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EMERGING TECHNOLOGIES APPLIED TO QUALITY ENGINEERING: CURRENT SCENARIO AND PERSPECTIVES

Rodrigo F. S. Gomes [1]
Ingrid Gois Cardoso

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A B S T R A C T

Among central challenges related to increasing organizational performance are the concerns associated with the productivity gain, cost reduction, employment of technology and qualification of the workforce. In this context, the concept of industry 4.0 has been expanding as a differentiation strategy for companies. This paper aims to evaluate the current scenario and the perspectives of the application of emerging technologies from Industry 4.0 regarding Quality Engineering, correlating them with the organization typology and the affected processes. The research is characterized by a systematic literature review in the Web of Science and Elsevier databases. The research results show certain emerging technologies are more strongly associated with Quality Engineering than others, suggesting different levels of maturity. The results suggest even greater adherence of emerging technologies by industrial type organizations instead of services, notably in processes of inspection, maintenance and production control. This study contributes to the academic community as it broadens the understanding of emerging technologies from industry 4.0 applied to Quality Engineering. Additionally, it identifies technologies with greater adherence in the current scenario and promotes a correlation with organizational typology, affected processes and expected impacts.

1. INTRODUCTION

Since the end of the 18th century, when the use of steam engines in manufacturing processes marked the beginning of the First Industrial Revolution, the continuous search for productivity and efficiency gains came with significant transformations in organizational models, especially in the production systems. The evolutionary process of the industry only reached new heights in the early twentieth century, when the mass production and division of labor from Fordism characterized the Second Industrial Revolution, having the electrical energy as a crucial factor for this production model (Bunse et al., 2014).

The evolution of semiconductor technology led to the Third Industrial Revolution in the early 1970s, which advanced the concepts of mechanization and automation relatively slowly (Griffiths and Ooi, 2018). Since 2011, when the concept of industry 4.0 first appeared in Germany, the Fourth Industrial Revolution had its

[1] Corresponding author: Rodrigo F. De Souza Gomes
Email: rodrigofrank@edu.unisinos.br

beginning, characterized by mass digitization, cyber-physical systems (CPS) and Internet of Things (IoT) (Pereira and Romero, 2017). Since then, the application of the industry 4.0 emerging technologies has progressed at exponential rates and it's been considered as a disruptive factor of existing systems and processes (Griffiths and Ooi, 2018).

Lasi, H., F. Peter, Thomas, F, Hoffmann (2019) point out that the approaches and ideas in the context of industry 4.0 are situated in multiple disciplines such as Computer Science, Administration, Systems and Information Engineering, Mechanical Engineering, Electrical Engineering, among others. Ahuett-Garza and Kurfess (2018) reinforce this concept by emphasizing that the industry 4.0 refers to the integration of multiple technologies in order to improve the efficiency and responsiveness of the production system.

More notably in recent years, several articles have presented concepts and applications relating both the industry 4.0 as well as the key emerging technologies that support this new Industrial Age, such as industrial integration, additive manufacturing, cyber-physical systems (CPS), artificial intelligence (AI), IoT, Industrial Internet of Things (IIoT), Cloud computing, Machine learning and Big Data (Agostini and Filippini (2019), Ahuett-Garza and Kurfess (2018), Bauza et al. (2018), Chen et al. (2017), Dalenogare et al. (2018), De Felice et al. (2018), de Sousa Jabbour et al. (2018), He et al. (2017), Kiel et al. (2017), Lasi, H., F. Peter, Thomas, F, Hoffmann (2019), Lu and Weng (2018), Malalalan and Jayakrishna (2019), Mohamed (2018), Pereira and Romero (2017), Ratasich et al. (2019), Sony (2018); Tarallo et al. (2018), Wang et al. (2017), Xu and Chen (2018), Xu et al. (2018)).

Way et al. (2015) highlights the importance of Industry 4.0 for the development of the supply chain as a whole, contributing to the reduction of lead times, improvement of product quality and, consequently, of operational performance. In his work, he highlights the importance of the development of the quality culture as a whole to support new techniques and production processes.

With the emergence of new production methods and systems, there is no doubt that, also for Park (2010), a new concept of Quality emerges which includes customized services, greater focus on product design and safety. In line with this development, Quality Engineering has been following the transformations promoted by emerging technologies within organizations as highlighted by Miller et al. (2018), emphasizing that decisions focused on quality at the organizational level can be seen as one of the greatest characteristics of a strategic plan.

By increasing the understanding of which emerging technologies are entering into the production processes are fundamental for the analysis of researchers and company managers regarding future scenarios. In addition, it is important to understand how Quality Engineering operates in this new scenario, since it plays an important role in the competitiveness level of organizations. This relationship between industry 4.0 and Quality Management is observed in a series of published articles, among which we highlight: Shin et al. (2018), Hyun Park et al. (2017), Song et al. (2017), Miller et al. (2018), Haorui et al. (2018).

In this context in which the Fourth Industrial Revolution has directly influenced the status quo of Quality Engineering, transforming its processes, it is relevant for researchers and managers of organizations to answer the following research question to deepen the understanding about this interaction: Which emerging technologies are present in the production environment related to Quality Engineering and how are the processes and different types of organization affected? Thus, the general objective of this paper is to evaluate the current scenario and the perspectives of the application of industry 4.0 technologies into Quality Engineering, the typology of the organizations in which they are present and the affected Quality processes.

This article is organized in 4 sections. In addition to the Introduction, section 2 displays the method used to conduct the research, highlighting the step-by-step applied in the systematic literature review. Section 3 displays the results and discussions about the analysis of the compiled data. Section 4 brings the Conclusion and suggestions for future works.

2. METHOD

The method of this paper consisted of a systematic literature review to identify published articles that made the combination of the Industry 4.0 theme with Quality Engineering. The following*online databases, Scopus Elsevier* and *Web of Science*, formed the bases for the conduct of the research. These bases were selected because they are related to the Quality Engineering theme and indexed in various journals and, besides, also went through the peer review process.

The data collection process consisted of crossing the main search terms: "*INDUSTRY* 4.0" *AND* ("*QUALITY MANAGEMENT* " *OR* "*QUALITY ENGINEERING*") in these databases. It is worthy mentioning that the consultations were held on May 23 and 26 of 2019 in the *Scopus Elsevier* and *Web of Science*databases, respectively, and that there was no temporal restriction during the publication period of the articles.

The initial sample included publications of articles indexed in these *online* databases after applying the following search filters: I) *final paper* - selected articles published in their final version; II) *language* - articles published in English; III) *Field* - articles that were related to the business and engineering fields. The use of the field

as criteria was due to the scope of the article, since it proposes to evaluate the technologies applied in the processes associated with quality engineering. After first classifying by applying the filters, we proceeded by screening the publications based on their titles. At this stage, we selected the titles of the articles that presented The second stage consisted of reading the titles of the selected articles, and then 45 articles were selected for the analysis of their abstracts. The title selective criteria considered the correlation with the research theme and the presence of specific keywords such as 'QUALITY' and 'INDUSTRY 4.0' or the presentation of technologies related to the Fourth Industrial Revolution.

3. RESULTS AND DISCUSSIONS

Initially, the numerical results of the searches performed using the previously presented descriptors will be presented. Sequentially, the analyzis of how these technologies are associated with Quality Engineering in manufacturing and business environments will be done.

The first stage of the bibliographic survey returned 461 results, 440 of which came from the research in the journal *Scopus Elsevier*. The *Web of Science* database, despite indexing citations from the entire world, possessed a scarcity of results on the subject. When applying the filters of the first selective criteria (*final paper*, English language and engineering and / or business fields), 301 articles were excluded.

Following the same criteria as the selection of titles, 21 articles were chosen for their adherence to the theme. The 21 articles were read in its entirety and selected to compose the basic structure of this literature review. The search and reading of the articles exposed other important references to the theme and, for this reason, another 6 articles were included to compose the basis of this research. Figure 1 presents the sequential detailing of the article selection method, as well as the number of articles returned after applying the exclusion and inclusion criteria.

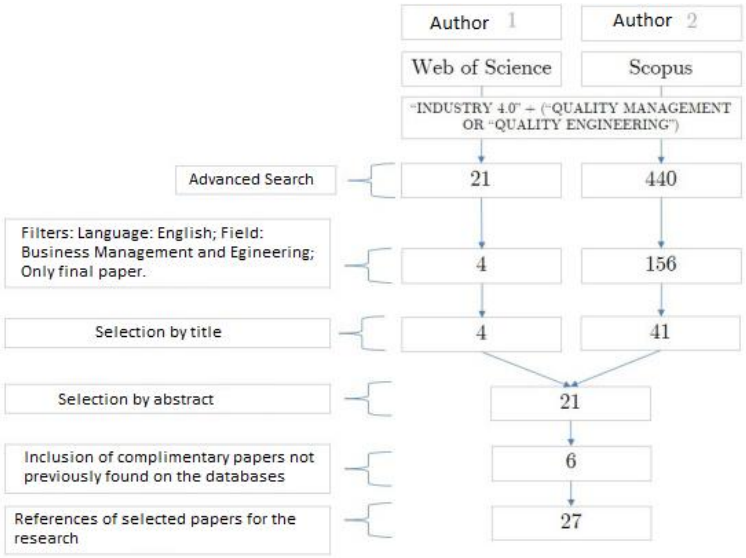

Figure 1. Research Method

The process of systematic literature review has indicated a significant increase in publications on the subject in recent years, notably since 2014. Of the 27 fully read articles, 20 were published between 2018 and 2019, that historical evolution is displayed in Figure 2.

As discussed in the Introduction, the concept of industry 4.0 is quite recent, having first appeared in an article published in November 2011 by the German government to define a high-tech strategy for their development industry until 2020 (Pereira and Romero, 2017). The results of the research reflect, in terms of scientific production on the subject, how new this discussion is.

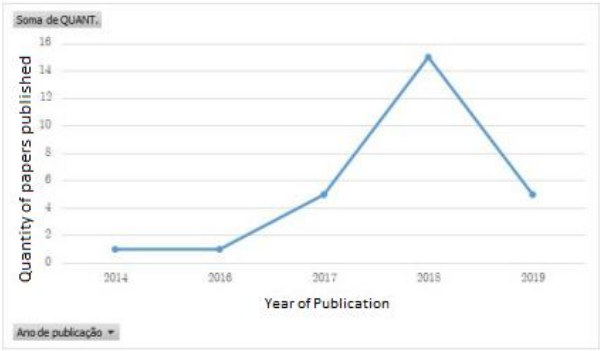

Figure 2. Publications by year

Conceptual and practical theoretical approaches are presented in the literature under different prospects when it comes to implications and consequences as evidenced by Mohamed (2018, p 258). The research results corroborate the previous statement: considering the methodological procedures, it is possible to observe that more than 50% of the articles are made of conceptual analysis. When considering the application of case studies, more than 80% of the selected articles are related to the research theme. Thus, just under 20% have a strong empirical approach.

The recent interest of researchers and companies in these subject stems from the great potential of benefits from the presence of emerging technologies in various processes, including those related to Quality Engineering. However, both the concepts and its applications are not yet consensual, despite many benefits, some challenges need to be conquered to allow reliable implementation, as highlighted by Xu et al. (2018).

Table 1 presents the list of emerging technologies addressed in publications contained in the systematic literature review. According to the data obtained, it is possible to verify that the Internet of Things (IoT), Big Data and Cyber-Physical Systems (CPS) were the emerging technologies most related to Quality Engineering. We will introduce the general concepts about these technologies.

Cyber-Physical Systems (CPS) consists of the interaction of physical and virtual environments, integrating, controlling and coordinating processes and operations, and simultaneously providing data processing (Monostori, et al. (2016) apud Pereira and Romero (2017)). According to several articles cited by Xu et al. (2018), CPS are the basis of industry 4.0 and will guide innovations in manufacturing, energy, transportation, agriculture, automation and health fields.

Table 1. Emerging Technologies Related to Quality Engineering

Emergent technologies	Authors
Internet of Things (IoT)	Ahuett-Garza and Kurfess 2018), Li et al. (2018), Chen et al. (2017), Hyun Park et al. (2017), Sony (2018), Bodrow (2017), Lee et al. (2019), Xu et al. (2018).
Industrial Internet of Things (IIoT)	Muller and Voigt (2018).
Internet of Services (IoS)	Pereira and Romero (2017), Mohamed (2018), Song et al. (2017).
Big data	Ahuett-Garza and Kurfess (2018), Wan et al. (2016), Chen et al. (2017), Mohamed (2018), Hyun Park et al. (2017), Lee et al. (2019).
Cyber-Physical System (CPS)	Ahuett-Garza and Kurfess (2018), Li et al. (2018), Pereira and Romero (2017), Tarallo et al. (2018), Sony (2018), Song et al. (2017), Lasi, H., F. Peter, Thomas, F, Hoffmann (2019).
	Ahuett-Garza and Kurfess (2018).
Machine Learning	Ahuett-Garza and Kurfess (2018), Colosimo et al. (2018).
Additive Manufacturing	Li et al. (2018), Chen et al. (2017), Sony (2018).
	Li et al. (2018).
Cloud computing	Sujova et al. (2019), Haorui et al. (2018) Mohamed (2018).
Industrial Information Integration (III)	Mohamed (2018).
Computer Simulation and Genetic Algorithms	Hyun Park et al. (2017), Lee et al. (2019).
Data Mining	Emmer et al. (2017).
Artificial Intelligence (AI)	Z´avadsk´a and Z´avadsky´ (2018), Song et al.
Measurement Data Management (MDM)	
RFID, WFNet and Others	

Internet of Things (IoT) is an emerging terminology that combines different technologies and approaches based on the connection between physical things and the internet. According to Xu et al. (2018), the term IoT initially referred only to objects using radio frequency communication (RFID) systems interconnected with the internet. Subsequently, other technologies such as GPS, NFC, Wi-Fi, Bluetooth and others were integrated with IoT and formed a dynamic global network infrastructure. In general, in the industrial environment, IoT applies to connections between machines, equipment, objects, people and systems to the Internet, promoting an integration known as *smart factory*.

Zavadská and Závadský (2018) presented the perspectives of quality managers regarding the use of technologies in the manufacturing process until 2025. Managers highlighted the strong presence of the IoT concept in the factories and indicated the expectation of the increased use of *smart gloves*, used to evaluate dimensional characteristics of some parts in the quality control processes. Among the main benefits, it is noteworthy that *smart gloves* do not increase process times and allow direct monitoring of specific product characteristics. However, the application of IoT is not limited to the manufacturing industry, since the same concepts can be applied to services. According to Pereira and Romero (2017), **IoS (Internet of Services)** is a concept that has recently emerged and will bring new opportunities for the Services industry. Also according to the authors, the concept pursues a similar

approach to IoT and can be described as a "new model of business that will profoundly transform the way services are offered".

Big Data refers to the analytical processing of a data set usually collected in an unstructured form. According to Hyun Park et al. (2017) the *Big Data* provides valuable information to society and, based on market segmentation, can create more value to the customer, designate customized services and become the critical competitive bridge for both Marketing and Sales in the Fourth Industrial Revolution. Figure 3 presents the synthesis of this evolution.

Hyun Park et al. (2017) discuss that the Fourth Industrial Revolution brings a new concept for Quality and for the Quality Management process:
"There is no doubt that the concept of Quality will be broadened by the Fourth Industrial Revolution to include quality of personalized services, as mass customization and custom production has become possible. Instead of product quality, more emphasis will be placed on design, safety and quality of service" (Hyun Park et al., 2017, p 4).

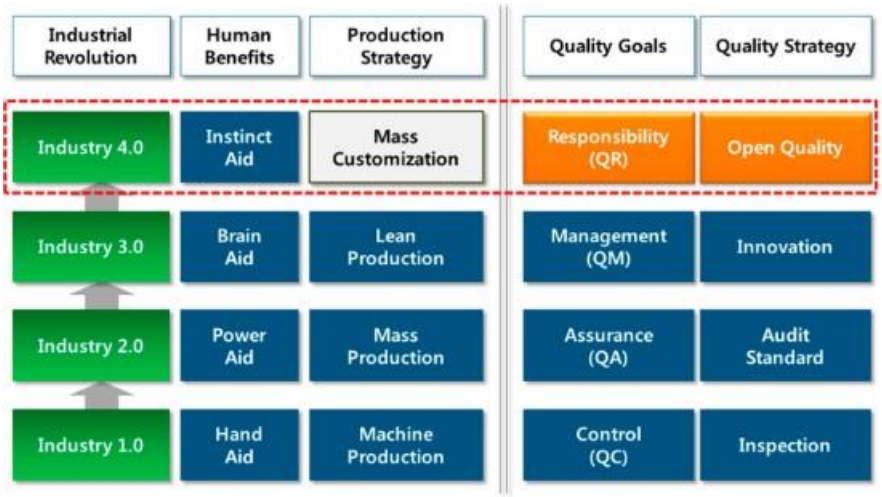

Figure 3. Industrial Revolution and the effects on Quality according to Hyun Park et al. (2017)

When inserted in the Quality context, emerging technologies allow a significant change in the Quality planning and control process, allowing to migrate from an unidirectional to multidirectional flow. In the first one, the unidirectional flow planning - design - production - marketing - sales and feedback does not allow continuous interaction between its phases and the feedback usually only occurs after the sales (Hyun Park et al. (2017). The multidirectional flow promoted from cyber-physical, IoT and Big Data systems enables a simultaneous interaction between processes, allowing organizations to process continuous diagnostics, adding value to products and services.

Corroborating the concept of multidirectional flow, Bodrow (2017) states that the increase in quality is associated to industry 4.0, as it allows tto visualize the process flows and the production in *real time*. Lee et al. (2019), when analyzing the impacts of technologies on quality management for maintenance, states that its approach changes from preventive to predictive. The Rolls-Royce Group, an aviation company, uses nanorobots in the inspection and predictive maintenance processes. The technology allows, among other benefits, a reduction of the inspection times, since nanorobots have access to the aircraft parts without the need to remove them.

Despite the industry 4.0 broad field of action, practical applications of these emerging technologies are still more concentrated in the literature regarding industrial organizations. The graph in Figure 4 presents the data about the researched articles. Of the fully read 27 articles, 18 are associated with a more industry-driven approach, 1 for small-sized industry, 4 related to industry and services, 1 dealing exclusively with Services and 1 more specific about the general supply chain.

The high concentration of publications with a targeted approach to the industrial sector is expected to some extent, as the foundations of the Fourth Industrial Revolution departed from this segment, as detailed before. Regarding the Services sector, which represents a relevant component of Gross Domestic Product for most countries, the number of publications that address the effect of using Big Data, IoT, data mining and others in Quality of Services and, when compared to industry, is not very expressive.

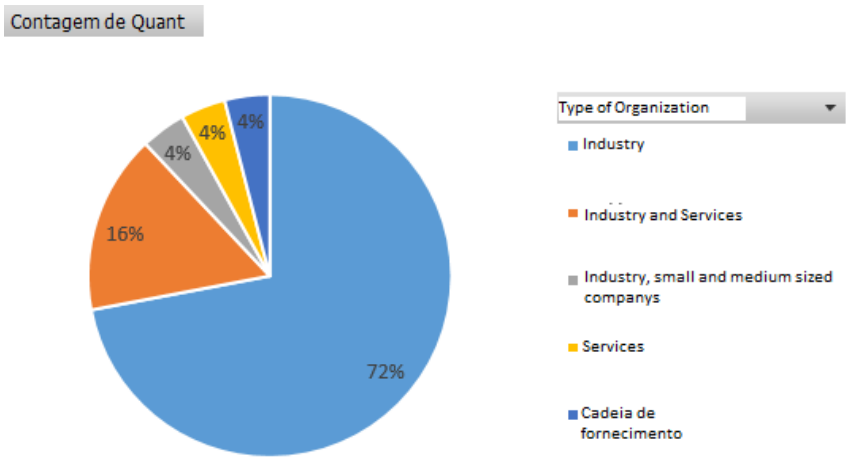

Figure 4. Industry 4.0: Approach of the articles searched by Type of Organization

Although less used in Services, it is possible to highlight the importance of these technologies in the field. An example is the case of John Deere, an agricultural company, which uses technology embedded in after-sales services in order to observe the machine's operation in the field through data. The purpose of this continuous monitoring, as presented by Lee et al. (2019), is to reduce the unavailability of machines, which represents an increase in quality and reliability of the product. In addition, the company offers services that, with the use of drones and sensors, allow constant observation of the soil, ensuring greater productivity for farmers.

In the additive manufacturing processes, Colosimo et al. (2018) highlights the opportunities and challenges of quality engineering. In their study, Colosimo et al. (2018) indicates that additive manufacturing is changing the production landscape by enabling customized production, and depending on the product, with dimensional accuracy and excellent mechanical properties. However, the definition of statistical control methods that allow the understanding of the process stability is pointed out as a challenge , since several products with the most varied levels of complexity are manufactured at once. This unique production aspect does not allow to predict material shrinkage characteristics, for example. As a consequence, additive manufacturing promotes the need to generate unique tools that can be able to perform quality inspection, monitoring, control and process optimization using *big data* and video images.

The processes impacted by the application of emerging industry 4.0 technologies are diverse, as stated. According to the categorization performed on this research, the following management and quality control processes were associated: production control, productivity and operational efficiency, performance indicators, maintenance processes and services, sustainability, safety, SCM and Lean. Table 2 below summarizes this data.

Table 2. Quality Processes Impacted by Emerging Industry 4.0 Technologies

Process Category	Authors that address the topic
1. Productivity and Operational Efficiency	Xu et al. (2018); Ahuett-Garza and Kurfess (2018); Mohamed (2018); Chen et al. (2017); Pereira and Romero (2017); Sujova et al. (2019)
2. Quality Performance Indicators	Wan et al. (2016); Emmer et al. (2017)
3. Quality in Maintenance processes	Lee et al. (2019); Chen et al. (2017)
4. Quality in Services	Song et al. (2017); Pereira and Romero (2017); Mohamed (2018)
5. Sustainability and Energy Efficiency	Ahuett-Garza and Kurfess (2018); Muller and Voigt (2018)
6. Security	Ahuett-Garza and Kurfess (2018)
7. SCM and Lean Manufacturing	Sony (2018); Tortorella et al. (2019)

In the production control, it is possible to observe the increase in efficiency when considering planning, monitoring and inspection, because it is feasible to analyze trends when applying these technologies. When considering Quality Planning, technologies such as additive manufacturing, for example, can be used as a way of validating a new product development concept (prototype) in a more agile and assertive way. (Colosimo et al., 2018). When developing parts with suppliers, for example, it is possible to test concepts and design specification deviations in advance that weren't foresaw in the project design.

Factory processes simulation models are another approach with direct effect on quality monitoring. The use of automated inspection processes, for example, that cameras and sensors used in the process, can check the presence or lack of components in the product, color

variations, among others other characteristics (Tarallo et al., 2018). Another positive impact is that the analysis through simulation allows the behavior of a process to be observed even before its effective implementation in the manufacturing environment. Thus, it allows a critical analysis and monitoring of how flow may affect the product/process characteristics (Sujova et al., 2019).

In the inspection processes, the use of IoT technologies, especially *smart watches*, should be the main technology in controlling nonconforming inseptions (Zavadská and Závadský, 2018). Another technology linked to the improvement of the quality inspection processes that should be explored and developed is the one presented by Emmer et al. (2017), which proposes better management of the part measurement data. A challenge in today's industries is to ensure the inspection of parts with the most varied characteristics which, due to complexity, increases the costs of this process. After all, the greater the variability, more resources are required for the analyzes to be made. Therefore, the proposal of using a single software capable of converting 3D design data for analysis and inspection in a variety of ways more quickly through its projection.

Regarding operational productivity and efficiency, there is the possibility of application of simulation technologies (Sujova et al., 2019), as previously mentioned, or even the development of mathematical methods for quality control, as presented by Haorui et al. (2018). According to the method proposed by Haorui et al. (2018) It is possible to perform quality evaluation and statistical process control through a multi-output mathematical model generated from the data gathered by the ERP (*Enterprise Resource Planning*). Therefore, techniques associated with the concepts of artificial neural networks and genetic algorithm were employed.

It's possible to observe impacts even on the management indicators of quality performance when it comes to Industry 4.0. Although almost unexplored in the literature, there is a publication in which Wan et al. (2016) states that, for the definition of a *Scorecard* in both manufacturing and services, it is necessary to consider costs associated with *scrap* and rework, visible or unrelated costs, failures, non-quality costs, waste, warranties, and other characteristic aspects of Quality Engineering. The data from these indicators, which were previously presented individually, can be crossed to observe a cause and effect relationship between them.

Regarding maintenance processes, the concept of "intellectual maintenance" is presented, in which the approach of the maintenance process goes from a preventive to a predictive character (Lee et al ., 2019). Intellectual maintenance involves *real-time* monitoring of equipment, *big data* processing, and the determination of scope and maintenance times, according to Lee et al. (2019) and Chen et al. (2017). The use of this approach has a direct reflection on the useful life of the product and allows interventions to be made, aiming to increase their availability.

The service sector is being strongly influenced by this new industrial paradigm, as indicated by Pereira and Romero (2017). Through this new conjuncture, more complex and intelligent products are developed. Although it is known that the concept is being strengthened in organizational practices, the presentation of interrelationships between Industry 4.0, services and quality engineering is still underexplored.

The concept of industry 4.0 and quality are also associated with sustainability and energy efficiency, although no direct correlation is established. According to **?** the study, the realation between these factors is still in its infancy, but there is potential to explore them. In a research work carried out by Hofmann and Rusch (2017) the concepts are presented correlated, indicating that industry 4.0 can contribute to a quality production process allowing effective logistic management, thus contributing to the called *Green Supply Chain*.

Although little explored in the literature, the concept of quality engineering and industry 4.0 appears associated with the concept of *lean manufacturing*. According to Sony (2018), industry 4.0 contributes to the *lean* process from the moment where it allows the creation of a continuous value stream through CPS integration in a vertical process, which indirectly improves product quality. Moreover, once you have a more accurate idea of demand forecasting, it is possible to better level the production process, which causes benefits in the process and ultimately, reflects the quality of the product.

Analyzing the contexts in which the concepts of industry 4.0 and quality engineering are enclosed, the next session will present the conclusions and opportunities for future research.

4. CONCLUSION

Organizational needs of significant productivity and efficiency gains have resulted on transformation of production's methods and systems. Emerging technologies from industry 4.0, also known as the Fourth Industrial Revolution, have been used as enabling mechanisms for this transformation, the effect of which is perceived in various organizational areas, which include Quality Engineering.

The broadening of Quality-related studies are relevant to researchers and business managers because of their strategic role and the intrinsic relationship with the economic outcome of organizations. Quality Engineering is directly related to various processes and organizational performance indicators such as: efficiency level, production planning and control, productivity and cost metrics.

The aim of this paper was to evaluate the current scenario and perspectives on the application of industry 4.0 technologies to Quality Engineering, correlating them with the type of organization and impacted processes. Three research questions guided the systematic literature review: (i) What emerging technologies are present in the production environment related to Quality Engineering? (ii) What is the typology of the organizations in which these technologies are inserted? (iii) What processes are impacted? The research results indicate that, in the current scenario, IoT (internet of things), CPS (physical cyber systems) and Big Data are the emerging technologies most present in Quality Engineering related processes. More complex technologies, from the point of view of their development and application such as Artificial Intelligence (AI) and Machine Learning, despite their great potential, are still underrepresented in the literature related to Quality Engineering. Regarding the organization typology, it was possible to conclude that the transformation industry (manufacture) still represents the most fertile environment for the application of the Industry 4.0. The Services sector, the civil construction industry and the agribusiness, despite the high economic potential, are still underrepresented in the literature regarding its emergent technologies application.

Among the quality processes impacted by emerging technologies, production control and operational efficiency represent the largest amount of research conducted, demonstrating significant benefits for industrial and service organizations. Although the concepts of quality engineering and industry 4.0 are more closely related to quality control and inspection processes, there are several other processes that promote their integration. There is a gap in the analysis of how the Fourth Industrial Revolution influences these processes other than just those related to manufacturing. The application of technologies in the processes, as it was observed, promotes better systems integration, real-time monitoring and allows the anticipation of potential product failures / defects. The benefits arising from the application of technologies associated with Industry 4.0 allows, as a first impact, an increased product reliability and productivity.

As for the future scenarios, the systematic literature review suggests a growth prospect of the application of emerging technologies, however, associated with a series of challenges that will require more time to implement by organizations, as a result of to digital security, infrastructure cost, qualification of the workforce in problem solving, fault analysis, and so on.

Regarding Quality, the new concept of "Open Quality" and multidirectional flow proposed by Hyun Park et al. (2017) based on the emerging technologies of IoT, Big Data and artificial intelligence demonstrates a new phase of creating new value for customers in the marketing and sales phases, characterized by creative thinking, Quality management inserted in the early stage of product and service development, and the disappearance of sample inspection in production processes.

This paper was based on a systematic literature review to assess the current scenario and perspectives on emerging technologies applied to Quality Engineering. As a recommendation for a future work, the authors suggests conducting empirical research to assess the current scenario of the Brazilian industry in order to identify how to accelerate the Fourth Industrial Revolution in the country.

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Rodrigo Frank de Souza Gomes
Universidade do Vale do Rio dos Sinos
Porto Alegre
Brazil
rodrigofrank@edu.unisinos.br

Ingrid Gois Cardoso
Universidade do Vale do Rio dos Sinos
Porto Alegre
Brazil
ingrid.prodeng@gmail.com