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Knowledge management and Industry 4.0: a critical analysis and future agenda

Gestão do conhecimento e Indústria 4.0: uma análise crítica da literatura e agenda futura

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Abstract: This paper aims to discuss how Knowledge Management (KM) can support the Industry 4.0 (I4.0) implementation. The paper analyzes the relevant literature and explores related research opportunities, which can provide insights and assist researchers in future studies. I4.0 technologies can influence work flexibility, autonomy, job performance and innovation, but the acquisition and dissemination of knowledge, especially on the shop floor, remain dependent on employees, indicating human concerns which can be supported by KM. We conducted a literature review on KM and I4.0 on 41 papers selected from the Clarivate Web of Science Core Collection, published between 2010 and 2021. Structured summaries were developed, that lead to broad themes. Findings indicate three themes relating KM and I4.0: Technology, which explores infrastructure demands for implementation and its influence on the knowledge creation process; KM and learning, which reinforces the importance of both hard and soft skills, and indicates the need to investigate enablers factors for knowledge creation and sharing; and Worker engagement, which consider communicational, cultural and trust-related aspects for worker's development. This paper explores the I4.0 implementation and indicate concerns involving workers and the technologies adoption, which can provide insights and assist researchers in future Operations Management practices and related researches.

Keywords: Knowledge management; Knowledge sharing; Industry 4.0.

Resumo: Este artigo tem como objetivo discutir como a Gestão do Conhecimento (GC) influencia a implementação da Indústria 4.0 (I4.0). O artigo analisa a literatura relevante e explora oportunidades de pesquisa relacionadas, que podem fornecer insights e auxiliar pesquisadores em estudos futuros. As tecnologias I4.0 podem influenciar na flexibilidade e autonomia do trabalho, no desempenho e na inovação, mas a aquisição e disseminação do conhecimento, principalmente no chão de fábrica, permanecem dependentes dos funcionários, indicando preocupações humanas que podem ser suportadas pela GC. Realizamos uma revisão de literatura sobre KM e I4.0 em 41 artigos selecionados da Clarivate Web of Science Core Collection, publicados entre 2010 e 2021. Foram produzidos resumos estruturados, que conduzem aos temas mais amplos. Os resultados indicam três temas que relacionam GC e I4.0: Tecnologia, que explora as demandas de infraestrutura para implementação e sua influência no processo de criação do conhecimento; GC e aprendizagem, que reforçam a

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importância das hard e soft skills e indicam a necessidade de investigar os fatores facilitadores para a criação e compartilhamento do conhecimento; e Engajamento do trabalhador, que considera aspectos comunicacionais, culturais e de confiança para o desenvolvimento do trabalhador. Este artigo explora a implementação da I4.0 e aponta preocupações envolvendo os trabalhadores e a adoção de tecnologias, que podem fornecer insights e auxiliar pesquisadores em futuras práticas de Gestão de Operações e pesquisas relacionadas.

Palavras-chave: Gestão do conhecimento; Compartilhamento do conhecimento; Industria 4.0.

1 Introduction

The adoption of new technologies in manufacturing, such as cyber physical systems, big data analytics, additive manufacturing, internet of things, artificial intelligence, robotics and cloud computing (Núñez-Merino et al., 2020; Klingenberg et al., 2019), are expected not only to transform the production and the distribution of goods and services, but also to have far-reaching consequences on issues from workers´ skill development to environmental impact, income distribution and social well-being (OECD, 2017). Their adoption has been broadly referred as Industry 4.0 in Germany and Brazil (Drath & Horch, 2014; Lasi et al., 2014), Manufacturing of the Future, Advanced Manufacturing Technology and Smart Factory in the U.S.A. (Fries et al., 2021; Chen et al., 2017; Wang et al., 2016; Thomas et al., 2008), Future Manufacturing in the United Kingdom (Mariani & Borghi, 2019; Peters et al., 2015), Digitalization in Germany (Peters et al., 2015), and Smart Manufacturing in Germany, U.S.A. and Korea (Kang et al., 2016). Industry 4.0 (I4.0), as it will be further referred in this paper, emerged as a new industrial revolution, as new technologies can create intelligent and autonomous systems able to produce customized products in small lots at low costs (Sony & Naik, 2020; Marnewick & Marnewick, 2019), improve labor conditions by automating repetitive tasks (Karre et al., 2017), ultimately bringing enhanced organizational performance and fast interaction with customers and suppliers (Szász et al., 2020; Abubakar et al., 2019; Schneider, 2018).

Knowledge and its sharing has long been considered an important asset for organizational development and competitiveness, and, as I4.0 technologies require learning, knowledge sharing and enhanced absorptive capacity to reap their full benefits (Manesh et al., 2021; Feng et al., 2017), Knowledge Management (KM) can play a crucial role in their adoption, by mitigating knowledge loss during its implementation (Sartori et al., 2022; Oztemel & Gursev, 2020), supporting knowledge creation (Abubakar et al., 2019), and assisting decision making (Núñez-Merino et al., 2020). Hence, organizational performance can be improved by better decisions, made not only at the managerial level but also on the shop floor, based on big data and fast interaction with suppliers and other partners (Manesh et al., 2021; Feng et al., 2017).

Also, I4.0 Technologies adoption can positively influence work flexibility and autonomy, leading to enhanced job performance and creativity and innovation (Malik et al., 2021; Cassia et al., 2020). Nonetheless, the acquisition and dissemination of knowledge within the organization, and especially on the shop floor, remain dependent on employees, and thus, KM and I4.0 can play a crucial duet, influencing organizational culture and supporting innovation (Manesh et al., 2021; Sartori et al., 2022; Ding et al., 2017). KM can support skill and competence development for I4.0, by facilitating knowledge sharing between experts and novices (Zangiacomi et al., 2020) operators´ training and organizational learning (Oztemel & Gursev, 2020).

However, the discussion on KM in I4.0 implementation is recent (Manesh et al., 2021; Cassia et al., 2020; Santos-Neto & Costa, 2019), and its influence on the digital transformation of production systems and HR management, and on the creation of favorable contexts for knowledge sharing is still little explored (Muniz et al., 2021, 2022). Although I4.0 technologies affect individual and group learning (Tortorella et al., 2020), reinforcing the need of updated training strategies (Buer et al., 2018), there is still not much on that. The related literature has focused on the technology base (Del Río Castro et al., 2021; Núñez-Merino et al., 2020), but it present a demand for research initiatives to explore human topics, such as the worker´s competencies and skills for I4.0 (Manesh et al., 2021; Sartori et al., 2022) and the human resources management required practices (Song et al., 2021). Also, the literature indicates that the enablers of knowledge sharing in different technological contexts (Manesh et al., 2021; Sartori et al., 2022), and a deeper understanding of the role of workers in I4.0 adoption implementation (Kaasinen et al., 2020; Kolyasnikov & Kelchevskaya, 2020) are issues that need further exploration. Thus, this paper aims to discuss how KM can support the I4.0 implementation, in order to provide insights and assist future research. It performs a literature review to answer the following question: How can knowledge management support the Industry 4.0 implementation?

To answer it, this paper is structured as follows: Section 2 presents a brief theoretical background of KM and I4.0, Section 3 presents the review method, Section 4 presents and discusses findings, which support the conclusions in Section 5.

2 Theoretical background

2.1 Industry 4.0

Industry 4.0 comes from the German term Industrie 4.0, and it is part of the German industrial policy since 2011 (Ghobakhloo, 2018). It implies a manufacturing system in which digital enabled machines perform routines while interacting with operators and other machines through the internet of things (Manesh et al., 2021). Although it can be regarded mainly as a digital technology application in manufacturing processes, its adoption requires man-machine interaction, and thus, it should include operators´ participation since its design phase (Trompisch, 2017). Therefore, I4.0 should not be regarded as only a technological issue aimed to increase productivity, as it also impacts work organization (Kaasinen et al., 2020).

I4.0 implementation demands qualified employees, modifies routines and affects planning and decision-making in order to produce high quality and customized products and services (Kolyasnikov & Kelchevskaya, 2020). There are several technologies associated with I4.0, which are listed on Table 1.

I4.0 requires the combination of knowledge about manufacturing technologies, total quality and supply chain management (Castro et al., 2021), which demands effective KM (Feng et al., 2017), as it requires increased data processing and the engagement of employees to seek autonomous solutions (Kaasinen et al., 2020; Trompisch, 2017). It requires operators to gain new knowledge and skills in order to cope with the challenges of digital transformation. KM can assist formal and on the job training for I4.0 (Sartori et al., 2022; Kaasinen et al., 2020; Oztemel & Gursev, 2020). Thus, new HR management strategies are required, which, in turn, will also demand new KM practices to support effective knowledge retention and sharing. For instance, Virtual Factory simulations can assist problem solving, continuous improvement, and decision-making practices that enable organizational culture development (Kolyasnikov & Kelchevskaya, 2020; Núñez-Merino et al., 2020; Sievert & Scholz, 2017; Feng et al., 2017).

Table 1. I4.0 related technologies.

Technologies	Definitions	Author
Additive manufacturing, fast prototyping or 3D impression	Versatile machines for flexible manufacturing systems (FMS), able to transform digital 3D models into physical products using additive manufacturing	Pagliosa et al. (2019); Dalenogare et al. (2018)
Artificial Intelligence	Computer-based algorithms using analytical and statistical methods to support data analysis and automated decision-making	Olsen & Tomlin (2020)
Big Data Analytics	Computer-based predictive analytics, data mining and statistical analysis to treat large and unstructured data sets, generated by sensors	Chehbi-Gamoura et al. (2020); Dalenogare et al. (2018)
Computer-Aided Design and Manufacturing	Computer-based systems for product design, manufacturing planning and management	Dalenogare et al. (2018); Feng et al. (2017)
Cloud computing	Storage and processing of large data volumes in remote computers	Pagliosa et al. (2019); Dalenogare et al. (2018)
Cyber Physical System	Production system combining several technologies, able to interact with other systems, communication networks and operators.	Klingenberg et al. (2019)
Sensor-based digital automation	Automated systems with embedded sensor technology	Dalenogare et al. (2018)
Digital Product-Service Systems	Digital services embedded in products, using IoT, sensors, processors and software enabled capabilities	Dalenogare et al. (2018); Pirola et al. (2020)
Flexible manufacturing lines	Digital automation of manufacturing processes using sensors that allow Reconfigurable Manufacturing Systems (RMS) able to change production.	Dalenogare et al. (2018); Del Río Castro et al. (2021)
Integrated engineering system	Integration of IT support systems for information exchange in product development and manufacturing	Dalenogare et al. (2018)
IoT	High-speed internet-based sensors that allow to remotely control equipments	Manavalan & Jayakrishna (2019); Del Río Castro et al. (2021)
Manufacturing Execution Systems (MES) and Supervisory control and data acquisition (SCADA)	Real time, remote shop floor monitoring that allow dynamic scheduling	Buer et al. (2018); Dalenogare et al. (2018)
Robotics	Application of programmable, autonomous manufacturing machines	Bai et al. (2020)
Simulations/analysis of virtual models	Application of analytical methods in engineering projects and systems simulate their properties and outcomes	Dalenogare et al. (2018)
Virtual Factory	Integrated factory simulation model to support decision making capability	Jain et al. (2001)

2.2 Knowledge management

Knowledge is an important asset for competitive advantage once it contributes to improving operational and innovation performance (Manesh et al., 2021; Cassia et al., 2020; Nonaka, 1994). KM aims to capture, preserve, share and reuse both tacit and explicit knowledge that are created and used by workers during routine tasks to improve production processes, generating measurable results for the organization and people (Muniz et al., 2009).

KM can assist employees' cognitive activities and his/her involvement in the organization (Kolyasnikov & Kelchevskaya, 2020; Muniz et al., 2022; Oztemel & Gursev, 2020). It can also support synergy between workers in order to achieve common goals (Muniz et al., 2021; van den Hooff & De Ridder, 2004), and thus it can be instrumental in I4.0 technologies implementation (Manesh et al., 2021; Abubakar et al., 2019).

I4.0 requires new competencies and skills from workers (Malik et al., 2021; Chaka, 2020; Vrchota et al., 2020; Holm, 2018) that can be classified in task-related (decisiveness, wide range of expertise, interdisciplinary approach, etc.), behavioral and cognitive (responsibility, systematic thinking, etc.), and social ones (flexibility and adaptability), which, in turn, require extensive creation and exploitation of both explicit and tacit knowledge. Thus, KM becomes important in organizational change processes such as I4.0 implementation, as it supports new knowledge creation, its combination with the existing one, and its sharing within the organization. However, although KM has been studied for more than 20 years, I4.0 is still in its infancy, and likewise the study of KM in I4.0. This interface is little explored when considering the adoption of both approaches in a broader way, and in a context of different implemented technologies. In order to grasp the current understanding on the issue, and the avenues for future research, a literature analysis was performed.

3 Papers selection

A literature search was conducted in the Web of Science (WoS) database, which gathers some of the most important journals related to manufacturing technologies and KM, with high impact factors. WoS is also multidisciplinary, composed of specialized indexes, including papers from other databases (such as Scopus, ProQuest and Wiley), journals with JCR (Journal Citation Report) impact factor (Carvalho et al. 2013), and all the major humanities, sciences, and social sciences subdisciplines (Meho & Yang, 2007). The paper set was assembled from the WoS core collection, using the following search string: "industr* 4.0" OR "manufactur* of the future" OR "future manufactur*" OR "advanced manufactur* technolog*" OR "smart* factor*" OR "digitalizat*" OR "smart* manufactur*" AND "knowledge management" OR "knowledge sharing". The main I4.0 terms were used (according to the term origin indicated in the introduction section). Knowledge management and knowledge sharing terms were used considering the relation of these two topics with the main KM concepts, and as a way to stablish the I4.0 and KM relation with secondary issues (such as organizational learning, human factors, or the tacit dimension) and avoid biased inductions to these issues. KM The results were narrowed to texts in English, which yielded 71 papers. All titles and abstracts were read, and only papers that discuss I4.0 and KM were selected, which resulted in a set composed by 14 literature reviews and 27 empirical papers. Table 2 summarizes the search criteria and results.

Table 2. Papers selection protocol.

Item	Description	Total
Data base	Web of Science core collection	
Period	2010 to 2021	
Search criteria	By "Topic"	
	Articles (empirical papers) and Reviews	
	Papers in English	
	Classified by Most Cited	
Search string	"Industry 4.0" OR "manufacturing of the future" OR "future manufacturing" OR "advanced manufacturing technology" OR "smart factory" OR "digitalization" OR "smart manufacturing" AND "knowledge management" OR "knowledge sharing"	114
Categories (1st. exclusion criteria)	Engineering Industrial, Engineering Manufacturing, Multidisciplinary Sciences, Business, Psychology Applied, Industrial Relations Labor, Management, Social Issues, Social Sciences Interdisciplinary, Social Work	71
		(57 empirical papers and 14 reviews)
Title and Abstract analysis (2nd. exclusion criteria)	Exclusion of papers without adherence to the topics Knowledge Management in Industry 4.0	41
		(27 empirical papers and 14 reviews)

All papers were analyzed according to the following sequence: first, a structured summary containing objectives, research questions, methods, findings, and suggested research opportunities was created for each paper. Those summaries contain interpreted, 1st order elements extracted from the texts. Summaries were examined from two perspectives: one related to KM and I4.0 implementation, and other to research opportunities. From that analysis, 2nd order elements were extracted from each paper, which were grouped by similarity, resulting in three broad themes for each perspective: I4.0 implementation and research opportunities.

4 Findings

The paper set is composed of 41 papers, from 35 different journals. Table 3 gives an overview of the methodological approach of each paper.

Not surprisingly, I4.0-related technologies adoption is the most prevalent theme (e.g. Buer et al., 2018; Oztemel & Gursev, 2020). Technologies include Big Data (Del Río Castro et al., 2021; Manesh et al., 2021), Artificial Intelligence (Malik et al., 2021; Chehbi-Gamoura et al., 2020), Information Technology Infrastructure (Cassia et al., 2020; Núñez-Merino et al., 2020; Chong et al., 2018), and Internet of Things (Manavalan & Jayakrishna, 2019).

Table 3. Research methods in papers.

Method	Number of papers	Authors
Literature reviews	14	Del Río Castro et al. (2021); Manesh et al. (2021); Patriarca et al. (2021); Sartori et al. (2022); Núñez-Merino et al. (2020); Schniederjans et al. (2020); Barbosa & Saisse (2019); Santos-Neto & Costa (2019); Cassia et al. (2020); Oztemel & Gursev (2020); Manavalan & Jayakrishna (2019); Chehbi-Gamoura et al. (2020); Chong et al. (2018); Ilvonen et al. (2018)
Structured questionnaires and multivariate analysis	8	Song et al. (2021); Crupi et al. (2020); Drašković et al. (2020); Hsieh et al. (2020); Stachová et al. (2020); Zangiacomi et al. (2020); Birasnav & Bienstock (2019); Tortorella et al. (2020)
Semi-structured questionnaires and qualitative analysis	3	Malik et al. (2021); Ngereja & Hussein (2021); Li et al. (2019)
Simulations and Experiments	4	Cotrino et al. (2021); Wang & Wan (2021); Yang et al. (2021); Dornhöfer et al. (2020)
Case studies	12	Jankowska et al. (2021); Wang et al. (2021); Barbosa et al. (2020); Bruno et al. (2020); Kaasinen et al. (2020); Kolyasnikov & Kelchevskaya (2020); Pinzone et al. (2020); Stentoft et al. (2020); Wilkesmann & Wilkesmann (2018); Sievert & Scholz (2017); Feng et al. (2017); Abubakar et al. (2019)

However, the relationship between KM and I4.0 is discussed not only from a hard, technology-related perspective, but also from a soft, people-related one (e.g. Kolyasnikov & Kelchevskaya, 2020; Feng et al., 2017). I4.0 implementation demands the identification of critical knowledge for each process (Arifiani et al., 2019). KM can help to integrate technology and human-related aspects and improve skill development, learning and collaboration (Abubakar et al., 2019), IT infrastructure design (Cassia et al., 2020) and product development, and process planning and control (Feng et al., 2017).

I4.0 requires operators to autonomously seek solutions and use digital resources to manage routine tasks in a collaborative way (Malik et al., 2021; Kolyasnikov & Kelchevskaya, 2020; Sievert & Scholz, 2017). They need to engage in self-learning and self-development (Kaasinen et al., 2020), and thus, I4.0 technologies require organizations to develop sociocultural aspects in order to fully benefit from them (Tortorella et al., 2020). Organizational culture influences how operators socialize, communicate, trust each other, create and share their knowledge (Sartori et al., 2022; Ding et al., 2017). It should grant operators access to technology (Chehbi-Gamoura et al., 2020; Chong et al., 2018), to operational and safety-related resources and protocols (Núñez-Merino et al., 2020), and provide learning capabilities (Tortorella et al., 2020), training (Kaasinen et al., 2020), and to performance metrics (Li et al., 2019). This can be particularly resource demanding for small and medium enterprises, and thus, I4.0 needs adaptation for those firms (Li et al., 2019).

How KM affects I4.0 implementation is discussed by Sartori et al. (2022), Manesh et al. (2021), Cassia et al. (2020), Kolyasnikov & Kelchevskaya (2020), Núñez-Merino et al. (2020), and Feng et al. (2017). The negative impact of knowledge loss is studied by Manesh et al. (2021), Sartori et al. (2022) and Oztemel & Gursev (2020), and new decision-making frameworks and the impact on organizational performance by Abubakar et al. (2019). KM maturity models adapted to I4.0 are proposed by Kolyasnikov & Kelchevskaya (2020) and Santos-Neto & Costa (2019). Kaasinen et al. (2020) and Li et al. (2019) discuss operators development and training, and the integration with Lean Manufacturing practices is analyzed by Sartori et al. (2022) and Núñez-Merino et al. (2020).

Operators are important agents in socio-technical systems, they are able to manage complexity, develop meaningful interaction and initiative (Sartori et al., 2022; Li et al., 2019). They can contribute during I4.0 implementation, and therefore, their early engagement, for instance, in workspace design is important. However, issues as stress related to technology implementation should also be considered (Malik et al., 2021). Also, lack of knowledge about technology by operators remains a barrier for I4.0 adoption (Sartori et al., 2022), hence, training and proper infrastructure are both I4.0 enablers (Manesh et al., 2021; Chehbi-Gamoura et al., 2020; Núñez-Merino et al., 2020; Chong et al., 2018).

Following theoretical elements, as previously indicated, the paper summary analysis resulted in 34 concepts, that were grouped under three overarching (1st order) themes (Table 4): Technology, KM and learning, and worker´s engagement. The analysed papers were categorized in these three themes considering the papers objectives and main focus, as well as the content dedication of the main theory and results. The technology group consider its integration with organizational and manufacturing objectives, as a facilitator to achieve better operational results. KM and learning include concerns of human knowledge adaption a management in technological contexts. Worker’s engagement considers initiatives and behaviours to integrate process, workers and technologies. The main themes and the papers categorization are summarized in Table 4.

Table 4. Knowledge Management and I4.0.

Themes	Description	Author
Technology	Contribution of digital technologies to achieve the Sustainable Development Goals	Del Río Castro et al. (2021)
	Knowledge sharing between manufacturing resources	Wang & Wan (2021)
	Analysis of KM practices and robotization expertise on automation implementation on the shop floor	Barbosa et al. (2020)
	Manufacturing and knowledge-based solutions interactions, and multi-agent-systems implementation	Dornhöfer et al. (2020)
	Big Data in Supply Chain Management (SCOR)	Chehbi-Gamoura et al. (2020)
	Digital Technologies application in Lean Supply Chain Management	Núñez-Merino et al. (2020)
	Knowledge and experience dissemination for Additive Manufacturing	Stentoft et al. (2020)
	I4.0 technologies (ERP, IoT) and sustainable supply chain	Manavalan & Jayakrishna (2019)
	Digital Manufacturing initiatives at leading universities in major industrial countries	Chong et al. (2018)
	Principles (interoperability, virtualization, local, real-time talent, service orientation and modularity) for I4.0 solutions (cloud computing, ensemble learning, big data, open-source software and Internet of Things)	Oztemel & Gursev (2020)
	Digitalization of work routines, workers' perception and impact on processes	Wilkesmann & Wilkesmann (2018)
KM and Learning	KM and I4.0 relationship (Smart Manufacturing)	Manesh et al. (2021); Kolyasnikov & Kelchevskaya (2020); Feng et al. (2017)
	Managerial implications of digital transformation	Zangiacomi et al. (2020)
	Knowledge-based design system for decision support in complex engineered systems	Wang et al. (2021)
	Framework to support KM enabling factors and organizational performance	Abubakar et al. (2019)
	Linkages between strategic leadership and supply chain integration	Birasnav & Bienstock (2019)
	Business maturity model level assessment	Santos-Neto & Costa (2019)
	Collaborative, web-based Knowledge Transfer Platform for Industry 4.0	Cotrino et al. (2021)
	KM (knowledge sharing) and Supply Chain digitization relationship	Sartori et al. (2022); Song et al. (2021); Yang et al. (2021); Schniederjans et al. (2020)
	Knowledge creation and conversion within cyber-socio-technical systems	Patriarca et al. (2021)
	Framework for knowledge storage and reuse on the shop floor	Bruno et al. (2020)
KM and Learning (cont.)	Framework for knowledge sharing, IT infrastructure, and innovative capability	Cassia et al. (2020)
	Organizational culture in traditional and knowledge economies	Drašković et al. (2020)
	Knowledge management maturity model	Hsieh et al. (2020)
	Digital innovation process as a knowledge broker	Jankowska et al. (2021); Crupi et al. (2020)
	Organizational knowledge value, knowledge sharing and knowledge base use	Stachová et al. (2020)
	Conceptual framework for new product development, integrating knowledge management, hybrid project management and sociotechnical values	Barbosa & Saisse (2019)
	Relationship between Organizational Learning (OL) capabilities, and operational performance	Ngereja & Hussein (2021); Tortorella et al. (2020)
	Knowledge protection and security requirements for digital transformation	Ilvonen et al. (2018)
Worker engagement	Employee technostress due to artificial intelligence (AI) adoption	Malik et al. (2021)
	Empowerment and engagement of workers for Industry 4.0	Kaasinen et al. (2020)
	Employee engagement (KM and leadership) by internal social media (communication)	Sievert & Scholz (2017)
	Cyber-Physical Production Systems implementation impact on workers´ health, learning and operative performance	Pinzone et al. (2020)
	Knowledge sharing in a human-focused Industry 4.0 context	Li et al. (2019)

4.1 Research opportunities relating Knowledge management and I4.0

Research opportunities related to Knowledge management and Industry 4.0 were also identified from the structured summaries, and were categorized using the same themes identified in the previous section: Technology, KM and learning and worker´s engagement. The opportunities were also categorized in these three themes considering its main objectives and contexts to be explored. Some opportunities could be related to more than one theme, but for those cases, the main context was analysed, and opportunities were integrated in the themes better representing each relation.

Technology-related research opportunities are associated with understanding how technologies such as big data can influence knowledge creation (Cassia et al., 2020; Núñez-Merino et al., 2020). They include the study of Cyber Physical Systems that enable the processing of large data volumes, which can be used to create new knowledge for operational and strategic applications (Manesh et al., 2021; Kolyasnikov & Kelchevskaya, 2020).

KM-related research opportunities are concerned to I4.0 implementation process, which can pose challenges to industries and even countries (Zangiacomi et al., 2020; Tortorella et al., 2020), as it requires the participation of multiple actors, such as universities and research institutions, government, companies, and others. The influence of organizational culture (Sartori et al., 2022; Li et al., 2019) and different decision-making styles on I4.0 implementation also need to be explored in future research (Núñez-Merino et al., 2020; Abubakar et al., 2019). More specifically, the influence of decision-making styles on KM (Manesh et al., 2021; Cassia et al., 2020), and its impact on organizational culture (Sartori et al., 2022; Li et al., 2019) need further discussion.

KM-related opportunities are also related to investigate factors and enablers to: facilitate knowledge creation and promote knowledge sharing and creating among workers (Manesh et al., 2021; Sartori et al., 2022; Abubakar et al., 2019), increase knowledge usage during innovation processes (Cassia et al., 2020; Núñez-Merino et al., 2020), increase knowledge sharing influence over organizational competitiveness (Manesh et al., 2021; Chehbi-Gamoura et al., 2020), and enhance workers´ participation in innovation processes (Kaasinen et al., 2020; Kolyasnikov & Kelchevskaya, 2020; Chong et al., 2018; Sievert & Scholz, 2017).

The relationship between organizational culture and KM, especially related to how knowledge loss demands continuous training requires deeper understanding. The influence of IT on knowledge sharing (Cassia et al., 2020; Núñez-Merino et al., 2020), and workers´ integration and coordination, its possible effect on transforming relevant data into organizational knowledge (Kolyasnikov & Kelchevskaya, 2020) and on favoring an appropriate context for knowledge sharing also needs further discussion. This is deemed important since it can result in sustainable competitive advantage, as a favorable context for knowledge sharing can contribute to improved operational performance (Manesh et al., 2021; Cassia et al., 2020). Additionally, the literature highlights the importance of knowledge sharing during transition periods, and thus, KM can act as a facilitator for I4.0 implementation (Buřita et al., 2018; Shadi 2017; Cassia et al., 2020). Finally, learning is regarded as a research opportunity both at the group and the individual levels, and it is linked to workers development, which includes training to I4.0, and I4.0 technology effects on individual and group learning (Manesh et al., 2021; Sartori et al., 2022; Oztemel & Gursev, 2020).

Research opportunities relating Knowledge management and Industry 4.0 literature are summarized on Table 5.

Table 5. Research opportunities related to Knowledge Management and I4.0.

Theme	Research opportunities	Author
Technology	Big data influence on knowledge creation and competitiveness	Manesh et al. (2021); Chehbi-Gamoura et al. (2020)
	Robot implementation in different production environments and products	Barbosa et al. (2020)
	Drivers and barriers for Additive Manufacturing networks, and related knowledge sharing practices	Stentoft et al. (2020)
	Knowledge-based approaches and technological resources for production process simulation	Wang & Wan (2021); Dornhöfer et al. (2020)
	Cyber-Physical Production System technologies implementation	Pinzone et al. (2020)
KM and Learning	Knowledge-based systems efficiency for decision-making support	Wang et al. (2021)
	Managerial perspectives on learning for innovation	Ngereja & Hussein (2021)
	I4.0 implementation challenges for different sectors and countries	Zangiacomi et al. (2020); Tortorella et al. (2020); Wilkesmann & Wilkesmann (2018)
	Decision-making styles influence on I4.0	Núñez-Merino et al. (2020); Abubakar et al. (2019)
	Sustainability aspects for stakeholders during technology implementation	Pinzone et al. (2020)
	Organizational culture influence on I4.0 implementation	Sartori et al. (2022); Drašković et al. (2020); Li et al. (2019)
	Environmental uncertainty, organizational structure and training influence on leadership behaviors for supply chain integration	Birasnav & Bienstock (2019)
	Knowledge Transfer resources for different manufacturing contexts	Cotrino et al. (2021)
	KM for innovation processes	Jankowska et al. (2021); Manesh et al. (2021); Cassia et al. (2020); Núñez-Merino et al. (2020); Schniederjans et al. (2020); Ilvonen et al. (2018)
	Knowledge sharing enablers in different technological contexts	Manesh et al. (2021); Sartori et al. (2022); Cassia et al. (2020); Núñez-Merino et al. (2020); Stachová et al. (2020)
	Digital innovation hubs as knowledge brokers in different industries, technology and partnership contexts	Jankowska et al. (2021); Crupi et al. (2020)
KM and Learning (cont.)	Knowledge creation enablers in different technological contexts	Manesh et al. (2021); Schniederjans et al. (2020); Abubakar et al. (2019); Patriarca et al. (2021)
	Quality indicators for knowledge sharing in supply chains	Yang et al. (2021)
	Explore data analysis techniques and resources for shop floor knowledge management	Bruno et al. (2020)
	KM maturity models in different manufacturing and service contexts	Hsieh et al. (2020)
	KM and supply chain digitalization	Song et al. (2021); Chehbi-Gamoura et al. (2020); Schniederjans et al. (2020)
	I4.0 technology impact on the employment and knowledge loss	Manesh et al. (2021); Sartori et al. (2022); Oztemel & Gursev (2020)
	KM and sociotechnical digital transformation	Barbosa & Saisse (2019)
	Critical knowledge protection the balance between knowledge sharing and protection	Ilvonen et al. (2018)
	I4.0 training strategies	Manesh et al. (2021); Sartori et al. (2022); Oztemel & Gursev (2020); Wilkesmann & Wilkesmann (2018)
	I4.0 technology effects on individual and group learning	Manesh et al. (2021); Oztemel & Gursev (2020)

Table 5. Continued...

Theme	Research opportunities	Author
Worker Engagement	Worker´s competencies and skills for I4.0	Del Río Castro et al. (2021); Malik et al. (2021); Manesh et al. (2021); Sartori et al. (2022); Zangiacomi et al. (2020); Li et al. (2019); Manavalan & Jayakrishna (2019); Oztemel & Gursev (2020); Wilkesmann & Wilkesmann (2018)
	HR management for I4.0 implementation	Song et al. (2021)
	Operators´ interaction with technology resources	Kaasinen et al. (2020); Wilkesmann & Wilkesmann (2018)
	The worker perspective on I4.0 implementation	Song et al. (2021); Wilkesmann & Wilkesmann (2018)
	The worker role in I4.0	Kaasinen et al. (2020); Kolyasnikov & Kelchevskaya (2020); Chong et al. (2018); Wilkesmann & Wilkesmann (2018); Sievert & Scholz (2017)

From the worker's engagement, the perspective on how blue collars engage in learning and knowledge sharing in order to develop new competencies and skills, is an opportunity for future research (Malik et al., 2021; Zangiacomi et al., 2020; Li et al., 2019; Manavalan & Jayakrishna, 2019; Oztemel & Gursev, 2020). More specifically, their role in knowledge sharing, learning processes and continuous training (Manesh et al., 2021; Sartori et al., 2022; Cassia et al., 2020; Núñez-Merino et al., 2020; Oztemel & Gursev, 2020), and adaptive learning solutions (Kaasinen et al., 2020; Oztemel & Gursev, 2020) can be further studied.

5 Conclusion

This paper aimed to discuss how KM can support the I4.0 implementation, in order to provide insights and assist researchers in future research. Guided by the question: How can knowledge management support the Industry 4.0 implementation? It was found that I4.0 technologies and their implementation, and the related management practices are currently the dominant issues. The literature can be organized around three themes: Technology, KM and learning and worker´s engagement. I4.0-related technologies adoption is a prevalent theme, but the relationship between KM and I4.0 is discussed not only from a hard technology-related perspective, but it indicates research demands to be explored from a soft people-related perspective, in which new skills, learning, adaptation, and the identification of critical knowledge for each process are pointed as relevant aspects. Knowledge sharing is an important factor to facilitate the innovation process, and to support transition periods. Knowledge creation and its application on processes and digital technologies application in KM is also a frequent theme. The influence of communication, culture and trust on worker engagement is also explored.

Opportunities for future research can also be classified in technology, KM and learning and workers´ engagement themes, which can offer insights to be considered for both academics and practitioners. Technology-related research opportunities are associated with understanding how technologies can influence the knowledge creation process, and how large data volume processing can be explored to create knowledge for operational and strategic applications. KM and learning themes indicate opportunities to investigate key factors and enablers to facilitate knowledge creation and promote knowledge sharing among workers. How blue collars engage in learning and knowledge sharing in order to develop new competencies and skills is also an opportunity for future research.

The categorized opportunities integrating the KM supportive potential to the I4.0 implementation process constitutes the main contribution of this paper, where the technology group consider that its integration with organizational and manufacturing objectives, have to be explored as a way to facilitate the achievement of better operational results. KM and learning include concerns of human knowledge adaption and management in technological contexts (Manesh et al., 2021; Sartori et al., 2022), which are based in the conventional literature of organizational and manufacturing management, and in terms technology, consider in majority isolated implementation initiatives, constituting a demand for empirical studies able to introduce and test new approaches considering the aspects indicated in Table 5. Worker's engagement considers initiatives and behaviours to integrate process, workers and technologies (Kaasinen et al., 2020), which is still little explored in the literature and requires deep empirical studies in the context of I4.0, where various technologies are integrated in a collaborative way with workers (Malik et al., 2021; Kolyasnikov & Kelchevskaya, 2020). The results indicate in general, other indirect opportunities to be explored, such as the knowledge sharing ways where the technological adoption implies in production environment of less employees, interacting by means of technological resources. Finally, the aspects of worker learning and engagement indicate possible interactions to be empirically tested in confrontation with social and cultural aspects, which may constitute barriers or facilitators in the adoption of new technologies.

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Authors contribution

All authors worked on the conceptualization, theoretical-methodological approach and theoretical review. Data collection was coordinated by Rafaela Brino de Oliveira and Vagner Batista Ribeiro. Data analysis included all authors. Davi Nakano, Jorge Muniz Jr. and Vagner Batista Ribeiro worked together in the writing and final revision of the manuscript.