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Ana Margarida Dâmaso Gomes Dias

A Capability Roadmap towards Quality 4.0

Universidade do Minho
Escola de Engenharia

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Trabalho efetuado sob a orientação do(a)
Professor(a) Doutor(a) Paulo Alexandre Costa Araújo Sampaio
Professor(a) Doutor(a) André Mendes Carvalho

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MODELO PARA A TRANSIÇÃO PARA A QUALIDADE 4.0

RESUMO

Á medida que a indústria evolui, os conceitos de qualidade são gradualmente adaptados. O uso de novas tecnologias tem o potencial de tornar as organizações mais inteligentes e adaptáveis e as abordagens de qualidade são essenciais para atingir esses objetivos. Ao mesmo tempo, a tecnologia permite o desenvolvimento de novas abordagens e ferramentas da qualidade, é uma situação de ganho para ambas as partes envolvidas. A Indústria 4.0 veio obrigar a uma adaptação por parte da qualidade. Esta nova era da qualidade, a Qualidade 4.0, marca a mudança das antigas eras através do uso de tecnologias para a transformação dos vários processos organizacionais, cultura, liderança e transição de funções. Através da revisão da literatura, foi possível entender que não existe um modelo que auxilie as organizações a preparar a transição para a Qualidade 4.0. Deste modo os objetivos desta dissertação passam pela contribuição para a investigação sobre o tema Qualidade 4.0 através de todo o trabalho de pesquisa que envolveu, assim como, o objetivo principal passa pela criação de um modelo de capabilidade que auxilie as organizações a entenderem a posição em que encontram nesta transição e também servir de guia para que tenham a perceção dos níveis a atingir e do caminho a seguir para os atingir. Para a elaboração do “Quality 4.0 Capability Roadmap”, foi analisada a literatura existente sobre os temas relacionados com Qualidade e Indústria 4.0, bem como modelos relacionados com qualidade no contexto da Indústria 4.0. Posteriormente à criação do modelo, este foi avaliado por especialistas na área. Como resultado, o “Quality 4.0 Capability Roadmap” apresenta três dimensões principais - Cadeia de valor e operações; Estratégia e Organização; Pessoas e Cultura - dividida em três subdimensões cada e seis níveis de preparação e maturidade - Interação com as partes interessadas; Integração de processos; Digitização; Automação; Conectividade; Inteligência - para ajudar as organizações a atingir o nível de capabilidade pretendido nesta transição. O modelo foi desenvolvido para uma transição sustentada em que os níveis mais fundamentais de qualidade são atingidos primeiro e só então as organizações devem avançar até atingirem níveis de inteligência.

PALAVRAS-CHAVE: Gestão; Indústria 4.0; Operações; Pessoas; Qualidade; Transição.

A CAPABILITY ROADMAP TOWARDS QUALITY 4.0

ABSTRACT

As Industry evolves, quality concepts also gradually change. The use of new technology has the potential to make the organization more intelligent and adaptable. Quality approaches are essential for achieving these goals, and technology enables the development of quality approaches, it's a win-win situation for both parties involved. Quality was compelled to adjust as a result of Industry 4.0. Quality 4.0, the next age of quality, symbolizes a change from previous eras by integrating technology into numerous organizational processes, culture, leadership, and role transition. The literature review revealed that there is no model to assist organizations in preparing for the transition to Quality 4.0. Thus, the goals of this dissertation are to contribute to the investigation of the Quality 4.0 topic through all of the research work that was done, as well as to create a capability model that will help organizations to understand where they are in this transition and serve as a roadmap for them to see what levels need to be reached and how to get there. The current literature on Quality and Industry 4.0, as well as models related to quality in the context of Industry 4.0, were analyzed for the development of the "Quality 4.0 Capability Roadmap." Then, experts reviewed the model once it was developed. As a result, the "Quality 4.0 Capability Roadmap" presents three major dimensions - Value Chain and Operations; Strategy and Organization; People and Culture – divided into three subdimensions each and six levels of readiness and maturity - Stakeholders Interaction; Process Integration; Digitization; Automation; Connectivity; Intelligence - to assist organizations in achieving the required level of capability in this transition. The model is developed for a sustained transition in which the most fundamental levels of quality are reached first and only then advance to levels of intelligence.

KEY- WORDS: Human-oriented; Industry 4.0; Management; Operations; Quality; Transition.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AM	Additive Manufacturing
AR	Augmented Reality
BD	Big Data
COBOTs	Collaborative Robots
CPS	Cyber-Physical Systems
CRMS	Customer Relationship Management systems
DLM	Digital Lean Manufacturing
DQM	Digital Quality Management
DR	Diminished reality
DT	Digital Twin
EQMS	Enterprise Quality Management Systems
I4.0	Industry 4.0
I5.0	Industry 5.0
IT	Information technologies
IoT	Internet of Things
KPIs	Key Performance Indicators
ML	Machine Learning
MR	Mixed Reality
OT	Operational Technologies
PLC	Product Life Cycle
PPE	Personal Protective Equipment
Q4.0	Quality 4.0
QMS	Quality Management System
QR code	Quick Response Code
R&D	Research and Development
RFID	Radio Frequency Identification Technology
RPA	Robotic Process Automation
S5.0	Society 5.0

SPC	Statistical Process Control
TQM	Total Quality Management
VCI	Virtual Customer Integration
VoC	Voice of the Customer
VR	Virtual Reality
XR	Extended Reality

1 | INTRODUCTION

The industry sector is a building block of the global economy and is key for societal progress. Industrial innovations allow the transition to a new level of development (Popkova, Ragulina, & Bogoviz, 2019). Ever since the beginning of industrialization, companies have and are still going through industrial revolutions. While previous eras technology did not have the same nature and magnitude as today, people have always been dependent on it.

Better, faster, inexpensive, and more informative technologies development enabled rapid advances in business models. Cost reduction and an organization's ability to constantly give customers high-quality products to meet their needs, contribute to business competitive advantage in order to survive and expand. However, technology is not the only element in a broader transformation. Supported by the development of smart technological solutions, organizations must be able to improve efficiency, effectiveness, satisfaction, and empower the existing human capital to continuous learning and adaptation. Quality 4.0 (Q4.0) combines quality management practices with technological tools that can become critical factors for organizational success in such organizational transformation (Sader, Husti, & Daroczi, 2017; Küpper, Knizek, Ryeson, & Noecker, 2019; Ralea, Dobrin, Barbu, & Tănase, 2019; Sony, Antony, & Douglas, 2020; Armani, de Oliveira, Munhoz, & Akkari, 2021).

For sustainable business and organizational progress, quality is key. In this scope, Quality 4.0 is key. Companies combining quality with technology can take advantage of real-time data and Big Data (BD) analytics, implement innovative products and processes successfully, incorporate emerging technologies and materials, and identify how to fulfill needs and requirements efficiently, and redefine them (Carvalho, Sampaio, Rebentisch, & Saraiva, 2019; Carvalho, Sampaio, Rebentisch, & Oehmen, 2020). An holistic integration of quality across an organization supports the application of these benefits in different areas such as finance, marketing, design, operations, supply chain, customer interactions, and innovation (Evans et al., 2015).

Despite all opportunities, the exponential growth of digital transformation brings considerable barriers to its adoption. Information quality is valuable for efficient decision-making; flexibility and agility become critical, as does the adoption of new technologies. But these changes demand new organizational competences and capabilities. New business approaches to deal with economic, human, and technological aspects are necessary, so it is essential to reshape risk and overall business management (Maier, Moultrie, & Clarkson, 2012; Carvalho et al., 2019; Gunasekaran, Subramanian, & Ngai, 2019).

Likewise, traditional quality methods and tools are required to be improved to make the connection between quality excellence and new era technologies.

The pursuit of excellence in the current disruptive digital transformation has an important role to play in the organizations of the future. In this scenario, the transformation process is key. In order to achieve a successful Q4.0 transition, organizations need to understand the concept and its importance together with a clear and structured way. In this project, a capability roadmap approach is proposed. Capability models provide the evaluation of the ability to perform or achieve certain actions or outcomes considering several stipulated criteria (Maier et al., 2012). Roadmapping consists of defining a clear path to use such resources to meet a set of objectives or ambitions. The notion of a roadmap is closely linked to technology. Roadmaps are widely used to help align future technology needs and articulate the research and development steps needed to meet them. Capability roadmaps detail the definition of basic resources to meet the organizational needs and how they can be developed, rather than just defining which routes by which the goals will be achieved. Besides, they provide a rational strategy and set of actions to ensure that capabilities are adequate to meet general ambitions and goals (Schumacher, Nemeth, & Sihn, 2019).

The literature on the assessment of the Q4.0 capabilities in the Industry 4.0 (I4.0) context is highly lacking (Chiarini, 2020; Glogovac, Ruso, & Maricic, 2020). The literature review of this dissertation sees its main objectives in the inclusion of a comprehensive analysis of the current state of research of Q4.0 and I4.0, identifying potential success factors and dimensioning Q4.0 to contribute to the definition of this concept and its importance.

Furthermore, the Quality 4.0 Capability Roadmap aims to serve academic researchers and professionals that wish to explore and promote Q4.0 capabilities as well as organizations that are (or aim to be) involved in the digital transformation journey. Initially, the framework can be viewed as a diagnostic tool of the organizational capability level in the transition for Q4.0. Then, a roadmap approach assists organizations to reach higher levels of improvement and consequently evidence greater readiness and progress for the digital transition. The concept of continuous improvement will be transversal to the whole model. Therefore, it is expected that it not only guides, but further motivates organizations to advance their Q4.0 capabilities.

The key research question of this project is: what is the role of quality in the digital transformation process? In order to answer it, a literature review and capability roadmap design process are used. The methodology is first described in section 2. In the following section, a literature review of I4.0 and Q4.0 dimensions and the current state of awareness and development are presented. Additionally, the identification and discussion of existing models related to quality in the I4.0 context is performed. In section 4 the conceptual and critical content related to the Quality 4.0 Capability Roadmap is defined. Finally, in section 5 the conclusions about the main findings are presented and future work is outlined.

2 | METHODOLOGY

There is no one-size-fits-all approach to creating a capability roadmap. However, detailed resources are frequently described in a taxonomy structure that helps with further mapping and explains the link between capabilities and practical actions to access them (Eagar, Ross, & Kolk, 2013). The framework methodology used to develop the Quality 4.0 Capability Roadmap is based a Schumacher et al. (2016) study methodology, also used by Armani et al. (2021). The methodology encompasses three distinct stages. The first stage entails obtaining a broad understanding of the subject. This exploratory study is followed by the framework design and architecture and, the model validation is the last stage.

In the first stage, a comprehensive literature review of Q4.0 was conducted, as well as a review of maturity models and readiness assessment tools as a starting point for the model's development. A narrative literature review was developed to allow a broad understanding of the Q4.0 subject through the research and review of the published body of knowledge. This type of review is used to interpret, summarize, or synthesize what has been written on a subject or issue in a qualitative way (Green, Johnson, & Adams, 2006; Paré, Trudel, Jaana, & Kitsiou, 2015). The narrative literature review process can be divided into three generic steps: literature search and screening; data extraction and analysis; and writing the literature review (Levy & Ellis, 2006).

Journal articles, conference proceedings, and books, reports, and materials from major quality societies, such as the American Society for Quality, were considered for review. For that, the databases used to collect the information sources include Scopus, and Web of Science; complementary, Google Scholar was also used. The references of selected articles were also used to expand the selection process. For this work, only English and Portuguese languages literature were considered. Since a few articles are identified on Q4.0 per se, the literature search was carried out based on a broad search string, identified in Table 1. All sources with substantively relevant content were included in the review after an initial screening analysis. The final content analysis provided us with a wide understanding of the topic as well as the ability to group information by key categories.

The search was conducted to have broad knowledge of the topic and maturity models and readiness assessment tools were also reviewed as a starting point for the Quality 4.0 Capability Roadmap conceptual development. The comparison of existing models was focused on those highlighting organizational capabilities. According to Maier et al. (2012), organizational capabilities entail the skills, abilities, and expertise of an organization and will be considered in the present study. The studies specially focused on the technical performance of new technologies and systems were excluded. Thereafter, the identified models were analyzed, categorized, and compared (Table 2). The detailed review of existing models helped to define the relevant concepts to build the model structure such as methodology, dimensions, levels, roadmap decision points, and assessment tools. The analysis of dimensions was also considered as a starting point for conducting the model design.

TABLE 1 | SEARCH STRING DEFINITION

"Quality 4.0"	-	"Quality 4.0"
"Quality" OR "Quality Management"	AND	"Digital" OR "Digital Transformation" OR "Fourth Industrial Revolution" OR "Industrial Revolution" OR "Technology"
"Industry 4.0"	AND	"Digital Quality" OR "Quality" OR "Quality Approaches" OR "Quality Assurance" OR "Quality Control" OR "Quality Culture" OR "Quality Management" OR "Quality Principles" OR "Quality Tools"
"Industry 4.0" OR "Quality 4.0"	AND	"Maturity Model" OR "Maturity Assessment" OR "Readiness Assessment"

In a next step, the Quality 4.0 Capability Roadmap was then created, based on the architectural design and presentation style of the studied models, the number of dimensions, number of subdimensions, maturity items, and number of maturity levels. The literature review was also taken into account while defining the model content.

Once completed the model development, the expert panel approach was used to validate the model. An expert panel's purpose is to provide a reliable method for obtaining impartial and scientific-based opinions from a domain experts (Nan, Hall, & Barker, 2008). As a result, based on the expert's knowhow, it is feasible to evaluate the model's scientific rigor, coverage, representativeness as well as usefulness and usability (Wagire, Joshi, Rathore, & Jain, 2020). In this way, it will be possible to understand the key aspects of the model, while also determining what should be reviewed or reconsidered.

In Chapter 4, these two stages will be addressed in greater detail.

3 | LITERATURE REVIEW

3.1 | INDUSTRY 4.0

Over the past centuries, industry has made significant progress. The First Industrial Revolution ensured the transition from manual production processes into mechanization systems. It has occurred between the end of the eighteenth and early nineteenth centuries and is connected to the invention of the water pump and the steam engine. This revolution allowed the establishment of industrial production and a consequent productivity increase progresses in logistics, scientific developments, and societal changes. The late nineteenth and early twentieth centuries marked the Second Industrial Revolution, which arises from the discovery of electricity and developments of machinery for mass production. Subsequently, in the last half of the twentieth century, the Third Industrial Revolution started. Progresses in automation and microelectronic technology led to a global production based on digital technologies and the use of intelligent objects begun (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014; Xu, Xu, & Li, 2018; Popkova et al., 2019; Sanchez, Exposito, & Aguilar, 2020).

Then, in 2011, a German strategic initiative introduced the term I4.0, which was advanced in connection to a possible Fourth Industrial Revolution (Kagermann, Wahlster, & Helbig, 2013). This new revolution, based on better-connected and intelligent ecosystems at both intra- and inter-organizational, was proposed as large-scale industrial transformation that faded the boundaries between physical and digital systems. In this scope, the term digital transformation was also advanced in relation to this new industrial revolution, as it likewise refers the use of digital and disruptive technology to transform the entire value chain, business model, and organizational as well as management aspects in order to meet its strategic objectives, build capabilities and enhance agility (Cots, 2018; Herceg, Kuč, Mijušković, & Herceg, 2020).

The smart factory is one of the fundamental concepts which are considered the key of I4.0. It is characterized by a highly digitalized, connected, autonomous, intelligent and dynamic environment. Machinery and equipment are data-driven, incorporate smart technology, and are able to improve processes through automation and self-optimization. Furthermore, smart factories converge information technologies (IT) and operational technologies (OT) by connecting the digital world of IT with the physical world of OT (Pollak, Hilarowicz, Walczak, & Gasiorek, 2020).

Cyber-Physical Systems (CPS) represent the combination of the physical and digital levels within the organization. A feedback relationship and embedded interactions provides information between physical and digital systems (Forero & Sisodia, 2020; Sony et al., 2020) thus allowing the adoption of decentralized systems. Instead, the interactions between the components of a system establish the coordination to achieve global goals. The decentralization of systems also encompasses their individualization in the distribution, procurement, and development of products and services.

Smart products represent another side of I4.0. This concept is related to products that change characteristics under external stimuli or are embedded with intelligence. As an example, products embedded with sensors and processors can provide feedback about the customer experience. Such a level of interaction with the customer allows organizations to better understand needs and expectations of their customer, and thus work to satisfy them. Furthermore, it allows with customer co-creation processes, contributing to the growing custom manufacturing trend (Lucke, Constantinescu, & Westkämper, 2008; Qin, Liu, & Grosvenor, 2016; Roblek, Meško, & Krapež, 2016).

Higher levels of efficiency and productivity can be reached at a lower cost, and it is possible to create a dynamic distribution of value chain activities as customer-specific production arises through the connectivity and communication between people, machines, and objects (Xu et al., 2018; Sanchez et al., 2020; Armani et al., 2021). As a result, the expected economic impact of the Fourth Industrial Revolution is very high. Industry 4.0 systems have the ability to self-plan and self-adapt, providing increasing operational efficiency, greater flexibility, and adaptability, opening the door for fulfilling customized customers' requirements together with the development of new business models, services, and products. However, I4.0 has not yet been widely implemented and several industries are in the testing and development stage (Kagermann et al., 2013; Salkin, Oner, Ustundag, & Cevikcan, 2018; Pollak et al., 2020).

Industry 4.0 requires that organizations have a formal strategy regarding digitalization benefiting from the technology and systems for optimal results. In order to create an efficient and viable strategy, understanding the drivers for the transition is mandatory. Not only technologies make this transition, but still, organizational change is also important. Thus, topics such as expertise acquisition, leadership, protection of know-how, standardization strategies, the security of networked systems, sustainability, research, and innovation should be considering when implementing I4.0 infrastructure – most critically, should be harmonized through the whole organization (Salkin et al., 2018; Herceg et al., 2020; Armani et al., 2021).

3.2 | QUALITY 4.0

As Industry evolves, quality concepts also gradually change. When organizations started to produce in large volumes, inspection became a must procedure to achieve product quality. The need for inspection was then minimized by the advancement of statistical models and data analysis; this was a lead-off for the start of planning, improving, and control processes performance which rapidly expanded to all organizational levels. Recently, due to information technology, electronic commerce, and global communication, new business capabilities changed the way society works and lives. Such changes also affect the way we think, measure, and manage quality, and organizations are taking advantage of it. The great amount of information and its accessibility increased the speed and reliability of decision-making and the decreasing cost of technologies led to improvements in both products and processes (Radziwill, 2018).

Digital transformation, I4.0, and Q4.0 concepts are interconnected. While digital transformation refers to the integration of emerging technology for connection, intelligence, and automation, with or without specific quality and performance objectives as drivers, Q4.0 matches this concept by using traditional quality methods and digital tools to accomplish quality objectives and pursuit performance excellence. Quality 4.0 can be considered an I4.0 approach that prioritizes quality and performance goals looking at how individuals, systems, and emerging technologies interact to improve connectedness, intelligence, and automation (Radziwill, 2020). Therefore, Q4.0 is considered an integral part of the I4.0 phenomenon, one which opens the way for quality to become a leading force in this transition (Aldag & Eker, 2018; Radziwill, 2018; Küpper et al., 2019; Zonnenshain & Kenett, 2020).

Rowlands & Milligan (2021) explore the perspectives of I4.0 and Q4.0. For the authors, the main focus and key driver for I4.0 is the technology, and Artificial Intelligence (AI) representing its main enabler. In contrast, Q4.0 has its driver on the customer, and sees technology as the enabler. Moreover, I4.0 evolves from automation to smart manufacturing, whereas Q4.0 goes from process to a customer-centric approach. In line with this, Salimova et al. (2020) emphasize that Q4.0 can be defined as the adaptive capacity of a product at any stage of its life cycle to meet the needs of customers, taking into account the interest of other stakeholders along the value chain. Also, Küpper et al. (2019) outline Q4.0 as the application of I4.0's digital technologies to quality management. From a broader viewpoint, Q4.0 can be seen as a new method by which digital tools can be used to drive improvements across the value chain (Sony et al., 2020).

Despite this perspectives, technology is not the only element in the transformation towards quality 4.0 (Küpper et al., 2019). In this sense, Jacob (2017) emphasizes that Q4.0 should be considered as a large-scale transformation with implications on culture, leadership, collaboration, and compliance. Radziwill (2018) adds that new era technologies should be used as catalysts of people, products, processes efficiency, performance, and innovation. The author emphasizes that the improvement of human capabilities, the evolution of human-machine interaction and relationships, and the shifting organizational boundaries opens the way to an agile Q4.0 transition. Similarly, Souza et al. (2021) emphasize that both technology and people must be involved in the I4.0 transition process based on total quality. The authors argue that this can be achieved through development of the Total Quality Management (TQM) 4.0 environment consisting of the convergence of I4.0, TQM, and quality control.

As described above, there are several viewpoints for the definition of Q4.0. The next subchapters will discuss in greater detail the dimensions that make up this concept.

3.3 | DIGITAL QUALITY

Quality management has benefited greatly from the use of digital technologies, and there are still many opportunities for progress if this direction is followed (Cots, 2018). Simpler examples include the transformation of quality records into digital files and databases, the transition to electronic work orders, and even documents generated and stored online (Cots, 2018). However, digital quality is more than just paperless organizations. The use of emerging technology has a variety of advantages for quality management. The majority of products, services, and processes can be controlled in an automated way and throughout the value chain. Smart machines, factories, and operator armed with Augmented Reality (AR) 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 (Sader, Husti, & Daróczi, 2019; Lim, 2020). Accordingly, people, machines, and data are all linked in new and insightful ways bound by technology. These links 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).

A new way of quality, digital quality, will bring a new level of interaction, production, products, and services (Lim, 2020); and the variety of technologies supporting these changes is broad. In order to better understand these technologies and their effect on quality, it have been clustered in four themes: connectivity, cybernetics (digitization and automation), data management, and simulation technologies.

3.3.1 | CONNECTIVITY

Industry 4.0 connects people, machines, and systems, often aiming to create closer relationships with customers. From the point of view of quality management, connectivity technologies - and most importantly, the interaction and integration that they allow - offer several opportunities.

Interaction with the customers gains reinforced attention in an ever-connected world. Technologies to support 24/7 Voice of the Customer (VoC) services present an interaction pathway (Lim, 2020). They may include but are not limited to call centers, automated online assistants, or chabot's. Furthermore, sensors which are built into the product are an example of obtaining customers' feedback after using the product as they work discreetly which facilitates authentic user behavior. Monitoring product usage data in the customer's hands after the sale can augment the traceability of defective products or streamline the diagnosis of potential failures before they occur, enabling to fix problems before a breakdown together with the upgrade of customer experience (Küpper et al., 2019).

While these examples relate more to customer and after-sales services (Carvalho et al., 2020), in the new concept of industry customer experience includes the participation in the design and development of the products/services (Radziwill, 2018; Mckendrick, 2020). Virtual Customer Integration (VCI) is an example of a collaborative system that allows customers to provide their 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, Füller, Mühlbacher, & Ernst, 2012). Accordingly, increased connectivity promotes quality management along the entire Product Life Cycle (PLC).

Each step may be redesigned in order to guarantee a closer relation with the customer, and compliance with the specified requirements is increased. Another example where the barriers between organizations and customers have been reduced is that of Customer Relationship Management systems (CRMS), where new technologies simplify access to all relevant customer information so that each customer can receive personalized treatment which can lead to a higher level of customer satisfaction. The most used CRMS currently available are Siebel, PeopleSoft, and Genesys, Salesforce; or cloud solutions like Microsoft CRM (Nettleton, 2014). Customer-organization interaction improves the relationship with the customer, and improves the organization's image by showing its concern and openness towards its consumers (Bodi, 2020).

In every step of the process, the integration of quality data from the customers/market and that from the manufacturing process should be connected. The understanding and translation of the customer's needs and experiences into functional and measurable technical specifications of the product are essential for product design, development, and improvement. The planning phase should also include measures that deal with the detection and prevention of several potential failures and their effects. Several well-established methods guarantee this aspect on a virtual level, such as software developed for this purpose as Qualica Planning Suite, Rektron FMEA, PTC Windchill FMEA, Byteworx FMEA (Wang & Shih, 2013).

In this context, customers can track and monitor in real-time their order and ask for changes live. Product customization is progressively preferable to mass production. New methods of consumption are largely based on the speed of design, production, and delivery. Park et al. (2017) emphasize that identifying customers' demand is a key factor, but speedy production is also an important factor for an organization to satisfy customers and survive. Service quality is also seen as an increasing dimension. The improvement of the customer experience has received greater attention in the field of quality. Attributes such as price, physical quality, or appearance are not the only ones valuable to meet and exceed the customer's expectations. The emotions involved in the process are valued, so personalized service is highlighted. The easy choice of the product or service also contributes to the reinforcement of personalized service and customer enchantment by the organization to make a difference between competitors (Sampaio & Saraiva, 2016; Carvalho et al., 2019).

Depending on the need for organizational autonomy and quality management strategy, different types of integration approaches exist: horizontal, vertical, and end-to-end integration systems. In horizontal integration, quality planning, control, and improvement are connected and can be used to share information across the organization's functional areas. As a result, new business models can be developed. Vertical integration includes quality planning, control, and improvement in a self-automated and organized mode by transferring data diagnosis from the shop floor straight to decision-makers or the opposite. End-to-end integration focuses on quality planning, control, and improvement of the several phases of the product life cycle (Sony et al., 2020).

Furthermore, Quality 4.0 contributes to connectivity throughout the value chain by knowledge exchange, collective decision-making, and collaborative problem solving (Armani et al., 2021). Connecting people (customers, stakeholders, and employees), machines, devices, products, services, and processes, gives the organization agility to adapt in a fast way to market trends, reduce failures and rework, increase productivity, optimize the reliability of the devices as well as drive innovation (Verhoef et al., 2017; Ralea et al., 2019; Armani et al., 2021). Radziwill (2020) emphasizes the importance of a networking system that incorporates both physical (internet infrastructure, Wi-Fi, and cellular networks) and conceptual (policies, procedures, protocols, and formats) communications to connect people, objects, and data. The networking system enables users to exchange information, transfer data, make decisions, and communicate in ways that help them accomplish their business goals collectively. Intra-organization, there are already digital tools that simplify information sharing. The usage of Apps facilitates the accessibility and visualization of processes, services, as well as encourages individual contributions in data analysis to avoid risks, suggest solutions, and adopt measures to increase efficiency (Jacob, 2017).

3.3.2 | CYBERNETICS (DIGITIZATION AND AUTOMATION)

Cybernetics is concerned with systems and their regulation (Beer, 2002). As physical and digital systems become increasingly embedded, cybernetics supporting technologies play an important role structuring, controlling, and regulating the interaction of development and manufacturing systems. As the business environment is increasingly reliant on CPS, digitization and automation become key for improved quality.

Here, it is important to understand that these technologies do not have the purpose of total replacement of human work. Instead, they should be used to collaborate and augment human capabilities. In nonconformity management, quality control, process monitoring, dispatching, and manipulation, some examples of such technologies include Collaborative Robots (COBOTs), AR linked to smart devices, and Quick Response Code (QR code) or Radio Frequency Identification Technology (RFID) (Carvalho et al., 2020). In addition, Personal Protective Equipment (PPE) like screens, smart glasses, gloves, and watches, as well as drones can monitor and alert the worker exposure to hazards such as environmental risks, emergency conditions on machinery, and also potential overburdening of physical or cognitive capabilities. When connected to a network, these wearables can automatically inform other workers in proximity to provide an early warning and also, report a real-time alert to a central software system for corrective and preventive interventions (Carvalho et al., 2020; Radziwill, 2020). Moreover, visual tools are user-friendly, familiar, and intuitive which becomes quite appealing to workers and operators engaged in activities (Rolfsen, Lassen, Mohamed, Shakari, & Yosefi, 2019). Workstations, tablets, smartphones, AR devices, and wearables can all access this data. Therefore, the cost of quality is minimized, as production defects will be detected early and the root causes will be analyzed and resolved in advance (Sader et al., 2019).

A work instruction is an important aspect of quality control since it ensures that staff and equipment recognize and obey the proper protocols to produce quality results. As an example, a checklist displayed on-screen can be useful for the operator do not to forget any step in the process. However, work instruction must be modified or give new ones each time minor changes in a product model occur. Many are now widely available on a manufacturing line. An RFID tag attached to a component or product can be read automatically as a product model moves through an assembly line, uploading visual work instructions on electronic screens in real-time. Thus, feedback provided by real-time quality data can ensure a dynamic work instructions update (Lim, 2020). Furthermore, digital panels give visibility to data such as Key Performance Indicators (KPIs) and quantities ordered and received, providing assessment to quality risks along the supply chain and deploying resources as needed (Kupper et al., 2019).

Image recognition technology has been used to guarantee industrial quality incorporated in production chains. A simple, inexpensive camera supported by AI features can monitor and extract useful information for quality management. Also, when nonconformity is detected, a voice-recorded report and a photograph are prepared on-situ, documenting that error (Cots, 2018). The "pick by light" process, where product separation is carried out according to a color code as well as the use of gloves equipped with barcode readers are examples of I4.0 technologies (Küpper et al., 2019). The use of sensors and inspection technologies in real-time allows the instant detection of defective products at all stages of production. These applications provide the decreasing of human error probability and thus make the process more reliable along with the reduction of poor-quality products.

Process quality can be improved with the use of greater automation. One example is Robotic Process Automation (RPA). RPA contributes to the elimination of operational risks when standardizing operations and processes. Automating routine processes and mitigating operational risk can reduce variability, leading to superior performance, cost savings, and higher quality (Jovanović, Đurić, & Šibalija, 2018; Mendling, Decker, Reijers, Hull, & Weber, 2018). However, Radziwill (2020) explains that the required level of automation for each process and how people, machines, and intelligent agents can collaborate must be consider. Humans have traditionally performed tasks that involve intelligence or higher-level thinking, while computers may perform routine or rule-based tasks. Some examples when automation must be considered are when the goal is to achieve operations that aren't possible to complete manually; to improve complex processes that are otherwise slow, labor-intensive, or error-prone; and to increase safety by delegating more dangerous tasks to robots and nonhumans. Among these benefits, there are some advantages of not automating. For example, if products are new or highly customized, production resources are costly and constantly changing, demand is unpredictable, or distribution is required quickly, it may be too complex to deploy automated processes in a limited period of time.

Additionally, bidirectional data flow between machines, equipment, systems, and virtual models open up great potential for decision support at the machine and shop floor level for short-term decisions

(Bodi, 2020). Due to the detection technologies and advanced analytical resources, measuring and predicting the quality of systems and products is possible (Ebrahimi, Baboli, & Rother, 2019). The traditional machine control and equipment involves stopping these for human intervention. Digital quality involves smart sensors which will do self-calibration and self-adjustment, and intelligently communicate with the system and humans when they need helps. Additionally, to improve production systems, machines can submit early updates for predictive maintenance to prevent downtime or system failure. Furthermore, a semiautonomous and real-time quality audit is now possible through real-time production information. An accurate quality audit report can be generated by the system to check how work is performed in each station. Also, real-time quality data allows auditors to see the particular problematic process and identify the exact position of the problem source much more easily and precisely. Moreover, real-time communication and analysis allow feasible risk management approaches (Lim, 2020).

At the same time, intelligent quality control systems decrease the use of traditional techniques such as Statistical Process Control (SPC) (Vandenbrande, 2019; Carvalho et al., 2020). However, the SPC can focus on controlling a system from an organizational management perspective as opposed to controlling isolated processes. Moreover, digital solutions which collect information in real-time, provide SPC in real-time (Costantino, Di Gravio, Shaban, & Tronci, 2015; Urban & Landryová, 2015). Automated process optimization in real-time can be achieved by calculating and implementing ideal process parameters to increase efficiency (Oditis & Bicevskis, 2010; D'Addona & Teti, 2013).

A detailed monitoring and in-depth observation of the manufacturing cycle in real-time allows proper corrective and preventive interventions based on empirical data. Thus, makes the activities related to quality inspection more efficient because allows determining the precise cause of the defect. Therefore, allows preventive actions to be taken immediately leading to a fast reach of high performance and reducing overall production costs (Lim, 2020). Also, improved environmental, health, and safety results and conditions can be seen, leading to increased employee capability or capacity. Leadership and governance are also improved as a result of improved decision-making capabilities. All of this contributes to better financial performance, increased capacity to achieve strategic goals, and increased innovation.

In addition to virtual simulation, physical models can also be obtained. In the simulation or modeling phase, a prototype is obtained by traditional manufacturing or Additive Manufacturing (AM), as known as 3D printing. Prototypes are considered a real truthful copy of the final project and are tested in different scenarios to validate products or systems. This way allows the validation of the product or system models, and many misunderstandings and failures are avoided as well as it is possible to find design alternatives to improve the quality, reliability, and safety of the project (American Society for Quality [ASQ], 2020; Carvalho et al., 2020).

3.3.3 | DATA MANAGEMENT (COLLECTION & ANALYSIS)

Nowadays, data-driven systems generate diverse data and diverse viewpoints to develop a deeper understanding of the problems in every context (Zonnenshain & Kenett, 2020). This represents both an opportunity and challenges for evidence-based decision-making, as data comes from a large amount of internal and external sources – thus labelled as "big data".

Many of the technologies discussed in the previous section are responsible not only for collecting and feeding information forward and backwards, but also for storing it in integrated databases, making widely available, and often, analyzing it. Obtaining data in real-time is possible not only from machines or automated workplaces but also from technological equipment, transport, warehouse, and auxiliary systems (Aleksandrova, Vasiliev, & Alexandrov, 2019). Moreover, data processing as close to the point of capture as possible can minimize costs and reduce the data volume of the system. In addition, data lakes protect organizations from losing knowledge when employees leave as the data can be able to track or access when stored in private or limited-access repositories. Also, it is important the definition of rules, policies, processes, and roles manage data and protect the know-how (Radziwill, 2020).

Several technologies, such as cloud computing and Internet of Things (IoT), contribute to the scalability by supporting data volume, by collecting data from users, devices, and partners on a global scale, extending control beyond the four walls of the factory (Cots, 2018). Blockchain is a transformative technology that allows for a secure, decentralized, and fully reliable registration system (Pilkington, 2016). Thus, has the potential to improve data quality and the quality of transactions as well as contributes to transparency, auditability, and trust. Blockchain technology provides through the value network a common source of truth for event and transaction data while allowing data producers to retain ownership and control over their data (Radziwill, 2020). Furthermore, using the blockchain to register, can reliably resolve the issue of registering evidence (Cots, 2018).

According to Jacob (2017) is important to manage five data elements: Volume - organizations must have a system or repository of stored data, for example, so-called data lakes; Variety - data systems include structured data is highly organized, unstructured data is unorganized and semi-structured data that has had structure applied to it but is unstructured; Transparency - a good data system should include both structured and unstructured data and collected data must be easy to work on it; Velocity – connected devices transmit data at a higher velocity, real-time data collection led to an increase of the efficiency of quality supervision; Veracity – high-quality data and trusted sources are essential for decision-making. Low veracity, can be due to fragmented systems and lack of automation.

Despite the importance of enlarging one's data collection capabilities, the true benefit for companies lies on the ability to use it correctly, ensuring value for an organization. The volume of data, per se, does not ensure superior results for an organization, nor do the variety and velocity with which they are collected. Instead, the true benefits come from the ability to generate value from that data. (Carvalho et al., 2019). Accordingly, Radziwill (2020) argues that analytics are the right way to make data-driven decisions. Advanced analytical capabilities are used to process large amounts of data and convert them into accessible information, which allows to performance of tangible metrics and can be used to improve and refine actions (Zonnenshain & Kenett, 2020). Data analysis decodes the insights captured in the data using the application of statistics, Machine Learning (ML), high-performance computing, predictive modeling, correlations and pattern recognition, neural networks, among others (Miloslavskaya & Tolstoy, 2016; Kibria et al., 2018; Armani et al., 2021).

According to Delen & Ram (2018), there are four types of data analysis: descriptive, diagnostic, predictive, and prescriptive. The descriptive analysis describes what has already happened or is in the process of happening. Professionals commonly use descriptive analysis for business analytics as this type of data analysis can uncover patterns or anomalies, and by presenting data in the form of charts and graphs, decision makers can make informed decisions. Some examples include scorecards, descriptive statistics, histograms, and Pareto charts. Diagnostic analytics uses data to define the most significant variables or features, identify causal relationships and uncover root causes to reveal why anomalies or patterns have emerged. Design of experiments, root cause analysis, clustering detection, and text mining are some diagnostic analysis technics.

In turn, the predictive analysis uses statistical models and forecasting techniques to understand the future. Predictive analysis can be the basis of deployment, control, and analysis of failures and elimination and prevention of accelerated deterioration through the implementation of countermeasures against weak points of machines. It is also associated with the implementation of new maintenance techniques, the definition of maintenance standards and best practices as well as plan a maintenance system. Efficient analysis of equipment information can be analyzed to predict and prevent possible failures related to its operation, making intelligent maintenance automated (Alexandru et al., 2016). The most common techniques used for predictive analysis include regression, neural networks, SPC, and risk assessment. Dynamic predictive decision-making is based on historical data and information used to predict events and then real-time data is used to readjust these predictive decisions (Ebrahimi et al., 2019).

The prescriptive analysis uses optimization and simulation algorithms, rules, and knowledge to explore the outcomes. Prescriptive analytics algorithms help in human decision-making by failure prediction and providing a large number of solution options. Also, in automatic decision-making through ML by making independent decisions (American Society for Quality [ASQ], 2020; Sony et al., 2020). The use of deep learning is mostly useful when quality control cannot be carried out effectively due to variation in the process. Though they can be useful in unsupervised learning to identify patterns, data dimensionality reduction to simplify predictors, anomaly detection using different methods, supervised learning to learn from instances, and reinforcement learning to learn from experience, among other things (Radziwill, 2020).

Traditional quality methods also gain reinforced importance with the use and analysis of large volumes of data. As an example, Six-Sigma methodologies should be directed towards the creation of data criteria concerning process quality improvement and analysis. Thus, integrated with new technologies must support the use of BD as well as be expanded with the use of predictive analysis and multivariate analysis (Bossert, 2018). Another example of integration with Six Sigma methodologies is the use of Process Mining techniques in process improvement initiatives (Graafmans, Turetken, Poppelaars, & Fahland, 2020). Process Mining allows the collection of data from different processes, based on their event records. Its application results in an improved description of processes, products, and organizational systems. It allows creating a standard operating procedure to increase the efficiency and effectiveness of process improvement efforts. Consequently, it reinforces the vision centered on the processes, essential in improving quality, auditing, compliance, and risk management (Van Der Aalst, Van Hee, Van Der Werf, & Verdonk, 2010; Caron, Vanthienen, & Baesens, 2013).

Digital Lean Manufacturing (DLM) is an example of a descriptive, predictive and prescriptive analytics application. The DLM system relies on new data acquisition, integration, processing, and visualization capabilities to detect, fix, predict and prevent ambiguous parameters and avoid quality issues inside defined tolerance ranges. These capabilities lead to fostering substantial feedback loops for quality assurance and quality management digitalization (Romero, Gaiardelli, Powell, Wuest, & Thürer, 2019).

Despite the great contribution of technologies to data analysis, data management becomes a critical aspects for success. First, there is a deeply human dimension to BD, and the combination of human systems and technology is very significant in shifts detection, identification, and causes understanding. Also, a sensitive and customized data management approach is critical for recognizing customers' true demands and providing personalized service (Carvalho et al., 2019). Furthermore, the use of data should be handled carefully and with diligence in order to avoid unwanted consequences from customer-tailored offers based on the analysis of personal data (H. J. Watson, 2014). Second, a data management strategy needs to be built to address critical pain points across functions, maximize objectives for quality, and mitigate their risks (Jacob, 2017; Sony et al., 2020). Organizations need to ensure a solid basis for data quality assurance and perform a systematic collection and evaluation of analytical methods. Finally, smartness and cybersecurity become a strategic imperative in data-driven systems (Carreras Guzman, Wied, Kozine, & Lundteigen, 2020; Chronopoulos, Guzman, & Humberto, 2021).

3.3.5 | SIMULATION TECHNOLOGIES

A key technology linked to I4.0 is simulation. Modern industry builds virtual or physical models for products, systems, or functional processes. Simulation programs are used to assess the behavior and performance of new design products, processes, and services or improve the existing ones, without committing any resources (American Society for Quality [ASQ], 2020).

Digital Twins (DT) - virtual systems synchronized to a real physical system – are one examples of the augmented simulation capabilities brought forth by increased computational and technological solutions DT provide organizations with the opportunity to create an experimental Virtual Reality (VR) under the influence of different internal and external inputs at any life cycle stage (Aleksandrova, Vasiliev, & Letuchev, 2018; Aleksandrova et al., 2019; Vasiliev, Aleksandrova, Aleksandrov, & Velmakina, 2020). This simulation model is performed based on data from sensors and connected smart devices, mathematical models, and real-time data elaboration (Garetti, Rosa, & Terzi, 2012; Ebrahimi et al., 2019). The collection and analysis of statistically relevant data allows a better understanding of processes, the adjustment and experimentation of parameters, as well as forecasts and predictions. As a result, it promotes maximum efficiency along the entire life cycle, reducing redundancies, unproductive working times, blockages and low-quality products and services (Bodi, 2020; Carvalho et al., 2020).

Another example of simulation is provided by Extended Reality (XR) technologies, such as VR, AR, or Mixed Reality (MR). These technologies work as a virtual assisting tools for the inspection, control, and interaction with the work environment (Bodi, 2020). They can be also useful for training purposes, simulating real situations on the manufacturing floor, without even having to create expensive mock-ups or pilot development facility, this cyber method of training will teach people how to work properly on the job. Workers may receive simulated training in a virtual factory environment using real-time sensors connected to their bodies and equipment. Workers may also simulate the results of potential failures and get a simulated experience of what could go wrong if they do not process things properly. Moreover, it also possible to learn how to digitally confirm quality problems and track them down to the source to determine the root cause - which, through the use of ML, can also be applied to equipment and machines (Lim, 2020). Diminished Reality (DR) is a complementary technique that removes stimuli from the workplace, allowing employees to concentrate better and increase cognitive processing (Fraga-lamas, 2018).

Simulation models can also be used in quality control by checking throughout the production process if the validated prototype is being complied with, thus attesting to the quality and conformity of the project. The models support and facilitate possible changes throughout the life cycle of products, services, and processes and cuts the time between design and production, accelerating of the development process (American Society for Quality [ASQ], 2020; Carvalho et al., 2020).

3.4 | QUALITY 4.0 & PEOPLE

While Q4.0 has so far been discussed from a technological perspective, there is a strong social side to this transformation – which aims not only to integrate these technologies with the people that use it, but also to make a culture of quality more attainable. However, there has been, so far, a limited number of works focusing on the social side of Q4.0 (Gunasekaran et al., 2019).

A quality cultural orientation is required for an organization to adapt to changes. A quality organizational mindset focuses on recognizing and solving key challenges, using BD to solve problems previously thought to be beyond solution, learning how to better address human variability, and costumers requirements, the ability to strengthen communication, connectivity, and cooperation among the value chain, as well as a transparent production system where every action is monitored, recorded and assessed in real-time (Evans et al., 2015). Furthermore, quality integration in the organization's finance, marketing, design, development, operations, supply chain, customer interactions will support the application of holistic improvement approaches. Elements such as teamwork, leadership, employee ownership, decision making and management based on information quality, customer sensitivity, and ethics are elements of an indispensable humanistic culture for Quality 4.0 (Srinivasan & Kurey, 2014; Durana, Kral, Stehel, Lazaroiu, & Sroka, 2019). According to Sony et al. (2020), Q4.0 organizational culture has four types: Clan - technologies are seen as new work tools and it is up to employees to work as a clan to promote the correct use of these technologies; Adhocratic - fostering a set of transformational and social skills that are useful in solving problems; Hierarchy - internal control and stability to achieve efficiency in creating value; and Market - elaboration of a sustainable strategy for the organization to differentiate itself from the competition.

Leadership is crucial for the success of the Q4.0 transition. The new era of quality requires a leadership style that combines the practice of quality management with the emerging capabilities of I4.0. Top management recognition and understanding of the importance of Q4.0 is vital in allocating resources and incorporating them across the organization, as well as in destroying barriers that prevent Q4.0 acceptance. Quality should be cross-functional and the future leadership of quality is shared through the distribution of leadership across various levels and functions (Evans et al., 2015). Leaders must ensure data, processes, and people working together to enable effective, data-driven, and bidirectional communication across the technological and operational departments. There is a need for a knowledge-oriented leadership style that promotes engagement and collaboration, the development of new skills, and a culture of learning and innovation (Jacob, 2017; Sader et al., 2017; Cudney & Antony, 2020; Sony et al., 2020; Armani et al., 2021).

In addition, connected with Q4.0 arises the term Open Quality. Park et al. (2017) describe this principle as the adoption of a new strategy in which products and services are designed, produced, marketed, and sold based on open and transparent quality approaches. The goal is to clarify the responsibility of quality and for management decisions in the interests of ensuring sustainable development. Linked with diverse tools contributes to attaining excellence in quality. The author also highlights as integral parts of I4.0 the quality responsibility, as a quality goal, and Open Quality as a quality strategy. Furthermore, Salimova et al. (2020) remark that Q4.0 and Open Quality reflect the development of digitalization of production and consumption.

As in previous industrial revolutions, new jobs will be created and thus increase the employment rate, but it will also make several positions redundant or obsolete. Workers must be prepared to update themselves to guarantee their work value. Quality controllers are one of the jobs most likely to become less essential in the next years, due to analytics and automation. Workers who are doing repetitive work may face the biggest challenge of staying in the industry. Project and process management among with statistics are data-driven activities that will be needed across quality roles in the I4.0 era (Zaidin, Diah, & Sorooshian, 2018).

Likewise, quality professionals need to adapt to technology. Most quality-centered I4.0 initiatives are being led by IT, operations, engineering, or sales and marketing rather than quality experts (Jacob, 2017; Carvalho et al., 2020). Watson (2019) states that the current distinction between quality professionals and data scientists will be mitigated by a collaborative approach. In order to plan a digital strategy, a working group consisting of members from many functional divisions is required. In the case of the implementation of a Quality 4.0 strategy, a strong and harmonious connection between the IT and quality management function needs to be developed to establish where and whether digital tools can provide a solution. IT has strategic knowledge of the IT infrastructure and quality management is in charge to incorporate digital technologies and tools. This complementarity is demonstrated by problem-solving operations performed during the transition process (Ponsignon, Kleinhans, & Bressolles, 2019).

Radziwill (2018) draws attention to quality professionals' fundamentals which will remain unchanged in the new era of Quality and are valuable for I4.0. These fundamentals include data-driven decision-making, processes definition systematic thinking, structured problem solving, as well as understanding how processes, policies, and decisions impact people: their lives, relationships, communities, well-being, health, and society in general, continuous improvement management, leadership for organizational learning and quality culture drivers.

Professionals who deal with I4.0 technologies must have specific training at a technical level, transformational skills such as adaptability, critical thinking, long-term planning, and creativity along with social skills such as communication, teamwork, and knowledge transfer (Küpper et al., 2019; Sony et al., 2020). Domingues & Sampaio (2020) studied the skills of the 21st-century quality professional that organizations are looking for. Leadership competencies are the most relevant followed by communication skills, including teamwork and persuasion. Personality traits such as altruism, ambition, innovation, and networking are emphasized. The adaptability that is related to problems solving and flexibility is also highlighted. The orientation towards quality, the relationship with technology, and analytical skills also contribute to the modernized quality professional. In such a way, there should be a new effort in skilling and reskilling current employees, as well as in training new quality professionals. Interactive and shared learning about quality throughout science, technology, business, social enterprise, and leadership development creates a more well-informed and skilled professional to deal with quality outcomes (Evans et al., 2015). Therefore, different forms of education must be presented to apply digital tools.

Quality management has always supported the change to ensure the transformation program is inclusive, collaborative, and co-constructed by all internal stakeholders. It is essential to raise awareness of educational and training programs among staff, and building thematic expert communities. An integrated philosophy of quality that encourages and facilitates knowledge, creativity, innovation, and boost talent as well as supporting the adaptation to modern ways of working that will have an impact on the entire value chain (Ponsignon et al., 2019). Social sustainability is also an important aspect in Q4.0. Aspects such as job satisfaction, equity and justice in the distribution of goods and services, and equal opportunities in education are related to the quality of life. In I4.0, the specific nature of human interaction with machines generates changes in the way of working and in the surrounding environment. While human-machine interaction can lead to increased employee satisfaction, remote jobs in which the form of communication and the surrounding environment change may require more challenging adaptation (Pollak et al., 2020).

The transition for Q4.0 requires continuous innovation and education that depend on organizational culture (Mohelska & Sokolova, 2018). An agile approach facilitates cross-functional collaboration (Küpper et al., 2019; Ralea et al., 2019). The knowledge shared and the creation of networks and interfaces generate the diffusion between ideas and experiences which leads to a positive effect on performance. The integration of innovation and quality allows innovations to become operational in a faster way and a better integration of quality and social responsibility (Evans et al., 2015; Durana et al., 2019).

Organizations improve not as a result of continuous improvement practices implementation, but also as a result of the learning that occurs as those practices are followed. Continuous improvement occurs as we collectively learn more about ourselves, our activities, our relationships, and the competitive world in which we operate. There are cost-effective approaches for improving training effectiveness, as well as innovative field interfaces for live data access that can enhance and strengthen cognitive function (Radziwill, 2020). Quality management's continuous improvement approach helps to ensure the transition process consistently meets its many objectives. A unified knowledge base on success and excellence is developed, fed, and maintained up to date, setting benchmarks for sharing digitalization-related practices (Ponsignon et al., 2019). In sense of this, continuous improvement activities must be managed in an integrated and multifunctional method and throughout the organization.

3.5 | QUALITY 4.0 AND MANAGEMENT SYSTEMS

The adoption of a new quality paradigm at the system involves changes at all levels. Together with the necessary behavioral and practice changes across the organization (Bogdan, Daniel, & Francisca, 2018; Durana et al., 2019), there are also critical changes impacting management systems. Quality Management Systems (QMS) (and their integration with other management systems) include both soft and technical aspects. Soft aspects, as mentioned above, comprise management concepts and principles related to social and behavioral dimensions. Technical aspects encompass technical strategies as well as management tools, practices, and systems to deal with the design, implementation, and improvement of products, services, and processes (Kanapathy, Bin, Zailani, & Aghapour, 2017; Babatunde, 2020; Sciarelli, Gheith, & Tani, 2020).

Quality management practices comprehend exploitation and exploration approaches that contribute to improving the organization's performance and robustness (Ponsignon et al., 2019). Quality exploitation assumes an orientation for structuring, controlling, and improving existing processes to ensure consistency and efficiency of results. Thus, it emphasizes the assessment of the needs and concerns of stakeholders through control, operational standardization, and training to improve specific skills. Otherwise, quality exploration encourages innovation and creativity to identify and explore new insights into unknown situations to adopt new solutions and approaches. The organizations' transition to digital approaches requires simultaneously leveraging exploitation resources and development exploration resources (Zhang, Linderman, & Schroeder, 2012; Ponsignon et al., 2019).

Quality 4.0 aligns quality management with the technologies of the digital era. In particular, the combination of known methods of quality management and information technology allows the creation of new principles for a modern quality management system (Aleksandrova et al., 2018).

Salimova et al. (2020) introduce the principles of quality management in the transition to I4.0. According to the authors, it is essential the transition from an individual to a shared leadership where the responsibility for quality is distributed among all team members under voluntary involvement and continuous improvement. Furthermore, there must be a change from a value chain to an active value network, including all stakeholders in the value creation processes. Mayakova (2019) supplements it is essential to add new principles of quality management in the context of total digitization, such as adaptability, innovation, and digitization, and the development of quality management programs and tools based on digital technologies.

The digitalization of QMS connects digital technologies and quality tools, methods, and systems. It has been shown to have indirect profits on organizations. Through a Digital Quality Management System (DQMS) it is possible to design high-performance work systems which allow employees to be aware of the procedures to be followed during daily tasks. This factor, linked to training and improvement of learning, significantly increases productivity, efficiency, and employee involvement. Furthermore, transparency is enhanced through greater collaboration and information sharing between departments, reducing the discrepancies which help to build a shared vision to achieve common organizational goals (Ibrahim, 2019).

A DQMS relies on the collection, storage, and continuous analysis of a large set of data to inform decision-making., promote corrective actions faster, and manage risk more efficiently. DQMS can categorize risks and events with their corrective actions and corresponding tracking policies to avoid potential adverse effects (Ibrahim, 2019). Moreover, this system develops and proposes approaches to respond to changes in the extra-organizational environment and optimizes functional and organizational structures (Vasiliev et al., 2020).

In comparison to conventional quality management systems, DQMS may also improve connectivity robustness. It is a dynamic system that provides speed and aims to reduce redundancy, and that can be easily adapted. Also, it considers environmental factors that may have an influence on processes and their quality results. This system uses simulation and forecasting technologies for testing and optimizing process on-project or virtual business prototypes before actual implementation to provide an ability to enhance and restructure activities and cost management. Moreover, enhances the optimization of parameters, allowing processes to respond favorably to instabilities with increased performance and a greater degree of predictability (Bodi, 2020).

Integrated management systems can lead to better compliance and efficiency of quality management all over the organization. For this purpose, Enterprise Quality Management Systems Software (EQMS) has been progressively adopted. It encompasses every part of the value chain and how it is managed to provide a scalable solution to automate workflows, connect quality processes, improve data veracity, outline centralized analytics, increase compliance and promote a collaborative digital environment (Zaidin et al., 2018; Ralea et al., 2019; Sony et al., 2020).

3.6 | QUALITY 4.0 AWARENESS

Organizations have been looking to accelerate their digital transformations and recognize that Q4.0 can create substantial value. However, Kupper et al. (2019) found that just a few of them have defined a strategy or implementation program for the Q4.0 transition. Frontrunners in this transition confirm they have seen significant improvements in quality-related performance at this time (Mckendrick, 2020), but recognize the need to commit more resources to Q4.0 over the next few years. Areas, where technology is currently having the greatest (perceived) impact on quality, include industrial sectors such as the automotive industry because of the high degree of automation that generates a large amount of data (Cudney & Antony, 2020).

In a study conducted by Sony et al. (2021), senior quality professionals from major manufacturing and service sectors were asked what factors motivated them to implement Q4.0. Results show that the adoption of Q4.0 is driven by the need for reliable and accurate data for quality management. Big data is often used to assess consumer needs to deliver high-quality goods and services. In line with this, quality management programs based on BD and increased customer willingness to be loyal are also driving factors for Q4.0 adoption. Furthermore, productivity improvement through technologies and new methods of quality inspection and control is also pointed as a motivating reason, as well as cost and time savings.

The transition to Q4.0 is often limited by the required investments, mostly in state-of-the-art technology. However, in the long term, these costs could be offset by a drastic reduction in internal and external failure costs as well as increased customer satisfaction will result in a rise in product and service market share. Besides, investments should not only be directed to expensive technological solutions, but also to specific areas that help demonstrate how improvements have been achieved, such as corporate culture and quality-oriented thinking (Zaidin et al., 2018; Cudney & Antony, 2020; Mckendrick, 2020; Sony et al., 2021). A lack of a conducive organizational culture is often cited as an obstacle to Q4.0 transition (Sony et al., 2021).

In addition to the high initial costs, the transition to Q4.0 is often challenged by a shortage of physical, intellectual, human, and financial resources (Sony et al., 2021). Besides, the shortage of digital skills and fragmented systems are pointed out as barriers to the transition to Q4.0 (American Society for Quality [ASQ], 2020). The fact that many quality teams are still trying to solve elementary quality problems such as fragmented systems, ineffective communication, basic prerequisites of a quality culture, causes a shortage of engaged quality leaders in digital quality transformation and prevents quality from becoming a leading force on Q4.0 transition.

The lack of I4.0 technologies understanding, application, and importance by quality professionals make IT, marketing, Research and Development (R&D), or operations departments in charge (Jacob, 2017; Küpper et al., 2019; Ralea et al., 2019; Mckendrick, 2020). Also, the resistance from organizations to adopt new technologies, the lack of perception of the need for quality management digitalization, and support from leadership as well, are pointed out as barriers to the transition to Q4.0 (American Society for Quality [ASQ], 2020; Mckendrick, 2020; Sony et al., 2021). Furthermore, the lack of a standardized and accepted framework for implementing Q4.0, which would make it simpler for an organization to do so, also creates a barrier.

The Sony et al. (2021) study also pointed out readiness factors for the Q4.0 transition. An organization ready to start the transition to Q4.0 has top management that is aware of and embraces the transition program, is open to accepting a new organizational culture of transparency, connectivity, collaboration, and insights, as well as has a Q4.0 vision and strategy that is consistent with the organization's vision and strategy. In line with this, creative and risk-taking leaders that encourage digital transformation, learning, and development are also pointed as a readiness factor. In addition, the incentive system promotes the implementation of innovative quality management practices. Another dimension of readiness is quality professionals' knowledge and awareness of Q4.0. Also, a customer-centric approach and an effective supplier management system al also readiness factors for the authors.

3.7 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0

Maturity models are used as an evaluative and comparative basis for development and to derive a well-informed approach to increasing a particular area's capability within an organization (de Bruin, Rosemann, Freeze, & Kulkarni, 2005). However, and more importantly for management practice, they provide detailed guidelines and introduce a roadmap to assist organizations (Santos & Martinho, 2019). Across different fields and disciplines, a significant number of maturity models have been developed. They were created to measure the maturity of, but not limited to, IT Service Capacity, Strategic Alignment, Innovation Management, Program Management, Corporate Architecture, and Knowledge Management Maturity (de Bruin et al., 2005). Similarly, quality management incorporated this type of model, with the levels of growth being expanded and provided as stages for organizational development (Schuh et al., 2020).

Roadmapping is about providing a straightforward route toward achieving future goals or ambitions. Roadmaps are useful resources because they outline rational plan and a collection of measures to ensure that the resource is available to achieve general ambitions and goals. They are also a tool for involving and facilitating communication with different stakeholders in a common development strategy. Furthermore, capabilities refer to a broader ability to act to accomplish, a goal and may include different elements of expertise, experience, capacity, and skills (Eagar et al., 2013).

In turn, capability roadmaps are concerned with defining what underlying capabilities need to be developed to meet the needs of the future and how they might be developed. Capability roadmaps are increasingly being used instead of, or in addition to, technology roadmaps in a market environment where organizations must be ever more flexible and adaptive to rapid changes and disruptions (Eagar et al., 2013).

In order to master the digital transformation, industry and academia have been working to update the existing literature as well as build and redevelop self-assessment models. The identification of these models is also critical as it allows organizations to assess antecedents and precedents in the digital transformation phase, which can then contribute to organizational transformation (Hizam-Hanafiah, Soomro, & Abdullah, 2020).

Since there is a lack of maturity and readiness models as well as roadmaps focused on Q4.0 and I4.0 which combine technological and human perspectives, it is valuable to analyze models in this context. The literature was explored to collect various maturity and readiness assessment models related to the present work subject. Represented in Table 2, the identification and analysis of the existing models is part of the first stage of content assessment in the literature. An exploratory analysis of the models allowed to decrease the number of models to be analyzed by selecting those focused on Q4.0 and the ones which are based on core principles and enabling technologies of I4.0 as well as organizational capabilities. Subsequently, the categorization and comparison of the twenty-one models include a detailed assessment of relevant information for the development of the Quality 4.0 Capability Roadmap.

Presented in chronological order of publication in Table 2, the analyzed models helped to determine the relevant concepts to build the model structure such as dimensions (minimum 3 dimensions to a maximum of 9 dimensions), number of subdimensions (5-17 subdimensions), maturity items (18–62 items), number of maturity levels (from level 0-lowest to 6-highest maturity), and validation method (survey or case-study).

The models have different developers or originators. However, it can be seen that there is no great discrepancy in the number of analyzed models from academia or consultancy firms. Interestingly, the models chosen for analysis have been developed at most 6 years ago. Thus, it can indicate that, since the introduction of the concept of I4.0 in 2011, the mindset that technology is the only important factor in the digital transformation has been changing.

In general, the analyzed models were developed to access an organization's overall maturity level in the transition to I4.0. In addition to the overall assessment, the models provide an assessment of maturity by the different structural areas. Similarly, readiness models assess the current state of readiness for the digital transition. The most common element in models that enable organizations to achieve a level of maturity or readiness is that organizations can see what they lack to meet the desired level of maturity by analyzing the maturity levels of each structural field in depth. As a result, it enables organizations to create a customized roadmap to help them achieve their goals in a strategic and directed way.

The methods for gathering and analyzing data for the creation of maturity and readiness models differ. Some research relies on analyzing the literature, while others collect input from experts and business practitioners, while still others combine the two approaches. Similarly, the method for calculating maturity levels also differs. Only the maturity of the specified structural areas can be evaluated, or, for benchmarking purposes, the overall maturity level is recommended. Even so, methods of assessing maturity highly differ. Furthermore, some models take various maturity weights into account.

Most models are validated by surveys, workshops, or case studies, and those who do not have this validation, consider it the next move. An online self-assessment tool was also verified in some models. This approach is a benefit since it provides a more complex and engaging way of accessing model templates for an application.

The presence of technology-related dimensions in the models is unavoidable. The main force of digital transformation is technology. Most models have a Technology dimension extent through operational and product lifecycle dimensions. Nonetheless, not just technology is used to deal with enterprise-wide topics but also people and organizational-related dimensions are highly available. Furthermore, organizational culture and strategy are also the concern of models. Customer focus is one of the dimensions that begins to be noticed in most models, even related only to I4.0, in line with one of the pillars of Quality. Leadership-related dimensions begin to have importance, making this dimension a field of study and application in future models.

However, the models differ in terms of content, quantity, and definition some of them are lacking in detail. The full or final version of the model is not publicly accessible, which composes research gaps. Even, it is possible to get a sense of the most researched areas and gain a better understanding of the dimensions that make up the I4.0 transformation. Furthermore, the overall review of the models resulted in findings that will serve as a foundation for the development of the Quality 4.0 Capability Roadmap.

TABLE 2 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0

Model designation	Authors	Source	Research context/area	Structural Areas										Maturity Scale	Validation method	Contribution and limitations
				Technology	Product and Services Lifecycle	Operations	Customer Focus	Organization	Leadership	Culture	Strategy	People	Quality Management approaches			
IMPULS: Industrie 4.0 readiness	Lichtblau et al., 2015	Consultancy Firm	Industry 4.0 transition	x	x	x		x			x	x	x	Six-scale (0–5)	Survey	- Assessment of organization readiness for the I4.0 transition and offers insights to improvement; - Online self-assessment tool; - The model's main focus is on operational excellence and not on organizational excellence.
Industry 4.0 Maturity Model	Schumacher et al., 2016	Academic	Industry 4.0	x	x	x	x	x	x	x	x	x	x	Five-scale (1–5)	Case-study in industrial enterprise	- Maturity items developed through experts survey and the results serve as basis for automatically calculate the maturity items weights by a software tool; - Transversal to an extended number of organizational capabilities; - Lack of details regarding maturity items, survey assessment, and maturity levels.

TABLE 2 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0 (CONT.)

Model designation	Authors	Source	Research context/area	Structural Areas: Technology	Product and Services Lifecycle	Operations	Customer Focus	Organization	Leadership	Culture	Strategy	People	Quality Management approaches	Maturity Scale	Validation method	Contribution and limitations
PwC maturity model	Reinhard et al., 2016	Consultancy Firm	Digital maturity	x	x		x	x		x			x	Four-scale (1–4)	Survey	- Assessment of organization readiness for the I4.0 transition and serve as roadmap; - Focus on the digitalization of industrial capabilities across the organization; - Online self-assessment tool; - Lack of details regarding maturity assessment and identification of maturity level.
Asset Performance Management Maturity Model (APM)	Dennis et al., 2017	Consultancy Firm	Asset performance; Industry 4.0	x		x		x		x		x	x	Five-scale (1–5) of maturity for each dimension	-	- Assessment of organization's maturity in the I4.0 transition and offers insights to build a roadmap strategy; - Only offers a detailed view of asset performance.
DREAMY- Digital Readiness Assessment Maturity Model	Carolis et al., 2017	Academic	Process-based Industry 4.0	x	x	x		x					x	Five-scale (1–5)	Survey	- Focus on a process-based approach; - Encompasses quality practices; - Lack of details regarding maturity items and assessment.

TABLE 2 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0 (CONT.)

Model designation	Authors	Source	Research context/area	Structural Areas: Technology	Product and Services Lifecycle	Operations	Customer Focus	Organization	Leadership	Culture	Strategy	People	Quality Management approaches	Maturity Scale	Validation method	Contribution and limitations
Industry 4 readiness assessment tool	Agca et al., 2017	Consultancy Firm	Industry 4.0	x	x	x	x	x	x	x	x	x	x	Four-scale (1–4)	Survey	- Assessment of organization's maturity in the I4.0 transition and offers insights to build a roadmap strategy; - Transversal to an extended number of organizational capabilities; - Lack of details regarding maturity assessment and identification of maturity level.
Industry 4.0-MM	Gökalp et al., 2017	Academic	Industry 4.0	x	x	x		x		x	x	x	x	Six–scale (0–5)	Not validated	- Assessment of organization's maturity in the I4.0 transition and offers insights to build a roadmap strategy; - Transversal to an extended number of organizational capabilities.
Quality 4.0 Impact And Strategy Handbook	Jacob, 2017	Consultancy Firm	Quality 4.0	x	x	x	x	x	x	x		x	x	-	Partial validation by use cases	- Assessment of organization's maturity in the Q4.0 transition; - Centered on quality methods; - Transversal to an extended number of organizational capabilities; - Lack of a detailed roadmap to the Q4.0 transition.

TABLE 2 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0 (CONT.)

Model designation	Authors	Source	Research context/area	Structural Areas: Technology	Product and Services Lifecycle	Operations	Customer Focus	Organization	Leadership	Culture	Strategy	People	Quality Management approaches	Maturity Scale	Validation method	Contribution and limitations
The Singapore Smart Industry Readiness Index (SIRI)	Singapore Smart Industry Readiness EDB, 2017	Consultancy Firm	Industry 4.0	x	x	x	x	x	x	x	x	x		Five-scale (0–5) of maturity for each dimension	Expert's panel and case-study in a group of industrial organiza-tions.	- Assessment of organization's readiness in the I4.0 transition and insights on how to start, how to improve, and how to sustain growth; - Online self-assessment tool; - The Index does not offer a specific evaluation scale.
Deloitte Digital Maturity Model	Anderson & Ellerby, 2018	Consultancy Firm	Industry 4.0	x		x	x	x	x	x	x	x		Not Provided	Case-study	- Design took into account key contributions from industry and subject matter expert; - Focused on technology and organizational capabilities; - Lack of details regarding sub-dimensions, individual criteria, and maturity assessment process, and scale.
Industry 4.0 maturity framework	Bibby & Dehe, 2018	Academic	Implementa-tion of Industry 4.0 technologies	x	x	x		x		x	x	x		Four-scale (1–4)	Case-study on defense manufactur-ing organization	-Focused on the implementation of I4.0 technologies at the operational level; - Lack of details regarding the maturity scale.

TABLE 2 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0 (CONT.)

Model designation	Authors	Source	Research context/area	Structural Areas										Maturity Scale	Validation method	Contribution and limitations
				Technology	Product and Services Lifecycle	Operations	Customer Focus	Organization	Leadership	Culture	Strategy	People	Quality Management approaches			
Readiness for Industry 4.0	Horvat et al., 2018	Academic	Industry 4.0 in emerging economies	x	x	x	x	x	x	x	x	x		Not Provided	Survey in the manufacturing sector	- Assessment of organization's readiness in the I4.0 transition; - Focused on automation and digitization of processes throughout the organization; - Lack of details regarding the assessment of the readiness level.
Smart Industry Roadmap Model	The Industry Working Group (IWG), 2018	Consultancy Firm	Human-touch aspects of I4.0	x	x	x	x	x	x	x	x	x	x	-	Not specified	- Transversal to an extended number of organizational capabilities; - Aims to contribute to the human-touch aspects of I4.0; - Although it is labeled as a roadmap, the model was designed to contribute to the definition of strategic research directions for the coming 10-15 years.

TABLE 2 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0 (CONT.)

Model designation	Authors	Source	Research context/area	Structural Areas: Technology	Product and Services Lifecycle	Operations	Customer Focus	Organization	Leadership	Culture	Strategy	People	Quality Management approaches	Maturity Scale	Validation method	Contribution and limitations
Maturity and Readiness Model for Industry 4.0 Strategy	Akdil et al., 2018	Academic	Industry 4.0	x	x	x					x	x		Four-scale (0–3)	Survey	- Assessment of organization's readiness and maturity in the I4.0 transition and offers insights to build a roadmap strategy; - Transversal to an extended number of organizational capabilities.
The strategic Roadmap for Industry 4.0 transition	Morteza, 2018	Academic	Industry 4.0 strategies	x	x	x	x	x			x	x		-	Not speci-fied	- Offers a general view that can be used as a starting point to define detailed strategies for organizational excellence; - Transversal to an extended number of organizational capabilities.
Quality 4.0 maturity framework	Armani et al., 2018	Academic	Quality 4.0 maturity assessment	x	x	x	x	x	x	x		x	x	Five-scale (1–5)	Case-studies	- Assessment of organization's maturity in the Q4.0 transition; - Transversal to an extended number of organizational capabilities; - Based on the 11 Axes of Quality 4.0 from (Jacob, 2017).

TABLE 2 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0 (CONT.)

Model designation	Authors	Source	Research context/area	Structural Areas: Technology	Product and Services Lifecycle	Operations	Customer Focus	Organization	Leadership	Culture	Strategy	People	Quality Management approaches	Maturity Scale	Validation method	Contribution and limitations
Industry maturity model	Santos & Martinho, 2019	Academic	Industry 4.0	x	x	x	x	x			x	x		Six-scale (0–5)	Survey and case-study in the automotive industry	- Assessment of organization's maturity in the I4.0 transition and offers insights to build a Roadmap strategy; - Transversal to an extended number of organizational capabilities.
Industry 4.0 maturity assessment	Schumacher et al., 2019	Academic	Industry 4.0 roadmap assessment	x	x	x	x	x	x	x	x	x		Not Provided	Survey and workshop	- Assessment of organization's maturity in the I4.0 transition and offers a step-by-step approach to a roadmap definition; - Maturity items developed through experts survey and the results serve as basis for automatically calculate the maturity items weights by a software tool; - Lack of details regarding survey assessment and maturity levels.

TABLE 2 | MODELS RELATED TO QUALITY IN THE CONTEXT OF INDUSTRY 4.0 (CONT.)

Model designation	Authors	Source	Research context/area	Structural Areas: Technology	Product and Services Lifecycle	Operations	Customer Focus	Organization	Leadership	Culture	Strategy	People	Quality Management approaches	Maturity Scale	Validation method	Contribution and limitations
Integrated Industry 4.0 - Total Quality Management framework	Sader et al. , 2019	Academic	TQM and Industry 4.0	x		x	x		x	x	x	x	x	-	Not specified	- Transversal to an extended number of organizational capabilities; - A quantitative method for maturity evaluation is pointed as future work.
Industrie 4.0 Maturity Index – Update	Schuh et al., 2020	Consultancy Firm	Industry 4.0	x	x	x		x		x		x		Five-scale (1–6) of maturity for each dimension	Survey and case-study in different industry organizations	- Assessment of organization's maturity in the I4.0 transition and offers insights to build a roadmap strategy; - Lack of details regarding the survey which is used to address the capabilities.
Industry 4.0 maturity model	Wagire et al., 2020	Academic	Industry 4.0	x	x	x	x	x	x	x	x	x	x	Four-scale (1–4)	Case-study in the area of mobility solutions, consumer goods, and building technology	- Assessment of organization's maturity in the I4.0 transition and offers insights to build a roadmap strategy; - Technology-focused; - Maturity items have different weights.

3.8 | QUALITY 4.0 INSIGHTS AND IMPROVEMENTS: LITERATURE REVIEW SUM UP

Technologies are getting better suited for widespread adoption in the coming years, and COVID-19 has sped up the process. The need for a connection between I4.0 and Q4.0 is becoming clear, quality is a strong base for transformation initiatives (Aldag & Eker, 2018; Zonnenshain & Kenett, 2020). When quality is the core element in digital transformation or I4.0 initiatives, quality and performance goals are prioritized over the digital transformation itself (Radziwill, 2020). New technologies have the potential to make the industry smarter, leaner, more flexible, and more sustainable as well as digital, cloud-based, smart, holonic, and agile. Quality approaches are a key element in reaching these goals, and technology enables the development of quality approaches. It's a collaboration in which both actors' profit.

A sustainable environment is key for continuous development. A sustainable development based on I4.0 and 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 (Park et al., 2017; Salimova et al., 2020). Preventive activities provide an understanding of the future. Furthermore, today's environment requires revolutionary changes rather than evolutionary (Ronen & Coman, 2020). One of the foundations of organizational development must be innovation.

The digital quality uses technology on the quality principle customer focus. The interaction between customer-organization can benefit from being carried out through new communication channels and taking into account the emotions involved in the process (Sampaio & Saraiva, 2016). Furthermore, the organization's openness in incorporating the customer through the value chain is linked to the shift to business as a service, with personalized services valued by consumers (Carvalho et al., 2019). Also, it is important to include all stakeholders in the value-creating process.

Quality management benefits from digital and automated production processes. Not only the quality inspection is more reliable and effective, since it shifts from sampling to total control, but also the work becomes automatic, capable, safe, and error-free (Mendling et al., 2018). This also allows that instead of spending time dealing with non-conformances, it is possible to anticipate and eliminate them. Depending on the extent of automation used, corrective and preventive measures may be done by the workers or by the machines themselves. There are some cases where entirely automation isn't the best option. In this situation, quality experts can be useful in identifying where and how much automation is possible and identify the associated risks (Radziwill, 2020).

The information's accessibility allows for a real-time perspective of the entire process (Küpper et al., 2019; Carvalho et al., 2020; Lim, 2020). Customer data allows for more flexibility in product and service development. Data collection from the supply chain in real-time is critical for process management. Real-time data collection from the supply chain is important for managing the process. Internally, real-time process data collection assists in the early identification of failures and hazards, allowing for appropriate correction and prevention actions. The information flow between the value network is also beneficial from compliance to innovation (Sader et al., 2019).

Data storytelling is critical to make decisions. This concept is useful in the four types of data analysis: descriptive, diagnostic, predictive, and prescriptive data analysis (Delen & Ram, 2018). The prescriptive analysis uses simulation as one of its approaches. Simulation technology can be used to create virtual versions of products, systems, and even work environments and drive innovation (American Society for Quality [ASQ], 2020). However, there is a need for a data management strategy. The identification and definition of information quality, the standardization of ways of obtaining and analyzing data, as well as applying data protection procedures and policies, and studying efficient storage strategies are necessary approaches in digital transformation (Radziwill, 2020). Quality can be an important driver in the data management strategy.

Besides digital quality, organizations need to look at organizational culture to ensure a sustainable transition and continuous improvement (Evans et al., 2015). Leadership is crucial in understanding the value of Q4.0, as well as allocating resources and implementing it within the organization. In line with this, leadership must become shared leadership with all team members sharing responsibility for quality through voluntary involvement and continuous improvement (Salimova et al., 2020). A knowledge-based leadership is pointed as a driver to destroy barriers for the transition for Q4.0 approach as well as promotes engagement and collaboration, the development of new skills, and a culture of learning and innovation (Jacob, 2017; Armani et al., 2021; Sony et al., 2021).

The digital transformation will not be effective unless the workforce is adapted to the new technologies. The most pressing topic regards current workforce skilling and reskilling needs (Evans et al., 2015). Since the new generations were born into a digitalized environment, they can more easily adapt to emerging technology; these generations are already being qualified to join the labor market of the future.

People are one of the foundations of an organization's development and continuous improvement. Even though it is important to skill people to adapt to emerging technology, it is also significant to adapt work to people and use technology to adapt the production process to the needs of the worker. It also entails ensuring that the use of emerging technology does not negatively impact employees' fundamental rights to privacy, autonomy, and human dignity (Breque, Nul, & Petridis, 2021).

Human-oriented perspectives are becoming increasingly important in the industry and are one of Industry 5.0's (I5.0) foundations. As a result, the rising of customized production had triggered new business models and future businesses based on customer experience will be profitable (Park et al., 2017). Moreover, in order to ensure that both organizations and the workforce benefit from the digital transition, rethinking and redesigning business models and ways of work are necessary. Furthermore, organizational culture has become crucial in enhancing workers to stay in the organization, allowing for progress. The importance of customer service and employee integration cannot be underestimated in Q4.0 transition. The Industry 5.0 (5.0) paradigm extents the worker's value to more valorized and appreciated, enabling both the organization and the worker to develop (Breque et al., 2021). In line with this, the workers skilling and reskilling pointed in Q4.0 as a necessity as well as social sustainability marks a strategic spot for human enhancement in I5.0.

A transformed industry will have a societal effect as well (Radziwill, 2018). Industry 5.0 complements and extends the existing disruptive economic and technological features of I4.0 by having important environmental and social dimensions to set up a sustainable, human-centric and resilient industry. Industry 5.0 aims to use technology for circularity and sustainability. Furthermore, aims to shift the focus from shareholder value to stakeholder value (Breque et al., 2021). In line with this, Q4.0 value network implementation is essential to shift for this perspective and to contribute to an agile and resilient industry (Salimova et al., 2020).

Quality 4.0 is gaining attention in the literature, but there is still a relatively recent topic. The first step in addressing the transition is the Q4.0 awareness of organizations, professionals, and academics as well as the understanding of the potential values and challenges in this transition. Organizations are beginning to understand the need for the transition to Q4.0 (Küpper et al., 2019), but are facing difficulties developing a strategy in part due to most information in the literature is focused on I4.0. Despite the abundance of knowledge available about I4.0, the majority focuses on technological advancements and application, leaving the human and organizational implications of production, adoption, and use of I4.0 technologies as a potential field of exploitation.

Since Q4.0 is still a recent phenomenon, there is still no agreed definition, sufficient case studies, or an overview of the application of quality tools to disruptive technologies as well as a model to guide organizations in the transition to Q4.0. This might end up making quality-focused I4.0 approaches difficult to comprehend and implement. Furthermore, the skills required by quality professionals to the transition for Q4.0 are identified (Domingues & Sampaio, 2020). However, how to instruct quality professionals to acquire the skills to cope with changes from I4.0 is not completely evident in the literature. There is a lot of potential for content development in quality dimensions and tools.

Society 5.0 (S5.0) and I5.0 are concerned with the human dimension in the workplace and greater human quality of life. Considerations for the human side of quality in Q4.0 are an important research issue (Gunasekaran et al., 2019; Carvalho et al., 2020). An enlightened search of quality for humanity is needed. Inequalities in technological access are a reality, and there are discrepancies in the state of readiness for the implementation of new techniques and ways of working. The costs of poor technological integration in society, as well as ways to avoid this condition, should be explored. Similarly, the evaluation of the risks of worker dissatisfaction and stress as a result of career insecurity or the inability to improve competencies and skills for the modern age must be address (Breque et al., 2021). In line with this, there is an opportunity to explore the risks involved with the use of technology such as cybersecurity, privacy, and data protection in the context of Q4.0 (Radziwill, 2020)

4 | QUALITY 4.0 CAPABILITY ROADMAP

4.1 | DESIGN AND DEVELOPMENT

To define the architecture of the model and its content, it was necessary to have a broad view of Q4.0 literature and to identify and analyze the existing models related to I4.0 and Q4.0. Previous chapters have detailed analysis of this valuable topics.

The model's design was decided in the first place. It consists of a table format model to simplify the perception of the intersection of dimensions and sub-dimensions with the levels of progression of technology use (readiness and maturity levels). The Quality 4.0 Capability Roadmap dimensions were defined taking into consideration the literature review, the analysis of the dimensions of the models studied in Chapter 3.7, and personal viewpoint. Since there was a wealth of details about each dimension and, also because the model required to be detailed to act as a roadmap, it was decided to break each dimension down into three subdimensions.

It is key to recognize that effective transitions occur in stages (Gökalp et al., 2017). This paradigm leads to the creation of a roadmap based on a series of capability levels, each of which builds on the preceding. As a result, it was decided to assign the first three levels to a readiness state and the final three to a more advanced state – maturity. The readiness and maturity levels were also developed using knowledge from the literature review, models studied, and personal viewpoint. This description yielded a conceptual model (Figure 1) that can be used to better understand capability levels where traditional quality tools and approaches are integrated with the use of technology.

The outcome is a fifty-four-field model that guides users from their initial interaction with Q4.0 through the development of company-specific fields of action utilizing state-of-the-art technologies. Furthermore, this model is aimed at organizations already embedded in a culture of quality, which will make it easier to understand the importance and applicability of the model.

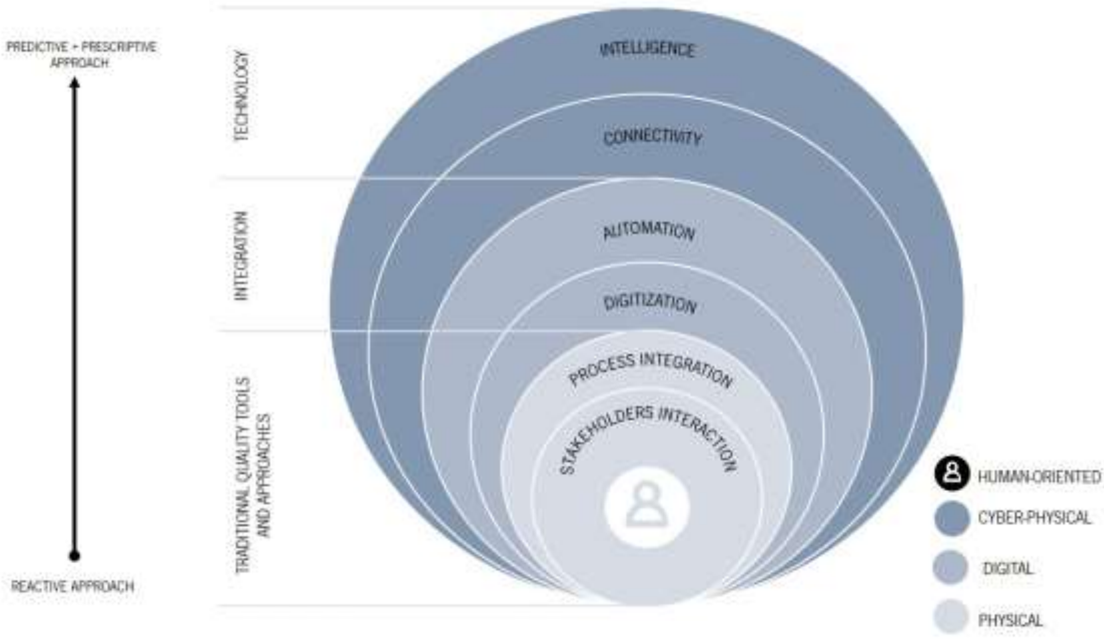

Figure 1 | Capability levels conceptual model

4.2 | VALIDATION PROCESS

The selection of experts considered academia vs. practice balance to validate not only scientific rigor, coverage, representativeness but also usefulness and usability. Experts were also chosen based on their expertise and research contributions in the areas of quality and digital transformation. Since the merging of these areas is a recent concept, finding experts in this domain was no easy task. However, a validation was able to be carried out with four experts. Further discussion towards the validation was obtained at a public session at a university, with the presence of about 20 students and workers enrolled in a quality-related master course.

Initially, the first version of the model, together with a brief explanation and the objectives to be achieved with it, was made available to experts for their first contact for an individual and impartial evaluation. Then, they were then invited to join in in a focus group workshop to discuss not only the model architecture and content but also the model applicability and general comments and suggestions. During the discussion of model's architecture and content the following topics were addressed: dimensions and subdimensions, readiness and maturity levels adequacy; model features fit between dimensions and levels; model's logical evolution; content coverage and representativeness; model's easy interpretation;

and model innovation compared to the existing ones. Regarding the model's applicability, the usefulness and usability were under discussion.

Face-to-face contact in groups encourages a higher degree of iterative involvement (Maier et al., 2012) and allows to discuss different points of view for a given topic, which was advantageous in the discussion of improvements to be implemented to the model.

Tree major suggestions were given concerning the model's dimensions: give more emphasis to the value chain in the first dimension which plays a central role in the management of organizational processes; add to education and training the individual will for change on the part of people and instead of human-centered approach, human-oriented approach. Regarding the model's levels, the major suggestions refer to the fact that the levels do not have different weights and thus it is not possible to quantify the capability of organizations for benchmarking purposes. The applicability of the model also triggered a debate in which a few model pitfalls were identified, which are highlighted in section 4.4.

Following the gathering of expert's opinions and comments, these were analyzed and considered in light of the model's goals, and the Quality 4.0 Capability Roadmap developed was updated.

4.3 | THE QUALITY 4.0 CAPABILITY ROADMAP

The Quality 4.0 Capability Roadmap is composed of three dimensions – "Value Chain and Operations", "Strategy and Organization" and "People and Culture". Each dimension is broken down into three subdimensions – "Customers", "Products and Services", "Processes"; "Strategy", "Integration", "Innovation and Improvement"; "Role Transition", "Organizational Culture", "Leadership". Therefore, each subdimensions is characterized in six levels. The first three are related to the readiness status and the final three with the maturity status. These six levels, in turn, represent the six levels defined in the conceptual model presented in Table 3, from "Stakeholders Interaction", to "Intelligence" level. Table 3 shows the Quality 4.0 Capability Roadmap in further detail.

TABLE 3 | THE QUALITY 4.0 CAPABILITY ROADMAP

Maturity			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

TABLE 3 | THE QUALITY 4.0 CAPABILITY ROADMAP (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
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

Although the entire model is based on the use of technology, the “Value Chain and Operations” dimension represents the technical field of the model. The intention is to support the idea that Quality is an integral part of the digital transformation process, and that while we face a technology-driven transformation, quality is at the basis of the processes. As a result, the subdimensions are focused on trying to integrate technology with "Customers," an integral part of any quality system, "Products and Services," as the development of new products and services changes, and "Processes," which, as a result of the other two dimensions changing, requires an adaptation of any organization's way of working.

In turn, the “Strategy and Organization” dimension is concerned with overall organizational growth. The “Strategy” sub-dimension focuses on creating, developing, and monitoring a strategy for the Q4.0 transition. One of the most relevant dimensions of the entire model - “Integration” - is also present in the other dimensions. Integration of technology, new ways of work, learning, and communication are all important aspects of organizational growth, and that is why it was also highlighted as a sub-dimension. Therefore, there can be no progress without "Innovation and Improvement." This sub-dimension was designed with the intent of giving organizations a fundamental premise of what they would face on their journey to creating new development approaches.

A great highlight was given to “People and Culture” in this model. People are the foundation of any organization, and progress does not imply that this foundation become altered. One of the most important purposes of Q4.0, and even more so of Q5.0, is to enhance rather than disregard people's capabilities. For this, it is very important to create new methods of "Role Transition" to skill and reskill people in the organization to adapt to new ways of working and also to address individual motivation to do it. In every organization, and especially in a more accentuated phase of transformation, the awareness of the "Organizational Culture" is critical, as it contributes as a facilitator in many aspects. Finally, “Leadership” is largely responsible for all this transformation and therefore has a prominent place in this model.

Readiness and maturity levels were designed to provide the Q4.0 transition a sense of progression. The main goal of this levels is to convey to organizations that without the basic foundations of quality, innovation will not be sustainable, that is, placing itself at higher levels of the model without having the previous ones will not result in sustainable progress in the long term. Thus, the order of levels was designed to be followed and get a sense of what's missing.

The first level, "Stakeholders Interaction," is a fundamental level that all organizations are expected to comply with since the model was designed for organizations already embedded in the quality culture. The next level, “Process Integration”, is intended to promote the integration of Q4.0 approaches into the various processes of the organization. The "Digitization" level, which is still in readiness status, is set aside to bridge the gap between the fundamentals and what begins to be an advanced level in the transition to Q4.0. This level aims to transfer organizational data to a digital format and, as a result, establish effective communication channels to assist in day-to-day management.

At a higher maturity level, the "Automation" level aims to employ technology to automate touchpoints in different organizational processes, easing not just data collecting and analysis, but also augmenting human capabilities and decision-making. As we progress to the intermediate level of maturity, "Connectivity," effective communication between people, machines, and systems will become possible, resulting in the simplification of information and knowledge exchange along with the active value network, which is made up of the various intra and extra organizational systems involved in the processes. Finally, the use of state-of-the-art technology allows organizations to reach the level of "Intelligence". At this level, organizations should be able to predict various process parameters, market changes, and progress towards Quality 5.0, which is a resilient, sustainable, and human-centered organization.

Considering the model is designed to be used as a Roadmap, a second layer (Table 4) was developed in which the concepts mentioned in the first layer of the model were turned into further detail. As a result, it is expected that the model will become even less complex and that organizations will be able to turn it into an easy-to-use assessment tool for self-assessing their Q4.0 readiness and positioning themselves to define a strategy for moving up the model's levels.

TABLE 4 | THE QUALITY 4.0 CAPABILITY ROADMAP – 2ND LAYER

			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	- Use of technology for customer needs prediction for improvement or new products/services development; - Use of technology for customer assistance prediction in case of failure (Küpper, Knizek, Ryeson, & Noecker, 2019).	- Product/service digital project and simulation (Santos & Martinho, 2019); - Development of smart products: embed with intelligent sensors to perform data analysis, including prediction of product/service failures in the usage phase (Sader, Husti, & Daróczi, 2019; Santos & Martinho, 2019; Wagire, Joshi, Rathore, & Jain, 2020).	- Digital project and simulation of processes and operations (Schumacher, Erol, & Sihn, 2016; Agca et al., 2017; Santos & Martinho, 2019); - Acquisition of smart equipment infrastructure for real-time processes optimization and automated event handling including machine failure (Reinhard, Jesper, & Stefan, 2016; Agca et al., 2017; Santos & Martinho, 2019);	- Definition of a system of indicators to give, in real-time, a sense of the status of strategy implementation (Lichtblau et al., 2015); - Use of simulation technologies for the exploration of future scenarios (Schumacher, Nemeth, & Sihn, 2019).	- End-to-end digital integration across the value network where systems function and interact autonomously, keeping the same level of coordination (The Industry Working Group (IWG), 2018); - Organizational remote connection and resource sharing enable geographically spread units to work together (Dennis, Ramaswamy, M Noorul, Jayaram, & Capgemini, 2017; Wagire et al., 2020)	- Use of technology to predict response to changes in the market environment and individual customer requirements (Agca et al., 2017);	- Associates continuously identify new training requirements in need and define training plans (The Industry Working Group (IWG), 2018); - Use of technology for simulation of work scenarios (Dennis et al., 2017)	- Promotion of a human-centered approach on organization's associates and customer interaction (Breque, Nul, & Petridis, 2021); - Definition of sustainable policies and procedures (Breque et al., 2021).	- Reliable data collection and analysis can be used in different scenarios simulation for real-time decision making or exploration of future scenarios (Anderson & Ellerby, 2018; Wagire et al., 2020).

TABLE 4 | THE QUALITY 4.0 CAPABILITY ROADMAP – 2ND LAYER (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	Connectivity	5	- Customer data sharing among the value network from customer order to the supplier, production, and logistics to service for real-time monitoring and optimization (Agca et al., 2017; Wagire et al., 2020)	- Value network data sharing for real-time monitoring and optimization (Agca et al., 2017; Wagire et al., 2020); - Interaction leads to the capacity of agile reconfiguration and individualization of products/services (Schumacher et al., 2016; Santos & Martinho, 2019).	- Use of a platform for real-time communication through the networked machines and the value network (Santos & Martinho, 2019; Wagire et al., 2020); - Digital process can be seen in real-time and remotely and changes can be made immediately (Bibby & Dehe, 2018; Wagire et al., 2020).	- Collaboration with external sources in defining and executing the transition strategy; - Reporting the development status of the transition to Q4.0 with the value network (Ponsignon, Kleinhans, & Bressolles, 2019).	- Development of a platform for information sharing with external stakeholders for real-time critical issues management collaboration (Santos & Martinho, 2019).	- Collaboration with external sources in defining and executing innovation and improvement initiatives (Agca et al., 2017); - Reporting the development status of the initiatives with the value network (Ponsignon et al., 2019)	- Development of a platform for shared work and collaborative innovation across the value network (Radziwill, 2020)	- Promotion of communication and interaction among the value network using organizations digital channels/platform (Aleksandrova, Vasiliev, & Letuchev, 2018).	- Quality is everyone's concern; - Distribution of leadership across various levels and functions (Evans et al., 2015)

TABLE 4 | THE QUALITY 4.0 CAPABILITY ROADMAP – 2ND LAYER (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	Automation	4	- Customers' ability to track the product in every stage of the lifecycle (Bibby & Dehe, 2018; Wagire et al., 2020); - Organizations automatically incorporate customer insights data in the process (Agca et al., 2017; Bibby & Dehe, 2018)	- Automation of data collection and analysis for product/service real-time follow-up, review, and validation among the organization processes (Aleksandrova, Vasiliev, & Alexandrov, 2019)	- Process flow automatically between defined parameters which allows the the system to dynamically respond to fluctuations (Radziwill, 2020; Wagire et al., 2020); - Automated digital data collection throughout the entire process (Agca et al., 2017)	- Define which operations, processes, products, and services to automate and define the level of automation (Agca et al., 2017; Radziwill, 2020).	- The organization uses connectivity technology between equipment, products, and people to obtain feedback between the functional areas of the organization (Bibby & Dehe, 2018; Wagire et al., 2020).	- Definition of the human interaction and autonomous improvement level in the organization's processes (Radziwill, 2020).	- Human Machine Interface training; - Use of smart devices and wearables to augment associates working capabilities and risk reduction in product development life cycle (Carvalho, Sampaio, Rebentisch, & Oehmen, 2020)	- Training and engagement of associates in the transformation process (Morteza, 2018); - Update of organizational work regulations for Q4.0, including technical standards and data protection regulation (Lichtblau et al., 2015; Schuh et al., 2020).	- Definition of reliable data analysis and automation of data collection is used in real-time decision-making (Agca et al., 2017)

TABLE 4 | THE QUALITY 4.0 CAPABILITY ROADMAP – 2ND LAYER (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
Readiness	Digitization	3	- Digital interaction through social media, websites, automated online assistants (AOA), chatbots (Küpper et al., 2019); - Creation of a digital platform gather customer insights and digitalization of sales/services (Schumacher et al., 2016)	- Creation of a digital platform for interaction with the customer, show product/services offerings and digitalization of sales/services (Schumacher et al., 2016); - Use of the digital platform for the facilitation of stakeholders' inputs in product/service lifecycle.	- Use of a digital platform for operational processes monitoring and optimization including traceability of production and inventory management (Horvat, Stahlecker, Zenker, Lerch, & Mladineo, 2018)	- Use of a digital platform for central coordination of Q4.0 activities (Schumacher et al., 2016, 2019) - Easy and real-time access to defined Q4.0 activities.	- Single source centralization of information to support organizational processes management (Dennis et al., 2017); - Take advantage of the digital platform for agile information shared across the organization and data integrity management (Santos & Martinho, 2019)	- Centralization of information makes associates have access to information and can participate in improvement and innovation in different areas.	- Establishment of an education/ knowledge platform for training and knowledge sharing (Radziwill, 2020); - Existence of e-learning and b-learning education.	- Existence of a knowledge repository for agile information sharing and intellectual property protection (Schumacher et al., 2016).	- Leadership transparency in Q4.0 transition strategy: management information can be available in a digital platform (Schumacher et al., 2016; Agca et al., 2017); - Leadership is responsible for the promotion of the organization's communication and interaction (Sony, Antony, & Douglas, 2020).

TABLE 4 | THE QUALITY 4.0 CAPABILITY ROADMAP – 2ND LAYER (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
Readiness	Process Integration	2	- Customers' needs and/or preferences are taken into account during the product/service development and production processes (Wagire et al., 2020).	- Stakeholders' needs and/or preferences are taken into account during the product/ service development and production processes (Wagire et al., 2020).	- Data sharing between operational processes and other organizational processes.	- Perception of organizational readiness for the introduction of new technologies and ways of work (Wagire et al., 2020); - Metrics and development plans are focused around Q4.0 objectives including resources allocation and risk assessment of investment in technology and IT infrastructure (Horvat et al., 2018; Santos & Martinho, 2019)	- Development of quality management programs and tools based on digital technologies (Mayakova, 2019); - Policy and procedures suitability for Q4.0.	- The organization's practices include encouraging innovation and pursuing continuous improvement approaches (Ponsignon et al., 2019).	- Openness of associates to new technology (Schumacher et al., 2016); - Time to explore and adopt new ways of work (Ponsignon et al., 2019).	- Personal development plans are focused around Q4.0 objectives (Agca et al., 2017); - Associates involvement and empowerment in Q4.0 initiatives (Morteza, 2018); - Existence of a company's continuous improvement culture to adopt Q4.0 (Wagire et al., 2020).	- Leadership takes the opportunity in acquiring the skills required to handle the transition to Q4.0 (Schumacher et al., 2016) and *is in charge of fostering in the organization a culture of openness for progress.
	Stakeholders Interaction	1	- Reactive communication with suppliers and customers on an ad hoc basis (Agca et al., 2017).	- Products/ services specifications are decided in the concept definition phase without product/service individualization. - No late reconfiguration of products and services availability.	- Data is collected manually when required; -Data is only used for quality and regulatory purposes (Dennis et al., 2017).	- Familiarity and understanding of topics related to I4.0 and Q4.0; - Understanding of the impact of Digital Transformation (Wagire et al., 2020).	- Participation of the different stakeholders of the organization in the definition and promotion of Quality 4.0 transition activities.	- The improvement or development of new products, services, and processes are based on corrective feedback (reactive approach).	- Categorization of the existent digital skills and definition of the required ones (Schumacher et al., 2016; Horvat et al., 2018; Santos & Martinho, 2019); - Education and training plan definition (Dennis et al., 2017);	- Innovation openness, creativity, and labor enrichment (Santos & Martinho, 2019); - Soft-skills acquisition promotion (Küpper et al., 2019; Sony et al., 2020).	- Leadership support digital transformation activities by promoting engagement and collaboration, the development of new skills, and a culture of learning and innovation (Wagire et al., 2020).

4.4 | STRENGTHS AND PITFALLS OF THE MODEL

When designing the Quality 4.0 Capability Roadmap, there was already suitable information on the topic to design a model. However, as developments in the technological area are disruptive, it is likely for the model to become obsolete in some time. Therefore, the model has already been built on a capability basis where it can easily be added levels when necessary, and future updates are guaranteed.

Despite having technology as a significant aspect, there is a noticeable presence of research connected not just to technology in the literature review. This model was also created taking into consideration some ideas from Q5.0, and hence has a very human-oriented feel to it. Therefore the most relevant topics identified in the literature were included and this was reflected in the design of this model, which has the scope of various dimension to offer a holistic overview of Q4.0.

Some models tend to fail if they are too complex making them unusable in practice. As a result, the amount of complexity and model architecture was developed to meet the demands of real organizations. As a result, the designed model enables organizations to not only place themselves at the Q4.0 transition level but also to have a basic tool to assist them in following the route to progress. The model was detailed in a 2nd layer (Table 4) to provide users with simplicity and a simple understanding of the path to take and the expected outcome, as well as to increase the model's applicability. When compared to existing the organizational applicability becomes an innovation since the models focused on Q4.0 reviewed in the literature are essentially conceptual.

At the Quality 4.0 Capability Roadmap validation stage were addressed the model's pitfalls. Some organizations may not be able to place themselves at the Q4.0 transition. As a result, they may begin their efforts at the incorrect level or rush the implementation of a Quality 4.0 program. That's why some organizations tend to start their digitization process from the outermost levels. This becomes a difficulty since there is no long-term sustained adaptation of technology to the organization's ways of working. The transition is supported by incomplete knowledge and skills, often not fully acquired by the organization or dependent on external knowledge. Organizations thus start at a new level without stabilizing or sustaining the previous one. Thus, when applying the model we can see organizations that try to develop a level of skills and knowledge without having the previous level.

Furthermore, it can limit in benchmarking. Benchmarking might, however, be done through a qualitative path. In addition, unlike other models that relied on questionnaires and case studies for validation, the model was validated by an expert panel. Nevertheless, based on the feedback from the experts involved, it is considered that promising outcomes are achievable. As in all works, despite the vast amount of literature reviewed, the experts' judgment and opinion involved in this process, the model still contains a certain level of subjectivity.

5 | CONCLUSION

5.1.| RESULTS DISCUSSION

The Quality 4.0 phenomenon has gained meaning and significance in recent years. It has already been realized that aligning quality and Industry 4.0 is an advantage (Aldag & Eker, 2018; Zonnenshain & Kenett, 2020). However, Quality 4.0 remains a topic of exploration. Thus, in this section, the results from literature review are commented to give a broad perspective from what has been done both academically and by practitioners.

In the literature, there are a few viewpoints on Quality 4.0 definition. Authors, usually, link Q4.0 to Industry 4.0 (Aldag & Eker, 2018; Zonnenshain & Kenett, 2020) either by applying I4.0's digital technologies to quality management (Küpper et al., 2019) or by implying large-scale transformations in people, culture, leadership, and collaboration (Jacob 2017; Radziwill, 2018).

Studies performed by Küpper et al. (2019), Bodi (2020), Carvalho et al. (2020), or Lim (2020) give importance to the closer relation with the customer. Besides, connectivity can be performed intra- and inter-organizationally by extending the connectivity throughout the value chain or value network (Salimova et al., 2020). With this, it is possible to exchange knowledge, perform collective decision-making, and collaborative problem solving (Armani et al., 2021). Digitization and automation seems to be a well-developed topic since it relates to Industry 4.0. A few studies relate the use of cybernetics to quality by giving some examples from when one benefits from the other. Process quality can be improved with the use of greater automation when in need and from augmenting people capabilities (Carvalho et al., 2020; Radziwill, 2020).

Furthermore, the use of state-of-the-art technologies unleashes an advanced level of organizational intelligence and is closely linked with simulation technologies. These technologies create predictive situations to assess the behavior and performance of new design products, processes, and services or improve the existing ones, without committing any resources. Simulation models can be used in quality control (American Society for Quality [ASQ], 2020; Carvalho et al., 2020) and also for training purposes by simulating real situations on the manufacturing floor (Lim, 2020).

With all this comes the need for data management strategy where quality can be an important driver. The identification and definition of information quality, as well as the standardization of methods for obtaining and analyzing data, the application of data protection procedures and policies, and the study of efficient storage strategies are all necessary steps in the digital transformation process (Jacob, 2017; Radziwill, 2020; Sony et al., 2020)

As quality concerns about people in the organization and there are not a lot of studies about Quality 4.0, consequently there a few studies about the social side of this transformation. The use of a human-oriented approach is presented in some studies emphasizing that people are the basis of organizations and the intention of this transformation is to augment people's capabilities and not discard them (Breque et al., 2021). In previous industrial revolutions, there were jobs that disappeared, however others appeared and with this comes the need for education and training, which is highly emphasized in the literature (Küpper et al., 2019; Domingues & Sampaio, 2020; Sony et al., 2020). A quality-oriented culture and leadership have a key role in this transformation.

When it came to assessing the existing models on Quality 4.0, only Jacob (2017) and Armani et al. (2013) had done so. These models have a strong representativeness of for Q4.0-related dimensions and the model developed in this dissertation also had this aspect as a goal. When analyzing models related to quality in the context of Industry 4.0, its prevalence in the literature is already well-known, however the technological side is the most prominent dimension.

An effective transition begins with the Q4.0 awareness of organizations and academics. This is one of the purposes of this dissertation. Following that, arises the need to understand the level of development toward Q4.0 and what needs to be done towards progress. The Quality 4.0 Capability Roadmap was developed as a descriptive model to assist academics in understanding Q4.0 as a whole and to serve as a foundation for organizations to position themselves at a level of capability and understand what they lack in order to make a smooth and sustainable transition to Q4.0.

Unlike the majority of the models analyzed, the Quality 4.0 Capability Roadmap is founded on the notion that organizations must first establish a quality foundation before using more advanced technological approaches. Such that, before moving on to state-of-the-art technologies, the most fundamental aspects of the model must be addressed. It's pointless to invest in state-of-the-art technology if the organization's systems are not prepared to receive it.

This model differed from others in both the design stage, which was based on a literature review and personal inputs, and the validation stage, which included a focus group as a first validation and the intention to share the model with the scientific community in article format as a second validation.

This dissertation allowed to deepen and gather knowledge related to Quality 4.0, Industry 4.0 and Digital Transformation. With this, a basis for research as well as for understating of this concepts resulted from the literature review. The Quality 4.0 Capability Roadmap is the main outcome of this project, and it allows to explore the dimensions of Q4.0 while also providing a well-founded and comprehensive guidance to help in the transition towards Quality 4.0.

5.2 | QUALITY 4.0 DEFINITION AND DIMENSIONS

Quality 4.0 marks a shift from conventional Quality. The use of technology and the adoption the new ways of work have a great impact in the progress of managing and application of quality. As seen in the literature review, a great focus is given to the application of technology and the need of acquisition of technology to have progress. This study aimed to give importance to the other actors responsible for progress. Quality is a great foundation for every organization, especially in a transition stage in which acts as a facilitator in many aspects.

The new era of quality is marked by the use of technology to augment people capabilities and quality tools and approaches. A technological side of quality is a requirement to define and dimension Quality 4.0. The use of technology and the adoption of different approaches is key to get closer to the customer, to manage the development of new and current products and services as well as processes. The connection of the value chain is essential for managing all of this and the use of technology make it easier.

A social side/view is also pointed as a foundation for Quality 4.0. Although human-centered approach is described as essential for a sustainable progress, the human-oriented approach is the current one. We are far from getting the work adapted to humans rather than adapt humans to work. In line with this, there is a need to skill and reskill professionals for the transition for new roles. Furthermore, it is also essential an individual motivation for the identification of new training needs and for the transition to new roles. The quality culture is regarded as a facilitator in transition stages. It is important to engage people for the new ways of work and leadership has key role for making that happen.

The shift to Q4.0, like any other sustainable advancement, entails developing, sustaining, and assessing a strategy. There can be no improvement without knowing what to improve, and there is not technological progress without a solid basis of quality to sustain it. To have Q4.0 there is a need to have a quality basis. A big step for quality relies on the predictive/prescriptive approach instead of a reactive approach. In line with this, this work developed a series of levels to guide organizations in the transition from traditional quality tools and approaches to the use of this integrated with technology for the delivery of superior quality. From integrating stakeholders in the organizational processes and consequently integrate all organizational processes it is a big step for the organization digitization which relies on quality basic approaches. The definition of the required levels of automation in the different organizational processes, the connectivity among the value network and to reach of the level of intelligence require an advanced quality tools and approaches linked to the use of technology.

Quality 4.0 is a recent phenomenon but organizations are already implicitly implementing it. The Quality 4.0 Capability Roadmap it will help these organizations that have some quality basis and want to see their progress towards the future built in a sustainable way.

5.3 | FUTURE WORK

The research carried out to obtain this dissertation, was also used for a literature review article entitled "Quality 4.0: literature review analysis, definition and impacts of the digital transformation process on quality" published in the International Journal of Quality & Reliability Management. In addition, it also contributed to an article that is under review entitled "The Profile of the Quality Leader 4.0" and will later be submitted for acceptance and review an article to share with the scientific community The Quality 4.0 Capability Roadmap.

The research conducted for this dissertation, as well as the outcomes, provide a useful reference point for future studies on Quality 4.0, Quality, and Digital Transformation. Notably, Society 5.0 (S5.0) and I5.0 are concerned with the human dimension in the workplace and greater human quality of life. Considerations for the human side of quality in Q4.0 are an important research issue. An enlightened search of quality for humanity is needed. Inequalities in technological access are a reality, and there are discrepancies in the state of readiness for the implementation of new techniques and ways of work. The costs of poor technological integration in society, as well as ways to avoid this condition, should be explored. Similarly, the evaluation of the risks of worker dissatisfaction and stress as a result of career insecurity or the inability to improve competencies and skills for the modern age must be address (Breque et al., 2021). In line with this, there is an opportunity to explore the risks involved with the use of technology such as cybersecurity, privacy, and data protection in the context of Q4.0.

The Q4.0 Capability Roadmap validation with a greater scope is also possible. The model will be submitted for publication in a scientific journal as future validation, gaining broader acceptance from academics and practitioners. In addition, a case study can also be carried out for the model's applicability validation in practice. Additionally, the model can serve as a basis for the development of other models in this context of action.

Also in the future, the model can be refined. One of the possible future first action is to consider the development of a model application pathway to enable organizations to develop a plan that identifies which dimension to begin working on in this transition, for example. Another future action may be a study of the definition of different weights for the model levels and the establishment of a strategy to apply the weights to the organizations' field of action and therefore use it for benchmarking purposes.

Furthermore, it is possible to conduct research to link this capability model to existing organizational models, particularly the European Foundation for Quality Management (EFQM) excellence model, since some of the developed model's dimensions are present in some way in the EFQM model, allowing for the creation of a connection with a well-known and commonly used organizational tool. With these investigations, the model can be refined and improved, resulting in increased resilience of the developed structures.

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