

Industry 5.0 Beyond Technology: An Analysis Through the Lens of Business and Operations Management Literature

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Background/purpose: In comparison to Industry 4.0 (I4.0), Industry 5.0 (I5.0) shows a more systemic transformation that includes business innovations driving the transition to a sustainable, human-centric, and resilient industry. I5.0 implies on rethinking business models, ecosystems, managerial practices, etc. while moving toward sustainable development. Despite the novelty of I5.0 and the growing interest in the subject, the literature is still scarce. Therefore, this study aims to analyze the state of the art and understand the approaches that constitute the study of I5.0, through the lens of business and operations management.

Method: A systematic literature review was performed through the lens of the business and operations management literature.

Results: Four major themes were identified: (i) technological application, (ii) Human Resources and workers, (iii) education, and (iv) business and operations management. For each theme, the implications, future avenues and practical considerations are presented.

Conclusions: Most I5.0 studies have focused on Human Resources and workers discussing the role of technological applications on operator safety. Despite I5.0 calls for a step forward in sustainable development, studies on it are scarce. Also, the literature is still missing practical contributions and frameworks for how I5.0 could impact on business management.

Keywords: Industry 5.0, Industry 4.0, Society 5.0, Sustainable development, Human-robot collaboration

1 Introduction

Formally coined in 2011, “Industry 4.0” (I4.0) was still in its infancy when Michael Rada brought the idea of Industry 5.0 (I5.0) to the fore in 2015 (Rada, 2017). More recently, after a decade of I4.0, the European Commission decided in 2021 that I4.0 is not the better framework for achieving Europe’s 2030 goals (Dixson-Declève et al.,

2021). Realizing the necessity of complementing the digital transformation of production systems by expanding their scope to “people-planet-prosperity,” rather than simply valuing extraction to benefit shareholders, the official launch to European industry of I5.0 as policy reinforced enterprises’ role in contributing to a better, fairer world (Xu, Lu, Vogel-Heuser, & Wang, 2021).

I4.0 has become the standard for applications in recent

years (Gürdür Broo, Kaynak, & Sait, 2022; Tay, Alipal, & Lee, 2021), as the rapid implementation of its technologies (Barata, 2021; Sindhwani et al., 2022) consolidates the Fourth Industrial Revolution, still in progress. Conversely, these developments still cannot achieve the desired outcomes, neglecting the environment by prioritizing machines over humans (Sindhwani et al., 2022). On the other hand, I5.0 is more a systemic transformation that includes impacts on civil society, governance structure, and human identity, in addition to solely economic and manufacturing ramifications. I5.0 is the next evolutionary step (Rada, 2017), with I5.0 complementing the existing I4.0 revolution by having research and innovation drive the transition to sustainable, human-centric, and resilient industry (Brequé, Nul, & Petridis, 2021). However, to enable I5.0, one enormous challenge lies in how to do it and understand what changes it will impose on businesses and operations management in directing the technological transformation of industrial production toward “planet-people-prosperity”. The concept of I5.0 has been strongly linked to Society 5.0. S5.0 advances the discussions on cyber-physical systems while reinforcing the relations between people and technology to improve the quality of life and ensure sustainable development (Roblek, Meško, & Podbregar, 2021).

The analysis of the current literature indicates that I5.0 has started to launch different approaches to the subject. As expected, concrete practices are still incipient, considering the infancy of the Fifth Industrial Revolution. Discussions around technological aspects prevail, followed by studies on the relationship between production automation and workers, some of them suggesting how to make such interaction more human-centric (Chin, 2021). Other studies raise concerns about the development of skills and competencies by workers and the challenges to universities that will contribute to this (Carayannis & Morawska-Jancelewicz, 2022; Gürdür Broo et al., 2022).

Despite the articles in this review, recent research on I5.0 reveals gaps that still require study. The literature shows scant discussion of how a firm could innovate its business model and put humans at the center, as a cultural mindset that enables the firm to generate new business opportunities (Mihardjo, Sasmoko, Alamsyah, & Elidjen, 2019). This idea of human-centrism as a cultural mindset can change the experience of customers from the personalization of customization into mass customization (Mihardjo, Sasmoko, Alamsyah, et al., 2019). In this paradigm, enterprises have a new role for workers, namely, using technologies to serve people rather than the other way around (Brequé et al., 2021). A circular economy, linked to long-term vision rather than short-term overproduction and consumption models, appears as an element to consider as a contribution to sustainable development (Dixon-Declève et al., 2021). Therefore, existing business models developed in light of the I4.0 paradigm are

endangered and must be rethought, to advance to the I5.0 paradigm. Accordingly, they should consider such issues as future viability and competitiveness, organizational and production alignment in the context of digital transformation, and employee qualification and acceptance (Carayannis, Christodoulou, Christodoulou, Chatzichristofis, & Zinonos, 2021).

The present study considers the novelty of I5.0 and the growing but still scarce attention it receives in the literature. Therefore, we must know the state of the art and understand the approaches that constitute the study of I5.0, through the lens of business and operations management. Additionally, affirming the role of the paradigm in moving toward sustainable development is crucial. To date, research shows no study that has carried out a systematic literature review (SLR) concerning I5.0 in the context of business and operations management. Accordingly, this study aims to systematize the related scientific knowledge, creating a debate among business and management scholars. The object of the analysis includes the contribution of I5.0 to sustainable development. The research questions are:

RQ1: How is Industry 5.0 positioned in the business and operations management literature?

RQ2: Which are the research themes in Industry 5.0 literature, seen through the lens of business and operations management?

RQ3: How does the Industry 5.0 literature present the role and contribution of Industry 5.0 for sustainable development?

The recent academic papers on this subject and their position in the business and operations management literature were analyzed. We identified four major themes by which to classify the analyzed papers: Technological Application in I5.0; Human Resources (HR) and Workers in I5.0; Education and Training in I5.0; and Business, Operations Management, and Sustainable Development in I5.0. For each group, the paper presents an analysis of the main findings and discussions. This SLR also identifies future questions and research avenues on the subject, representing a useful tool for researchers to develop new inquiries.

Next, the detailed method for proceeding with the SLR appears, after which concepts and a general view of I5.0, results of the SLR, analysis of the literature, discussion and future avenues for research, and the study's conclusions follow.

2 Method

We selected the Systematic Literature Review (SLR) as an appropriate approach to performing a detailed analysis of the literature and achieving the research purpose. An SLR constitutes a well-defined process to identify, evaluate, and interpret all available recorded documents (Kirst,

Borchardt, de Carvalho, & Pereira, 2021). This study follows the steps presented in Kirst et al. (2021). The relevance and novelty of I5.0 and (our research showed) the absence of an SLR that considers it from the perspective of business and operations management reinforces the relevance of this study. Add to this the lack of an organized analysis of different themes on the subject, and the present study aims to contribute to the field's development by filling this research gap.

This study demonstrates the following steps: formulating the research questions; establishing academic-paper inclusion and exclusion criteria; locating and identifying studies that meet those criteria; data extraction and coding; data synthesis and analysis; and results (Kirst et al., 2021). The aim of the study and research questions appear in the Introduction.

The search utilized the Web of Science and Scopus databases, seeking published articles and reviews from peer-reviewed journals written in the English language. Books and conference papers were excluded, following Kirst et al. (2021). The study considers all published papers up to the date of the authors' last search of the databases, January 30, 2022.

The selection criteria for including papers (articles and reviews) in the SLR encompassed the following aspects.

First, we considered the results of seeking the string "industry 5.0" in the article title, abstract, and keyword fields. The search kept to the subject areas related to business and management operations as follows: (a) Scopus: business, management and accounting, social sciences, decision science, environmental science, multidisciplinary, and economics, econometrics and finance; (b) Web of Science: management, engineering multidisciplinary, engineering industrial, environmental science, environmental studies, engineering manufacturing, social science interdisciplinary, development studies. This screening resulted in 153 items from Scopus and 83 from Web of Science.

Second, we read the title and abstract of each article, and excluded those that still did not study I5.0 from the perspective of business and management operations. This means that in some way, papers must present the impact, contributions, challenges, or implications for organizations leveraging 5.0 implementation. Also, excluding duplicates, the resulting list comprised 114 items from Scopus and 35 from Web of Science.

Third, the authors of this study carefully read, coded, and analyzed each paper, considering the extent to which the papers align with the scope of this study. Figure 1 illustrates this process and the final number of articles.

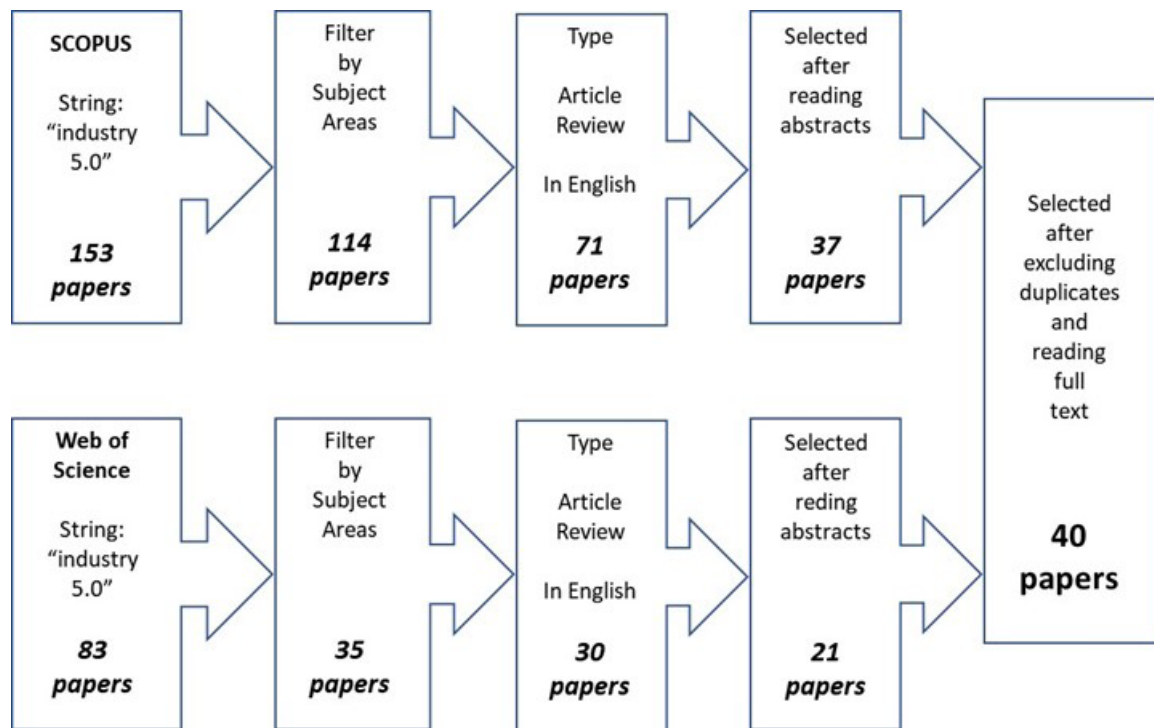


Figure 1: Understanding the process of article selection and its final amount

After excluding the duplicate papers, three of the authors performed the final analysis. They read the 40 articles and proposed four distinct themes based on the keywords and full-text content. After discussing the suggested themes with all authors and consolidating them into four cohesive groups, the three mentioned authors classified the papers according to their best-related theme. These authors also indicated the corresponding methodological approach described in each paper. Table 1 presents the journals where the papers were published, and Table 2 summarizes the result of this final paper's screening.

The first theme, "Technological Applications in Industry 5.0," encompasses the articles that discuss such applications and their potential impact on operations and/or businesses. The second theme, "Human Resources (HR) and Workers in Industry 5.0," presents articles that analyze challenges, avenues, and impacts of I5.0 that intersect with workers' skills, competencies, and abilities, and how organizations manage these. The third theme, "Education and Training in Industry 5.0," includes articles that explore how educational institutions (mainly higher education) could prepare students for this new context of I5.0 and contribute to businesses leveraging I5.0. Finally, the fourth theme, "Business and Operations Management in Industry 5.0," encompasses the articles that analyze the impact of I5.0 on business models, business management, supply chain, and customers' focus and relationship, as well as how I5.0 could contribute to sustainable development (SD).

3 Industry 5.0 – Concepts and General Venue

The Hannover Fair saw the term "Industry 4.0" (I4.0) arose in October 2011, when the working group on I4.0 presented a set of I4.0 implementation recommendations to the German Federal Government. The introduction of the term "Industry 5.0" (I5.0) occurred on December 1, 2015, just four years after the first introduction of I4.0, in an article that Michael Rada published within the LINKEDIN social network (Rada, 2017). At the ten-year mark of I4.0's introduction and six years after Rada's I5.0 introduction, the European Commission announced I5.0 (Xu et al., 2021). Through the I5.0 paradigm, the European Commission recognizes the power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity by making production respect the boundaries of our planet and place the industry worker's well-being at the center of the production process (Dixson-Declève et al., 2021).

The I4.0 paradigm is essentially technological. It focuses on the optimization of production systems and business models, and economic thinking supports it. One challenge is that I4.0 facilitates the creation of the techno-

logical monopoly and giant wealth inequality (Breque et al., 2021). Therefore, I5.0 requires a new economic orientation for industry performance, new designs for business models, value chains, and supply chains, new purposes for digital transformation, new approaches to policymaking in partnership with business and industry, new capabilities and approaches to research and innovation, and vertical and horizontal coherence by acting at all levels of government and through international standards (Dixson-Declève et al., 2021). Rather than taking emergent technology as a starting point and examining its potential for increasing efficiency, a human-centric approach in industry puts core human needs and interests at the heart of the production process. Rather than asking what we can do with new technology, we ask what the technology can do for us (Dixson-Declève et al., 2021).

I5.0 centers around three interconnected core values: human-centricity, sustainability, and resilience (Xu et al., 2021). The authors understand the human-centric approach to mean that technology is to serve people and societies, including the needs and diversity of industry workers. Sustainability relates to circular processes and leads to a circular economy with better resource efficiency and effectiveness (Dixson-Declève et al., 2021). Resilience refers to developing a higher degree of robustness in industrial production while ensuring critical infrastructure in times of crisis (Dixson-Declève et al., 2021).

Before the European Commission launched the I5.0 paradigm, the first academic papers to appear in Scopus and Web of Science, relating to I5.0 and its impact on businesses and processes, were published in 2019. The emphasis is on the integration of human beings with technology and reinforcing the customer experience by mass customization (Mihardjo, Sasmoko, & Elidjen, 2019; Pathak, Pal, Shrivastava, & Ora, 2019; Rahman et al., 2019). Some concerns started to grow, such as the lack of knowledge and skills to operate and manage a technological world leveraged by I4.0 initiatives (Correia Simões, Lucas Soares, & Barros, 2020; Nahavandi, 2019). How to build a business model and implement human-centricity as a cultural mindset while guaranteeing organizational agility in the context of digital transformation has intrigued some authors (Mihardjo, Sasmoko, Alamsyah, et al., 2019). This study has investigated the literature on I5.0 and its study and discussion, until the present.

4 Results from the Systematic Literature Review

Table 1 presents the journals that published the papers and the CiteScore per journal. Diverse journals have published representative articles on the subject of I5.0, some with high Cite Scores.

Table 1: Journals related to business and operations management that have published on I5.0.

Journal	Total published (until January 30, 2022)	CiteScore Scopus (January 2022) ^a
<i>Journal of the Knowledge Economy</i>	5	4.2
<i>Sustainability (Switzerland)</i>	3	3.9
<i>Applied Sciences (Switzerland)</i>	3	3.0
<i>Journal of Industrial Integration and Management</i>	2	3.3
<i>Sensors</i>	2	5.8
<i>Journal of Industrial Information Integration</i>	1	22.1
<i>Journal of Manufacturing Systems</i>	1	12.7
<i>International Journal of Production Economics</i>	1	12.2
<i>Technological Forecasting and Social Change</i>	1	12.1
<i>International Journal of Hospitality Management</i>	1	9.4
<i>Computers and Operations Research</i>	1	8.2
<i>Advances in Production Engineering & Management</i>	1	5.1
<i>The TQM Journal</i>	1	4.3
<i>Technology in Society</i>	1	4.2
<i>Asian Journal of Shipping and Logistics</i>	1	4.2
<i>Organizacija</i>	1	3.3
<i>IET Communications</i>	1	3.2
<i>Social Sciences (BASEL)</i>	1	2.3
<i>Anais da Academia Brasileira de Ciências</i>	1	2.1
<i>Applied System Innovation</i>	1	1.9
<i>IBIMA Business Review Journal of Human Resources Management Research</i>	1	1.2
<i>Journal of Legal, Ethical and Regulatory Issues</i>	1	1.1
<i>International Journal of Evaluation and Research in Education</i>	1	0.9
<i>Cultural Management: Science and Education</i>	1	0.9
<i>International Journal of Systematic Innovation</i>	1	0.2
<i>Logistics (BASEL)</i>	1	No
<i>International Journal of Supply Chain Management</i>	1	No
<i>International Journal of Innovation, Creativity and Change</i>	1	No
<i>International Journal of Recent Technology and Engineering</i>	1	No
<i>International Journal of Engineering and Advanced Technology</i>	1	No

Source: <https://www.scopus.com/sources.uri>. Accessed on January 30, 2022

Aiming to understand the main keywords that relate to I5.0, we produced a cloud of words with the keywords extracted from the selected papers (Figure 2). Analyzing the cloud enabled observing the terms that appear most frequently with Industry 5.0 (I5.0): Industry 4.0 (I4.0), Society 5.0, human-robot collaboration, artificial intelligence (AI), human factor, sustainability, COVID-19, personalization, Internet of Things, transformational performance,

and knowledge.

The cloud of keywords indicates human-robot collaboration, human factors, and knowledge as subjects that relate to I5.0. Indeed, this study indicates that most articles from the SLR relate to human factors and how to prepare workers and leaders for I5.0 in the context of human-robot collaboration.

The keywords Society 5.0 and Industry 5.0 directly relate to the literature (Roblek et al., 2021). After 2016, Society 5.0 became a new research phenomenon, which Japanese government policies introduced to establish a better, super-smart, and more prosperous human-centered society (Roblek et al., 2021). In this society, products and services will be readily available to satisfy various potential needs and reduce economic and social gaps, so all people can live a comfortable and vigorous life (Fukuda, 2020). The authors see the strategy as the Japanese response to other socio-technological strategies, such as I4.0 in Europe and the Industrial Internet in the United States.

As the I5.0 literature points out, Society 5.0 also represents a new paradigm that places humans at the center of innovation (Roblek et al., 2021). It applies I4.0 technolo-

gies and innovations to solving human problems that affect all countries, enabling them to meet sustainable development goals (Bartoloni et al., 2021). It involves social and human aspects beyond the industrial system, with the aim of achieving a sustainable environment in this technological context.

5 Analysis of the Literature

We analyzed and classified the 40 papers (Table 2), considering the journal where each was published, the research method, and the research theme. The next subsections illustrate each research theme.



Figure 2: Cloud of keywords. Produced using <https://www.wordclouds.com/>

Table 2: Authors, journals, research method, and theme

Author	Journal	Methodological approach			Research theme			
		Revision / theoretical	Qualitative	Quantitative / modelling	Technological application	HR / Workers	Education	Business / operation management
(Pathak et al., 2019)	International Journal of Engineering and Advanced Technology	x						x
(Mihardjo, Sasmoko, Alamsyah, et al., 2019)	International Journal of Recent Technology and Engineering			x				x
(Nahavandi, 2019)	Sustainability (Switzerland)	x				x		
Mihardjo, Sasmoko, & Elidjen, 2019)	International Journal of Innovation, Creativity and Change			x				
(Rahman et al., 2019)	International Journal of Supply Chain Management		x					
(Javaid et al., 2020)	Journal of Industrial Integration and Management	x			x			
(Javaid & Haleem, 2020)	Journal of Industrial Integration and Management	x						
(Longo, Padovano, & Umbrello, 2020)	Applied Sciences (Switzerland)			x		x		
(Carayannis, Campbell, & Grigoriadis, 2021)	Journal of the Knowledge Economy	x						
(Carayannis, Christodoulou, et al., 2021)	Journal of the Knowledge Economy	x						
(Carayannis, Dezi, Gregori, & Calo, 2021)	Journal of the Knowledge Economy		x					x
(Orlova, 2021)	Social Sciences (BASEL)			x		x		
(Ojstersek, Javernik, & Buchmeister, 2021)	Advances in Production Engineering & Management			x		x		x
(Frederico, 2021)	Logistics (BASEL)	x						
(Roblek et al., 2021)	Organizacija	x						
(Rega et al., 2021)	Applied Sciences (Switzerland)	x				x		
(Brunzini, Peruzzini, Grandi, Khamsi, & Pellicciari, 2021)	Applied Sciences (Switzerland)		x			x		
(Madsen & Berg, 2021)	Applied System Innovation	x						
(Xu et al., 2021)	Journal of Manufacturing Systems	x						
(Fraga-Lamas, Lopes, & Fernández-Caramés, 2021)	Sensors		x		x			
(Rachmawati, Multisari, Triyono, Simon, & da Costa, 2021)	International Journal of Evaluation and Research in Education			x			x	
(de Miranda, Córdoba-Roldán, Aguayo-González, & Ávila-Gutiérrez, 2021)	Sustainability (Switzerland)	x				x		
(Ávila-Gutiérrez, Aguayo-González, & Lama-Ruiz, 2021)	Sensors		x			x		
(Pillai, Haldorai, Seo, & Kim, 2021)	International Journal of Hospitality Management	x			x			

Table 2: Authors, journals, research method, and theme (continues)

Author	Journal	Methodological approach			Research theme			
		Revision / theoretical	Qualitative	Quantitative / modelling	Technological application	HR / Workers	Education	Business / operation management
(Cillo, Gregori, Daniele, Caputo, & Bitbol-Saba, 2021)	Journal of Knowledge Management	x				x		
(Chin, 2021)	IBIMA Business Review Journal of Human Resources Management Research			x		x		
(Duggal et al., 2021)	IET Communications	x						
(Esthela, Rafael, & Bayardo, 2021)	Journal of Legal, Ethical and Regulatory Issues			x		x		
(Sivarethnamohan, Kavitha, Koshy, & Toms, 2021)	International Journal of Systematic Innovation		x			x		
(Mondal & Samaddar, 2021)	The TQM Journal		x			x		
(Taverner, Trojan, Simion, & Szkudlarek, 2021)	Cultural Management: Science and Education		x		x			
(Margherita & Braccini, 2021)	Technological Forecasting and Social Change		x			x		
(Alvarez-Aros & Bernal-Torres, 2021)	Anais da Academia Brasileira de Ciências	x				x		
(Carayannis & Morawska-Jancelewicz, 2022)	Journal of the Knowledge Economy	x					x	
(Nourmohammadi, Fathi, & Ng, 2022)	Computers and Operations Research			x		x		
(Shahbakhsh, Emad, & Cahoon, 2022)	Asian Journal of Shipping and Logistics	x				x		
(Fonda & Meneghetti, 2022)	Sustainability (Switzerland)		x			x		
(Gürdür Broo et al., 2022)	Journal of Industrial Information Integration	x					x	
(Sindhvani et al., 2022)	Technology In Society			x				
(Nguyen, Duong, Nguyen, Zhu, & Zhou, 2022)	International Journal of Production Economics	x						x

5.1 Technological Application in Industry 5.0

The main aspect of the theme Technological Application in I5.0 is to observe the contribution of technological application in business and operations management. This research theme relates to three papers (Fraga-Lamas et al., 2021; Javaid et al., 2020; Pillai et al., 2021).

One approach to this theme emphasizes that I5.0 consists of innovative technologies that connect wirelessly and can enhance automation in manufacturing and healthcare (Javaid et al., 2020). The discussion of potential applications of I5.0 technologies to create a smart healthcare environment with real-time capabilities in the context of

COVID-19 is based on theoretical studies. Considering the impact of COVID-19, specifically in the hospitality industry, I5.0 technologies center on customer journeys that could ensure hygiene, cleanliness, and safety (Pillai et al., 2021).

Other approaches in this theme call attention to the IoT technologies and their potential for the digital transition toward sustainability. However, the study we present indicates that they are not contributing to the Sustainable Development of the IoT sector itself (Fraga-Lamas et al., 2021)—an open space for advancing an understanding of the relationship between digital transition and sustainability.

5.2 Human Resources (HR) and Workers in Industry 5.0

The theme Human Resources (HR) and Workers in I5.0 encompasses most of the papers in this SLR (Brunzini et al., 2021; Esthela et al., 2021; Ojstersek et al., 2021; Orlova, 2021). They focus mainly on human-robot collaboration and its potential to improve safety, ergonomics, and productivity. Such applications positively impact workers' well-being (Nourmohammadi et al., 2022). In general, robots can perform repetitive, labor-intensive, or dangerous work, while humans can work on customization and thinking critically and radically, in and out of the box. The adoption of new technologies requires both time and investment. The main challenge comes from equipping people with the necessary technical and soft skills (Chin, 2021).

The establishment of human-robot collaboration demands a collaborative workplace (Ojstersek et al., 2021), in which personalization in labor relations with employees is a key element (Orlova, 2021). Also, it demands of workers new skills, capabilities, and competencies (Ávila-Gutiérrez et al., 2021). Technologies, such as virtual training, sensing technologies, and machine cognition, have the potential to support workers' adaptation to I5.0 (Nahavandi, 2019). However, the reskilling of workers has a huge cost and substantial risk, due to the significant distance between traditional and digital competencies (de Miranda et al., 2021). Micro, small, and medium-sized enterprises could face particular challenges with such costs, as well as with access to proper training programs (Fonda & Meneghetti, 2022). The main point is how to achieve a fair balance between capital development and labor welfare (Margherita & Braccini, 2021).

In general, I5.0 demands the ability to work with data, knowledge of interaction with computers, robots, and machines, and technical know-how in the areas of sustainable development, interdisciplinary knowledge, and mastering product, process, and system complexity (de Miranda et al., 2021). Soft skills are in the roll, including the art of communication and the ability to think in a creative and critical manner (Chin, 2021), as well as green skills or those that relate to the environment (Taverner et al., 2021). Despite these generic suggestions of abilities and skills, the literature calls attention to I5.0 presenting with unknown skills, competencies, and characteristics, due to its recent appearance in concept and little practical application (Shahbakhsh et al., 2022).

In addition, the question arises of whether reskilling workers and upgrading their competences to I5.0 creates different needs and requires different approaches between developed economies and emerging economies (Alvarez-Aros & Bernal-Torres, 2021). Developed economies prioritize technological advances through a more comprehensive R+D-plus-innovation system, to build technology

and prioritize operability throughout the supply chain. Emerging economies attend main aspects like sustainability and business survival that the results and its structure reflect. They do not prioritize the technological vanguard and prefer the adoption or appropriation of technology that impacts technological competitiveness. Such contexts characterize training and education of the workforce. In developed economies, the orientation of such personnel elements as the competencies, abilities, and skills of the personnel moves toward engineering techniques education, technological knowledge, and soft skills. In emerging economies, the need to develop the general skills arises but is not a priority, nor does it represent the same commitment as in developed economies.

Planning the transition to I5.0 involves human resources (HR). The literature presents five critical categories of human factors to consider: cohesive force (related to coordination and culture), motivating force (linked to job satisfaction, commitment, and flexibility), regulating force (concerning ethics and mindfulness), supporting force (regarding leadership, training, individual competencies), and functional force (related to responsiveness and interpersonal relationships) (Mondal & Samaddar, 2021). Without having concrete answers yet on how to leverage such transitions, the workforce strategies in the digital future should consider organization goodwill, collaborative training, organizational culture, clear purpose with the best talent, and freelance projects per demand (Cillo et al., 2021). HR challenges include how to implement and manage the transition to I5.0, considering both organizational and workforce perspectives.

Still in this theme, ethical concerns regarding the impact of technologies on humans arise. These include information and communication technologies and robotic engineering (Longo et al., 2020). The literature discusses ethical concerns that relate to job positions and workers, due to extensive replacement of human labor with machines, and to decision-making activities (Margherita & Braccini, 2021). Other concerns refer to human-robot co-working that could promote psychological issues around the lack of social interaction, with the potential to shrink the human workforce (Longo et al., 2020).

5.3 Education and Training in Industry 5.0

The literature in the Education theme focuses on Engineering Education (Gürdür Broo et al., 2022), the role of universities in the digital transformation (considering the social context inherent in I5.0) (Carayannis & Morawska-Jancelewicz, 2022), and the factors explaining social science students' resilience in dealing with the future I5.0 (Rachmawati et al., 2021).

In the I5.0 context, factors and trends that forge the profile and competencies of the engineers will influence

engineering education. The I5.0 environment will likely include social and environmental aspects in addition to utilizing data and technological advancements. We selected twelve influencing factors to consider in I5.0 education: automation, connectivity, data, data ethics, electrification (to deliver equivalent energy service with less energy input), higher education environment, AI, labor market, SDG, technological development, trust in technology, and lifelong learning (Gürdür Broo et al., 2022). Accordingly, higher education institutions should rethink their strategies concerning lifelong learning and transdisciplinary education; sustainability, resilience, and human-centric design modules; hands-on data fluency and management courses; knowledge of human-agent, machine, robot, and computer interaction (Gürdür Broo et al., 2022).

The role of the university in digital social innovation—in line with I5.0 concepts—calls for rethinking. Three proposed pillars would support such alignment: (i) a university provides knowledge that supports creating innovation; (ii) a university shares its tangible and intangible assets; (iii) a university supports (digital) social innovation development by advising social innovators and involving interested parties. University response to I5.0 should: (i) create proper structure and mechanisms supporting the development and implementation of social and digital transformation; (ii) promote cross-sector and multi-actor collaboration; (iii) incentivize utilization of AI wherever it can offer benefits to the economy and society; (iv) promote new curricula that focus on green, digital quantitative, and ethical skills necessary to ensure the effective and appropriate utilization of AI. Apart from digital, green skills, and digital literacy, those programs must also teach cognitive skills (critical thinking, creative thinking), social and emotional skills (empathy, cooperation), and practical and physical skills (communication and technology devices) (Carayannis & Morawska-Jancelewicz, 2022).

Changing universities to an I5.0 context demands student adaptation and resilience. One study in this theme is a survey that indicates the resilience of social science students considering I5.0 challenges. Such resilience includes having the knowledge and skills to deal with difficult situations and the efficacy to face them; good personal qualities; the ability to contribute to oneself and others; the skills to overcome difficulties positively and adaptively; control of actions and decisions (Rachmawati et al., 2021). Interestingly, the main aspects relate to personal abilities, likely relevant to universities and higher education institutions and HR areas in preparing their programs.

5.4 Business and Operations Management in Industry 5.0

The literature that relates to this theme illuminates (though without answers) how a firm could innovate its

business model and adopt human-centrism as its cultural mindset (Mihardjo, Sasmoko, Alamsyah, et al., 2019). It also presents some challenges that could influence business models—challenges in improving people competence, a culture of innovation and process regarding the use of technologies, customer experience based on collaborative platforms, and organizational agility (Mihardjo, Sasmoko, & Elidjen, 2019). Increasing customer experience demands considering investments and co-creation (Mihardjo, Sasmoko, Alamsyah, et al., 2019) in the business model. A good possible starting point for rethinking I5.0 business models is considering the umbrella of sustainable business practices (Madsen & Berg, 2021).

I5.0 also affects all ecosystems. The reorganization of the production process starts within the business perspective and spreads toward all ecosystem components. Such aspects promote the participation of all stakeholders who contribute to feeding the circuit of knowledge-creation and sharing (Carayannis, Dezi, et al., 2021).

The development of I4.0 technologies still cannot achieve the desired outcomes and has neglected the environment by prioritizing machines over humans. Therefore, I5.0 focuses on concepts of sustainability, bioeconomy, and a collaborative environment of technology and human beings, thus establishing a resilient industry that incorporates human social values (Frederico, 2021; Sindhwani et al., 2022). The I5.0 human-centric technologies could provide excellent protective support through the use of intelligent devices, systems, automation, and material (Javaid & Haleem, 2020). However, the focus of intelligent “things” alone on the environment is not enough; technologies also should economically sustain business activities (Rahman et al., 2019). Customer relationships, supply chains, and ecosystems will increasingly integrate digital technologies and green computing (Pathak et al., 2019; Rahman et al., 2019). Emphasis on enablers will boost progress toward meeting select criteria for resiliency in I5.0: bionic technologies; IoT; sustainable agricultural production; advanced simulation; big data (Sindhwani et al., 2022).

6 Discussion and Future Avenues for Research

This study sheds light on the topical issue of I5.0. The researchers perceive this as the first study that analyzes I5.0 through the lens of the business and operations management literature. Now, we present the discussions that relate to each research question and suggest future research avenues.

The first research question (RQ1) is “How is Industry 5.0 positioned in the operations management and business management literature?”. The findings indicate that despite the European Commission’s recognition in 2021 of a relevant paradigm, in which organizations surpass

digital transformation (Dixon-Declève et al., 2021), the I5.0 idea and concepts bubbled up from the exposure by Michael Rada in 2015 (Rada, 2017). The screening filters used to perform this study and produce the SLR identified the publication of the first academic articles in 2019 (five papers). In 2020, three papers appeared, and in 2021 and the beginning of 2022, the subject of I5.0 gained strength. Journals with high CiteScore ratings (Scopus) published papers relating to I5.0.

This study contributes to the literature in business and operations management, in the context of I5.0, by indicating a greater presence of conceptual and theoretical studies in the first publications. Out of 40 papers, 20 are theoretical or conceptual. No papers present practical applications of I5.0 in the global scope of operation or business management, suggesting possibilities for future studies focusing on applied research in I5.0 and its impact on businesses and operations management.

The SLR results indicate a strong association between I5.0 and Society 5.0. Although for some authors the concept of Society 5.0 (Chin, 2021) is broader than that of I5.0, the literature offers no clear, consensual definition. Despite its correlation with Society 5.0, this study shows that most papers study I5.0 from the perspective of challenges to workers and HR departments and/or the need to reskill workers (Shahbakhsh et al., 2022; Sivarethinamohan et al., 2021). This study contributes to the literature by indicating the need to deeply understand Society 5.0 and I5.0 definitions and limits, correlations, and complementarity and to enlarge the scope and means of potential contributions from I5.0 to Society 5.0.

The second research question (RQ2) is “Which are the research themes in Industry 5.0 literature seen through the lens of operations management and business management?”. This study answers this question and contributes to the literature by proposing four themes for classifying the selected papers: Technological Applications, Workers and Human Resources, Education and Training, and Business and Operations Management in I5.0.

In the theme Technological Applications in I5.0, two conceptual theoretical papers discuss possibilities for using innovative technologies to enhance automation in manufacturing (Javaid & Haleem, 2020) and healthcare (Pillai et al., 2021). One presents a case of digital technologies to improve operator safety and results (Fraga-Lamas et al., 2021). This study contributes to the literature by indicating the lack of papers that analyze the role of technological applications in business performance or operations management. The scope of the present literature centers on operator safety, certainly relevant, and on automation, which the I4.0 literature discusses (Bravi & Murmura, 2021; Correia Simões et al., 2020). The literature is still missing practical contributions and frameworks for how technology in the I5.0 context could contribute to business and operations management.

Most of the literature concentrates on the theme of Workers and Human Resources in I5.0. However, discussions in the I5.0 papers invert the role of technology to humans, asserting that technology should serve humans (Chin, 2021). In addition, the I5.0 literature emphasizes human-robot collaboration and its potential to improve safety and productivity, not necessarily well-being. Also, this study contributes to the literature by indicating that human-robot collaboration demands new worker skills, capabilities, and competencies, still in generic form, e.g., work with data and knowledge of interaction with computers (de Miranda et al., 2021). One unsolved question is how to achieve the balance between the investment in new technologies (Chin, 2021) and the huge costs to reskill workers (de Miranda et al., 2021), considering the potential need for yet unknown skills (Shahbakhsh et al., 2022) for HR to manage in the context of I5.0. This study contributes to the literature by identifying that the competency profiles, abilities that all functions and organizational competencies require, have generic descriptions (Cillo et al., 2021; Fonda & Meneghetti, 2022) but are still unknown. Will mature workers demand more training in new skills than younger generations? How do experience and maturity impact the new context?

This study also identifies ethical concerns regarding human-robot collaboration. Concerns on potential ethical issues when humans relate to the use of information and communication by digital systems, as well as psychological issues have been added to discussion (Longo et al., 2020). Although the focus of this theme is the human-robot collaboration, the literature fiercely points out the potential extensive replacement of human labor with machines (Margherita & Braccini, 2021). This study contributes to the literature by indicating that human-robot collaboration in the I5.0 literature, in which the human-centric approach is the direction to go, is a cultural, organizational, economic, and social challenge, without answers or practical analyses.

The third theme, Education and Training in I5.0, reinforces the need for lifelong learning for workers in a context of constant challenges (Gürdür Broo et al., 2022), highlighting the challenge to workers resident in the previous theme. This study contributes to the literature by signaling that universities and educational institutions face severe challenges in the context of I5.0. For example, digital and technological advancements in engineering courses are not enough (Gürdür Broo et al., 2022). Transdisciplinary education, cognitive skills, social and environmental aspects that technologies support (Carayannis & Morawska-Jancelewicz, 2022; Gürdür Broo et al., 2022) require consideration. Such challenges redefine the role of universities in supporting the I5.0 so that its results indeed contribute to a fairer society. The practical results on how to implement these considerations are yet unknown.

Table 3: Main findings and further avenues for research

Research Question	Findings and Considerations	Further Avenues for Research in I5.0
RQ1: How is I5.0 positioned in the business and management literature?	The first academic paper was published in 2019. The SLR identified 40 papers in 30 different journals; journals have CiteScore (Scopus) until 22.7; from 40 papers, 20 are theoretical or conceptual	
	I5.0 correlates with Society 5.0; practical results from I5.0 implementation are not available yet; conceptual limits between I4.0 and I5.0 are not clear yet.	Deeply understanding Society 5.0 and I5.0 definitions, limits, correlations, and complements.
	The findings evidence the novelty of the subject I5.0 through the lens of business and operations management; however, the subject is still in its infancy.	Analyzing practical applications of I5.0 and its implications for business results and operations management.
RQ2: Which are the research themes in Industry 5.0 literature seen through the business and operations management lens?	Theme 1: Technological Application in I5.0. The literature has been centered on operators' safety and automation. The role of technological application and how it could affect business performance and operations management are still missing.	Proposing frameworks and presenting practical contributions on how digital technologies applied in the context of I5.0 could contribute to business performance and operation management.
	Theme 2: Human Resources (HR) and Workers in I5.0. Human-robot collaboration is the main focus. It will demand new skills, capabilities, and competencies from workers and managers, still presented in a generic way in the literature. How to achieve the balance between the investment in new technologies and the costs to reskill the workers is one point to unveil. HR departments will have to reorganize soon, but for now, new competencies, profiles, and abilities of workers and organizational infrastructure and culture are unknown. Ethical concerns regarding human-robot collaboration came up, taking into account the potential use of information and communication by digital systems as well as psychological stress.	Analyzing the new skills, capabilities, and competences of workers and managers and how to develop them in the context of human-robot collaboration. Studying how to balance investments in new technologies and the huge costs to reskill the workers, determining the limit of the use of digital technologies under the economic perspective. Studying the limits and potential impacts on society from the potential extensive replacement of human labor with machines. Analyzing the ethical and psychological issues for humans related to the use of information and communication by digital systems.
	Theme 3: Education and Training in I5.0 The need for lifelong learning by workers. Universities and educational institutions must provide transdisciplinary education, cognitive skills, social and environmental aspects, supported by digital technologies.	Analyzing the challenges to universities and educational institutions in the context of I5.0, as well as the role of universities and curricular structure for a human-centric, resilient, and sustainable approach.
	Theme 4: Business and Operations Management in I5.0. The need to innovate in business models, putting humans in the center as a cultural mindset has predominantly focused on the competencies of the workers and the need to reskill them. The aspect customer / consumer of the business model 5.0 has been restricted to improve customer experience based on digital technologies. The literature mentions the need to evolve all stakeholders from the ecosystem to improve businesses' performance in the context of I5.0. There is a lack of answers on how to put humans in the center of business, including the ones outside of the organization but it could affect.	Studying how to innovate in business models putting humans in the center, not only as workers but also considering customers, partners, society. Proposing how to measure environmental and social value generation. Analyzing the contribution and impact of I5.0 implementation on business performance.

Table 3: Main findings and further avenues for research (continues)

Research Question	Findings and Considerations	Further Avenues for Research in I5.0
RQ3: How does Industry 5.0 literature present the role and contributions of I5.0 for Sustainable Development?	Despite the literature mentioning that I5.0 should relate to SD and the role of enterprises is to contribute to a better world, the literature does not emphasize the role of I5.0 for SD. Even in the word cloud (Figure 2), this connection does not appear. Shyly, some practices and approaches such as circular economy and bioeconomy have been mentioned. However, detailing or proposing how I5.0 effectively could contribute to SD is still missing. Additionally, it is suggested that business models for sustainability could be the basis for organizations that intend to implement I5.0 focusing on SD. This aspect needs to be unveiled.	Proposing frameworks and analyzing practical studies on how I5.0 contributes to SDGs and/or sustainable development. Circular economy, bioeconomy, sustainable business models, ecodesign, and other approaches could be integrated into these studies.

The last theme, Business and Operations Management in I5.0, calls out the need to innovate in business models that put humans at the center, as a cultural mindset (Mihardjo, Sasmoko, Alamsyah, et al., 2019). However, this study indicates that, until now, most of the literature has put humans in the center by discussing worker competencies that require reskilling in the I5.0 environment. On the other hand, some authors suggest improving customer experience based on digital technologies (Mihardjo, Sasmoko, & Elidjen, 2019). The perspective includes evolving all stakeholders from the ecosystem when considering I5.0 implementation (Carayannis, Dezi, et al., 2021). This study points out that the literature's main perspective is still internal to the organization, restricted to workers and competencies, supply chain, or ecosystem. We contribute by indicating the lack of studies considering the impact of I5.0 on business and operations management. How to put humans at the center of businesses, including those outside of the organization that it could affect, remains without answers or practical studies.

Regarding businesses, the main challenges for I5.0 are social heterogeneity in terms of value and acceptance; measurement of environmental and social value generation; integration, from customers across entire value chains to SMEs; interdisciplinary research and system complexity; ecosystem-oriented innovation policy with an agile outcome orientation; productivity; and large investments (Xu et al., 2021). However, practical applications to overcome challenges are not evident. This lack of practical results indicates how interesting and prosperous the field of I5.0 could be to businesses and operations research, if deeply analyzed.

In the scope of the last theme, we analyze the third research question (RQ3) ("How does the Industry 5.0 literature present the role and contribution of Industry 5.0 for sustainable development?"). Surprisingly, despite the I5.0 revolution's call for a step forward toward achieving Sustainable Development Goals, by having research and innovation drive the transition to a sustainable, human-centric, and resilient industry (Breque et al., 2021), the results of

this study indicate that studies focusing on the contribution of I5.0 to sustainable development are scarce. Some studies suggest reinforcing the role of bioeconomy (Frederico, 2021) to leverage the results of I5.0 for the planet. The notion of applying Intelligent systems to sustainable agriculture has arisen (Javaid & Haleem, 2020). A circular economy, linked to long-term vision rather than short-term overproduction and consumption models, appears as an element for consideration (Dixson-Declève et al., 2021) but without practical studies. This study contributes to the literature by indicating that I5.0 papers focusing on the alignment of digital technologies with SDG goals still do not show effective results. Therefore, how I5.0 could effectively leverage the contribution to sustainable development requires further studies.

Table 3 presents a synthesis of the main findings that relate to each research question, as well as further avenues for research based on the results and analysis of this study.

This study was limited to an SLR, centered on the Scopus and Web of Science databases. The previously defined research area aimed to encompass papers on I5.0 in areas that study business and operations management. However, some papers addressing the subject and scope of this research could not join the defined research area. The authors conducted the categorization of the papers into four themes, through individual analysis followed by discussion. This understanding and categorization could assume different approaches performed by a different group of authors.

7 Conclusion

This study focuses on a topical issue: Industry 5.0 (I5.0). I5.0 aims to include human, social, and sustainability aspects amid the current and highly focused technological scope of I4.0 (Gürdür Broo et al., 2022). To the best of the authors' knowledge, no study has been conducted to proceed with an SLR through the lens of business and management operations literature. Although the literature

is still recent and scarce, a growing trend toward discussions about I5.0 by academic and practical audiences is evident. This study contributes to these academic discussions by analyzing how the business and operations management literature presents the implementation of I5.0 and its impacts on businesses. Papers were grouped according to four different themes to organize the analysis and discussion, the basis for suggesting future avenues for research to advance the studies in this field.

Practical insights for managers and decision-makers could emerge from this study. However, few field results are available yet. Concerns about balancing investments in digital technologies and reskilling workers and managers in a human-robot-collaboration context require consideration. Also, uncertainties of this new revolution challenge HR preparations to look ahead and plan. The literature has not yet deeply explored the field regarding innovative business models to insert the organization into the I5.0 era, considering sustainable issues and human-centric approaches behind workers' qualifications and safety. These two aspects, new economic orientation and business models, as well as sustainability issues and human-centric approaches, seem to be the great challenge for such actors as organizations, governors, and universities. Will new economic orientation and business models be possible, or is this just utopian? Some emerging lights are coming up, and putting our academic lens on them is the minimum contribution to a better planet.

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