Industry 4.0 Evolutionary Framework: The Increasing Need to Include the Human Factor

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Abstract: Since 2011, when it appeared as a concept, "Industry 4.0" has been expanding worldwide, impacting many organizations' productivity, performance, and supply chain, especially in developed economies. Prior research has focused mainly on conceptualization, modeling, and technological and operative improvements in the supply chain. Based on a systematic literature review and considering the onset of the COVID-19 pandemic as a major milestone in the global industry, this study proposes a new framework for the analysis of Industry 4.0's evolution, which is divided into three phases: (a) from the beginnings through 2011, (b) Industry 4.0 Process Development: 2012-2019, and (c) the human factor challenge after the COVID-19. In this last phase, the human factor is equally essential as technology selection and change management. To achieve long-term business success, the implementation of Industry 4.0 must consider human aspects, such as middle management leadership, the challenges of empowering operators 4.0, and workers' well-being. Finally, Industry 4.0 could foster a more sustainable, inclusive, and diverse business.

Keywords: Industry 4.0; human factor; digital transformation; operator 4.0; evolution framework.

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I. Introduction

Through human evolution, along with its technological and population growth, all cultures wanted to be more productive and more efficient (Dong et al., 2016). The first industrial revolution of 1750, where steam engines replaced horses, was one of the most radical changes in performance history (Nascimento et al., 2019). Then came the second industrial revolution during the first decades of the 20th Century (Muhuri et al., 2019). Electricity and mass line production attracted European immigrants and contributed to the emerging hegemony of the United States, shifting from a rural to an urban economy (Hirschman & Mogford, 2009). The third industrial revolution arrived in the 1970s, providing manufacturing automation thanks to the more common usage of computers and robotics (Nascimento et al., 2019). Practitioners and researchers consider that the fourth industrial or Industry 4.0 revolution began in 2011 (Mariani & Borghi, 2019; Ozkan-Ozen & Kazancoglu, 2021), when industrial processes became digitalized and integrated through disruptive technologies, allowing machines to coordinate themselves as well as with humans, on a quickly, intelligently, and real-time manner (Agostini & Nosella, 2020; Neumann et al., 2021).

According to the literature, there is no one universal definition for Industry 4.0, finding more than "one hundred definitions for this topic" (Culot et al., 2020, p. 1; Frederico et al., 2020). For Ivanov et al. (2019), the term industry 4.0 works as an umbrella to cover a series of digitalized processes. For other academics, it is the grouping of distant technologies such as blockchain, cloud information, the internet of things, artificial intelligence, additive manufacture, among others (Culot et al., 2020; Neumann et al., 2021). Unlike the previous industrial revolutions, we are experiencing the evolution of this one, and it is possible to study the phenomenon while reshaping our paradigms (Neumann et al., 2021).

Despite the extant literature, previous studies do not include the Industry 4.0 evolution analysis, being hard to identify the factors that should be considered in the assessment and implementation of Industry 4.0 components throughout different industries. As stated by Xiao and Watson (2019), "to push the knowledge frontier, we must know where the frontier is" (p. 93). An evolution analysis allows the development of future empirical research, and this study examines the evolution of Industry 4.0 during the last decade and proposes a new framework to fill the body of knowledge gap. This framework is divided into three stages: (a) the beginning, (b) the development, and (c) the human challenges after COVID-19.

Research Objectives

Organizations that cannot react quickly to the more common global changes would not survive in the long term (Ivanov et al., 2019). Industry 4.0 is a paradigm that facilitates the flexibility and reaction capacity to those changes and can be applied in different sectors, from manufacturing to health or construction (Turner et al., 2021). In light of the emergence of the concept in 2011 to the accelerated digitization supported by disruptive technologies and considering the human factor (Farooq et al., 2021; Ghobakhloo & Iranmanesh, 2021); this study has two objectives: (a) to identify the main factors that have not been thoroughly studied in Industry 4.0 to find gaps in current knowledge, and (b) to propose a framework that describes the major stages in the Industry 4.0 evolution.

Research Questions

The research questions this study seeks to answer are: (a) what milestones have marked the evolution of Industry 4.0?, and (b) which is the main factor with an urgent need to be considered in the following Industry 4.0's phase?

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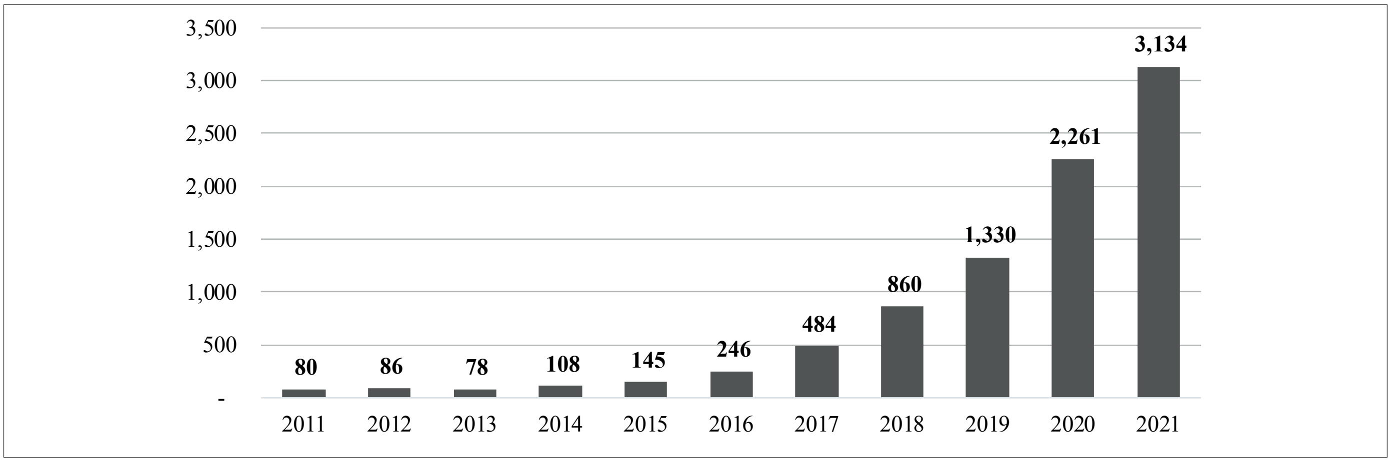
II. Methodology

This exploratory study is based on a systematic literature review (SLR) as the primary approach for data collection. Wee and Banister (2016) state that a literature review describes a selected topic's state of the art while identifying its gaps. Firstly, to get an overview of the topic "Industry 4.0," a comprehensive search was conducted using the Web of Science database, which yielded 9,320 results: (a) 8,489 articles (91.1%), (b) 410 early access (4.4%), and (c) 421 other document types (4.5%). In line with Muhuri et al. (2019), Figure 1 shows an increasing trend in academic research since 2018. In 2021 there were published more than 3,100 articles. As shown in Figure 2, China, the United States, Germany, Italy, and India are the countries where the topic was most studied. Secondly, we adapted the "Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)" methodology (Moher et al., 2010) as per the four steps described below:

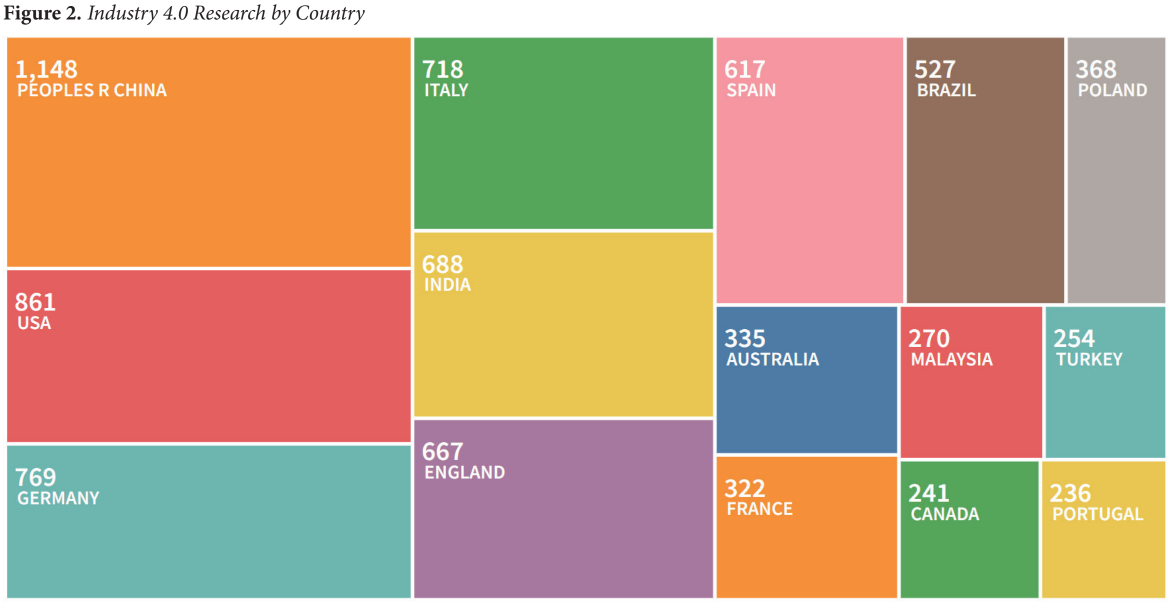
Figure 1 *Number of Publications per Year in the Web of Science Database*



Note. Taken from *Web of Science* database. Copyright 2021 by Clarivate Analytics.

1. Because of its extent and well-recognized academic content, "Web of Science Core Collection" was chosen as the database for the literature search. Exclusion criteria were set based on the Boolean database operators. Firstly, including only peer-reviewed articles, giving a total of 8,489. Secondly, only articles published in English in social sciences or multidisciplinary engineering left 698 articles. Finally, the following inclusion criteria were considered: "industry 4.0," "fourth industrial revolution," "operator 4.0," "leadership on Industry 4.0," "empowerment on Industry 4.0," and "COVID-19;" the final list included 126 articles. Using the *In Ordinatio* formula (Pagani et al., 2015), which sorts publications by seeing the journal impact factor, the citations number, and publishing year, only the articles belonging to Q1, Q2, and Q3 journals with the highest values were chosen.

Figure 2. *Industry 4.0 Research by Country*



Note. Taken from *Web of Science* database. Copyright 2021 by Clarivate Analytics.

2. In this phase, we selected only those papers with their abstracts related to the study's purposes. All the articles "not available in full-text version" (Cerić et al., 2021, p. 3) were removed, resulting in sixty-nine articles.

3. Then, each short-listed article was deeply analyzed and tabulated in MS Excel using the following information: authors, title, year, paradigm, methodology, country, findings, and future investigations. Those papers focused on technical aspects of Industry 4.0 modeling or programming were also excluded, giving a final list of 55 papers.

Each selected paper was qualitatively coded in the final phase using Seuring and Gold (2012) recommendations. Based on the articles' findings and conclusions, nine main topics appeared during the in-deep review and were coded as "sub-variables." These sub-variables were grouped into four major "variables:" (a) technology, (b) operations, (c) human factor, and (d) framework, as seen in Table 2.

III. Results

From the selected papers, 13 (23.64%) were published in 2019, 22 (40.00%) in 2020, and 20 (36.36%) in 2021. According to Elsevier's Scimago journal ranking, 78.2% of articles belong to Q1 journals, 16.3% to Q2 journals, and 5.5% to Q3 journals. Forty-five articles followed a quantitative approach, nine qualitative, and one mixed. Using the Mendeley Desktop app, the most cited papers were: (a) Ivanov et al. (2019) with 226 citations; (b) followed by Xu and Duan (2019) with 161; (c) Tao and Qi (2019) with 112, (d) Nascimento et al. (2019) with 108; and (e) Muhuri et al. (2019) with 107 citations. Table 1 shows the selected articles sorted by journal name, authors, year, and the number of citations. Figure 3 shows the geographical distribution of the selected papers.

As seen in Table 2, most of the papers studied the dimensions "Technology" and "Operations," and just one included a "framework" of the industry 4.0 evolution. These results are aligned with Büchi et al. (2020) and Mariani and Borghi (2019) findings, in which literature centered on the phenomenon description, their components, and productivity. In the "Technology" dimension, fifty-one studies defined the concepts associated with industry 4.0 (i.e., the digital transformations, including models, client service process, and long-term strategies in complex environments), and fourteen papers described the steps and procedures related to cybersecurity. Under the "Operations" dimension, thirty-five studies focused on supply chain improvements, forty-five on productivity and flexibility advantages in the overall company strategy, and twelve on the operation management and risks associated.

Table 1. *Selected Papers Sort by Journal Name*

Published in	SJR Quartile	Author(s)	Year	Methodology	Total
International Journal of Production Economics	Q1	Culot et al. (2020)	2020	Quantitative	1
		Dubey et al. (2020)	2020	Quantitative	1
		Frank, Dalenogare, et al. (2019)	2019	Quantitative	1
		Narayanamurthy and Tortorella (2021)	2021	Quantitative	1
		Neumann et al. (2021)	2021	Quantitative	1
		Raj et al. (2020)	2020	Quantitative	1
		Tortorella et al. (2020)	2020	Quantitative	1
International Journal of Production Economics Sub Total					**7**
Journal of Manufacturing Technology Management	Q1	Aziz et al. (2020)	2020	Quantitative	1
		Ghobakhloo and Fathi (2020)	2020	Qualitative	1
		Ghobakhloo and Iranmanesh (2021)	2021	Quantitative	1
		Nascimento et al. (2019)	2019	Qualitative	1
		Veile et al. (2019)	2019	Qualitative	1
Journal of Manufacturing Technology Management Sub Total					**5**
Journal of Cleaner Production	Q1	Bag et al. (2021)	2021	Quantitative	1
		Gupta et al. (2021)	2021	Quantitative and Qualitative	1
		Khanzode et al. (2021)	2021	Quantitative	1
		Mubarik et al. (2021)	2021	Quantitative	1
		Persis et al. (2021)	2021	Quantitative	1
Journal of Cleaner Production Sub Total					**5**
Sustainability	Q2	Črešnar and Nedelko (2020)	2020	Quantitative	1
		Farooq et al. (2021)	2021	Quantitative	1
		Herceg et al. (2020)	2020	Quantitative	1
Sustainability Sub Total					**3**
Technological Forecasting and Social Change	Q1	Büchi et al. (2020)	2020	Quantitative	1
		Frank, Mendes, et al. (2019)	2019	Quantitative	1
		Mariani and Borghi (2019)	2019	Quantitative	1

Published in	SJR Quartile	Author(s)	Year	Methodology	Total
Technological Forecasting and Social Change Sub Total					**3**
Computers and Industrial Engineering	Q1	Fantini et al. (2020)	2020	Qualitative	1
		Kaasinen et al. (2020)	2020	Qualitative	1
		Segura et al. (2020)	2020	Quantitative	1
Computers and Industrial Engineering Sub Total					**3**
IEEE Transactions on Industrial Informatics	Q1	Jiang et al. (2020)	2020	Quantitative	1
		Pace et al. (2019)	2019	Quantitative	1
		Turner et al. (2021)	2021	Quantitative	1
IEEE Transactions on Industrial Informatics Sub Total					**3**
International Journal of Production Research	Q1	Dolgui et al. (2020)	2020	Quantitative	1
		Dolgui et al. (2019)	2019	Quantitative	1
		Ivanov et al. (2019)	2019	Quantitative	1
International Journal of Production Research Sub Total					3
International Journal of Manpower	Q2	Agarwal et al. (2021)	2021	Qualitative	1
		Ozkan-Ozen and Kazancoglu (2021)	2021	Quantitative	1
International Journal of Manpower Sub Total					2
Journal of Technology Management and Innovation	Q3	Arredondo-Trapero et al. (2020	2020	Quantitative	1
	Q3	Borges et al. (2021)	2021	Quantitative	1
	Q3	Ibujés-Villacís & Franco-Crespo (2022)	2020	Qualitative	1
Journal of Technology Management and Innovation Sub Total					**3**
Manufacturing and Service Operations Management	Q1	Olsen y Tomlin (2020)	2020	Quantitative	1
Journal of Intelligent Manufacturing	Q1	Viriyasitavat et al. (2020)	2020	Quantitative	1
Total Quality Management and Business Excellence	Q1	Tortorella et al. (2021)	2021	Quantitative	1
Management Decision	Q1	Agostini and Nosella (2020)	2020	Quantitative	1
Journal of Technology Transfer	Q1	Cucculelli et al. (2021)	2021	Quantitative	1
Applied Ergonomics	Q1	Kadir and Broberg (2021)	2021	Qualitative	1
Structural Change and Economic Dynamics	Q2	Cirillo et al. (2021)	2021	Qualitative	1
Supply Chain Management	Q1	Frederico et al. (2020)	2020	Quantitative	1
International Journal of Productivity and Performance Management	Q2	Acioli et al. (2021)	2021	Quantitative	1
Engineering Applications of Artificial Intelligence	Q1	Muhuri et al. (2019)	2019	Quantitative	1
Enterprise Information Systems	Q2	Xu and Duan (2019)	2019	Quantitative	1
Global Policy	Q2	Albert (2020)	2020	Quantitative	1
Future Generation Computer Systems	Q1	Wan et al. (2019)	2019	Quantitative	1
International Journal of Operations and Production Management	Q1	Bigdeli et al. (2021)	2021	Quantitative	1
IEEE Transactions on Systems, Man, and Cybernetics: Systems	Q1	Tao and Qi (2019)	2019	Quantitative	1
Race and Class	Q1	Robinson (2020)	2020	Quantitative	1
Information Fusion	Q1	Diez-Olivan et al. (2019)	2019	Quantitative	1
Journal of Competitiveness	Q1	Kubickova et al. (2021)	2021	Quantitative	1
Other Journals Sub Total					**18**
Grand Total					**55**

Figure 3. *Selected Publication's Origin Country*

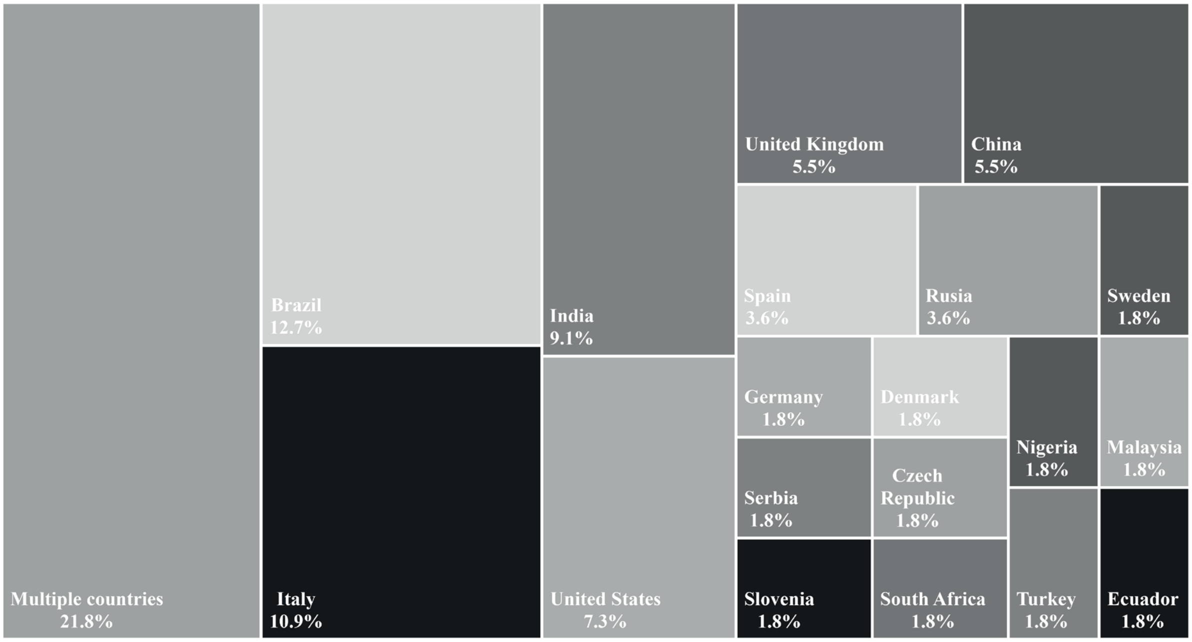


Table 2 *Industry 4.0 Literature Coding – Main Variables/Sub Variables Studied*

ID	Dimension / Sub dimension / Autor	Technology		Operations			Human Factor			Framework
		Industry 4.0	Cyber security	Supply Chain Mng.	Productivity / Flexibility	Risk Mng.	Operator 4.0	Well-being	Leadership	Framework
1	Acioli et al. (2021)	✓		✓	✓				✓	
2	Agarwal et al. (2021)	✓			✓	✓		✓	✓	
3	Agostini and Nosella (2020)	✓		✓					✓	
4	Albert (2020)	✓	✓		✓	✓		✓	✓	
5	Arredondo-Trapero et al. (2020	✓		✓	✓					
6	Aziz et al. (2020)	✓		✓	✓					
7	Bag et al. (2021)	✓		✓	✓					
8	Bigdeli et al. (2021)	✓		✓	✓					
9	Borges et al. (2021)	✓		✓	✓					
10	Büchi et al. (2020)	✓	✓	✓	✓			✓		
11	Cirillo et al. (2021)	✓			✓			✓	✓	
12	Črešnar y Nedelko (2020)	✓				✓		✓	✓	
13	Cucculelli et al. (2021)	✓						✓	✓	
14	Culot et al. (2020)	✓	✓	✓	✓					
15	Diez-Olivan et al. (2019)	✓		✓	✓	✓		✓		
16	Dolgui et al. (2020)	✓		✓	✓	✓				
17	Dolgui et al. (2019)	✓			✓					
18	Dubey et al. (2020)	✓		✓	✓	✓				
19	Fantini et al. (2020)	✓		✓	✓	✓	✓	✓		
20	Farooq et al. (2021)	✓		✓	✓	✓				
21	Frank, Mendes, et al. (2019)	✓		✓	✓					
22	Frank, Dalenogare, et al. (2019)	✓		✓	✓	✓				
23	Frederico et al. (2020)	✓		✓	✓					
24	Ghobakhloo and Fathi (2020)	✓	✓	✓	✓			✓		
25	Ghobakhloo and Iranmanesh (2021)	✓		✓	✓	✓				

ID	Dimension	Technology		Operations			Human Factor			Framework
	Sub dimension / Autor	Industry 4.0	Cyber security	Supply Chain Mng.	Productivity / Flexibility	Risk Mng.	Operator 4.0	Well-being	Leadership	Framework
26	Gupta et al. (2021)	✓		✓	✓			✓		
27	Herceg et al. (2020)	✓			✓	✓		✓	✓	
28	Ibujés-Villacís & Franco-Crespo (2022)				✓				✓	
29	Ivanov et al. (2019)	✓	✓	✓	✓	✓				
30	Jiang et al. (2020)	✓			✓					
31	Kaasinen et al. (2020)	✓		✓	✓			✓	✓	
32	Kadir and Broberg (2021)	✓					✓	✓	✓	
33	Khanzode et al. (2021)	✓		✓				✓		
34	Kubickova et al. (2021)									
35	Mariani and Borghi (2019)	✓	✓	✓	✓			✓	✓	✓
36	Mubarik et al. (2021)	✓		✓	✓					
37	Muhuri et al. (2019)	✓	✓	✓	✓		✓			
38	Narayanamurthy y Tortorella (2021)	✓			✓			✓		
39	Nascimento et al. (2019)	✓		✓	✓					
40	Neumann et al. (2021)	✓	✓	✓	✓		✓	✓		
41	Olsen y Tomlin (2020)	✓		✓	✓			✓		
42	Ozkan-Ozen and Kazancoglu (2021)	✓					✓	✓	✓	
43	Pace et al. (2019)	✓	✓		✓					
44	Persis et al. (2021)	✓		✓	✓			✓		
45	Raj et al. (2020)	✓	✓	✓	✓			✓		
46	Robinson (2020)	✓	✓					✓	✓	
47	Segura et al. (2020)	✓			✓		✓	✓	✓	
48	Tao y Qi (2019)	✓	✓	✓	✓					
49	Tortorella et al. (2020)	✓			✓			✓		
50	Tortorella et al. (2021)	✓			✓			✓		
51	Turner et al. (2021)									
52	Veile et al. (2019)	✓	✓	✓	✓			✓		
53	Viriyasitavat et al. (2020)	✓		✓	✓					
54	Wan et al. (2019)									
55	Xu y Duan (2019)	✓	✓	✓	✓					
	Total	51	14	35	45	12	6	26	15	1
	Potential Gaps						✓			✓

Although Industry 4.0 is considered a socio-technical process (Kadir & Broberg, 2021; Raj et al., 2020), there are few studies under the "Human Factor" dimension, and they have been published mainly since 2020 (Cirillo et al., 2021; Kaasinen et al., 2020; Kadir & Broberg, 2021; Narsayanamurthy & Tortorella, 2021). These studies include topics such as "Operator 4.0," "Wellbeing," and "Middle managers leadership." Seventeen papers studied the workers' and supervisors' leadership and empowerment because they are "crucial elements of the process" (Neumann et al., 2021; Tao & Qi, 2019, p. 86; Tortorella et al., 2021).

Ghobakhloo and Fathi (2020) and Veile et al. (2019) found that agile organization management, open communication, and adequate training (under the "Human Factor" dimension) related to the new process and systems were fundamental in thriving industry 4.0 implementation. However, they did not include the required training level or new necessary soft skills (Ozkan-Ozen & Kazancoglu, 2021). Nascimento et al. (2019) concluded that Industry 4.0 does not directly impact the "human capital," being an opportunity to develop more specialized workers. Ivanov et al. (2019) studied the advantages of digitalization; however, the organization's structural changes, workers' training, and middle managers' skills and empowerment behaviors were not analyzed in-depth (Neumann et al., 2021). Büchi et al. (2020) recommended further studies on the personnel rotation and the number of personnel after a digital transformation process.

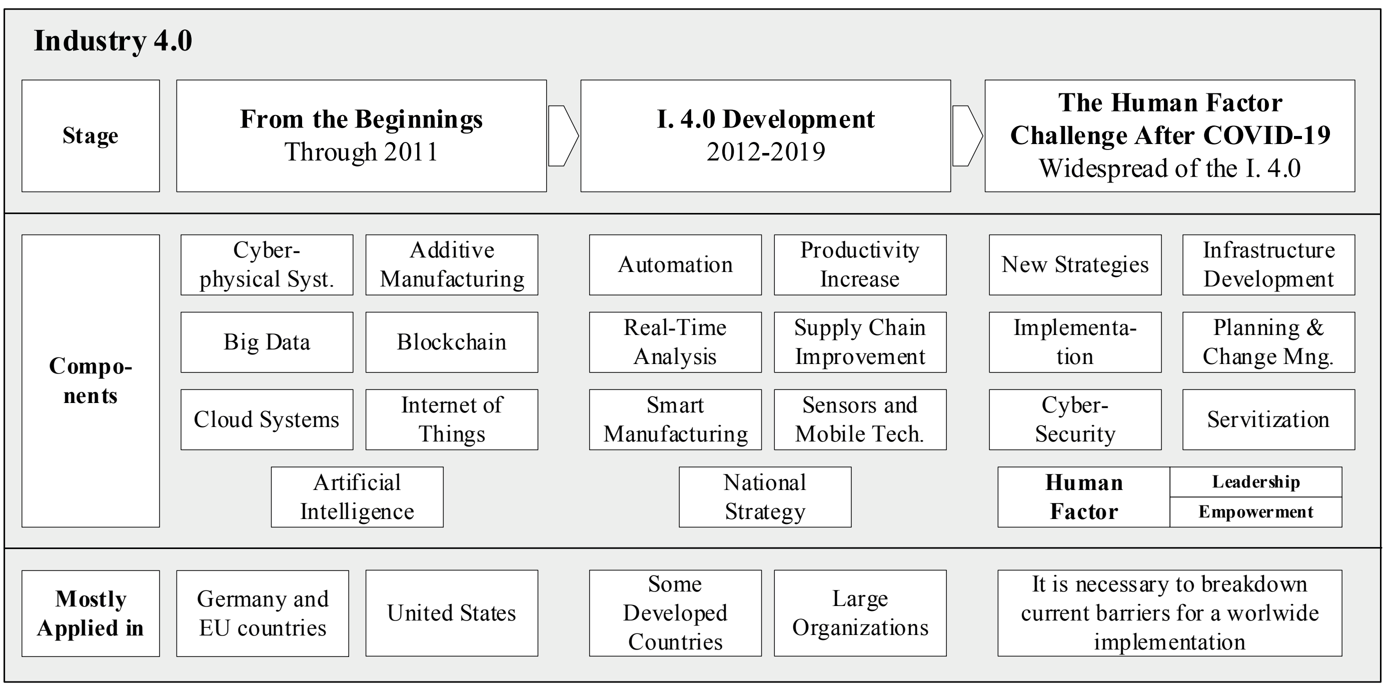
IV. An Emergence of a New Framework in the Industry 4.0 Evolution

The SLR showed that just one study included a general framework of the evolution of Industry 4.0 from its beginnings to 2016 but focused on the technology dimension (Mariani & Borghi, 2019). To have a broader and updated general framework, this study proposes a new framework considering that the COVID-19 pandemic marked a milestone that pushed an acceleration in the digitalization process in companies around the world, which included different approaches to Industry 4.0. This new framework has three main stages, as shown in Figure 4. The first stage started in 2011 when different new concepts started to be grouped under the “Industry 4.0” concept (Culot et al., 2020). The second stage began in 2012 and finished in 2019, in which Industry 4.0 was applied in organizations from developed countries. The third phase started with the COVID-19 pandemic spread and is still ongoing (Acioli et al., 2021), which has forced companies around the world to digitize their processes (Narayanamurthy & Tortorella, 2021), supported by technologies associated with Industry 4.0 (Ghobakhloo & Iranmanesh, 2021). In this last stage, the literature showed that the human factor started to gain importance.

Phase 1 - From the Beginnings Through 2011

Since the 1980s, manufacturing organizations have looked for synergies among their networks, technologies, and operations systems without human interventions to speed up the existing process while improving efficiency and customer services (Boyd & Johnston, 1987; Mosier & Taube, 1985). Nevertheless, the 21st-century technologies recently allowed these integrations intelligently and productively (Cirillo et al., 2021; Tao & Qi, 2019) under the industry 4.0 umbrella (Neumann et al., 2021). This new concept became popular in 2011 after the presentation of the Research Union Economy-Science of the German Ministry of Education and Research at the Hanover Fair (Culot et al., 2020). It should be noted that the United States and other European countries have already been working on strategies for using technology networks and systems (Culot et al., 2020; Fantini et al., 2020).

Figure 4. *Proposed Industry 4.0 Evolution Framework*



Veile et al. (2019) pointed out that the concepts of Industry 4.0 and the internet of things are equal. However, other researchers consider the industry 4.0 group different technologies like the internet of things, cloud systems, collaborative robots, additive manufacturing, big data, and cyber-physical systems (Neumann et al., 2021). They all look for increased production efficiency and flexibility during higher and lower demand seasons while increasing customer services (Xu & Duan, 2019). Industry 4.0 goes beyond the simple grouping, meaning synergistic technology integration, applied in isolation or combination (Olsen & Tomlin, 2020).

Before the fourth industrial revolution began in 2011, there had been existing technologies such as “enterprise resource planning (ERPs), computing aid drawing (CAD), computer-aid-manufacturing (CAM), and electronic data interchange (EDI),” which usually worked in isolation looking for organization’s agility (Culot et al., 2020, p. 2). However, industry 4.0 achieved an “interconnection between man, machine, and information/communication technologies” in real-time, substantially improving the organizations’ flexibility and productivity (Veile et al., 2019, p. 977), originating a profound change in companies and consumers, through synergies between technologies and system's models (Culot et al., 2020). These models can be descriptive (correlative, clustering, and generative), predictive analysis models (regression, decision tree, neural networks), and prescriptive (mathematical, stochastic, and heuristic programs) (Xu & Duan, 2019). It is worth mentioning that the fourth industrial revolution grew thanks to the drastic reduction in the cost of sensors and the increase in the capacity of microprocessors (Olsen & Tomlin, 2020).

Phase 2 - Industry 4.0 Process Development: 2012-2019

During this stage, large companies (with more resources) and their supply chains benefited the most from the implementation of Industry 4.0 on their processes (Ghobakhloo & Fathi, 2020), which helps manufacturers minimize risks and improve the production cycle before the final delivery to consumers (Ivanov et al., 2019). As stated by Raj et al. (2020), "switch to automated production 4.0 from conventional production can improve productivity by 45%-55%" (p.2). This can be exemplified by a pair of Adidas sneakers that usually reached the final buyer in Germany three months after being manufactured in China, Vietnam, or Indonesia; however, using the Speedfactory 3D philosophy, the entire process was reduced just to five hours, with entirely German manufacturing (Ivanov et al., 2019). The case of General Electric using 3D printers can illustrate the same idea because the company optimized the manufacturing process for some special motors, reducing the components from 855 to a dozen (Olsen & Tomlin, 2020). Achieving these improvements requires managing a large amount of information and relying on efficient cyber-physical systems (CPS) and big data; otherwise, the supply chain's scalability, security, resilience, and efficiency could be affected (Xu & Duan, 2019).

In the same way, during this period, the blockchain (i.e., databases distributed in many nodes) dabbled in the supply chain with the promise of "increasing your trust, visibility, and evidence-based efficiency" (Dolgui et al., 2020, p. 1). An accurate blockchain eliminates intermediaries, reduces costs, and makes more straightforward transactions between producers and clients (Olsen & Tomlin, 2020). It also allows: (a) reducing risks in the event of a database failure, (b) adding more databases without affecting the process, (c) security and encryption, (d) autonomy, and (e) impossibility of altering the process (Viriyasitavat et al., 2020). It can even improve the quality of customer service through mutual feedback processes (Dolgui et al., 2020).

Germany and the United States were the countries that implemented Industry 4.0 with a better velocity (Frank et al., 2019). China launched the national strategy "Made in China 2025" to generalize the implementation of Industry 4.0 in its organizations (Tao & Qi, 2019). Similarly, South Korea initiated the "Manufacturing Industry Innovation 3.0" program (Ghobakhloo & Fathi, 2020). Other developed countries have been facilitating the adoption of 4.0 technologies through government and tax strategies, plus developing the necessary infrastructure (Büchi et al., 2020). Likewise, there was a significant increase in academic production during those years, led by Germany and China (Muhuri et al., 2019). In this period, following the "Smart Manufacturing" trend, the industries integrated their processes under a service-oriented ecosystem, with customized products for their customers. (Aziz et al., 2020; Muhuri et al., 2019; Tao & Qi, 2019).

In the developed world, small and medium enterprises (SMEs) tried to implement the technical and non-technical aspects of Industry 4.0 (Culot et al., 2020). They started with pilot projects, analyzing the cost/benefit ratio, and verifying the level of optimization of the specific process (Veile et al., 2019). The goal of these companies is for the value chain systems to operate in an integrated manner (Agostini & Nosella, 2020), just like large companies, knowing the status of any point at any time and eliminating potential bottlenecks (Muhuri et al., 2019). Diez-Olivan et al. (2019) recommended that these companies implement the systems in a balanced way both on local computers and in the cloud.

Phase 3 - The Human Factor Challenge after the COVID-19

The start of the COVID-19 pandemic was an inflection point (Acioli et al., 2021); it has affected the worldwide supply chains and the worker's performance; and organizations that previously established some Industry 4.0 practices or quickly adapted their digitization processes were the least affected (Farooq et al., 2021; Narayanamurthy & Tortorella, 2021).

The competencies of empowerment, intervention space, control, and autonomy started to gain importance in the Industry 4.0 adoption (Cirillo et al., 2021, p. 2). Human capital management in the fourth industrial revolution means a more significant challenge (Agarwal et al., 2021) since highly qualified personnel are needed at all levels (Herceg et al., 2020; Khanzode et al., 2021). They must be attracted and retained in an environment where the demand exceeds supply (Diez-Olivan et al., 2019; Ozkan-Ozen & Kazancoglu, 2021). For booming Industry 4.0 implementations, blue-collar workers must be considered at every stage (Tortorella et al., 2021). Bearing in mind their stress, safety, cognitive changes, and fear of being replaced by machines; valuing their effectiveness, flexibility, satisfaction, and safety towards the new processes (Kaasinen et al., 2020; Kadir & Broberg, 2021).

Companies should be aware of the welfare of their workers because even though the machines perform repetitive tasks, people will be under strict controls, with less autonomy and new standardized processes (Cirillo et al., 2021). Industry 4.0 tools will influence their performance as long as a new kind of leadership is adapted to this new normal (Narayanamurthy & Tortorella, 2021). Consequently, companies must migrate to a new organizational culture, horizontal, flexible, and agile, with open communication, redesigned jobs, and special long learning and training plans (Ozkan-Ozen & Kazancoglu, 2021; Veile et al., 2019). Companies are required to be adapted to the new competencies, training workers with greater capacity for abstraction, creativity, decision making, and social interaction (Fantini et al., 2020; Raj et al., 2020), interacting efficiently with machines and systems (Olsen & Tomlin, 2020). So, it is not enough to establish a more productive Operator 4.0 or Worker 4.0, who will be more empowered with more information (Segura et al., 2020); it is necessary to take care of their welfare, training, safety, and mental health, because unlike machines and systems "human beings cannot be redesigned" (Fantini et al., 2020; Neumann et al., 2021, p. 11).

Agostini and Nosella (2020) stated that management support is essential for implementing innovative technologies. Organizations must recruit and train future leaders in a more consolidated Industry 4.0 era. These professionals will belong to the generations Y and Z, who are more familiar with technology and appreciate their free time, highlighting values of inclusion, diversity, ethics, and collaborative work (Črešnar & Nedelko, 2020). In parallel, organizations must set up a new delegation of authority processes and policies (Agarwal et al., 2021; Khanzode et al., 2021), where matrix organizations are recommendable due to their capacity to solve issues quickly via digitalized cross-functional groups (Ozkan-Ozen & Kazancoglu, 2021).

Widespread of the Industry 4.0

Although Industry 4.0 positively impacts productivity, there are limitations to its faster spread: (a) the relatively prohibitive cost of investment and (b) organizational barriers to successful implementation in the medium term. High investment is a severe limitation, especially for SMEs, both in developed and developing countries, with fewer resources for investment in technological infrastructure (Borges et al., 2021; Dubey et al., 2020; Frank, Mendes, et al., 2019). For example, German companies are barely implementing them (Kadir & Broberg, 2021), and in Italy, only 17.4% of medium and large companies have implemented any of the 4.0 technologies (Büchi et al., 2020). In the latter, barriers such as lack of commitment from senior management, underestimation of the competition, "lack of knowledge of the immediate needs of customers, lack of differentiation, and ineffective marketing" limit a successful implementation (Dubey et al., 2020, p. 6; Nascimento et al., 2019).

Due to these restrictions, before starting a digital transformation process, it is recommended to analyze and know all the pros and cons that Industry 4.0 technologies can provide (Ghobakhloo & Iranmanesh, 2021). Manufacturing companies have been the most receptive to Industry 4.0; therefore, it is suggested to consider the following steps in these companies: (a) first select and acquire a cloud ERP provider, or select a cloud solution and upload the company's data in order to optimize procurement, maintenance, quality, human resources processes; (b) then train workers in CAD tools and cybersecurity; (c) implement sensors, equipment with radio frequency (internet of things) to automate systems in the supply chain; (d) use smart cameras or augmented reality gadgets, big data analysis, and additive manufacturing to make all processes more flexible and digitalized prior the final delivery; and finally (e) extend these practices to customers and suppliers (Frank, Dalenogare, et al., 2019; Ghobakhloo & Fathi, 2020; Persis et al., 2021). Other researchers suggest, in parallel to the implementation: (a) analyzing which information that can be uploaded to the cloud and which must stand within the company; (b) taking advantage of mobile technology like cell phones, smartwatches, and other wearables; and (c) not neglect continuous improvement and knowledge management processes (Pace et al., 2019; Tortorella et al., 2021; Turner et al., 2021).

Another consideration in the implementation of Industry 4.0 is cybersecurity, as it requires interacting using the internet all the time, and cloud services imply designing cybersecurity systems before, during, and after the implementation to avoid hacker attacks or losing sensitive information (Veile et al., 2019). Though, the system configuration should consider a balance between cybersecurity and flexibility among all network devices, granting recovery times and reliability during potential issues (Xu & Duan, 2019). Thus, descriptive, predictive, and prescriptive prognosis (i.e., ability to anticipate any event) will continue gaining relevance in the coming years (Diez-Olivan et al., 2019). Cybersecurity remains a barrier for SMEs because it is influenced by the technology that top management chooses during the "technology upgradation" (Khanzode et al., 2021, p. 11).

In addition to productivity increase, industry 4.0 could help the sustainability of organizations. Given the current need for green capitalism, capable of contributing to new sustainable growth (Albert, 2020), Industry 4.0 could support developing a sustainable and resilient supply chain to help countries and businesses achieve the long-awaited circular economy. (Acioli et al., 2021; Bag et al., 2021; Mubarik et al., 2021). Starting, for example, with an intelligent selection of hazardous materials (previously properly recycled), as inputs for 3D printers to produce new innovative products (Nascimento et al., 2019). Industry 4.0 promotes intelligent waste reduction and production in a way that respects our planet (Albert, 2020; Bag et al., 2021).

Another factor contributing to the expansion of industry 4.0 is the emergence of a new concept in the manufacturing industry. Before the spread of COVID-19, a growing trend was to go beyond smart manufacturing and move to "servitization," integrating processes from manufacturing inputs to delivery to the final consumer and subsequent post-sale (Diez-Olivan et al., 2019), reinforcing the relationship between manufacturers and customers (Bigdeli et al., 2021). For the development of servitization, big data, cloud services, and mobile Internet through the cyber-physical system are required (Tao & Qi, 2019). Because servitization involves strategic and organizational alignments, it needs to reshape the company's external and internal boundaries of power, competence, and identity (Bigdeli et al., 2021). However, Frank, Mendes, et al. (2019) argued that servitization is achieved when companies and their products have a certain maturity in the market, and it is necessary to continue giving more value or attract new customers.

Additional Challenges

The literature associated with the last stage of the proposed evolution framework for Industry 4.0 reflects that "humans will remain essential to the functioning of systems," if they are not considered in the early stages of the change process, the digital transformation will not meet all of its objectives (Agarwal et al., 2021; Neumann et al., 2021, p. 1). Furthermore, since Industry 4.0 is still expanding, its growth and development require alignment with all stakeholders, seeking a favorable national political climate; because enterprise infrastructure is not enough, the expansion of Industry 4.0 also needs a robust national infrastructure (Culot et al., 2020). Therefore, emerging countries' governments are called to encourage and facilitate the adoption of 4.0 technologies to improve their overall competitiveness (Büchi et al., 2020). Being optimistic, in developing countries, Industry 4.0 can improve their aggregated productivity, economy, and human resource skills (Culot et al., 2020). However, it is still impossible to know the improvement level, given the current informality and working conditions (Fantini et al., 2020).

In addition, universities and research centers could contribute to the standardization, regulation, and development of technological infrastructure (Büchi et al., 2020; Cucculelli et al., 2021). Thus, Industry 4.0 can become a socially responsible practice, capable of creating better paid and skilled jobs than it would eliminate during the difficult phase of implementation (Ghobakhloo & Fathi, 2020). It would even allow more inclusive workplaces, giving more opportunities to new workers with disabilities (Segura et al., 2020). Finally, global leaders could use the lessons learned from COVID-19 to reduce inequality by utilizing all the advantages offered by Industry 4.0 for the benefit of humanity (Robinson, 2020).

Industry 4.0 can become a double-edged sword; on the one hand, it could contribute to social development (Nascimento et al., 2019); on the other hand, governments could use these technologies against people by controlling their movements and behaviors (Albert, 2020). Even technological giants and transnational survivors after the COVID-19 pandemic could emerge with more power, concentrating on global capital and supply chains (Robinson, 2020).

V. Theoretical Implications

According to the literature review, Industry 4.0 has been widely studied, with a growing trend in recent years. However, considering the findings of the studies in the last stage of the proposed framework, few studies consider the human factor in Industry 4.0, as well as its expansion in developing countries (Cirillo et al., 2021; Fantini et al., 2020; Kadir & Broberg, 2021; Narayanamurthy & Tortorella, 2021; Olsen & Tomlin, 2020). This gap in the knowledge implies specific challenges for theory, new studies should focus on the impact of the human being in the implementation of Industry 4.0 to achieve long-term business success, through (a) the correct inclusion of the human factor in the redesign of processes, (b) empowerment of personnel, and (c) establishment of the right leadership and organizational culture to support it. Regarding the processes, organizations should not ignore the emotional component of the personnel, such as stress and fear of being replaced by machines (Kaasinen et al., 2020; Kadir & Broberg, 2021) during the implementation of Industry 4.0. In addition, digitized and standardized processes in Industry 4.0 affect the autonomy of personnel (Farooq et al., 2021; Narayanamurthy & Tortorella, 2021; Cirillo et al., 2021) which causes an additional emotional impact. It is necessary to study how the emotional effect on the personnel can affect a correct implementation.

Regarding the second challenge, the implementation of new technologies requires highly qualified personnel (Agarwal et al., 2021) who need to develop new skills, such as a greater capacity for abstraction, creativity, decision-making, and social interaction (Fantini et al., 2020; Raj et al., 2020). Organizations must understand that the implementation of Industry 4.0 requires technical training and a holistic approach to human competencies to obtain a better human-machine complement. Further studies must analyze the impact of considering both types of instructions during the implementation and ongoing stages.

Concerning the third challenge, the implementation of Industry 4.0 requires that organizations' leadership and organizational culture adapt to the new reality (Ibujés-Villacís & Franco-Crespo, 2022; Ozkan-Ozen & Kazancoglu, 2021; Veile et al., 2019; Narayanamurthy & Tortorella, 2021), which includes the two previous challenges. So, additional studies must focus on determining what kind of leadership (i.e., with particular attention to middle management) and organizational culture are necessary to ensure long-term success (Ibujés-Villacís & Franco-Crespo, 2022).

Considering the onset of the COVID-19 pandemic as a major milestone in the global industry, as stated by Acioli et al. (2021), it is also important to study the brands that the COVID-19 pandemic has triggered, so there are opportunities to conduct exploratory studies addressing machine-worker interaction (Fantini et al., 2020) or to develop longitudinal studies related to the implementation of Industry 4.0 in developing economies during and after COVID-19 (Dubey et al., 2020). Finally, new research could study the barriers to the implementation of Industry 4.0 in small and medium-sized enterprises in developing countries (Arredondo-Trapero et al., 2020; Nascimento et al., 2019).

VI. Practical Implications

Industry 4.0 came to change the paradigms of existing organizations, allowing them to react better in VUCA (volatile, uncertain, complex, ambiguous) environments (Büchi et al., 2020; Ghobakhloo & Fathi, 2020; Viriyasitavat et al., 2020). Productivity has increased in horizontal, agile, decentralized organizations with a smart, resilient supply chain focused on personalized customer service (Bigdeli et al., 2021; Mubarik et al., 2021; Veile et al., 2019). These significant changes create technical, human, and cultural challenges during an Industry 4.0 implementation, where proper planning is crucial. (Tortorella et al., 2021).

Companies need to survive in a VUCA environment, and Industry 4.0 can help them to be constant innovators by anticipating their customers' needs (Frank, Mendes et al., 2019; Shibata et al., 2021). Industry 4.0 fosters collaboration and can benefit the environment and society (Nascimento et al., 2019; Tao & Qi, 2019). Like any process of change, it must start from the initiative of the CEOs with the support of experts in the field to deploy the business strategy (Cucculelli et al., 2021; Raj et al., 2020) and accompanied by adequate management support (Agostini & Nosella, 2020). Then, during the planning and implementation stage, workers must be actively involved to ensure its success (Kaasinen et al., 2020; Kadir & Broberg, 2021); taking care of workers' welfare, achieving a good balance between human, technological and organizational aspects, at all levels of the organization, with open and transparent communication (Agarwal et al., 2021; Persis et al., 2021; Veile et al., 2019).

VIII. Conclusions

Although the SLR confirmed Industry 4.0's importance and positive trend, some gaps are pending to fill; one of them is related to the definition of a framework that draws the evolution of the theme up to date. A gap that this research intends to fill by defining three phases: (a) starting the first in 2011 with the coining of the concept by Germans researchers; (b) then proceed to the phase where under the Industry 4.0 umbrella, these disruptive technologies were mainly applied on developed economies and large and wealthy companies; and finally (c) the human factor challenge, which was linked to the COVID-19 impacts. A growing literature is shaping the urgent need to be more focused and worried about the welfare of the human capital and the Operator 4.0 involved in the Industry 4.0 process, from the planning and implementation through the operations and maintenance phases.

The human factor challenge is critical for successfully implementing Industry 4.0 technologies in SMEs, especially in developing economies. Nevertheless, despite the VUCA contexts of the XXI century (Persis et al., 2021), Industry 4.0 can become a catalyst for sustainability (Kadir & Broberg, 2021) and strengthen modern businesses' inclusion and diversity. To this end, close coordination and mutual support are vital between private organizations, governments, research centers, and universities. Finally, it is concluded that it is not enough to develop more autonomous machines; it is necessary a previous cultural and organizational change (Veile et al., 2019), considering the human factor as a crucial element of the entire process (Neumann et al., 2021).

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