Knowledge Management benefited by Industry 4.0 integration – A scoping review

Ana Paula Lista[1]
Dr. Guilherme Luz Tortorella[2]
Dr. Marina Bouzon[3]

Abstract: This paper aims at identifying the main knowledge management (KM) abilities benefited by Industry 4.0 (I4.0) integration. For that, a scoping review was carried out to examine the relevant literature. Firstly, fourteen abilities of KM were identified, from which 'Transferring knowledge with I4.0 technologies' stands out in number of citations. Secondly, ten categories of technologies were examined according to their role. Regarding the integration of I4.0 and KM, results indicate that companies that adopt I4.0 technologies, such as internet of things or visualization technology, are more likely to systemically reinforce their learning and knowledge sharing abilities across the organization. Overall, results reveal that the positive effect of I4.0 technologies is especially observed when considering the learning development at the organizational level.

Keywords: Industry 4.0; Fourth Industrial Revolution; Knowledge management

Resumo: Este artigo tem como objetivo identificar as principais habilidades de gestão do conhecimento (GC) beneficiadas pela integração da Indústria 4.0 (I4.0). Para tanto, foi realizada uma revisão de escopo para examinar a literatura pertinente. Primeiramente, foram identificadas quatorze habilidades de KM, das quais 'Transferir conhecimento com tecnologias I4.0' se destaca em número de citações. Em seguida, dez categorias de tecnologias foram examinadas de acordo com seu papel. Em relação à integração de I4.0 e KM, os resultados indicam que tecnologias de I4.0, como IoT ou tecnologias de visualização, são mais propensas a reforçar sistemicamente suas habilidades de aprendizagem e compartilhamento de conhecimento. No geral, os resultados revelam que o efeito positivo das tecnologias I4.0 é especialmente observado quando se considera o desenvolvimento da aprendizagem no nível organizacional.

Palavras-chave: Indústria 4.0; Quarta revoluçãoindustrial; Gestão do conhecimento

1. INTRODUCTION

The Fourth Industrial Revolution, also denoted as Industry 4.0 (I4.0), refers to an increasingly automatized industry through the integration of disruptive technologies such as

[1] Programa de Pós-graduação em Engenharia e Gestão do Conhecimento – Universidade Federal de Santa Catarina (UFSC) Florianópolis – Brasil. ORCID: https://orcid.org/0000-0002-7143-9331. e-mail: anapaulalista@gmail.com

[2] Programa de Pós-graduação em Engenharia e Gestão do Conhecimento – Universidade Federal de Santa Catarina(UFSC) Florianópolis – Brasil. The University of Melbourne. IAE Business School. ORCID: https:// orcid.org/0000-0003-2396-4665. e-mail: gtortorella@bol.com.br

[3] Programa de Pós-graduação em Engenharia e Gestão do Conhecimento – Universidade Federal de Santa Catarina (UFSC) Florianópolis – Brasil.. ORCID: https://orcid.org/0000-0002-8994-5021. e-mail: marinabouzon@gmail.com

artificial (AI), big data, cloud computing, and cyber-physical systems (CPS) (Stocker et al., 2014). I4.0 technologies enable to interpreting data, learning from it, and using those learnings to more efficiently achieve the expected goals. I4.0 entails an interconnected environment in which products, processes and services are monitored in real-time and large amounts of data constantly collected, increasing the potential for knowledge creation (Sivanathan et al., 2017). However, such enhanced sensoring and data acquisition may produce more unstructured data, adding complexity to the information systems. I4.0 technologies facilitate the handling of this data, although organizing it into new and applicable information remains challenging (Ghadge et al., 2020). Further, as employees present different backgrounds, new knowledge capture approaches required to not only to convert this data in an understandable way, but also to integrate different types of knowledge representations cohesively (e.g. visual and written instructions of a workstation) (Camarillo et al,. 2017; Tsourma et al., 2019). Despite that, organizations still struggle to turn that information more visible and transparent, especially in contexts where most of it is shared through gestures, word of mouth or with pen and paper (Li et al., 2019).

Hence, new knowledge management (KM) approaches may emerge with the use of I4.0 technologies so that organizations can scan and detect meaningful pieces of information and develop more sophisticated uses of this knowledge (Manesh et al., 2020). KM comprises the abilities of acquiring, developing, sharing, exploiting and protecting organizational knowledge to improve organizations competitiveness (Caputo et al., 2019). Some scholars (e.g. Manesh et al., 2020; Garad and Gold, 2019) reinforce the use of KM approaches to enable reasoning based on the massive amount of data generated from the increased automatization and CPS. Tortorella et al. (2020) argued that companies embracing the Fourth Industrial Revolution might develop specific skills and approaches to manage knowledge at individual, team and organization levels, making decisions based on more accurate data. Similarly, Li et al. (2019) emphasize that an organization undergoing I4.0's path should create, acquire and transfer knowledge in a way that it can adapt to unpredictable market conditions more quickly than competitors.

Although a few studies (e.g. Waris et al., 2018; Hoffmann et al., 2019; Schu et al., 2019) suggested the association between KM and I4.0, no empirical validation of such relationship has been provided. Further, existing studies in the literature fall short in exploring the ways in which embodied knowledge is articulated and made manifest in practice, especially when considering the use of new I4.0 technologies in favor of diffusion of knowledge within organizations (Caputo et al., 2019). In order to truly benefit from I4.0 adoption, KM should integrate different types of information in a cohesive and understandable manner, while ensuring that each required information is received in an agile way (Mourtzis et al., 2019).

This is a major shortcoming in I4.0 publications, given the practical importance of I4.0 technologies on KM (Ilvonen et al., 2018). Based on these arguments, this paper aims at identifying the main KM abilities benefited by the integration with I4.0. For that, a scoping review was carried out in order to consolidate the main contributions based on different theoretical lenses. According to Arksey and O'Malley (2005) and Fink (2019), a scoping review is an appropriate method when it is desired to reinforce the proposed research problem, summarize and disseminate research findings, which is aligned with this study's purpose. The contributions of this study are two-fold. First, in theoretical terms, it complements the existing literature on KM by identifying the emerging benefits derived from the integration of novel technologies from I4.0. Second, in practical terms, this research allows companies to find ways to improve their KM abilities while increasing the chances of a successful response to ongoing changes in the business environment.

2. BACKGROUND

2.1 KNOWLEDGE MANAGEMENT

In recent years, drivers of growth are mainly based in technology advances and the constant innovation generated by companies, associated with knowledge development initiatives (da Silva Nascimento et al., 2020). The massive explosion of knowledge represents a new systemic logic experienced today, which assumes knowledge as a fundamental element for both physical and intellectual production, and as a driver of modernization in the business environment (Waris et al., 2018). Yet, knowledge alone is not enough to foster innovations and new emerging technologies, as it needs to be managed so that it is available in the right moment with the right content (Ferreira et al., 2018).

During the past decade, numerous publications dealing with KM reviews from different perspectives have been published. Abubakar et al. (2019) proposed a theoretical framework composed of six KM processes, as shown in Table 1. 'KM creation' summarizes the ability to transform tacit knowledge into explicit, more specifically, both learning from experience as well as from theoretical research. 'KM capture' comprises abilities that create new knowledge and replace the existing ones. 'KM organization' gathers the abilities of sharing, modelling, evaluating and selecting knowledge. 'KM storage' is focused on the ability of retrieving experiences from learning by personal memory as well as information archives. 'KM dissemination' represents abilities of transferring knowledge among individuals, groups or organizations using a variety of means or communication channels. Finally, 'KM application' includes the abilities of applying knowledge into problem-solving as well as recovery, transformation and reuse.

Table 1. KM abilities

KM abilities	KM processes[a]
Learning from experience	CR
Learning from theoretical research	CR
Creating new content	
Replacing the existing content	CA
Structuring knowledge	OR
Sharing knowledge within a structure	OR
Modeling knowledge within a structure	OR
Evaluating knowledge	OR
Selecting knowledge	OR
Store and retrieving	ST
Transferring knowledge by mouth-to-mouth	DI
Transferring knowledge with digital support	DI
Applying knowledge problem-solving	AP
Recovery, transformation and reuse	AP

Note: [a]CR- creation; CA- capture; OR- organization; ST- storage; DI- dissemination; AP- application
Source: Abubakar et al. (2019)

2.2 INDUSTRY 4.0

I4.0 has been recognized as a new paradigm in industry (Li et al., 2019). Given the growing number of I4.0 technologies, new opportunities that may disrupt the traditional approach of manufacturing companies are being generated. Yet, there is not a consensus on the portfolio of I4.0 technologies. Among them, Zheng et al. (2020) consolidated a list of ten technologies, as shown in Table 2.

Despite the technology driven approach implied by I4.0, people-related aspects (e.g. employees' skills and active participation into problem-solving activities) will remain a key role for organizations performance improvement (Tortorella et al., 2020). I4.0 technologies do not only influence the technical factors of an organization, they can also impact on emotional or intangible elements usually underestimated, but deemed as relevant for enhancing organizational performance (Meredith, 1993; Tranfield et al., 2003). Such factors integrate the way organizations, teams and individuals learn, contributing to behavioral shifts that underpin performance results (Al-Kurdi et al., 2018; Pereira & Tortorella, 2018). In fact, Marsick and Watkins (2003), and more recently Marsick (2013), proposed three contextual levels for learning development, they are: individual, team and organization. In the individual level, learning takes place when surprises or challenges act as triggers that stimulate a cognitive response. Meanwhile, in the team level, activities and discussions in group are fostered as a way to generate new knowledge. Finally, in the organizational level, learning is seen as a collective experience, based on a up-to-date database, electronic bulletin boards, or town hall/open meetings.

Table 2. I4.0 technologies

Technology	Definition
Cyber-physical systems (CPS)	Collection of technologies to monitor physical systems while creating a virtual copy
Internet of Things (IoT)	Information network of physical objects (that enables the collection and exchange of data
Big data analytics	Collection and analysis of large amount of data using a series of techniques to filter, capture and report insights
Cloud computing	A system for the provision of online storage services for all applications, program and data
Artificial intelligence (AI)	A system that think humanly and rationally according to data provision and patterns
Blockchain	A database that creates a distributed and tamperproof digital ledger of transactions
Simulation and modelling	Technologies to mirror the physical world data in a virtual world, aiming for simplification and affordability of the design, creation, testing and live operation of the systems
Visualization technology	Comprise both augmented and virtual reality
Automation and industrial robots	Refer to machinery and equipment to automize operational processes
Additive manufacturing	Process of joining materials in successive layers to create objects from 3D model data

Source: Zheng et al. (2020)

3. RESEARCH METHOD

The proposed method is a scoping review based on the indications from Abdulla et al. (2019). A scoping review is an extensive overview of literature which enables researchers to offer a critique on theory, and recognizing systematic patterns, disclosure of unnoticed trends and gaps (Meredith, 1993). A brief literature review using the Scopus database was initially carried out to obtain a better clarification of the research scope and terms selection (Tranfield et al., 2003). Results from this preliminary research indicated that the development of I4.0 technologies and their incorporation into KM are rapidly evolving, being investigated and discussed in many relevant disciplines, such as engineering, business, and computer science. Therefore, to properly guide the scoping review, a research question was formulated:

RQ: What are the main KM abilities benefited by the integration with I4.0 technologies?

The review process began with an identification of the search terms. Considering that this work aims *at* identifying the main I4.0 technologies that have a significant impact on KM, two research axes were selected: (*i*) KM and (*ii*) I4.0. Table 3 shows some combinations of keywords that were used to retrieve publications. Initially, some variations of keywords were chosen based on those found in the literature related to the theme. A comprehensive search was carried out in May 2021 using the keywords (“Knowledge *Management”) AND (“Industry 4.0” OR “Fourth Industrial Revolution” OR “smart” OR “technology” OR “digital”), resulting in 958 publications. To validate the set of keywords used in this initial search, a test of adherence was conducted. Following recommendations from Snyder (2019), ten publications from the past five years were randomly selected out of the 958 initially retrieved, and theirkeywords were compared with those used in the initial search. Since no additional keyword was identified, the adherence of the initial search was considered satisfactory. Hence, four databases were used due to their relevance already evidenced in similar studies, such as Al-Kurdi et al. (2018) and Pereira and Tortorella (2018).

The used databases were Web of Science, Scopus, Science Direct and Emerald Journals. For this search, there was a temporal delimitation for selecting publications, only papers published after 2011 were evaluated since I4.0 was not formally acknowledged before that year (Tortorella et al., 2020).

Table 3. Screening of publications

Keywords	
"knowledge *management" AND "Industry 4.0" OR "Fourth Industrial Revolution" OR "Smart" OR "Digital"	
Databases	Papers retrieved in databases
Scopus	493
Science Direct	120
Web of Science	329
Emerald Journals	16
Total	958
Filtering process	
Initial	958
Without duplicates and published after 2011	750 (-208)
Title alignment	271 (-479)
Abstract alignment	99 (-172)
Full content alignment	40 (-59)
Final publications	
44 (+4)	

Source: The authors

Publications were either included or excluded after meeting pre-defined criteria, as recommended by (Crossan & Apaydin, 2010). To be included in this review, papers had to approach KM development in the context of I4.0. Only articles written in English and published in peer-reviewed journals and conferences were considered. Mendeley® software was used to support the filtering process. Initially, duplicate papers and the ones that occurred before 2011 were eliminated. Subsequently, papers whose titles mismatched the research topic were eliminated. Then, papers' abstracts were verified to check if they converged to the research topic. Finally, papers' full content was investigated to verify its adherence to the research field, remaining 40 publications. As this is a recent topic, a backward snowballing procedure was applied using references from these 40 articles, as recommended by Wohlin (2014). References that appeared in more than two publications were verified and included in this review. The screening process was conducted by two of the authors. Whenever a consensus was not reached, a third author was asked to give an opinion, which untied the decision. A final corpus of 44 publications was obtained. Based on this portfolio, a content analysis was performed, which was divided in two stages (Seuring & Gold, 2012). In the first stage, numerical and descriptive methods were applied to examine papers regarding year of publication, journals and authors on the theme. In the second stage, the latent content of those papers was explored through a qualitative analysis. For that, structural attributes and corresponding analytic categories were selected to classify the content of the publications.

Two axes were initiallyfor this analysis: (*i*) KM abilities; and (*ii*) I4.0 technologies contribution on KM. In the first axis, papers were evaluated regarding the outcome of the implementation of I4.0 technologies on fourteen KM abilities. Those abilities are grouped according to their association to six KM processes (Abubakar et al., 2019), namely: creation (CR); capture (CA); organization (OR); storage (ST); dissemination (DI); and application (AP). It is worth mentioning that there may be more than one ability that was reported as pertaining to one KM process. Meanwhile, the second axis clustered publications according to ten I4.0 technologies suggested by Zheng et al. (2020) (Table 2). The analysis also verified the learning development level enabled by such technologies, as recommended by Marsick and Watkins (2003) and Marsick (2013), namely: individual (l_1), team (l_2) and organizational level (l_3).

4. RESULTS

Table 4 shows the results for the descriptive analysis of the corpus of publications. Studies that combine I4.0 technologies and KM are quite recent, with a significant increase in the number of publications in the past two years (84% of the papers were published after 2018). Further, several journals and conferences, such as the European Conference on Knowledge Management, Journal of Knowledge Management, Sustainability, Procedia Manufacturing, Procedia CIRP and Engineering Management Review hosted publications on the theme. Finally, out of 144 authors who have been investigating KM and I4.0, four authors stood out, participating in two publications each. These results suggest a scattered distribution of the topic among authors, conferences and journals, emphasizing its cross-disciplinary nature.

Table 4. Descriptive analysis of the examined literature

Publications per author	
Author	No. publications
Kaasinen, E.	2
Fast-Berglund, Å.	2
Belkadi, F.	2
Aromaa, S.	2
Others	36
Publications per jornal/conferece	
Journal/ Conference	No. publications
European Conference on Knowledge Management	3
Journal of Knowledge Management	3
Sustainability	2
Procedia Manufacturing	2
Procedia CIRP	2
IEEE Engineering Management Review	2
Others	30

Publications per year	
Year	No. publications
2011	0
2012	0
2013	0
2014	4
2015	0
2016	3
2017	4
2018	10
2019	17
2020	5
2021	5

Source: The authors

4.1 KM abilities

Table 5 displays the main KM abilities benefited by I4.0 technologies integration. Fourteen abilities were identified and grouped into six KM processes. Among them, 'a_{12}- Transferring knowledge with I4.0 technologies', which was included as part of the KM dissemination process, stood out in number of citations (30). This suggests that KM scholars have been using dissemination initiatives as a way to effectively manage knowledge in the Fourth Industrial Revolution era. For example, Waris et al. (2018) developed a smart semi-automatic tool for facilitating KM and product innovation process. The developed tool is a database for collective sharing from past experiences which allows the experienced-based knowledge to be stored more systematically for a wide range of similar manufactured products. Similarly, Camarillo et al., (2017) proposed a KM system to facilitate the capture and reuse of knowledge and best practices, integrating product life development with case based reasoning technology.

In opposition, the ability 'a_4- Replacing the existing content' was less explored in the studies (6 citations). Although some works have reported benefits from I4.0 for this ability enhancement (Manesh et al., 2020; Laroche et al., 2016; Di Maria et al., 2018), their ubiquity does not seem to be as evident as the others. Despite the large amount of data collected through I4.0 sensing and communicating technologies, little attention has been given to managing such knowledge and replacing the existing content with more valuable information (Di Maria et al., 2018). Concerning KM processes, KM organization and dissemination were the most frequent ones reported in the publications. According to (Meski et al., 2019), KM faces several challenges in the business field due to the absence and divergence of roadmaps to guide the implementation of KM approaches systematically and gradually. KM models supported by I4.0 technologies may be developed based on different theories and methods, varying in terms of focus and scope (Botha, 2018; Tinz et al., 2019). The high frequency of publications fostering KM dissemination and organization might indicate the prominence of I4.0 contribution to those processes.

Table 5. KM abilities and processes

	KM abilities	KM processes[a]	Frequency[b]
a_1	Learning from experience	CR	27
a_2	Learning from theoretical research	CR	21
a_3	Creating new content	CA	20
a_4	Replacing the existing content	CA	6
a_5	Structuring knowledge	OR	24
a_6	Sharing knowledge within a structure	OR	26
a_7	Modeling knowledge within a structure	OR	12
a_8	Evaluating knowledge	OR	10
a_9	Selecting knowledge	OR	15
a_{10}	Store and retrieving	ST	15
a_{11}	Transferring knowledge by mouth-to-mouth	DI	8
a_{12}	Transferring knowledge with digital support	DI	30
a_{13}	Applying knowledge problem-solving	AP	19
a_{14}	Recovery, transformation and reuse	AP	9

Note: [a]CR- creation; CA- capture; OR- organization; ST- storage; DI- dissemination; AP- application; [b]Frequency of citations
Source: The authors

4.2 I4.0 technologies contribuition on KM

Table 6 shows the main I4.0 technologies used for developing KM abilities. Ten technologies were initially verified. Citations of nine technologies were fairly-well balanced across all examined publications. Nevertheless, two of them appeared to be more emphasized to support KM development; they are: 't_2- Internet of Things' and 't_7– Simulation and modelling'. The role of t_2 for data and knowledge acquisition has reported in many works, such as Zangiacomi et al., (2020) and Kaasinen et al., (2020). Meanwhile, t_7 was particularly evidenced for predicting future situations or for decision-making (Schniederjans et al., 2020). According to Caputo et al. (2019), simulation increases the ability of data interpretation, enabling the identification of causes and interactions of objects. Considering the increasing volume of data, in addition to the growing demand for quick and assertive decisions, simulation represents an important tool to test scenarios and assess implications (Mourtzis et al., 2019; Botha, 2018).

In addition, results indicate that I4.0 based technologies can significantly contribute to learning development at all levels (i.e. l_1- individual; l_2- team; and l_3-organizational). In other words, companies that adopt I4.0 technologies, such as t_2 or t_7, are more likely to systemically reinforce their learning and knowledge sharing across the organization. Such findings are also aligned with the recommendations envisioned by Manesh et al. (2020), who argue that since I4.0 technologies are supposed to facilitate and catalyze data gathering and communication, then individuals, teams and organization as a whole can benefit from such support, exchanging information and making decisions in a more efficient fashion.

The positive effect of I4.0 technologies is especially observed when considering the learning development at the l_3 level, as evidenced in 86% of publications. For example, Sivanathan et al. (2017) developed a knowledge-based system to digitalize and collect data regarding anomalies at the shop floor, and to integrate them with data coming from the design phase, in order to reduce the time for finalizing a new product. Similarly, Waris et al. (2018) proposed a platform to retrieve information on product development and automatically transmit it to different units of a company, increasing the overall expertise of the organization.

Table 6. I4.0 technologies used for KM

I4.0 Technologies		References			
		l_1^a	l_2	l_3	Total
t_1	Cyber-Physical Systems (CPS)	12	3	13	17
t_2	Internet of things (IoT)	15	9	20	23
t_3	Big data	14	6	15	19
t_4	Cloud computing	12	6	15	18
t_5	Artificial Intelligence (AI)	9	6	10	12
t_6	Blockchain	1	1	2	2
t_7	Simulation and modelling	17	8	19	24
t_8	Visualization technology	14	7	15	19
t_9	Automation and industrial robot	13	7	14	18
t_{10}	Additive manufacturing	11	7	11	15
Total		32	16	38	-

Note: [a] number of citations at the l_1-individual level ; l_2- team level ; l_3-organizational level
Source: The authors

5. FUTURE DIRECTIONS

Despite the widespread dissemination of KM principles and practices over the past three decades, results from this study show this research agenda is still in the early stages of development.

Overall, results show that existing studies of I4.0 are predominantly devoted to the development of KM under the organizational level. However, the acquisition of knowledge in engineering companies on a regular basis is generally restricted to a single department or neither formally conducted in engineering companies due to time and cost restraints (Sivanathan et al., 2017). Another limitation identified is that learning through the use I4.0 technologies are rarely evaluated in publications, most assessment approaches have their analysis focused on the verification of concrete improvements which are triggered by the implementation of I4.0 technologies (Nardello et al., 2017; Yang et al., 2018). These shortcoming demonstrate that there is still a gap for further research to investigate the main benefits and shortcomings in KM associated with I4.0 technologies, especially for capturing and applying knowledge.

6. CONCLUSIONS

The purpose of this article was to identify the main KM abilities benefited by the integration with I4.0 technologies. For that, an extensive scoping review was carried out in the main databases, which enabled a descriptive and content analysis. Through this investigation, it was possible to examine complementarities, redundancies and gaps on the topic, which allowed the indication of future research directions. The contributions of this study are two-fold. First, in theoretical terms, it complements the existing literature on I4.0 by identifying the main contribution of such technologies to manage knowledge effectively. Second, in practical terms, this research allows organizations to find ways of improving KM development, increasing the chances of a successful decision-making process, which is a key issue nowadays.

Results identify the main KM abilities benefited by the integration with I4.0 based on two main analysis. Firstly, fourteen abilities of KM were identified, from which 'Transferring knowledge with I4.0 technologies' stands out in number of citations. Secondly, ten categories of technologies were examined according to their role, from which 'Internet of things' and 'Simulation and modelling' stand out for managing knowledge effectively. Regarding the integration of KM and I4.0, results indicate that companies that adopt I4.0 technologies, such as IoT or visualization technology, are more likely to systemically reinforce their learning and knowledge sharing abilities across the organization.

Overall, results reveal that technologies can significantly contribute to learning development at all levels (i.e. individual; team; and organizational). The positive effect of I4.0 technologies is especially observed when considering the learning development at the organizational level.

It is also worth mentioning some limitations of this work. First, the inferences were obtained from searches during a specific time. Thus, indications are limited to the availability of the papers published until this period. Second, findings were built upon the research available in four of the main databases. However, papers published in journals indexed in other databases may bring additional contributions to the results observed here. Finally, the analysis of papers is restricted to KM abilities and processes. Future studies could analyze literature content under lenses of other approaches and cognitive theories, to complement and even compare results.

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