Industry 4.0 and Knowledge Management: A Review of Empirical Studies

Mauro Capestro and Steffen Kinkel

Abstract The recent Industry 4.0 paradigm is revolutionizing the manufacturing processes, the way companies create value and interact with suppliers and customers. The new technologies allow manufacturing companies to gather huge amounts of data that they can use to tailor production, develop customized products and services, as well as improve operation activities in terms of efficiency, productivity, and flexibility. In this new technological scenario, new digital skills and competences (i.e., data management) become strategically important as they could assure new knowledge manufacturing companies to achieve superior competitive advantage. Such new knowledge depends not only on the use of Industry 4.0 technologies but also on the interactions with suppliers and customers as well as on the upgrading of employees' competences. With the aim of deepening the understanding of these dynamics, the chapter reviews the empirical studies related to the adoption of Industry 4.0, by highlighting the role of knowledge management.

1 Introduction

The current manufacturing landscape requires key factors such as efficiency, flexibility, faster responsiveness to market changes and customer demand, as well as a higher focus on product quality and customization that are essential for the survival of manufacturing companies (Almada-Lobo, 2015). Moreover, to compete successfully manufacturing firms need higher level of digitization and automation that means an extensive connectivity between manufacturing processes and other business areas—that is high integration of operation systems with the overall organization structure (Berman, 2012; Rashid & Tjahjono, 2016). In addition to internal

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integration, manufacturing companies also need higher integration with the external environment and specifically with suppliers and customers (Hakanen & Jaakkola, 2012).

In this sense, the new technological revolution known as Industry 4.0 plays a key role, since it enables the integration between manufacturing operations systems and new Information and Communications Technologies (ICT)—such as cloud computing, big data analytics, Artificial Intelligence (AI), and Internet of Things (IoT)—creating the so-called cyber-physical systems (CPS) (Dalenogare, Benitez, Ayala, & Frank, 2018). Essentially, Industry 4.0 highlights the usage of new technologies with the integration among objects, humans, and machines across organizational boundaries to create not only a cyber-physical manufacturing environment but also a new type of networked value chain (Kagermann, 2015). Through the Industry 4.0 technologies, manufacturing companies may be able to implement three types of integrations: (1) horizontal, (2) vertical, and (3) end-to-end integration, which allow them to improve both the operation (efficiency, productivity, quality, etc.) and the marketing (new product development, customization, time-to-market response, etc.) activities (Schwab, 2017).

Although most of the Industry 4.0 technologies are not completely new, the full potential of these technologies has not been exploited in the current manufacturing system (Fatorachian & Kazemi, 2018) due to the higher integration of different information systems previously limited to single business areas (Panetto & Molina, 2008) and the presence of many Industry 4.0 technologies. Industry 4.0 technologies also offer the opportunity to gather and manage a huge amount of data used to improve the firm's offering, both in terms of efficiency and response to customer needs (Büchi, Cugno, & Castagnoli, 2020). In this perspective, knowledge becomes an essential variable that manufacturing companies should consider and manage in an effective way for the successful implementation of Industry 4.0 (Feng, Bernstein, Hedberg, & Barnard Feeney, 2017). In particular, Industry 4.0 technologies enable companies to create new knowledge coming from the use of new technologies in production processes, but also from external environment and precisely through the acquisition and elaboration of data gathered from suppliers and through higher involvement of customers that become active partner (co-creation) in the design process (Lu, 2017). Moreover, knowledge also becomes essential in terms of skills and competences that employees and managers should have to get the highest potential from Industry 4.0, as the new knowledge created should be used in a timely manner (Ardito, Messeni Petruzzelli, Panniello, & Garavelli, 2019).

Therefore, manufacturing companies should take into relevant consideration the strategic relationship between new technologies and knowledge management for the successful implementation of Industry 4.0 technologies. Indeed, this aspect represents one of the main challenges manufacturing companies must overcome to implement successfully Industry 4.0 (Whysall, Owtram, & Brittain, 2019). In this respect, the purpose of this chapter is to highlight the role of knowledge in the Industry 4.0 paradigm by means of literature review of the empirical studies focused on the implementation of Industry 4.0 technologies.

2 Theoretical Background

2.1 The Industry 4.0 Paradigm

Industry 4.0, also known as "fourth industrial revolution," is a current hot topic in both professional and academic fields (Liao, Deschamps, Loures, & Ramos, 2017). Industry 4.0 is a disruptive phenomenon that is changing the rules of competition, allowing companies taking advances in different business processes. Specifically, it is affecting the firms' overall strategy, changing organizational mindset, business models, value creation process, supply chain activities, production processes, products, skills, and stakeholder relationships (Reinhard, Jesper, & Stefan, 2016).

The term *Industry 4.0* comes from Germany as *Industrie 4.0* being a part of the "High-Tech Strategy 2020 for Germany" (Kagermann, Lukas, & Wahlster, 2011). Germany introduced such a term when the government decided to promote and support the technological integration of manufacturing plants with products and business processes to strengthen Germany's position as a leading manufacturing power worldwide (Kagermann, Helbig, & Wahlster, 2013; Lasi, Kemper, Fettke, Feld, & Hoffmann, 2014). Before other countries, the German Government was confident that the future of manufacturing industries will be characterized by a strong product personalization under the conditions of highly flexible production and with the extensive integration of business partners and customers in value creation and business models (Thoben, Wiesner, & Wuest, 2017). Later, besides Germany, other national and international institutions started to give importance to the new phenomenon supporting the implementation of the new technologies. The European Union promoted a public–private partnership under the name *Factories of the Future* to sustain the competitiveness of production. The Italian Government launched in 2016 the *Industry 4.0 National Plan*. France promoted the implementation of Industry 4.0 through the *Aliance Industrie du Futur* initiative and the *Future of Manufacturing* in the United Kingdom (Büchi et al., 2020; da Silva, Kovaleski, & Negri Pagani, 2019). Moreover, in the USA similar efforts are underway through the *Industrial Internet Consortium*. In China, the *Internet Plus initiative* and *Made in China 2025* represent technological initiatives similar to Industry 4.0 (Müller & Voigt, 2018). In addition to China, the other Asian countries that proposed similar initiatives to facilitate the development of their own manufacturing industries are Japan with the *Connected Industries* and Korea with *Smart Factory* (da Silva et al., 2019; Mittal et al., 2019).

Notwithstanding the specific technological representation of the fourth industrial revolution, also as a consequence of the several worldwide initiatives, a common definition of Industry 4.0 has not been accepted. Indeed, both scholars and practitioners in addition to the governments used several synonyms to depict it. In particular, *Industry 4.0* (and/or *Industrie 4.0*) is predominantly used in Europe. *Smart manufacturing* is the term predominantly used in the USA and *smart factory* in Asia (Kagermann, Gausemeier, Schuh, & Wahlster, 2016; Mittal, Khan, Romero, & Wuest, 2018). Moreover, other terms most used in the business management field are *Cyber-physical system* (CPS), *(Industrial) Internet of Things* (IoT/IIoT), *digital* *manufacturing/factory*, and i*ntelligent manufacturing systems* (IMS) (Agostini & Filippini, 2019; Büchi et al., 2020; Thoben et al., 2017). Table 1 reports a description of Industry 4.0 definitions.

Despite some differences in their definitions, the terms can be considered interchangeably. Most of them focus principally on manufacturing and operation activities, but all of them highlight the digitization of business activities (Müller, Buliga, & Voigt, 2018). Other common elements regard the automation systems, the connections between the physical and digital worlds, the extensive use of Internet, and the changes in the relationships with stakeholders and in business governance (Büchi et al., 2020).

Industry 4.0 is a broader concept that considers all the different aspects emerged from the abovementioned definitions (see Mohamed, 2018). It encompasses the adoption of industrial automation systems that support companies in managing the production and value creation processes, the supply chain activities, and all their related processes (Reischauer, 2018; Yin, Stecke, & Li, 2017). One of the most accepted definition of Industry 4.0 is provided by McKinsey Company that considers it as the digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyber-physical systems, and analysis of all relevant data (Wee, Kelly, Cattel, & Breunig, 2015). More generically, Industry 4.0 can be defined as a new business approach for controlling production processes by providing real-time data analysis and by enabling the unitary customization of products (Kohler & Weisz, 2016).

Thus, the concept of Industry 4.0 is mainly embedded in smart manufacturing and CPS, whose technological infrastructure bases on the concept of IoT that allows connection of machines, products, systems, and people (Kagermann et al., 2013; Lasi et al., 2014; Schmidt et al., 2015). Together with cloud computing, CPS and IoT are considered as the central pillars of Industry 4.0 (Müller, 2019a). Finally, the integration of CPS with innovative production, logistics, and services practices led to the Industry 4.0 factory (Lee, Bagheri, & Kao, 2015). Indeed, Industry 4.0 is often identified with a set of technologies that bring together the CPS domain (IoT, big data and analytics, cybersecurity) with other production technologies such as advanced manufacturing systems, additive manufacturing, 3D printing, horizontal/vertical integration, and simulation systems (Agostini & Filippini, 2019; Tortorella & Fettermann, 2018).

2.2 The Industry 4.0 Enabling Technologies

The implementation of Industry 4.0 paradigm in the manufacturing sectors covers a wide range of applications from product development and design to operation and logistic activities. For this reason, Industry 4.0 comprises a very large set (estimated more than 1200) of enabling technologies (Chiarello, Trivelli, Bonaccorsi, & Fantoni, 2018), even if scholars and practitioners focused only on some enabling

Table 1 Industry 4.0 definitions

Term	Definition	Author(s)
Smart manufacturing	Smart Manufacturing is the integration of information technology (IT) and data with different manufacturing technologies, processes, and resources to enable intelligent, efficient, and responsive operations. It relies on the digitalization and interconnection of entire value chains, products, processes, and business models	Kagermann (2015), Thoben et al. (2017), Kusiak (2018), Lu and Weng (2018), Mittal et al. (2019)
Smart factory	A smart factory is a factory that is context-aware and assists people and machines in execution of their tasks by systems working in background. It differs from smart manufacturing as it focuses on a single plant rather than on a broader supply network concept	Hozdić (2015), Jung, Choi, Kulvatunyou, Cho, and Morris (2017), Mittal et al. (2018), Prause (2019)
Cyber-physical (production) system (CPS)	CPS refers to the use of technologies for the management of interconnected systems between its physical assets and computational capabilities. It focuses on the data gathered, stored, and shared to operate autonomously	Schlechtendahl, Keinert, Kretschmer, Lechler, and Verl (2015), Agostini and Filippini (2019), Müller, Buliga, et al. (2018), Müller (2019a)
(Industrial) Internet of Things (IoT/IIoT)	IoT and IIoT rely on the digital connection between physical entities and digital components for a completely intelligent, inter-connected, and autonomous factory. It results not only in a production change but in an extensive organizational change	Arnold, Kiel, and Voigt (2016), Kiel, Arnold, and Voigt (2017), Arnold and Voigt (2019)
Digital manufacturing/ factory	Digital manufacturing/factory concept relies on the use of computer-assisted applications, analytics, simulation, three-dimensional (3D) visualization, and various collaboration tools, integrated in a common communication infrastructure Data management systems and simulation technologies are concurrently used to optimize the manufacturing processes and match the customer demands	Chen et al. (2015), Byrne et al. (2016), Cavalcante, Frazzon, Forcellini, and Ivanov (2018)
Intelligent manufacturing systems (IMS)	The notion of IMS is quite similar to smart manufacturing, but it stresses the role of control on production activities. It relies on the ability to self-regulate and/or self-control to manufacture the products within the design specifications. Moreover, it relies on a new way of interacting between humans and production machines with the aim of creating a whole smart factory	Zhong, Xu, Chen, and Huang (2017), Zhong, Xu, Klotz, and Newman (2017) and Stadnicka, Litwin, and Antonelli (2019)

technologies considered the pillars of manufacturing technological digitalization (Agostini & Filippini, 2019; Moeuf et al., 2020).

Considering Industry 4.0 as a new manufacturing approach that relies on technologies able to gather and analyze data in real time, to control and customize the production processes, we have limited the scope of our review to empirical studies concerning the adoption of the following enabling technologies (Agostini & Filippini, 2019; Büchi et al., 2020; da Silva et al., 2019; Mittal et al., 2018; Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018; Moeuf et al., 2020):

- *Industrial Internet of Things*: new digital technologies, devices, and sensors that facilitate communication between people, products, and machines. Internet is the center of connectivity for all the intelligent devices in which real-time communication provides valuable feedbacks and information that improve production process and delivery and facilitate the decentralization of decision-making.
- *Cloud computing*: technologies that facilitate the storage and processing of huge amounts of data with high performance in terms of speed, flexibility, and efficiency. Cloud computing allows in real time information sharing across multiple systems and networks ensuring data for the production system, including monitoring and control functions, and improving the quality of operations.
- *Big data and analytics*: technologies, tools, and techniques useful to capture, archive, analyze, and disseminate large quantities of data derived from products, processes, machines, and people interconnected in a company, as well as the environment around it. Big data and analytics may assure benefits in terms of higher product customization, higher flexibility due to the possibility of demand estimations, a better product quality and less production waste, and the optimization of supply chain.
- *Virtual and Augmented reality*: a series of technologies and devices used to simulate an environment containing real and virtual objects with the aim of improving production processes by enhancing design and prototyping and product development, reducing setup costs and process time, receiving information in real time, and providing virtual training. In this way, the human performances increase through the ability to reproduce and reuse digital information and knowledge to support the operation activities.
- *Additive manufacturing*: the most important example is the 3D printing technology that is grounded in the additive production creating layers by layers the shape of object deriving from a 3D design file. 3D printing can use several different materials, such as plastics, ceramics, metals, and resins and others, eliminating the assembling of the final product. This kind of technology enables companies to improve the design, prototyping and production of complex products, as well as product customization. Additive manufacturing is beneficial for the supply chains where the production of spare parts is a key part of the business due to high-level after-sales services.
- *Artificial intelligence*: automated solutions developed by the massive amounts of data gathered and that are able to act alone without the intervention of humans to solve problems that otherwise require human intervention. It is “a system’s ability

to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation" (Haenlein & Kaplan, 2019, p. 5). The application of artificial intelligence to production processes can support both productivity and quality taking decisions and carrying out actions based on the evaluation of the current environment.
- *Advanced manufacturing solutions*: interconnected and modular systems by means of robots and embedded sensor technologies that are becoming increasingly flexible, communicative, and cooperative guaranteeing the complete automation of industrial plants. These technologies include different automatic machinery used in the production processes, such as the material-moving systems, autonomous and advanced robotics, the collaborative robots (cobots), and automated guided vehicles or unmanned aerial vehicles. These technologies do not eliminate the workforce but improve the collaboration with them, with new tasks focused mainly on planning and control phases, eliminating the structural and technological constraints of automatic and fixed systems.
- *Horizontal and vertical integration systems*: The integration offered by Industry 4.0 is characterized by two dimensions: internal versus external. The first (horizontal integration) concerns the integration and exchange of information among the different areas in the company. The second (vertical integration) concerns the company's relationships with its suppliers and customers. Integration systems allow us to reduce setup and production costs and, at the same time, to improve product quality due to the better connections in the incoming and outgoing supply chain activities, with positive effects also on productivity.
- *Simulation*: integration of different computer tools to reproduce the physical world in the virtual models allowing all company operators (managers, designers, production workers) to test and optimize the production settings and simulate the performance of production system. Modeling enables the analysis of materials, production line and product performance, as well as the multisite coordination with the aim of improving and optimizing the overall operations and reducing setup costs, errors, and machine downtimes.

Indeed, the two key factors for Industry 4.0's successful implementation are *integration* and *interoperability*. Integration affects networking with stakeholders, both horizontally and vertically. Interoperability helps the production processes, within and beyond the boundaries of the organization, interconnecting systems and exchanging knowledge and skills (Lu, 2017). This means that companies to implement successfully the Industry 4.0 paradigm should be open to organizational changes (Arnold et al., 2016).

The advent of manufacturing digitalization induces, therefore, companies to evolve and change their own structure accepting knowledge-based, dynamic, and collaborative learning governance models, with the implementation of new technologies being extremely knowledge intensive (Ghobakhloo, 2018). The decision-making process of manufacturing companies that implemented Industry 4.0 requires information and knowledge from the data that technologies allow to collect (Feng et al., 2017).

2.3 *The Role of Knowledge in the Fourth Industrial Revolution*

In the fourth industrial revolution, the main goal of the implementation of new technologies is related to the effective and efficient customer-oriented adaptation of products (and thus production) and services in order to increase the value added for companies, raising their competitive position, while for customers improving satisfaction and loyalty (Roblek, Meško, & Krapež, 2016). In order to achieve this goal, manufacturing companies need to develop and manage new knowledge that is crucial for the organization's decision-making process and the achieving of the related business goals (Abubakar, Elrehail, Alatailat, & Elçi, 2019).

Industry 4.0 reflects a combination of digital and manufacturing technologies which enable vertical integration of the company' systems, horizontal integration in collaborative networks, and end-to-end solutions across the value chain that guarantee automated, flexible, and self-configurable intelligent processes to enable the creation of new revenue sources (Schneider, 2018). Specifically the new technological transformation embraces technological advances that concern the production process (i.e., advanced manufacturing systems, autonomous robots, additive manufacturing), the use of smart products (e.g., IoT and IIoT), and/or data tools and analytics (big data, AI, cloud, etc.) (Porter & Heppelmann, 2014, 2015). Within the manufacturing process, the adoption of autonomous and/or collaborative robotics (Adamson, Wang, & Moore, 2017) or 3D printing is opening up new opportunities to create new knowledge concerning products and processes (Anderson, 2012; Bogers, Hadar, & Bilberg, 2016). At the same time, smart products and "data-driven technologies" enable the successful acquisition of useful data from several sources within the organizational boundaries as well as from customers and suppliers (Klingenberg, Viana Borges, & Valle Antunes Jr., 2019). Therefore, Industry 4.0 stresses the huge potentialities of data that can be used in real time, enriching contextual knowledge or generating new one in the way products can be produced and used, as well as in the practices concerning value generation (from product to service), allowing firms to take actions and make decisions based on such knowledge (Tao, Qi, Liu, & Kusiak, 2018). Moreover, it is essential to consider a holistic view of manufacturing processes, integrating data from different sources to achieve the business benefits of new technologies (Schneider, 2018).

Finally, the huge amount of data produced by the new technologies needs humans for the creation and management of new useful knowledge (Ramzi, Ahmad, & Zakaria, 2018). In this sense, Industry 4.0 opens another issue for the manufacturing companies that choose to implement and use the new technologies successfully, namely the acquisition of new skills and competences (Schwab, 2017). In this case, new knowledge to manage (acquisition, conversion, application) data and processes needs to be acquired by employees and managers (Dragicevic, Ullrich, Tsui, & Gronau, 2019). People have to gain knowledge that will enable the development of *digital thinking* so that they may manage the process in a new way (Schniederjans, Curado, & Khalajhedayati, 2019). The networking of production systems in the smart manufacturing context, for example, relies on *interconnectivity* and *interoperability* across the different intelligent components requiring knowledge of intelligent vertical and horizontal networking. Manufacturing companies with digital skills within their human resources would be more ready to start digital transformation (Gilchrist, 2016). Moreover, the integration between technologies, knowledge, and human competences and capabilities should allow companies to be more ready for digital transformation and improve their competitiveness achieving their strategic goals (Dalenogare et al., 2018).

3 Research Goals and Methodology

Currently, the attention of researchers and practitioners on the implementation of Industry 4.0 focuses on the impacts of new technologies on business processes and performance as well as on the relationships with customers and suppliers to achieve a superior competitive advantage (Wagire, Rathore, & Rakesh, 2019). In this process, the new knowledge companies created through both the use of Industry 4.0 technologies and the new forms of relationships with suppliers and customers (Di Maria, Bettiol, Capestro, & Furlan, 2018; Schniederjans et al., 2019) has a key role (Karia, 2018). Our main goal is to identify the empirical (quantitative and qualitative) studies to better explain the relationship between Industry 4.0 and knowledge management. Specifically, reviewing the recent empirical studies, we analyze more in depth how the manufacturing companies that adopted the Industry 4.0 technologies gather data, create new knowledge for processes (and strategy), products (and related services), and people (workers/customers/suppliers), and use it for the achievement of business results and the improvement of competitive advantage. In doing so, we try to answer the following research questions.

RQ1. How is Industry 4.0 linked to the company's knowledge management process?
RQ2. How do companies create new knowledge within the Industry 4.0 paradigm?
RQ3. How do companies manage and use new knowledge related to Industry 4.0 technologies to sustain their competitive advantage?

To reach the research purposes and answer the abovementioned research questions, we reviewed papers published in scholarly international journals, specifically business and management journals (Durach, Wieland, & Machuca, 2015; Tranfield, Denyer, & Smart, 2003). The literature review focuses on articles dealing exclusively with empirical studies (qualitative and quantitative) on the adoption of Industry 4.0 technologies. In this regard, we selected the papers considering the following searching criteria. Firstly, we considered the papers that have in abstracts, keywords, and title at least one (OR) of the Industry 4.0 definitions before mentioned and specifically: Industry 4.0, Industrie 4.0, smart manufacturing, smart factory, cyber-physical systems, industrial Internet of Things, digital manufacturing, digital factory, and intelligent manufacturing systems. In addition, we also considered (AND) both the presence of keyword "knowledge" and that of at least one of the following keywords (OR), "empirical studies," "survey," "in-depth interview," or "case study." Finally, the articles were searched on Scopus, ScienceDirect, and Web of Science that are the databases most used in the business and engineering management disciplines (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018, 2020).

Moreover, taking into consideration the evolving of research and number of publications on Industry 4.0 (Wagire et al., 2019), we focused the analysis on articles (only published articles and not conference proceedings and book chapters) published starting from 2016. As result of this first step of the review process, 251 articles were found. A following analysis of the titles and abstracts of the papers identified enabled a selection of 60 articles excluding those that were incompatible with the research criteria and purposes. A final full-text analysis of the 60 papers selected made it possible to focus the review of empirical studies on 50 articles that enable us to answer the research questions and highlight the role of knowledge in the Industry 4.0 paradigm. Consistently with our theoretical premises, we focused on the studies that investigated the adoption and use of a set or a specific group (i.e., data-driven technologies) of enabling technologies rather than one single technology (i.e., big data or additive manufacturing or IoT, etc. might be explored in future research).

3.1 Results and Discussion

The analysis of the paper selected focused on the implementation of Industry 4.0 technologies and on the relationship with knowledge management. Specifically, we aimed to analyze the empirical studies highlighting the key role of knowledge in the successful implementation of the Industry 4.0 paradigm. In doing so, we focused on the drivers and barriers of the Industry 4.0 adoption as well as on the (economic and organizational) benefits of the new technologies implementation, trying to understand the role of knowledge (sources, value, and management) from the viewpoint of business and production *processes*, *products* and related services, and internal (human resources) and external (suppliers and customers) *people* involved with the new technologies (Cepeda Carrión, Luis Galán González, & Leal, 2004; Santos et al., 2017). Before the presentation of the results of analysis referred to the processes, products, and the people dimensions of Industry 4.0 and knowledge management relationships, Table 2 summarizes the papers analyzed from the viewpoint of technologies, country, research method (qualitative and quantitative), topic, and main findings.

Firstly, Table 2 shows that the number of empirical studies started to grow significantly since 2018. In particular, in the last 2 years the number of surveys has grown significantly. Germany, Italy, and Brazil are the most active countries in terms of empirical studies carried out to explore the phenomenon of Industry 4.0. After a first understanding of the drivers, barriers, and challengers (Feng et al., 2017; Kiel, Müller, Arnold, & Voigt, 2017; Prause & Atari, 2017) related to the new technological revolution and to the implementation patterns, research focused on the

Table 2 Overview of the empirical studies analyzed

Year	Author(s)	Technologies	Country	Method		Drivers-Barriers	Benefits	Process	Product	People	Main findings
				Quali	*Quanti*						
2020	Büchi et al.	Industry 4.0 technologies	Italy		x		x	x	x	x	Integrating industrial automation systems both vertically and horizontally facilitates production processes and knowledge and skills exchange improving production process and outcomes
2020	Kamble et al.	Industry 4.0 technologies	India		x	x	x	x			Industry 4.0 affects sustainable organizational performance (SOP) and lean manufacturing practices (LMP) Lack of competency is an organizational challenge
2020	Moeuf et al.	Industry 4.0 technologies	International	x		x		x		x	Lack of technological and strategical expertise is the main barrier. Training, data management, and exploitation are the main critical success factors
2020	Tortorella et al.	Cloud IoT Big data and analytics	Brazil		x		x	x		x	Organizational capabilities positively mediate the impact of I4.0 for achieving higher operational performance

(continued)

Table 2 (continued)

Year	Author(s)	Technologies	Country	Method		Drivers-Barriers	Benefits	Process	Product	People	Main findings
				Quali	*Quanti*						
2019	Agostini and Filippini	Industry 4.0 technologies	Italy		x	x		x		x	Organizational and managerial practices and suppliers/customers technological integration affect the implementation of I4.0 technologies
2019	Agostini and Nosella	Industry 4.0 technologies	Italy Germany Austria Poland Hungary		x	x		x		x	Internal and external social capital, management, and prior investment in advanced manufacturing technologies support the adoption and the intensity of I4.0 technologies
2019	Ardito et al.	Industry 4.0 technologies	International	x			x	x			Key role of I4.0 in terms of information acquisition, storage, and knowledge elaboration for supply chain integration
2019	Arnold and Voigt	IIoT	Germany		x	x				x	Company's top management is one of the main drivers of IIoT implementation
2019	Butschan et al.	IIoT	Germany		x	x				x	High developed cognitive and processual competencies promote the company's digital transformation

2019	Dachs et al.	Industry 4.0 technologies	Austria Germany Switzerland		x		x	x	x	x	Positive relationship between backshoring and I4.0 through increased coordination in production process and integration with suppliers with positive impacts on product customization and time to market
2019	Dalmarco et al.	Industry 4.0 technologies	Portugal	x		x	x	x	x	x	Data management and the integration of new technologies with available ICT are the main challenges New data allow improvements of production process, product quality and services, and business model innovation through the integration with external partners
2019	Frank et al.	Smart manufacturing IoT Cloud Big data and analytics	Brazil		x	x					I40 implementation is affected by three maturity clusters (vertical integration and traceability; automation; flexibilization) with cloud implemented in the first stage; IoT in the second; and big data and analytics in the third stage

(continued)

Table 2 (continued)

Year	Author(s)	Technologies	Country	Method		Drivers-Barriers	Benefits	Process	Product	People	Main findings
				Quali	*Quanti*						
2019	Ghouri and Mani	Industry 4.0 technologies	Malaysia		x		x			x	Positive role of cloud technology and real-time information sharing in enhancement of customer experience
2019	Jerman et al.	Smart factory	Slovenia	x			x	x			Technological transformation encourages the creation of new knowledge that affects organization and business model
2019	Kohnová et al.	Industry 4.0 technologies	Slovakia Czech Republic Austria Germany Switzerland		x	x		x	x	x	Industry 4.0 is affected by external and internal factors, such as the education system, external partnerships, corporate culture, and the new knowledge about processes and new products firms are able to develop and share among workers
2019	Mihardjo et al.	Industry 4.0 technologies	Indonesia		x	x		x		x	Digital capabilities to establish good customer experience and to innovate business model
2019	Mittal et al.	Smart manufacturing Industry 4.0 technologies	International	x		x	x	x		x	SMEs may exploit the benefits of automation improving employee skills and data management

2019a	Müller	Cyber-physical systems	Germany	x		x		x		x	Value proposition, customers, and key activities are the main drivers of Industry 4.0 providers Key partners and customer relationships are the main drivers of Industry 4.0 users
2019b	Müller	IIoT	Germany	x		x	x	x		x	The main potentials of digital platforms on business and production processes depend on coordination and information
2019	Prause	Big data analytics, cloud, IoT Simulation	Japan		x	x					Market complexity, relative advantage, and top management are the main drivers of adoption
2019	Rajput and Singh	Industry 4.0 technologies	International		x	x	x	x			The I4.0 technologies and the data generated enable firms to achieve eco-efficiency, eco-effectiveness, and eco-design optimizing logistics and manufacturing processes
2019	Rauch et al.	Smart manufacturing	Italy USA Austria Thailand	x		x				x	Drivers of adoption refer to organizational practices, human resource, technological asset, and networking. Barriers refer to organizational culture and strategy, and human and financial resources

(continued)

Table 2 (continued)

Year	Author(s)	Technologies	Country	Method		Drivers-Barriers	Benefits	Process	Product	People	Main findings
				Quali	*Quanti*						
2019	Schroeder et al.	IoT Product-use data	UK	x		x	x	x	x		Benefit and opportunities relate to the product-use data provided to the network actors. Lack of digital and data processes capability is the main barrier to I4.0 implementation
2019	Seetharaman et al.	IIoT Big data analytics	India		x	x	x	x			Digitalization and advantages of advanced analytics improve business decisions, performance, and connectivity
2019	Sivathanu	IIoT	India		x	x				x	Digital expertise, infrastructure, relative advantage are the main drivers of adoption
2019	Ślusarczyk et al.	Cyber-physical systems Smart factory	Malaysia		x		x	x	x		I4.0 and data generated affect production processes and activities as well as the development of products-related services
2019	Stentoft and Rajkumar	Industry 4.0 technologies	Denmark		x	x	x	x		x	Customer requirements are the most important drivers of adoption. I4.0 technologies affect the company's globalization strategies and in particular with backshoring

2019	Szalavetz A	Industry 4.0 technologies	International	x		x	x	x	x	x	I4.0 improves production and technological capabilities as well as new knowledge development for products development
2019	Whysall et al.	Industry 4.0 technologies	UK	x		x				x	Industry 4.0 requires changes in talent management practices and the nature of work skill-sets (not only technical knowledge but also networked and collaborative interdisciplinary)
2018	Ardolino et al.	IoT Cloud Data analytics	International	x			x		x		Use of cloud, data analytics, and IoT enables firms to improve product-related services and product customization
2018	Basl	Industry 4.0 technologies	Czech republic		x	x		x	x	x	Customer demands, efficiency, and employee's creativity are the most important motivations of adoption
2018	Bienhaus and Haddud	Big data IoT AI	International		x		x	x		x	Industry 4.0 automatizes buying and other operative activities, supports strategic initiatives driven by humans, and improves buyer–supplier relationships

(continued)

Table 2 (continued)

Year	Author(s)	Technologies	Country	Method		Drivers-Barriers	Benefits	Process	Product	People	Main findings
				Quali	*Quanti*						
2018	Dalenogare et al.	Industry 4.0 technologies	Brazil		x		x	x	x		I4.0 technologies could be (i) product development and (ii) manufacturing with impacts on operation and products. Data technologies are still at a very early stage of adoption
2018	Fettermann et al.	IoT Cloud Augmented reality Data analytics Additive manufacturing	Germany Japan	x			x	x	x		Use of I4.0 technologies allows manufacturing firms to gather data that they use to improve operation performance and products and service development
2018	Lin et al.	Smart manufacturing	China		x	x	x	x			The perceived benefits such as related to the use of advanced production technology affect the adoption as well as several organizational processes
2018	Lugert et al.	Industry 4.0 technologies	International		x		x	x	x		Integration between simulation and lean and the use of data in real time affect production and product development

2018	Müller and Voigt	IIoT Smart factory	Germany China		x	x	x	x		x	IIoT enhances the competitiveness of both German and Chinese firms allowing them to respond to customer requests and reduce production time. Both German and Chinese firms consider partners and suppliers skills very important
2018	Müller, Buliga, et al.	Industry 4.0 technologies	Germany	x			x	x	x	x	Industry 4.0 favors cooperation and new value creation sharing production-related data with suppliers and customers. Servitization by means of data leads to innovative business models
2018	Müller, Kiel, et al.	IIoT	Germany		x	x	x	x		x	Industry 4.0 positively affects operation activities and employee skills are drivers of adoption
2018	Neirotti et al.	Big data IoT Simulation	Italy		x	x				x	Firm size and the environmental conditions (dynamism; complexity; munificence) have a combined effect on the development of capabilities that affect the successful use of I4.0 technologies

(continued)

Table 2 (continued)

Year	Author(s)	Technologies	Country	Method		Drivers-Barriers	Benefits	Process	Product	People	Main findings
				Quali	*Quanti*						
2018	Nagy et al.	Industry 4.0 technologies	Hungary	x	x		x	x	x	x	The huge amounts of data produced by devices, systems, and suppliers and customers support production process, new product development, and all value chain activities
2018	Saniuk and Saniuk	Industry 4.0 technologies	Poland		x	x				x	One of the main barriers of adoption is among others the lack of qualified employment and qualified engineering staff
2018	Schneider	Industry 4.0 technologies	Germany	x		x		x		x	Managerial challenges refer to analysis and strategy; planning and implementation; cooperation and networks; business models; human resources
2018	Tortorella and Fettermann	Industry 4.0 technologies	Brazil		x		x	x			Industry 4.0 and lean practices are positively related; thus knowledge developed for one approach favors the implementation of the other one

2017	Feng et al.	Smart factory	USA	x		x		x		x	Industry 4.0 requires different levels of knowledge for the different technologies and business process companies have to manage
2017	Kiel, Arnold, et al.	IIoT	Germany	x			x	x	x		Data from technologies allow new products, services, the optimization of production systems, and processes, the integration of customers and suppliers into product and service but also the need for appropriate workforce
2017	Kiel, Müller, et al.	IIoT	Germany	x		x	x	x			IIoT enhances production and resource efficiency, and business model innovation Technical integration, organizational transformation, and data security are the most important challenges
2017	Krzywdzinski	Industry 4.0 Automation	Germany Eastern Europe		x	x				x	Automation needs of the introduction of new technological skills to manage processes and new product development

(continued)

Table 2 (continued)

Year	Author(s)	Technologies	Country	Method		Drivers-Barriers	Benefits	Process	Product	People	Main findings
				Quali	*Quanti*						
2017	Prause and Atari	Industry 4.0 technologies	Germany North-Eastern Europe	x		x	x				Industry 4.0 needs of a successful networked approach with agile and responsive supply chain structures and dynamic capabilities
2016	Arnold et al.	IIoT	Germany	x			x	x		x	The production automation requires qualified workforce and key partner networks to the benefit of operation efficiency

Note: Studies are listed *per* year and alphabetic order. Industry 4.0 technologies refer to the main enabling technologies effects of the new technologies on business processes and strategies (Dalenogare et al., 2018; Kamble, Gunasekaran, & Dhone, 2020; Tortorella, Msc Cawley Vergara, Garza-Reyesc, & Sawhneyd, 2020). Scholars focused the attention on the impacts on production processes and operation performance highlighting the effects on efficiency, productivity, and flexibility (Kiel, Arnold, et al., 2017; Müller, Kiel, & Voigt, 2018; Rajput & Singh, 2019), but also on the international production strategies (Dachs, Kinkel, & Jäger, 2019; Stentoft & Rajkumar, 2019). Moreover, scholars analyzed the role of external interactions with suppliers and customers and the integration with them for the development and sustaining of competitive advantage (Agostini & Filippini, 2019; Frank, Dalenogare, & Ayala, 2019; Ghouri & Mani, 2019; Müller, 2019a). Finally, in addition to the relevance in terms of business advances, the empirical studies aimed at understanding the key role of digital skills and capabilities as drivers of adoption and as a necessary condition to get benefits from the use of new technologies (Büchi et al., 2020; Mittal et al., 2019).

In this new technological scenario, data and the new knowledge they allow to create assume a key role for the successful implementation of Industry 4.0 (Dalmarco, Ramalho, Barros, & Soares, 2019; Ferraris, Mazzoleni, & Devalle, 2019; Jerman, Erenda, & Bertoncelj, 2019). Specifically, some specific technologies such as data technologies (IoT, big data, cloud, AI) enable manufacturing companies to create new knowledge that can be used to improve processes, product, and services (Ardolino et al., 2018; Kiel, Arnold, & Voigt, 2017; Seetharaman, Patwa, Saravanan, & Sharma, 2019). New knowledge can also come from external source and, in this case, depends on the interactions with suppliers and customers (Müller, Buliga, et al., 2018; Nagy, Oláh, Erdei, Máté, & Popp, 2018). New knowledge is needed to manage new technologies; indeed, digital skills and capabilities are the most important challenges companies need to face (Schroeder, Ziaee Bigdeli, Galera Zarco, & Baines, 2019; Sivathanu, 2019; Szalavetz, 2019).

For the research purposes, we considered the relationships between Industry 4.0 and knowledge management from the viewpoints of three main domains. Firstly, we considered the organizational *processes*, as the new technologies need to rethink how the organization operates. Secondly, we considered the *products*, as the new technologies enable the development of new customized products and related services. Finally, we focused on *people*, as the new technologies allow the development of new ways of interactions with suppliers and customers but mainly require new skills and competences.

3.2 *Industry 4.0 and Knowledge Management for Processes*

The concept of Industry 4.0 and the transformation of industrial production were born with the aim of facing global competition and of adapting manufacturing to the ever-changing market requests. These requirements fostered radical advances in current manufacturing processes introducing new technologies such as autonomous robots, additive manufacturing, advanced manufacturing technologies, and simulation, which allow firms to be more competitive in terms of efficiency and productivity (Rojko, 2017). However, Industry 4.0 is a more complex approach based on integration of the business and manufacturing processes and integration of all actors along the value chain (suppliers and customers). In this sense, data and new knowledge are essential to improve all business processes (Agrawal, Schaefer, & Funke, 2018).

The analysis of empirical studies reported in the Table 2 confirms the key value of knowledge coming from data for the improvement of business processes. The main potentials of digital transformation on business and production processes depend on coordination and information (Müller, 2019b). The new knowledge related to the use of new technologies affects several processes (Lin et al., 2018) starting from operation performance as well as the products and service development (Dalenogare et al., 2018; Fettemann et al., 2018). To achieve different benefits, company needs different levels of knowledge related to the different technologies and business process they have to manage (Feng et al., 2017). In this sense, empirical research shows that knowledge developed within the Industry 4.0 paradigm as well as the use of data in real time affects other production approaches such as lean (and vice versa) (Lugert et al., 2018; Tortorella & Fettermann, 2018). New technologies positively affect operation activities, and employee skills are drivers for adoption (Müller, Kiel, et al., 2018), but also the supply chain integration, favored by the opportunity of higher data acquisition, storage, and knowledge elaboration (Ardito et al., 2019). Empirical research also shows the key role of data for the internationalization strategies and, in particular, for the backshoring of production activities performed abroad by means of increased coordination in production process and integration with suppliers, with positive impacts on product customization and time-to-market response (Dachs et al., 2019; Stentoft & Rajkumar, 2019).

More broadly, the technological transformation boosts the creation of new knowledge that improves decision-making process (Seetharaman et al., 2019) and affects both organization processes and business model (Jerman et al., 2019). Data from technologies allow the optimization of production systems and processes, the development of new products, services, and the integration of customers and suppliers into product and services, but also the need for appropriate workforce (Kiel, Arnold, et al., 2017; Kiel, Müller, et al., 2017).

3.3 Industry 4.0 and Knowledge Management for Product

Digital transformation aims at automating the manufacturing processes, improving productivity and production efficiency (Holmström, Holweg, Khajavi, & Partanen, 2016) and, at the same time, satisfying the dynamic customer requests through higher product and service personalization (Wang, Hai-Shu Ma, Yang, & Wang, 2017). Knowledge from customers created by means of new interaction ways and the use of smart products (Porter & Heppelmann, 2014) becomes a strategic data source that firms may use to deliver tailored products and services to the market.

Specific industry 4.0 technologies, such as additive manufacturing, allow firms to improve the participation of customers in the design and production processes (Acharya, Singh, Pereirac, & Singh, 2018).

Past empirical studies stress the role of new technologies and of customers on data gathering and on new products and services development (Ślusarczyk et al., 2019). In addition to customers, also interactions and integration with suppliers allow companies developing new products by means of new knowledge created with them (Kiel, Arnold, et al., 2017). The huge amounts of data produced by devices, systems, and suppliers and customers support production process and product quality as well as all the related services (Dalmarco et al. 2019; Nagy et al., 2018). Indeed, Industry 4.0 enables cooperation and new value creation process through the sharing of production-related data with suppliers and customers. Use of cloud, big data and analytics, and IoT enable firms to improve product-related services and product customization (Ardolino et al., 2018). Therefore, products and services are highly influenced by this new industrial paradigm. Products become more complex, modular, and configurable supporting mass customization to meet specific customer needs. Hence, Industry 4.0 is characterized by innovation and introduction of new products and services as embedded systems based on knowledge created along the value chain (Fettermann, Gobbo Sá Cavalcante, & Domingues de Almeida Tortorella, 2018).

The servitization strategy usually shows lack of knowledge regarding the service offering associated with their manufactured products; thus, acquiring external knowledge from suppliers and customers can be a way to tackle this problem. The service-oriented approach by means of data and new knowledge leads to new business models (Müller, Buliga, et al., 2018). In this case, the main sources of knowledge are both the new technologies and the interactions with the suppliers and customers and the benefits of data depend on digital and data processes capabilities that are, as for the processes, the main challenge companies need to face (Schroeder et al., 2019).

3.4 Industry 4.0 and Knowledge Management for and from People

Manufacturing companies approaching the Industry 4.0 revolution need to consider the human resources as strategically essential to benefit effectively from new technologies and knowledge they allow to create. The fourth industrial revolution is strategically driven by creative and open-minded people, rather than on technology itself (Ramzi et al., 2018). The new disruptive technologies such as big data, artificial intelligence, and cloud computing are penetrating all manufacturing industries and others bringing together the physical and virtual worlds with higher interconnections inside and beyond the company's boundaries. This new digital scenario needs humans both in terms of interactions with external environment and of upgraded competences to manage technologies, data, and knowledge (Agolla, 2018).

Empirical studies stressed the strategic role of people for the success of Industry 4.0 and for the exploitation of benefits connected to the new technologies. People are considered both as a driver of adoption (Arnold & Voigt, 2019) and as an enabler for the business processes improvements and the achievement of company' strategic goals (Tortorella et al., 2020). Indeed, several studies highlight the digital skills and competences as one of the main challenges of Industry 4.0. High-developed cognitive and processual competencies promote the company's digital transformation (Butschan et al., 2019). Lack of technological expertise (Rauch et al., 2019), qualified employment and qualified engineering staff (Saniuk & Saniuk, 2018), data management skills (Müller, Kiel, et al., 2018; Schroeder et al., 2019), and new technological skills to manage processes and new product development (Krzywdzinski, 2017) are the main critical success factors (Mihardjo et al., 2019; Sivathanu, 2019). In this case, new knowledge is needed to manage digital transformation; thus, companies should support the creation of new skills and competences through different ways, such as training (Mittal et al., 2019) and interactions among works of internal departments (Kohnová et al., 2019).

In addition to organizational and managerial digital practices and capabilities also the horizontal and vertical integrations affect the implementation of Industry 4.0 technologies (Agostini & Filippini, 2019; Bienhaus & Haddud, 2018) facilitating the creation and sharing of knowledge with positive effects on production process and products (Buchi et al., 2020). Data management coming from the integration of new technologies with both company and partner's technological endowment allows improvements of production process (with effects also on backshoring strategies), product quality, servitization, and business model innovation (Dachs et al., 2019; Dalmarco et al., 2019; Jerman et al., 2019).

New technologies have a positive role also in enhancing the customer experience basing on the real-time information sharing (Ghouri & Mani, 2019). Customers are the other essential factor of Industry 4.0. They are precious source of knowledge to personalize products and services (Müller, Buliga, et al., 2018), but also have a key role for the innovation of business model (Kohnová et al., 2019), and thus they are seen as drivers of Industry 4.0 implementation (Moeuf et al., 2020; Müller, 2019a).

People are the most important factor from the viewpoint of knowledge creation and management in the Industry 4.0 paradigm. This new technological approach 4.0 requires changes in talent management practices and the nature of work skill-sets (technical knowledge, networked and collaborative skills, and interdisciplinary skills) (Whysall et al., 2019). The manufacturing digitalization requires qualified workforce and key partners to benefit from operation and marketing opportunities (Arnold & Voigt, 2019; Paruse, 2019).

4 Conclusion

Manufacturing companies approach Industry 4.0 as part of the overall firm strategy (Kane, Palmer, Phillips, Kiron, & Buckley, 2015). Firms adopt new technologies because they expect to improve business processes (operation, marketing, internationalization, value chain, etc.) and sustain their competitive position (Bharadwaj, El Sawy, Pavlou, & Venkatraman, 2013). In the Industry 4.0 paradigm, knowledge assumes a key role as both driver and enabler affecting the decision to implement the Industry 4.0 technologies (Wilkesmann & Wilkesmann, 2018). In this sense, Industry 4.0 is a data-driven paradigm because it enables better use of data produced by technologies and also by interactions along the value chain to create more value (Klingenberg et al., 2019). Not surprisingly, many Industry 4.0 technologies are in some way related to data (named data-driven technologies), which enable successful acquisition of useful data, but also other technologies more related to operation activities depend on data gathered within and outside the firm boundaries. Indeed, the achievements of production and/or marketing outcomes through the digital technologies are linked to the creation of new knowledge for both production and product improvements (Lee, Davari, Singh, & Pandhare, 2018). Thus, the decision-making process in the Industry 4.0 and smart manufacturing systems requires information and knowledge, which can be mined from large amounts of production data (Tao et al., 2018).

The review of empirical studies about the adoption of Industry 4.0 technologies allows us a better understanding of the role of knowledge in the fourth industrial revolution. Firstly, we need to specify that Industry 4.0 is a knowledge-based approach and that knowledge coming from different sources, from the use of new technologies and, thus, from internal processes, but also from the interactions with suppliers and customers. In this case, company should have internally the right digital competences to manage successfully the data gathered, but also to create and manage new knowledge to improve business processes. Digital skills and competences are the most important variable of the relationship between Industry 4.0 and knowledge management because of their strategic role in achieving the business goals (Ferraris et al., 2019) and improving decision process (He, Wang, & Akula, 2017) and firm strategy (Xu, Frankwick, & Ramirez, 2016).

Theoretically, the review of empirical studies allows us to advance the literature on the relationship between Industry 4.0 and knowledge management stressing the holistic role of knowledge in the new digital revolution. The new technologies allow manufacturing companies to improve business processes and customize products and services through data and the new knowledge they are able to generate. The creation of new knowledge depends both on the use of new technologies and on the interactions along the value chain (suppliers and customers). However, the achievement of business benefits strictly depends on human resources and, more specifically, on digital skills and competences. From this perspective, manufacturing companies that approach the Industry 4.0 paradigm should consider such new technologies as new tools that enable new knowledge creation; therefore, they should give attention to the digital skills and competences needed to manage this technological transformation, fostering internal competence upgrading.

The chapter gives some hints about the future directions. Future research should consider the role of firm strategy (in terms of data-driven products/services and human resource) on knowledge management. In particular, more papers (such as conference proceedings and book chapters) from different disciplines would be considered for an overall understanding of the topic.

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