changes, mainly from older employees, but they are still at the beginning of the testing for the introduction of tablets, and on the opposite side, they have some more interventive workers who are proactive in sharing their ideas for management to evaluate. Leadership has a policy of considering all suggestions, applying the ones they consider feasible at that moment and offering explanations to the staff about the ones that are either not possible to implement or not a priority at that particular time. This makes the employees feel heard and appreciated and encourages them to continue to come forward in the future.

5 | DISCUSSION

Most published models are oriented towards I4.0 maturity or readiness assessment and review, with few models focusing primarily on Q4.0 assessment, and very few case studies of their implementation, nonetheless, some principles and fundamentals of these models can be adapted to Q4.0 maturity assessment methodology (Nenadál et al., 2022). By providing an assessment of maturity for I4.0 or Q4.0, models show organizations their current state of readiness for the digital transition allowing them to see what they lack to meet the desired level of maturity through an analysis of each dimension of the model in depth. As a result, organizations can end up with a customized roadmap to help them achieve their strategic goals (Dias, 2021).

Furthermore, most published models include a technology dimension, either specifically or extended through other dimensions like operations or product lifecycle. Dimensions related to people and organizational management also appear often, as well as ones related to organizational culture and strategy. Customer focus and leadership-related dimensions also seem to have gained importance in the most recent models (Dias, 2021; Hizam-Hanafiah et al., 2020). However, these models differ in terms of content, quantity, definition and in the methods of assessing maturity (e.g., Dias, 2021; Hizam-Hanafiah et al., 2020; Lichtblau et al., 2015; Nenadál et al., 2022; Santos & Martinho, 2020).

Zulfiqar et al. (2023) developed a readiness model for Q4.0 meant to be applied in manufacturing organizations. This model takes the form of a questionnaire, with the dimensions – “Top management commitment and support”, “Leadership”, “Organizational Culture”, “Employee competency” and “ISO QMS Standard Implementation”. A five-point Likert scale was used to assess each of the dimensions and readiness was divided into 5 levels. They implemented the model at 6 packaging companies in Pakistan that already had some Q4.0 initiatives in place, having placed three of the companies at level 3 and the other three at level 4, marking these organizations as mature (Zulfiqar et al., 2023). This model has a big focus on leadership, similar to the Capability Roadmap (Dias, 2021) we tested, which is understandable since leadership should be the driving force behind a sustainable transition towards Q4.0. However, it does not appear to place a strong focus on technology, which is a big theme in other models like the one developed by Jacob, 2017, which encompasses 11 dimensions including “Connectivity” and “App development”, and our own Capability Roadmap that even without a specific dimension has technology diluted across all the others, especially in higher readiness and maturity levels. Quality 4.0 is not about the acquisition and application of technology, but about the synergies this technology can create with people, systems, and processes, however, it is undeniable the role technology can have on the transition.

Technology can enable organizations to collect and analyse massive amounts of data from their processes, while ML and AI can provide insights that allow prescriptive analytics to predict loss and assist in clarifying what steps to take to improve results. Smart devices, like sensors connected to an organization's information systems, like their ERP, can provide information in real time, whereas rapid and efficient data collection from different sources can lead to a more agile decision-making process. EQMS technologies can lead to optimized quality systems that improve compliance and efficiency. AI and ML systems as well as AR and VR can be used to upskill employees, enhance their capabilities, and facilitate and potentiate training while improved systems autonomy frees workers from repetitive low-value-added tasks to perform more innovative and high-value tasks (Alzahrani et al., 2021; Jacob, 2017; Tambare et al., 2022).

Tambare et al. (2022) report the case study of Rolls-Royce, where advanced technology, like Big Data, is used to manage aircraft engines and generate massive amounts of data, while ICT technologies are used for data analysis, looking at operational strategies in order to reduce losses by preventing errors or failure during the design phase. Rolls-Royce used robots for predictive maintenance and inspections in the production plant, in situations where inspection is dangerous or inaccessible to humans. They provide an after-sales service that combines thousands of hours of operation information of the engines, collected through various sensors (like vibration, temperature, velocity, or flow sensors), and environmental information like the weather and air traffic to provide information to airline maintenance crews allowing for predictive maintenance before any system failure happens. And this is just one example that showcases the potential benefits, across a variety of metrics - from customer and employee satisfaction to safety, performance, and compliance - of an effective I4.0 and Q4.0 transition, where technology is employed to potentiate an organization's capabilities leading to operational excellence and innovation to realize its vision, mission and goals.

Another recently published model aimed specifically for the assessment of maturity towards Q4.0 was developed and implemented in 121 Czech production companies (Nenadál et al., 2022). The model has four main dimensions – “strategic direction”, “people and culture”, “processes” and “methods and tools” - and 22 partial items, creating 7 levels of maturity. The assessment was made using electronic questionnaires sent to representatives of each company, most being quality managers. The results showed that nearly 60% of the participating companies had a below average maturity score, between levels 1 and 3, while only 6,3% had already achieved the highest levels of maturity, levels 6 and 7. The companies from the automotive sector also had an average maturity level higher than the organizations from other industrial sectors. The main limitation identified was the fact that the study happened during

the pandemic which prevented the researchers from validating the data collected from the questionnaires with personal interviews and observations (Nenadál et al., 2022). However, there was no research made towards the development of a strategy for the implementation of Q4.0 projects based on the companies' results even if a severe lack of awareness related to Q4.0 was registered by the authors.

The Capability Roadmap towards Q4.0 was created with the assumption that it would be applied in organizations that already have some culture for quality, like for example, effective ISO 9001 certifications, so the first level – Stakeholders Interaction – already presupposes the existence of some practices like the collection of customer feedback and the implementation of improvement and innovation actions based on that feedback, the involvement of the organization's leadership in those actions as well as some awareness to the Digital Transformation, I4.0 and Q4.0 and their potential impact. This was observed in all three of the case studies, with all three being certified not only for ISO quality standards but also for other standards, like environmental management, health and safety management or IT security.

In a study by Antony et al. (2023), Q4.0 seemed to be adopted mainly by large enterprises from manufacturing sectors in the European continent. The main factor for manufacturing industries to proceed with the transition towards Q4.0 was the ability to handle Big Data in quality management followed closely by the reliability of the data collected and the increase in productivity. On the other hand, service industries listed their main benefit as improved customer satisfaction, and while they also placed handling Big Data at the top, the increased accuracy that leads to fewer errors and the improved decision-making process were also mentioned. In large enterprises, in addition to handling Big Data, the other top benefit was the long run time and cost savings, whereas, in small enterprises, exclusively, faster, and more transparent processes appear in the top 3. Understandably, the ability to handle Big Data is considered a main benefit across industries, big or small, since reliable data can be a significant factor in the quality of design, conformance, and performance (Antony et al., 2023).

When moved to the topic of challenges, manufacturing industries list organizational culture in the top 5 whereas service industries list the training. Antony et al. (2023) reason that since service industries are people-dominated organizations, intensive training of the workforce takes on more importance compared to organizational culture, and manufacturing industries tend to have a more mature organizational culture for general quality management than service ones. This is clearly not the case with the case study where the Capability Roadmap was tested, since the BDO, a service organization, had a strong organizational culture not only for general quality management but also for innovation and

continuous improvement, where the training and upskilling of employees was seen not as a great challenge but as an opportunity that should be encouraged in order to maximize the potential benefits obtained through the use of technology. This awareness and the fact that the technological tools and software needed for digitization and automation, and further to reach intelligence, lack a high degree of specificity, consisting mainly of computers and Power BI tools already in the market, that are relatively simple to adapt to what they do, means that BDO has a solid transition strategy and is making effective and sustainable progress towards “Intelligence”.

Becri, a manufacturing industry, highlighted the existence of technological barriers to their transition towards Q4.0, with the available machines, robots and technologies representing, at present, a very big investment for a very specific task, lacking the adaptive capacity necessary to justify their acquisition facing the predicted added value. A similar situation was reported at SNA Europe, where, even though they are still in an initial stage of transition, the machines used in their production processes are very specific to what they do, with most being approximately 80 years into their lifecycle, and right now there is simply no viable alternative in the market that could replace them. This makes automating the production processes difficult, leading to both organizations focusing on the digitization of data collection and analysis first. These two organizations also have a relatively older workforce, especially in production, which created some resistance to the changes, including the introduction of technology. Nonetheless, in Becri, after some time during the testing phase, and with the encouragement of middle management and leadership, this resistance seems to have lessened and workers see the benefits these changes bring to the organization and how technology can make some tasks easier, faster, and less repetitive.

The Capability Roadmap towards Quality 4.0 developed by Dias (2021) was only validated theoretically by a group of experts and a public session. Through our attempt of empirically validating the model on three different organizations – one service and two manufacturing - we found the model adequate to evaluate the readiness or maturity of each organization, with the three dimensions and nine subdimensions covering the essential changes or conditions an organization needs to undergo, across all of its the structure - from processes to strategy and organizational culture - in order to transition. Nevertheless, due to each of the case studies unique characteristics and the fact that we want the model to be applicable to all types of organizations, be they manufacturing or service, there were some conditions of the model that need refining. For the model to be fully applicable to a service industry like BDO, where the value network is BDO itself, having no suppliers (except for general services like electricity, water and telecommunications) or permanent partners, and the client, some conditions, particularly in levels 3 – “Digitization” – and 5 – “Connectivity” – need to be reworked since they focus on aspects like

suppliers, logistics, wearables or inventory management, none applicable in BDO's case. Another particularity of one of the case studies, SNA Europe, is that the plant where we tested the model has no external customer interaction, their customer would be SNA's distribution centres or sales points, which would mean they only have internal customers. One of the subdimensions of the "Value Chain and Operations" is the "Customer", focusing on the organization's interaction with the customer, their integration in the product or service lifecycle and even after-sale services, which, once again, is not really applicable. Ultimately, despite the successful application in the three case studies, the Capability Roadmap towards Quality 4.0 was found to have a strong focus on the typical functioning of a manufacturing industry, needing some refining if it is to be adopted, in general, by any kind of industry, including services.

6 | STRATEGIC GUIDELINES

After the application of the model, and based on each organization's current state, strong and weak points, we developed a series of strategic guidelines meant to help the three organizations continue their Q4.0 transition journey effectively and sustainably.

The first guideline applies to all three case studies, and it is the following:

Creation of Q4.0 indicators: At the moment, none of the organizations has specific Q4.0 indicators to inform their transition, measuring only the typical KPIs. However, specific indicators for the Quality 4.0 transition might help to unify strategies across the groups, allocate resources more efficiently and effectively, measure the success of implemented initiatives and assist the decision-making process. By understanding what works and what does not, as well as the degree of improvement brought by each approach, the organizations can make informed decisions, backed by data, about the path to take and what is the best strategy to continue their pursuit of organizational excellence, not only through Q4.0 but even further, through I5.0 and beyond.

6.1 | BDO

BDO Braga, even though, it achieved a level 4 almost across the board, with some subdimensions reaching level 5, had some weaker points that could be improved upon in order to consolidate its current maturity level 4, opening up the path to further advance its maturity levels.

Interoperability of systems: BDO Braga, having been a later acquisition, operates with a different ERP than the rest of the group. This ERP presents some limitations, especially in terms of data collection and automation. Having the same ERP across the whole group might facilitate not only the automation of data collection in the Braga office but also improve integration with the rest of the group by standardizing procedures across the whole organization and possibly improving information flow due to using the same system.

Automatization of communication: While acknowledging that customers and projects need individualized communication, some level of automation might be useful, for example, automatic alerts for approaching submission deadlines or automated checklists for needed documents and confirmation of reception. BDO Braga utilizes the Microsoft 365 universe tools to share information with the clients and manage projects. They are developing their own platform for customer interaction, intended to have,

for example, a checklist for the documents the client needs to submit and their validation, however, using a different platform might bring problems with the interoperability of the other Microsoft tools.

Digitization of value network integration: At present, information sharing is predominantly happening at meetings, with meeting minutes and notes being shared across several platforms with limited access. A global platform divided by functional teams, for example, that centralizes all these documents and notes might facilitate and accelerate the sharing of relevant information. By centralizing this information in a single platform, it might be possible to prevent the duplication of discussions, to easily access decisions made in previous meetings as well as the path taken to get to those decisions, and to facilitate access to everyone across the various offices that integrate the BDO group.

6.2 | Becri

Becri, among the several companies that constitute the group, seemed to be the one that is further ahead in the transition towards Quality 4.0, achieving the early stages of readiness level 2 – Process Integration. The following guidelines, in no particular order, are meant to help Becri consolidate its current level and prepare the path for advancing in the transition towards Q4.0.

Level progress: While Becri was the focus of the implementation of the Capability Roadmap, it is but one of the many constituents of the Becri group and from our understanding not all follow the same processes, especially in terms of data collection and analysis or quality control. Thus, our first suggestion would be to standardize procedures across the group and, also by defining the indicators, identify what data they need to collect and analyse to have the information they want and need. It could compromise the long-term sustainability of the Q4.0 transition if Becri kept advancing while the other locations are playing catch-up. It could mean that systems, processes, and procedures become incompatible across the group making the job more difficult and taking up more resources instead of optimizing operations.

Digitize customer interaction: At present, the initial contact with the client and customer acquisition is made through salespeople who go to the client's location with samples to showcase the work. Becri has a platform where clients can see a 3D rendering of their request, evaluate the fit and request changes, however, this platform is only accessible after the customer already put in a request. It could be beneficial to have a version of this platform that could work as a digital catalogue for prospective clients to see what the organization can do and, if necessary, at an initial phase, be used in conjunction with the physical samples.

Cybersecurity: Becri has been investing in some technological tools and software to integrate with its ERP in order to ensure interoperability, as well as IT infrastructure, to protect the servers and keep operating in case of failure or energy cuts. Yet, they have not adopted any particular measures to protect their data as they make the transition to digitization. Implementing some cybersecurity systems early on could be advantageous not only for the obvious reason of data protection but also for the future if they decide to implement technologies like blockchain to connect and share information through the value network.

Competencies gap analysis: By analysing the current skills, competencies and capacity of its employees and comparing them to the ones needed to implement Becri's transition strategy, the organization can understand where to allocate more resources, including human resources, and what skills and capabilities those resources need to have, to implement the Q4.0 initiatives effectively and sustainably long-term since the introduction of technology only changes the ways of work, it does not replace human resources.

6.3 | SNA Europe

Since SNA Europe is still at the very beginning of its transition, staying at readiness level 1 – Stakeholder Interaction, our proposed guidelines are more related to the foundations and first steps, so that the initial interaction with Q4.0 can be positive and encouraging.

Increase Q4.0 awareness: A deeper understanding of I4.0, Q4.0 and technological advances could assist the organization in finding partners for the transition, benchmarking its progress and optimizing and customizing its strategy according to their vision and requirements and the technology and capabilities available and affordable.

Integration of Q4.0 strategy: Integrating the Q4.0 strategy with the organization's current innovation and continuous improvement strategies can prevent duplicate actions, optimize resource allocation, and ensure alignment with the organization's needs and requirements. It is important to understand what changes should be made, how they should be implemented, and how to ensure stakeholders' buy-in so that the transition can be as smooth as possible.

Competencies gap analysis: Similar to what happens at Becri, SNA Europe can also benefit from a gap analysis of current competencies and skills and what will be required to transition. Doing this at the very beginning of the journey will allow SNA Europe to manage risk, plan and allocate resources more effectively, and understand possible training or recruitment needs.

7 | CONCLUSION

The adoption of Quality 4.0 involves social and technological changes but also critical changes impacting management models and systems (Dias et al., 2021). Digitization and technological development enabled rapid advances in business models and management approaches, creating new opportunities for organizations to integrate those advances to achieve organizational excellence, superior performance, and innovation (Antony, McDermott, Sony, et al., 2022; Dias et al., 2021). Although some work has already been done on the topic of Quality 4.0, there is no single clear path or methodology that can tell them how to proceed with the transition and be successful. So, frameworks for implementation of Quality 4.0, like maturity and readiness models or capability roadmaps can provide organizations with customized guidelines to assist their transitions and help ensure its suitability to their reality and long-term sustainability (Santos & Martinho, 2020).

This work proposed to demonstrate the application and empirical validation of the Capability Roadmap towards Quality 4.0 developed by Dias (2021) and to understand if it could serve as a basis for the development of a customized strategy for the Quality 4.0 transition of three case studies. The model was found adequate and allowed a broad evaluation of the current state of three very different organizations - one service organization, one textile industry and one tool manufacturer. Through the results of the model implementation, we managed to determine each organization's current readiness or maturity level and develop some strategic guidelines that could help them consolidate and continue their transition and advance through the model's levels. Thus, the two research questions we proposed ourselves to respond to were successfully resolved.

Nonetheless, the model was found to need some refining, particularly in the wording of some conditions that are currently too geared to the typical manufacturing industry and do not allow some room to adapt to different realities. So future work can pass through refining the model to accommodate a wider range of organizations and through further case studies.

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Appendix I – Informative Leaflet and signed Collaboration



Universidade do Minho
Escola de Engenharia

FOLHETO INFORMATIVO

Título da dissertação: Do conceito à aplicação: implementação de um *capability roadmap* e desenvolvimento de estratégias para a Qualidade 4.0

Curso: Mestrado em Engenharia e Gestão da Qualidade

Breve introdução sobre a investigação: Este estudo insere-se no âmbito da dissertação de mestrado em Engenharia e Gestão da Qualidade, que decorre no Departamento de Produção e Sistemas em conjunto com o Centro de Investigação ALGORITMI/LASI, na Universidade do Minho.

Objetivo do estudo: implementar, testar e refinar o *capability roadmap* para a Qualidade 4.0 e, com base nesses resultados, desenvolver estratégias para a implementação de projetos de Qualidade 4.0.

As principais fontes de dados serão entrevistas semi-estruturadas, a decorrer presencialmente na localização da empresa ou de forma virtual, bem como observação direta de processos e cultura organizacional da empresa participante, que serão gravadas e transcritas, sendo os ficheiros de áudio mantidos durante a realização da dissertação.

Também será realizada observação no local e serão recolhidos e mantidos apontamentos acerca da mesma.

Implicações da participação: a participação neste projeto é voluntária e implica a gravação e transcrição das entrevistas realizadas e a recolha de informação escrita, sendo os ficheiros de áudio e texto mantidos durante a realização do projeto e, posteriormente, arquivados.

Política de publicações futuras dos resultados da investigação: Excetuando autorização expressa das empresas participantes, a informação recolhida será mantida em confidencialidade por período de tempo a determinar, sendo quaisquer elementos identificadores removidos de quaisquer publicações futuras resultantes deste projeto, incluindo a dissertação.

Informações de contato do(s) investigador(es):

Ana Rita Silva Dias; pg28879@alunos.uminho.pt

Paulo Sampaio; paulosampaio@dps.uminho.pt

Assinatura do estudante: Ana Rita Silva Dias

Data: 14 julho 2023

Agreements



Universidade do Minho
Escola de Engenharia

Mestrado em Engenharia e Gestão da Qualidade

TERMO DE COLABORAÇÃO

(a) **Pedro Oliveira Almeida**, (b) **Manager da área de Incentivos** da empresa **BDO Advisory II S.A**, declaro colaborar na aplicação e recolha de dados da dissertação de mestrado “Do conceito à aplicação: implementação de um *capability roadmap* e desenvolvimento de estratégias para a Qualidade 4.0”, tal como descrito no folheto informativo disponibilizado, elaborada por Ana Rita Silva Dias, aluna nº PG28879, no âmbito da Tese de Dissertação de Mestrado do curso Mestrado Engenharia e Gestão da Qualidade, da Escola de Engenharia – Universidade do Minho.

Braga, 13 de Julho de 2023

(assinatura)

(a) Nome completo.

(b) Cargo/posição na instituição.



Universidade do Minho
Escola de Engenharia

Mestrado em Engenharia e Gestão da Qualidade

TERMO DE COLABORAÇÃO

(a) Marta Alexandra Ferreira d'Silva, (b) Responsável Qualidade
da empresa Borei-Matex e Condições SA, declaro colaborar na
aplicação e recolha de dados da dissertação de mestrado "Do conceito à aplicação:
implementação de um *capability roadmap* e desenvolvimento de estratégias para a
Qualidade 4.0", tal como descrito no folheto informativo disponibilizado, elaborada por
Ana Rita Silva Dias, aluna nº PG28879, no âmbito da Tese de Dissertação de Mestrado
do curso Mestrado Engenharia e Gestão da Qualidade, da Escola de Engenharia –
Universidade do Minho.

Rancelos, 20 de Setembro de 2011

Marta Silva
(assinatura)

(a) Nome completo.

(b) Cargo/posição na instituição.



Universidade do Minho
Escola de Engenharia

Mestrado em Engenharia e Gestão da Qualidade

TERMO DE COLABORAÇÃO

(a) PEDRO MANUEL CARLOS E. C. AZEVEDO, (b) DIRETOR GERAL

da empresa SNA Europe, declaro colaborar na aplicação e recolha de dados da dissertação de mestrado "Do conceito à aplicação: implementação de um *capability roadmap* e desenvolvimento de estratégias para a Qualidade 4.0", tal como descrito no folheto informativo disponibilizado, elaborada por Ana Rita Silva Dias, aluna nº PG28879, no âmbito da Tese de Dissertação de Mestrado do curso Mestrado Engenharia e Gestão da Qualidade, da Escola de Engenharia – Universidade do Minho.

Braga, 27 de Outubro de 2011


(assinatura)

(a) Nome completo.

(b) Cargo/posição na instituição.

APPENDIX II

Table 2 | The Capability Roadmap towards Quality 4.0

			Value Chain and Operations			Strategy and Organization			People and Culture		
			Customers	Products and services	Processes	Strategy	Integration	Innovation and Improvement	Role Transition	Organizational Culture	Leadership
Readiness	Digitization	3	Digitization of organization - customer interaction	Digitization of product/service specifications, available for remote stakeholder review	Digital and real-time access to processes and operations information	Digital platform for strategic coordination of Digital Transformation agenda	Digitization and centralization of organizational processes management documentation	Digital platform for managing grassroots for innovation and improvement initiatives and risks mitigation	Digital education and training platform for competencies acquisition	Knowledge repository in the organization	Leadership is responsible for managing the Q4.0 transition strategy and ensuring effective communication
	Process Integration	2	Customer integration in product/service lifecycle, specifications are discussed and reviewed at gates	Stakeholders integration along product/service lifecycle, specifications are discussed and reviewed at gates	Operational processes integrated within organizational processes	Integration of Q4.0 dimensions with the organization's Digital Transformation strategy	Integration of Q4.0 dimensions with the organization's Quality Management System	Innovation and improvement integration in organizational processes	Trainign plan towards digital competencies and new ways of work	Cross- functional cultural development initiatives focused on Q4.0	Leadership driving company wide effort for the recognition and understanding of Q4.0
	Stakeholders Interaction	1	Basic organization - customer interaction based on customer feedback	Products and services specifications are decided in the concept definition phase	Siloed, local and non-informalized operations management	Digital Transformation awareness	Intra and inter-organizational interaction for Quality initiatives definition	Basic improvement and innovation approaches based on corrective actions	Gap analysis of the current competencies and skills compared to the required ones	Associates engagement and empowerment	Leadership is responsible for associates engagement and commitment

Table 3 | The Capability Roadmap towards Quality 4.0 (cont.)

			Value Chain and Operations			Strategy and Organization			People and Culture		
			Customers	Products and services	Processes	Strategy	Integration	Innovation and Improvement	Role Transition	Organizational Culture	Leadership
Maturity	Intelligence	6	Customer data predictive analysis for product/service development and improvement	Integration of simulation techniques since concept definition phase and constant information feeds	Smart and predictive processes and operations, smart organizations	Analysis of the Digital Transformation strategy impacts in the organization for the exploration and definition of future scenarios	Decentralized networks	Predictive analysis to anticipate business environment changes	Personalized and self-directed education and training	Promotion of a Quality 5.0 culture: resilient, sustainable, and human-centered organization	Use of information quality for predicting decision-making outcomes
	Connectivity	5	Customer data integration across the active value network for product/service individualization and improvement	Data-driven decision reviews based on product/service data connected through the active value network	Connected and decentralized operations, virtual organizations	Strategy promotion through the active value network	Connectivity for real-time information sharing throughout the active value network	Collaboration with the active value network for innovation and improvement initiatives	Active value network connected for knowledge-sharing and to identify new training needs	Collaboration /Effective communication across the active value network	Shared quality ownership and leadership decentralization
	Automation	4	Automated organization-customer digital interaction	Automation to support specification follow-up, review, and validation	Automated processes and operations, both cyber and physical	Definition of appropriate levels of automation	Automated information flow across the organization	Automated and autonomous systems working collaboratively with humans (Human-machine interaction)	Use of technology to augment associates capabilities	Adaptation to new technologies and ways of working	The decision-making process is supported by automation and reliable information