Industry 4.0: Critical Investigations and Synthesis of Key Findings

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Abstract

The concept of Industry 4.0 has been one of the most debated and trending topics over the last few years. Progressively, it has attracted the attention of academicians, practitioners, and policymakers worldwide. However, there needs to be more systematic review of research in the current literature that captures the current state of this new paradigm. This study aims to address this gap by conducting a comprehensive review of Industry 4.0 previous studies to identify its technological, organisational, and managerial enablers, as well as its implementation challenges and benefits. A systematic literature review was conducted, in which 244 peer-reviewed journal papers were analysed in the Scopus database until the end of May 2022. This study excluded conference papers, book chapters, and journal papers not written in English. The study indicated that industry 4.0 is still an immature topic, and applying this new paradigm is not a matter of technology only. Organisational and managerial aspects should be considered. Additionally, the transition towards Industry 4.0 is a complex task, many obstacles exist, and manufacturing companies should be aware of these challenges for successfully implementing this new paradigm. The obtained results in this study synthesise recent studies published on Industry 4.0 and provide a comprehensive picture of Industry 4.0 and potential research directions for future research. Also, this study offers significant guidelines for managers interested in implementing Industry 4.0.

Keywords Industry 4.0, Digitisation, Review, Fourth Industrial Revolution

1. Introduction

Manufacturing is not anymore about the production of physical products. The manufacturing environment is becoming more complex and dynamic and is characterised by many challenges that significantly affect manufacturing companies. Among these challenges are the growing levels of competition, labour market changes, technological innovation, scarcity of resources, and rapidly changing customer requirements and demands (Bibby & Dehe, 2018a; Fatorachian & Kazemi, 2018a; Gajsek et al., 2019; Weking et al., 2020). To respond to these challenges, manufacturing companies strive to implement new solutions to survive and stay competitive. One of the most accepted approaches among manufacturing companies in the last few years to cope with the radical changes is Industry 4.0.

It is commonly agreed among scholars and practitioners that three previous industrial revolutions throughout history occurred since the 18th century. The term Industry 4.0 is often referred to as the fourth industrial revolution. It is considered one of the most popular worldwide topics in the last few years among researchers, manufacturing companies, and governments due to its numerous benefits (Klingenberg et al., 2019; Sunil Luthra & Mangla, 2018; Mourtzis et al., 2021; Pagliosa et al., 2019).

The term Industry 4.0, commonly seen by many authors as the fourth industrial revolution, was first introduced in November 2011 by the German government at the Hanover Trade Fair, where this concept was born and known as "Industrie 4.0" (Aceto et al., 2019; Dalenogare et al., 2018; Ghobakhloo, 2018; Horváth & Szabó, 2019; Núñez-Merino et al., 2022; Plawgo & Ertman, 2021). Since then, Industry 4.0 has progressively attracted the attention of many other governments worldwide. These governments started developing local programs to implement this new approach (Dalenogare et al., 2018; Ghobakhloo, 2018). Thus, many other similar concepts to Industry 4.0 have also been introduced (Črešnar, Potočan, Nedelko, et al., 2020; Kiel et al., 2017a).

Despite the popularity of Industry 4.0 and the increasing number of research conducted in this domain in the last three years, there is no precise and generally accepted definition of Industry 4.0 among researchers (Fettermann et al., 2018; Fratocchi & Di Stefano, 2020; Ivanov et al., 2019a; Klingenberg et al., 2019; Lu, 2017a; Piccarozzi et al., 2018a; Schneider, 2018a).

Technology is a fundamental component in this new paradigm. The transition towards Industry 4.0 includes many technologies, such as the Internet of Things (IoT), Cyber-Physical Systems (CPS), Cloud Computing, Big Data, autonomous robotics, augmented reality, and many other technologies (Alcácer & Cruz-Machado, 2019a; Bibby & Dehe, 2018b; Dalmarco et al., 2019a; Fatorachian & Kazemi, 2018b; Ghobakhloo, 2018; Moeuf et al., 2018a; Moktadir et al., 2018a; Schniederjans et al., 2020). Many scholars and experts have investigated Industry 4.0 technological enablers, and numerous technologies have been mentioned. However, these technologies do not always match, and it is not easy to determine the most relevant technologies for implementing Industry 4.0 (Klingenberg et al., 2019).

While most scholars have investigated the technological enablers of Industry 4.0, few studies have considered the organisational and managerial enablers of Industry 4.0 (Kiel et al., 2017b; Oesterreich & Teuteberg, 2016a; Rodríguez-Espíndola et al., 2022; Schneider, 2018b; Somohano-Rodríguez & Madrid-Guijarro, 2022). However, modern technology is a central element in this new paradigm; Industry 4.0 cannot be limited only to the sum of technologies.

Although the implementation of Industry 4.0 has been recognised as providing manufacturing companies with many benefits, its practices are a challenging task. Manufacturing companies must overcome many barriers to get the expected gains from Industry 4.0. The transition towards Industry 4.0 requires significant modifications in the organisation's strategy, management, workforce, and culture. These organisational and managerial aspects must be considered and investigated (Frank et al., 2019; Moktadir et al., 2018b; Müller et al., 2018a; Prause, 2019).

The Industry 4.0 concept is still in the introductory phase, and its literature review studies remain limited (Bibby & Dehe, 2018b). There is no clear, comprehensive view for manufacturing companies about the technological, organisational, and managerial enablers and the benefits and challenges of this new paradigm (Müller et al., 2018b). Thus, a comprehensive analysis and investigation covering all the factors related to Industry 4.0 are necessary (Kiel et al., 2017b; Schneider, 2018b; Xu et al., 2018a).

Consequently, this study aims to fill this research gap by offering a comprehensive picture of Industry 4.0 through a systematic review to identify the main technological, organisational, and managerial enablers that are fundamental for its implementation, as well as to determine the expected benefits and barriers of adopting this new approach in order to provide a practical guide for the manufacturing organisations to adopt and implement Industry 4.0 practices successfully.

2. Other related concepts to Industry 4.0

In the last few years, many concepts used interchangeably and partially overlap with Industry 4.0 have emerged among researchers (Aceto et al., 2019). These concepts have some differences, and they should not be used synonymously. Moreover, some of these concepts emerged and were used by researchers before the introduction of Industry 4.0 (Klingenberg et al., 2019; Schneider, 2018b).

Some of these concepts are collected from previous studies and presented in this section according to their levels of popularity expressed in terms of the number of publications (exact match in the title) in the last six years using the Scopus database, as presented in Figure 1. It is evident that the term Industry 4.0 is the most used and accepted concept among researchers in their publications in the last six years, as shown in Table I.

2.1. Smart manufacturing

According to the National Institute of Standards and Technology (NIST), smart manufacturing, also called intelligent manufacturing (Grabowska, 2020) and can be defined as "fully-integrated, collaborative manufacturing systems that respond in real-time to meet changing demands and conditions in the factory, in the supply network, and customer needs" (Moghaddam et al., 2018).

Smart manufacturing can be considered to integrate manufacturing technologies and advanced information technologies to optimise manufacturing operations to meet the dynamic market (Horváth & Szabó, 2019; Xu et al., 2018; Zhong et al., 2017). The main focus of smart manufacturing is the manufacturing operation itself, particularly the shop floor. Thus, Industry 4.0 can be considered a broader concept, and smart manufacturing is a part (Gastaldi et al., 2022; Thoben et al., 2017).

2.2. Cloud manufacturing

Cloud manufacturing is a new manufacturing service-oriented model that is based on cloud computing technology to enhance manufacturing systems via transforming and sharing manufacturing resources over cloud platform from all the stages of the product lifecycle to provide on-demand services to customers (Alcácer & Cruz-Machado, 2019b; Bongomin et al., 2020; Fisher et al., 2018; Liu et al., 2019; Zhong et al., 2017). Cloud manufacturing "covers the extended whole life cycle of a product, from its design, simulation, manufacturing, testing, and maintenance" (Zhong et al., 2017). Thus, cloud manufacturing can be seen as a tool that can be used to implement Industry 4.0.

2.3. Industrial Internet of Things (IIoT)

Industrial Internet of Things (IIoT) is the application of Internet of Things (IoT) technologies in industrial production (Boyes et al., 2018; Kiel et al., 2017b). Many authors consider IIoT as equivalent to Industry 4.0. However, according to (Piccarozzi et al., 2018), Industry 4.0 is a more complex concept, and IoT is only one of the technological enablers used during the implementation of Industry 4.0(Radanliev et al., 2020).

2.4. Smart factory

A smart factory is considered to be one of the critical elements of Industry 4.0 (Alcácer & Cruz-Machado, 2019b; Grabowska, 2020), according to which the production processes are highly digitalised, and production facilities, machines, and logistic systems are connected and self-managed without human intervention (Kamble, Gunasekaran, & Gawankar, 2018a; Rejikumar et al., 2019a). Smart factory can be considered one of the outputs that manufacturing companies will realise from Industry 4.0 in the manufacturing processes.

2.5. Advanced manufacturing

Advanced manufacturing is the application of the most recent innovative technologies such as computer-aided manufacturing (CAM), computer-aided engineering (CAE), computer-aided design (CAD), robotics, and automated storage and retrieval systems by manufacturing companies to improve products and/or manufacturing processes (Ardito et al., 2019a). Thus, the central point of advanced manufacturing is utilising the latest technological advancements (Culot et al., 2020).

2.6. Cyber-Physical Production System (CPPS)

Simply, CPPS refers to the use of CPS in the manufacturing processes (Cardin, 2019). CPPS is a system of "autonomous and cooperative elements and subsystems that are connected based on the context within and across all levels of production, from processes through machines up to production and logistics networks" (Szász, 2020).

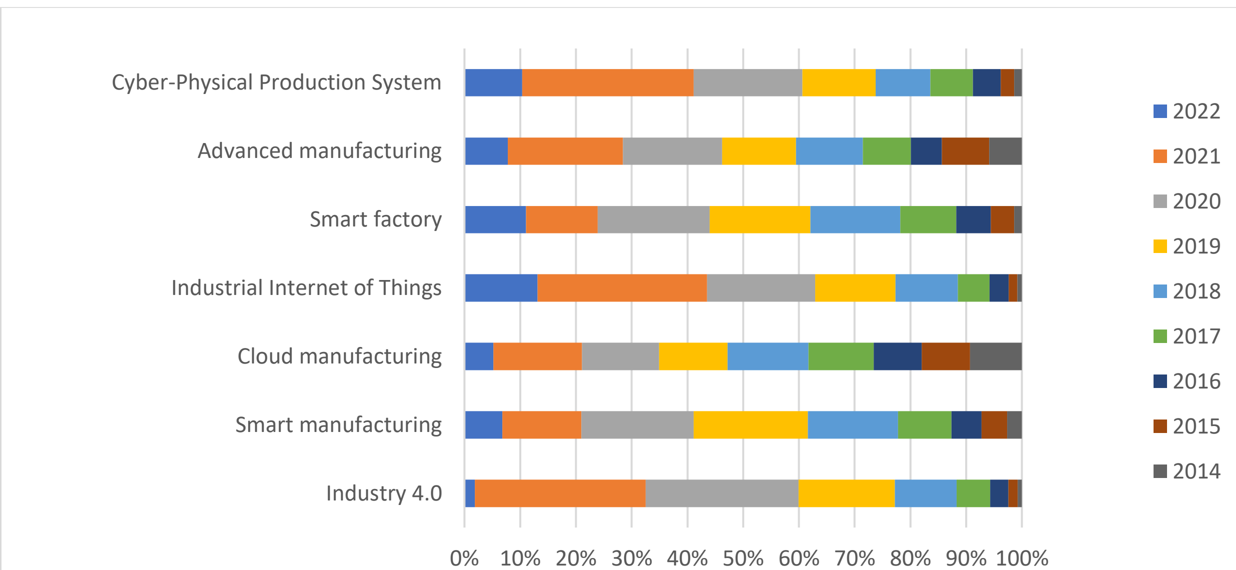

Figure 1. Popularity of Industry 4.0 and other related concepts based on the number of publications of each concept in the last seven years. Extracted from the Scopus database using exact match in the title

	Till May 2022	2021	2020	2019	2018	2017	2016	2015	2014	Total
Industry 4.0	132	2153	1929	1215	779	423	227	117	55	**7030**
Smart manufacturing	92	192	273	278	219	130	73	62	36	**1355**
Cloud manufacturing	45	137	119	106	125	101	74	75	80	**862**
Industrial Internet of Things	167	387	247	183	143	72	44	20	10	**1273**
Smart factory	89	104	162	146	130	81	50	34	11	**807**
Advanced manufacturing	56	148	128	95	86	62	40	61	42	**718**
Cyber-Physical Production System	60	178	113	76	57	44	29	14	8	**579**

Table I. Popularity of Industry 4.0 and other related concepts based on the number of publications of each concept in the last eight years. Extracted from the Scopus database using exact match in the title

3. Research Methodology

Although the concept of Industry 4.0 is still an emerging topic introduced in 2011, it is currently an exciting topic that has attracted the attention of many researchers, companies, and governments. Nevertheless, according to (Ghobakhloo, 2018), the term lacks a clear consensus definition among researchers, and there is a disagreement among companies on its main enablers and how to implement them successfully. Thus, in this research, a systematic review is used as a research methodology to offer a clear understanding and provide directions in an emerging topic like Industry 4.0 by collecting, evaluating, and discussing contributions of all relevant sources.

A systematic review is a comprehensive research methodology that is used to build a solid view on a specific topic of interest by determining relevant studies, summarising state of the art, identifying possible research gaps and future research directions (Aiassa et al., 2015; Jones & Gatrell, 2014; Tranfield et al., 2003). Hence, a systematic review is a valuable and explicit tool that can be reproduced to strengthen the topic of interest by providing extensive coverage of the literature. Additionally, it is a methodology that many researchers in different disciplines use to collect and evaluate the findings from multiple studies. The same method was selected and applied as a research methodology for the present study for the previously mentioned reasons.

A six-step review methodology was applied to guarantee transparency and replicability in the research as presented in Figure 2, adapted from (Kamble, Gunasekaran, & Gawankar, 2018a; Schneider, 2018b). This research process will identify four search parameters related to four questions: what, where, when, and how to look for papers (Klingenberg et al., 2019) as presented in Table II.

What	Where	When	How
Industry 4.0	Scopus database	From any date up to the end of May 2022	Title, Abstract, Keywords

Table II. Search parameters

3.1. Selection of database

The search strategy was developed by identifying the scientific database used to extract the academic publications and documents. The publisher Elsevier, founded and owned the Scopus database, was selected to retrieve the main academic papers. The Scopus database includes all publications that already exist in any other databases (Rajput & Singh, 2019a), where data covered in the Scopus databases are more significant and more extensive than the Web of Science database by approximately 60% (Mariani & Borghi, 2019). Additionally, to conduct a literature analysis, the Scopus database was recommended by many authors as the most comprehensive and reliable source of data (Rajput & Singh, 2019b).

3.2. Keyword selection

Even though many other concepts partially overlap and are used as synonyms for Industry 4.0 like smart manufacturing, Industrial Internet of Things (IIoT), Cyber-Physical Production System (CPPS), smart factory as mentioned in the previous section, only one term, "Industry 4.0" was selected to conduct the research.

Selecting Industry 4.0 as a keyword because it is the most commonly used term among researchers in the scientific community in the last six years, as mentioned in Table I. Moreover, some of these concepts emerged and were used by researchers before the introduction of Industry 4.0 (Klingenberg et al., 2019; Schneider, 2018b). Thus, Industry 4.0 was searched for in the Scopus database's title, abstract, and keywords. The period defined for this study was from any date up to the end of May 2022.

3.3. Collection of articles

The outcome of the first search query resulted in a total of 9359 publications. Most of the publications were in engineering, computer science, business, management, and accounting. Additionally, 59.5% of the articles were published in conferences, while only 30.4% of the documents were published in journals.

3.4. Filtering (inclusion/exclusion)

This stage aims to refine the results obtained from the previous stage. Documents were selected using the following filters: conference papers, book chapters, editorial notes, etc., were excluded. Also, papers written in non-English languages and papers not relevant to the aim of the current study were excluded. Only peer-reviewed articles were included in this research as a trusted source of knowledge. After applying the inclusion and exclusion criteria, the total number of articles dropped to 998.

3.5. Analysing

The 998 papers collected from the previous stage were analysed during this phase by reading the titles, keywords, and abstracts. As the criteria of inclusion/exclusion was previously determined in the previous step, 754 papers were excluded because they were irrelevant and did not match this research's objectives. This stage helped determine only 244 relevant papers that will be investigated and analysed to elaborate the review.

3.6. Synthesising

At this stage, the full text of the remaining papers was read in detail to be analysed and synthesised. The results will be presented in the following sections.

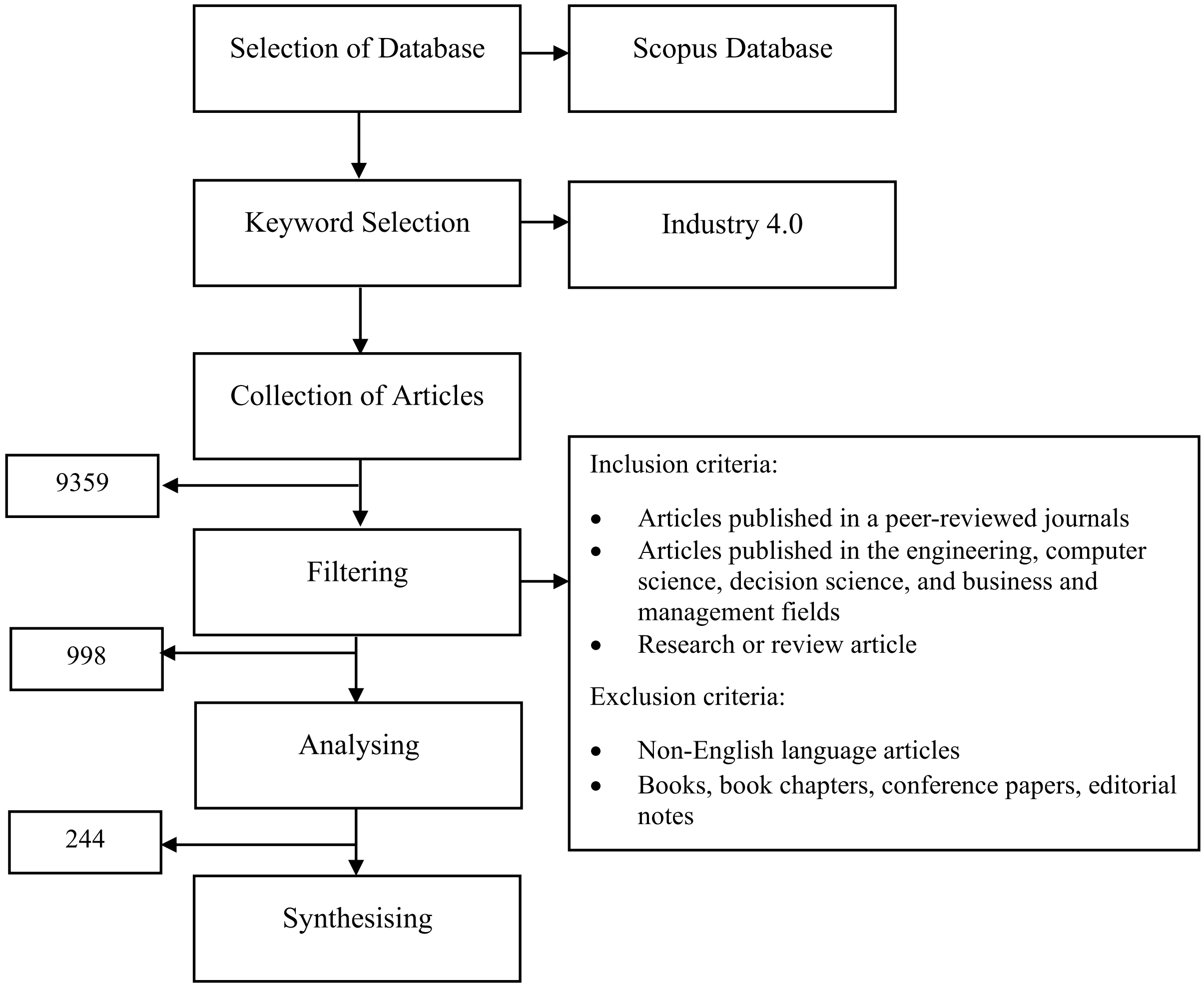

Figure 2. Research process

4. Results and discussion

In this section, all the results obtained from the comprehensive literature review and presented and discussed. This section covers most of the key aspects related to Industry 4.0. The main principles of Industry 4.0, the technological, organisational, and managerial enablers of Industry 4.0, are demonstrated in this section. Additionally, the benefits and challenges of Industry 4.0 are highlighted.

According to (Pacchini et al., 2019), Industry 4.0 is "a set of disruptive digital and physical technologies that offer new values and services to customers and organisations". Also, Industry 4.0 can be considered "a group of technologies and concepts that establish real-time interconnection and communication among people, equipment and products" (Pagliosa et al., 2019). (Rejikumar et al., 2019) defined Industry 4.0 as "a structure that relies upon integrating the vertical and flat esteem chains, the digitalisation of administrations and items, and introduction of inventive models for business". (Bibby & Dehe, 2018) stated that Industry 4.0 is "the physical digitalisation of all assets within an organisation to create a connected infrastructure combined with partners leading to create an e-value chain".

To sum up, Industry 4.0 represents a manufacturing philosophy that includes the application of digital technologies in the internal and external manufacturing operations in a way that enables a real-time integration (vertical, horizontal, end-to-end) among all participants of the value chain to enhance operations and improve competitiveness (Ardito et al., 2019; Fatorachian & Kazemi, 2018; Kamble, Gunasekaran, & Gawankar, 2018; Moeuf et al., 2018; Sony & Naik, 2019).

4.1. Industry 4.0 key principles

The key principles and features of Industry 4.0 will enable manufacturing companies to investigate the transition towards Industry 4.0. Moreover, these principles characterise the Industry from any other initiatives. The following are the main principles:

4.1.1. Interoperability

Interoperability can be defined as "the capability of systems to transact with other systems" (Ghobakhloo, 2018). Interoperability is related to the ability of the elements and everything of the Industry (devices, machines, people, object) to communicate, collaborate, and operate with each other through IoT to share and exchange information and data (Ghobakhloo, 2018; Klingenberg et al., 2019; Lu, 2017b; Wankhede & Vinodh, 2021).

4.1.2. Virtualisation (Information transparency) (virtual entities)

Virtualisation is the process of creating a digital and simulation-based model using data collected from the sensors in the real world to create a virtual copy of the physical world (Ghobakhloo, 2018; Kamble, Gunasekaran, & Gawankar, 2018a; Rejikumar et al., 2019a). So, the physical world is linked to the digital world, and a virtual copy of everything is created. Virtualisation enhances maintenance by identifying systems failure without human interventions, which improve production lines productivity.

4.1.3. Real-time capacity

Real-time capacity is not only the ability to collect data immediately from different sources about machines, products, suppliers, and customers but also the ability to analyse the data and make prompt decisions according to the surrounding environmental changes (Baroroh et al., 2021; Ghobakhloo, 2018; Kamble, Gunasekaran, & Gawankar, 2018a; Rejikumar et al., 2019a). Real-time capacity will significantly impact organisations' flexibility and reactions to new findings in an instant manner.

4.1.4. Service orientation

Service orientation is the ability of all the integrated and connected elements of the system to quickly react to changes in the market and customers' demands. Thus, companies can be customer-oriented to produce bespoke and customised products and services that add value to customers and introduce new services models (Kamble, Gunasekaran, & Gawankar, 2018a; Schiavone et al., 2022).

4.1.5. Modularity

Modularity is the manufacturing system flexibility to adapt smoothly and quickly to dynamic market requirements by substituting or expanding individual modules. Modularity can be considered a shift from the rigid and linear manufacturing system towards a modular and agile system (Ghobakhloo, 2018; Kamble, Gunasekaran, & Gawankar, 2018a; Rejikumar et al., 2019a).

4.1.6. Decentralisation

Decentralisation creates a self-organised system in which the system's components (companies, machines, people) work independently and autonomously. Thus, this system will gather and process information and make the required decisions. Decentralisation will enable organisations to be flexible to produce customised products and improve their decisions and problem-solving capabilities (Ghobakhloo, 2018; Kamble, Gunasekaran, & Gawankar, 2018a; Lattanzi et al., 2021).

4.1.7. System integration

System integration can be defined as "the process of bringing together the component subsystems into one system in a way the system can deliver the intended functionality" (Ghobakhloo, 2018).

The implementation of Industry 4.0 requires three types of integration. Vertical integration (intra-company) across the various units inside a single organisation, so these units can communicate and coordinate easily to create a smart and intelligent organisational environment (Ghobakhloo, 2018; Santos & Martinho, 2019a; Sony, 2018a). Horizontal integration (intra- and inter) across various organisations over the value chain, either forward or backward, creates a collaborative environment (Konur et al., 2021; Moktadir et al., 2018b; Saucedo-Martínez et al., 2018a). Finally, end-to-end integration across the entire product life cycle creates customised products and services that satisfy customers' needs (Moktadir et al., 2018b; Saucedo-Martínez et al., 2018b; Sony, 2018b).

4.2. Industry 4.0 technological enablers

The utilisation of modern technologies is one of the main features characterising Industry 4.0 from other initiatives. Industry 4.0 is simply "The transformation of organisations to the digital form" (Sony & Naik, 2019b). Thus, technology is a significant component in the transition towards Industry 4.0, and it is necessary to identify the technologies that are primarily associated with the implementation of Industry 4.0.

In this section, the most popular technologies related to Industry 4.0 are collected from literature and discussed. Figure 3 and Table III present the popularity of Industry 4.0 related technologies mentioned in researchers' publications in the last six years based on data gathered from the Scopus database using exact matches in title, abstract, and keywords. An example of a research query is ((TITLE-ABS-KEY ("Industry 4.0") AND TITLE-ABS-KEY("simulation")))

4.2.1. Internet of Things (IoT)

The most frequently used technology in Industry 4.0 is IoT. IoT can be considered the foundation of other Industry 4.0 technologies and contributes to shaping Industry 4.0 (Alaloul et al., 2020; Pagliosa et al., 2019). IoT can be defined as "an inter-networking world in which various objects are embedded with electronic sensors, actuators, or other digital devices so that they can be networked and connected for the purpose of collecting and exchanging data" (Awan et al., 2021; Zhong et al., 2017). It is a collection of everything that is connected to the internet.

IoT provides permanently or intermittently connectivity not only among an infinite number of things, devices, and objects in the network but also among people (Klingenberg et al., 2019), allowing the collection, transmission, accessibility, and ubiquitous of data to coordinate decisions (de Sousa Jabbour et al., 2018a; Ghobakhloo, 2018; Pacchini et al., 2019b). IoT offers connectivity and flexibility to allow a computer system to autonomously sense information without human intervention (Bibby & Dehe, 2018b).

IoT can be achieved through other enabling technologies such as Bar codes, Wireless Sensor Networks (WSN) and Radio Frequency Identification (RFID), Software Defined Networking (SDN) (Alcácer & Cruz-Machado, 2019b; de Sousa Jabbour et al., 2018b).

4.2.2. Cyber-Physical System (CPS)

CPS is considered one of the core technological enablers for Industry 4.0 (Dalmarco et al., 2019b; Fatorachian & Kazemi, 2018b; Xu et al., 2018b; Yıldızbaşı & Ünlü, 2020). CPSs can be defined as "industrial automation systems that are interconnected through communication networks. This interconnection enables the performance of collective operations and the exchange of information between the physical devices and the software infrastructure" (W. Maisiri, H. Darwish, 2020).

CPS merges and intertwines the physical system and the cyber "digital" system, enabling them to interact to swap information; thus, the limits between these two systems evaporate where anything that occurs in any system will impact the other system and vice versa. (Alcácer & Cruz-Machado, 2019b; Fortuny-Santos et al., 2020; Klingenberg et al., 2019; Xu et al., 2018b; Zhong et al., 2017). CPS can be considered the highest degree of integration between the digital and physical systems.

CPS is based on vital technical components such as embedded systems, sensors, and actuators. Embedded systems facilitate the coordination between the physical elements and digital elements. Sensors are used to retrieve, monitor, and report manufacturing process information in real-time to computers. Actuators use the obtained information to control the physical processes and movements (Alcácer & Cruz-Machado, 2019b; Fatorachian & Kazemi, 2021; Kamble, Gunasekaran, & Gawankar, 2018a; Zhong et al., 2017).

CPS increases the availability of real-time information for decision making, enhances communication, coordination, autonomy, and flexibility of the production process, as well as, CPS improves productivity, efficiency, energy consumption, and quality of goods (Dalmarco et al., 2019b; de Sousa Jabbour et al., 2018b; Lu, 2017b).

4.2.3. Cloud

Cloud computing cannot be considered a new technology; however, there is no common definition of cloud computing (Ghobakhloo, 2018). Cloud computing can be considered "the provision of computing capacity and services or storage capacity for distributed storage of the required data" (Stock et al., 2018a).

It is a general term that enables organisations to virtually store, organise, and communicate a vast amount of data and information from different sites across organisation boundaries in an external environment (Osterrieder et al., 2020). Thus, information and data can be accessed independently, remotely, and quickly from any location via the provided storage capacity and high-speed computing (Ardito et al., 2019a; Fatorachian & Kazemi, 2018b; Gaffley & Pelser, 2021; Moktadir et al., 2018b; Pacchini et al., 2019b; Stock et al., 2018b).

Cloud computing can lead to several advantages such as: improving system agility and responsiveness, reducing costs, promoting sustainability as a result of using large virtualised data centres instead of physical storage, and improving collaboration (Aceto et al., 2019; Alcácer & Cruz-Machado, 2019b; Kamble, Gunasekaran, & Gawankar, 2018a).

4.2.4. Simulation

Simulation uses different computer tools and technologies to imitate real manufacturing operations, systems, processes, product design, and factory layout to create virtual testing models and prototypes before converting them to reality (Dalmarco et al., 2019b; Moktadir et al., 2018b; Urban et al., 2020).

The use of simulation improves the feasibility analysis of any new solutions. Additionally, it optimises manufacturing processes and operations by minimising production process downtime, amount of waste, production failure rate, and errors (Moeuf et al., 2018a; Wang et al., 2021).

4.2.5. Big data analytics

Manufacturing companies nowadays are dealing with a massive volume of data from different sources due to the development in the manufacturing industry, and managing and processing these data is considered one of the main challenges for manufacturing companies (Bibby & Dehe, 2018b; Moeuf et al., 2018a; Yıldızbaşı & Ünlü, 2020).

Big data in itself is not a technology, but it is a term that represents a huge volume of structured, unstructured, and semi-structured data obtained from different sources (Alcácer & Cruz-Machado, 2019b; Klingenberg et al., 2019; Pacchini et al., 2019b).

5Vs characterise big data: Volume: (massive data scale that requires large storage capacity), Variety: (numerous data types structured, semi-structured, or unstructured obtained from many sources), Velocity: (speed of collecting and generating data), Veracity: (degree of accuracy and truthfulness of the collected data), value: (degree of the benefits and worth obtained from the collected data) (Aceto et al., 2019; Alcácer & Cruz-Machado, 2019b; Fernández-Rovira et al., 2021; Ivanov et al., 2019b).

For manufacturing companies to make the best use of enormous data, it is crucial for them to have data analytics capabilities to manage them and convert them into valuable knowledge (Alcácer & Cruz-Machado, 2019b; Klingenberg et al., 2019). Thus, big data analytics play an essential role to help manufacturing companies capture, process and analyse the massive amount of data that are generated continuously from various sources to gain better value and knowledge for real-time decision making (Dalmarco et al., 2019b; Ghobakhloo, 2018; Moktadir et al., 2018b).

4.2.6. Autonomous robotics

Autonomous or collaborative robot is considered one of the key technological enablers for implementing Industry 4.0 (Bibby & Dehe, 2018b; Moktadir et al., 2018b). Autonomy can be described as the ability to organise and manage the organisation activities and decisions. Therefore, autonomous robots can be considered intelligent devices that can perceive their environment, perform their own activities, and make decisions with a high degree of autonomy without human interaction (Alcácer & Cruz-Machado, 2019b; Arrais et al., 2021; Dalmarco et al., 2019b). Autonomous robots will deal with highly repetitive or restricted tasks that workers cannot perform, leaving more complex tasks for workers (Dalmarco et al., 2019b; Moktadir et al., 2018b).

Autonomous robots will help manufacturing companies reduce batch sizes focusing on batch size one at a reasonable cost to produce a wider variety of products and implement mass customisation. Moreover, autonomous robots improve productivity and quality by reducing defect rates, wastes, cycle time, workers' workload (Alcácer & Cruz-Machado, 2019b; Bibby & Dehe, 2018b; Bongomin et al., 2020; Ghobakhloo, 2018; Moeuf et al., 2018a; Rojko et al., 2020).

4.2.7. Digital Twins

The pairing between physical activities and the digital world refers to the digital twin (Tao et al., 2019a). Digital twins can be considered a digital replica and representation of physical objects or systems to simulate their behaviours in the real world and provide feedback (Stock et al., 2018b; Tao et al., 2019b).

Therefore, the digital twin will provide manufacturing companies with the opportunity to explore physical issues better, quickly and accurately, improve manufacturing processes, and produce products with high quality (Schmetz et al., 2020).

4.2.8. Augmented Reality

Augmented reality is one of the up-and-coming technological trends that can enhance the implementation of Industry 4.0 with its ability to bridge the gap between the digital world and the natural world (Alcácer & Cruz-Machado, 2019b; Bongomin et al., 2020; Ghobakhloo, 2018). Augmented reality "expands the information in the environment surrounding a human, allowing the human to interact with virtual objects that coexist simultaneously with a physical environment in a virtual way, in the same space of the real environment" (Bottani et al., 2021; Pacchini et al., 2019b).

Manufacturing companies can use augmented reality to improve manufacturing processes through real-time operation auditing, exploring errors, designing, and testing new products (Dalmarco et al., 2019b; Ghobakhloo, 2018). Additionally, one of the main contributions of augmented reality is improving employees' training and working skills by turning the environment surrounding workers into a digital interface (Ardito et al., 2019a; Dalmarco et al., 2019b).

4.2.9. Additive Manufacturing

Additive manufacturing also is known as 3D printing (Ivanov et al., 2019b; Pacchini et al., 2019b), is a set of technologies used in creating three-dimensional objects through joining materials (plastic or metal) layer upon layer until the prototype is completed (Ardito et al., 2019a; Culot et al., 2020; Dalmarco et al., 2019b).

As customers' needs and demands are rapidly changing, additive manufacturing technologies will improve manufacturing companies' capabilities to meet this challenge and produce small batches of customised products by speeding up the process of designing new products (Ghobakhloo, 2018; Moktadir et al., 2018b; Pacchini et al., 2019b; Pagliosa et al., 2019). Additionally, additive manufacturing will enable manufacturing companies to minimise production time and reduce the amount of raw materials used, waste generated, and the amount of inventory on hand (Dalmarco et al., 2019b; Kamble, Gunasekaran, & Gawankar, 2018a; Pagliosa et al., 2019). Thus, additive manufacturing technologies will significantly impact Industry 4.0 (Jwo et al., 2021; Kamble, Gunasekaran, & Gawankar, 2018a).

4.2.10. Cybersecurity and Blockchain technologies

Cybersecurity is a set of technologies used to defend networks, systems, programs, devices, data, and users from digital attacks and unauthorised access (Dalmarco et al., 2019b). In the context of Industry 4.0, a huge number of devices are connected, many IT resources are shared, and sensitive information is generated that increases the probabilities of cyberattacks (Alcácer & Cruz-Machado, 2019b; Ardito et al., 2019a; Bongomin et al., 2020). Thus, cybersecurity is imperative for the successful deployment of Industry 4.0 to provide a secure and reliable communication framework (Moeuf et al., 2018a; Moktadir et al., 2018b).

A blockchain is a digital distributed ledger that permanently maintains and records online transactions. (Ghobakhloo, 2018) stated that "blockchain technology is critical to Industry 4.0 because cryptocurrencies allow countless smart devices to perform transparent, secure, fast and frictionless financial transactions, fully autonomous without human intervention in the IoT environment".

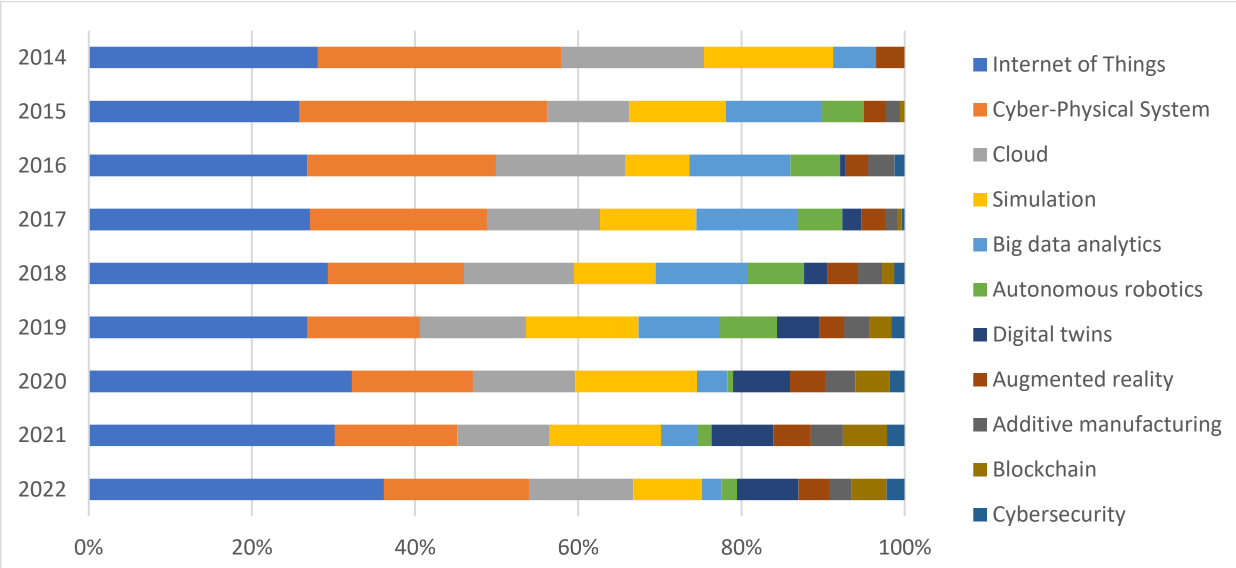

Figure 3. The popularity of Industry 4.0 technological enablers is based on the number of publications of each technology in the domain of Industry 4.0 in the last six years. Extracted from the Scopus database using exact match in title, abstract, and keywords

	Till May 2022	2021	2020	2019	2018	2017	2016	2015	2014	Total
Internet of Things	851	1348	1169	957	602	284	132	46	16	**5405**
Cyber-Physical System	418	672	538	492	344	227	114	54	17	**2876**
Cloud	302	502	457	464	277	145	78	18	10	**2253**
Simulation	198	614	541	493	206	124	39	21	9	**2245**
Big data analytics	56	197	136	356	233	130	61	21	3	**1193**
Autonomous robotics	44	78	26	248	141	57	30	9	0	**633**
Digital twins	178	341	251	187	60	25	3	0	0	**1045**
Augmented reality	89	204	156	109	77	30	14	5	2	**686**
Additive manufacturing	63	175	136	108	60	15	16	3	0	**576**
Blockchain	102	241	153	98	31	6	0	1	0	**632**
Cybersecurity	52	98	66	58	26	4	6	0	0	**310**

Table III. The popularity of Industry 4.0 technological enablers is based on the number of publications of each technology in the domain of Industry 4.0 in the last six years. Extracted from the Scopus database using exact match in title, abstract, and keywords

4.3. Industry 4.0 organisational and managerial enablers

Even though modern technologies have a significant role in implementing Industry 4.0, the organisational and managerial enablers cannot be ignored and are crucial in the transition towards Industry 4.0. This section collects and presents the most important organisational and managerial enablers.

4.3.1. Management commitment and involvement

It is well known in the literature that top management commitment and involvement are crucial for any new initiative to be successful. Management commitment reflects the belief that senior management has regarding Industry 4.0 as a critical strategy for the company, and this belief is demonstrated in their degree of participation in the implementation process. A committed and involved manager have been widely recognised as vital for the success of Industry 4.0 (Agostini & Filippini, 2019a; de Sousa Jabbour et al., 2018b; Sony & Naik, 2019b).

Top management should clearly understand everything pertaining to Industry 4.0, affirm the importance of Industry 4.0 as a major strategic orientation, explain the potential benefits of Industry 4.0, set goals for all the levels in the organisation, sustain and allocate all the needed resources, provide the required training for employees, review the achieved progress, give a lead and motivation to the whole company, solve any resistance issues. Thus, the role of top management support in the implementation of Industry 4.0 is imperative (Dzwigol et al., 2020).

4.3.2. Organisational structure

In today's accelerating and hyper-connected environment, the organisational structure emphasises the organisations' ability to cope with these frequent changes and develop a flexible, learning, and innovative climate (Santos & Martinho, 2019b; Shamim et al., 2017a).

The rigid form of organisational structure characterised by vertical hierarchy, centralised decision-making, lower autonomy, one-way communication, bureaucratic rules and policies, and specialised tasks is no longer suitable for the current situation.

Industry 4.0 needs a more flexible organisational structure that can respond quickly to environmental changes. This structure is characterised by flat hierarchy, decentralisation of decision making with more empowerment of employees, diversity of team skills, more collaborative teamwork, open communication, self–dependent work, flexible rules and policies, and knowledge networking (Santos & Martinho, 2019b; Shamim et al., 2017b). This flexible structure will result in more responsible and competent employees that are able to take action.

4.3.3. Organisational culture

Organisational culture plays a vital role in implementing Industry 4.0 and is considered one of the critical success factors when adopting any new initiative (Bibby & Dehe, 2018b; de Sousa Jabbour et al., 2018b; Mohelska & Sokolova, 2018a; Nafchi & Mohelská, 2020; Santos & Martinho, 2019b).

Organisational culture represents the identity of any organisation. It is the collective set of beliefs, values, attitudes, norms, and traditions shared by a group of people and how they will behave in a specific situation (de Sousa Jabbour et al., 2018b; Mohelska & Sokolova, 2018b; Rajput & Singh, 2019b).

For organisational culture to be influential, it should have sympathised with its mission, goals, strategies, environment, needs, and available resources. The implementation of Industry 4.0 needs an organisational culture that emphasis innovation, creativity, continuous improvement, collaboration, and challenging work (Bibby & Dehe, 2018b; Santos & Martinho, 2019b).

4.3.4. Strategic planning

A corporate strategy defines the overall goal and vision that an organisation desire to achieve and the roadmap for reaching them. Implementing any new initiatives may fail because of the lack of alignment between the new initiative and the corporate strategy (de Sousa Jabbour et al., 2018b).

The implementation of Industry 4.0 is considered a critical strategic decision that should be demonstrated in the corporate strategy and reflected in the corporate vision, mission, and goals. Thus, strategic planning is the first step for the successful implementation of Industry 4.0, identifying how the implementation will take place, how resources will be allocated, and how challenges will be solved (Črešnar, Potočan, & Nedelko, 2020; de Sousa Jabbour et al., 2018b; Sony & Naik, 2019b).

4.3.5. Digital leadership

Leadership is the ability of an individual to influence, direct, guide, inspire, and motivate others to reach the target outcomes (Mihardjo et al., 2019a; Shamim et al., 2017b). Leadership plays a notable role in supporting the transition towards Industry 4.0 (de Sousa Jabbour et al., 2018b; Hizam-Hanafiah et al., 2020; Kusmiarto et al., 2021; Mihardjo et al., 2019b; Oberer & Erkollar, 2018a; Santos & Martinho, 2019b; Shamim et al., 2017b).

(Santos & Martinho, 2019) and (de Sousa Jabbour et al., 2018), mentioned that a transformational leadership style is necessary to implement Industry 4.0 successfully. In this style, the leader will motivate, encourage, and inspire employees to create an innovative, creative, and learning environment to boost the desired change. However, Shamim *et al*., (2017) stated that Industry 4.0 implementation requires something beyond the transformational leadership style. As claimed by (Mihardjo et al., 2019) and (Oberer & Erkollar, 2018), the transition towards Industry 4.0 needs a "digital leadership or leadership 4.0" which is "a combination of transformation leadership style and the use of digital technology" (Mihardjo et al., 2019b). The digital leader is characterised by facing severe market competition and changes (Thought leader). Innovative and creative mind to think out of the box to find new ideas and implement them (Creative leader), the capability to influence and guide employees during the digital transformation era (Global Visionary Leader), the competency to predict environmental changes and deal with them (Inquisitive Leader), and finally the intellectual capabilities to gain knowledge, provide justifications and interpretations, and arrange information to make decisions (Profound Leader) (Kusmiarto et al., 2021; Mihardjo et al., 2019b; Oberer & Erkollar, 2018b).

4.3.6. Employees skills and competencies

The implementation of Industry 4.0 will require specific abilities and skills that employees inside should possess (de Sousa Jabbour et al., 2018b; Sony & Naik, 2019b). Therefore, the successful transition towards Industry 4.0 needs customised training programs and continuous development of the employees to improve their competencies to be qualified for the digital workplace (Agostini & Filippini, 2019b; Antonio et al., 2020; Santos & Martinho, 2019b).

The training programs should enhance employees' technical skills (data analytics, automation technology, data security) and non-technical skills (problem-solving, system thinking). These kinds of training will equip employees to deal with the new technological environment. Additionally, Industry 4.0 will significantly influence other human resources activities such as staffing, performance appraisal, compensation, and job design (Gaffley & Pelser, 2021; Shamim et al., 2017b; Sony & Naik, 2019b).

4.3.7. Project management

The implementation of Industry 4.0 can be considered a strategic project managed and directed by a project champion, who will take responsibility for this project and divide it into a series of planned and scheduled projects (de Sousa Jabbour et al., 2018b; Haipeter, 2020).

4.4. Other external enablers

Apart from the previously mentioned enablers, other stated factors can either support or hinder the successful implementation of industry 4.0, such as national culture and regional differences among collaborating companies (de Sousa Jabbour et al., 2018b). Additionally, government policies and support in terms of legislation, taxes, financial support and industrial standards can impact the adoption of Industry 4.0 (Lin et al., 2018a). Moreover, the company's size can influence the ability to implement Industry 4.0, where large companies can shift to Industry 4.0 easily due to the availability of the required resources, skills, and experiences (Lin et al., 2018b). Finally, Agostini and Filippini (2019) mentioned the IT infrastructure, an essential precondition within the digital transformation process.

4.5. Industry 4.0 expected benefits

The implementation of Industry 4.0 promises many opportunities for manufacturing companies. This section discusses the expected gains from the transition towards Industry 4.0.

4.5.1. Revenue gains and cost reduction

Industry 4.0 will provide organisations more rooms to develop customised products and services to serve new markets that can increase sales volumes and generate more revenues (Horváth & Szabó, 2019; Kiel et al., 2017; Moeuf et al., 2018; Oesterreich & Teuteberg, 2016; Schneider, 2018). The implementation of Industry 4.0 will significantly reduce costs in terms of material and resources costs, operating and maintenance costs, inventory and stock costs, investment into tangible engineering, and R&D costs. Additionally, Industry 4.0 technologies will reduce production quality issues, machines, and production line downtime and failure.

According to global Industry 4.0 survey, about 60% of manufacturing companies predict that the implementation of Industry 4.0 will have a positive impact on their Return on Investment (ROI) in less than two years and the remaining companies expect this impact within five years (Fatorachian & Kazemi, 2018b; Götz & Jankowska, 2020).

4.5.2. Improved operations efficiency and productivity

The deployment of Industry 4.0 will enable manufacturing companies to do more with less. Industry 4.0 will optimise the manufacturing process, particularly in terms of resources consumption. The manufacturing process is enhanced due to the automation of physical tasks, reducing manual activities, and the optimum use and allocation of resources (Fatorachian & Kazemi, 2018b; Kiel et al., 2017b; Moeuf et al., 2018a; Müller et al., 2018b; Rejikumar et al., 2019a; Rojko et al., 2020; Sader et al., 2019a; Schneider, 2018b).

4.5.3. Flexibility

Industry 4.0 will enhance the real-time planning and control capabilities of manufacturing companies, as well as improve their responsiveness to uncertainties and rapid market fluctuations, through facilitating last-minute changes into the production process thanks to the availability of real-time data throughout the entire supply chain (Moeuf et al., 2018a; Müller et al., 2018b; Rejikumar et al., 2019a; Sader et al., 2019b; Sasiain et al., 2020).

4.5.4. Improved collaboration and communication and integration

Industry 4.0 promotes the interconnection and integration with key partners throughout the entire supply chain, starting from suppliers and ending with customers and vice-versa (Fatorachian & Kazemi, 2018b; Moeuf et al., 2018a; Müller et al., 2018b; Oesterreich & Teuteberg, 2016b; Sader et al., 2019b).

4.5.5. *Environmental and social benefits*

Industry 4.0 technologies will positively impact manufacturing companies' environmental and social aspects. Digital technologies will help manufacturing companies be more sustainable and environmentally friendly via green and eco-friendly products, services, processes, and supply chains and the optimised consumption of resources. Therefore, reducing the negative impact those manufacturing companies have on the environment (Luthra et al., 2020).

Concerning the social impact, Industry 4.0 will create a safe working environment for employees where robots will perform dangerous, routine, and repetitive tasks. This will reduce the physically required work, improve employees' satisfaction, motivation, and productivity (Ghobakhloo, 2018; Horváth & Szabó, 2019; Oesterreich & Teuteberg, 2016b; Schneider, 2018b).

4.5.6. *Improved decision making*

With the vast amount of real-time data collected and analysed in the manufacturing system via Industry 4.0 technologies, managers will have all the valuable information required to make better decisions and respond quickly to the changing circumstances (Fatorachian & Kazemi, 2018b; Osterrieder et al., 2020; Rejikumar et al., 2019a; Sader et al., 2019b).

4.5.7. *Mass customisation*

Manufacturing companies operate in a dynamic environment where the customers' needs and expectations are frequently changing. Industry 4.0 will allow manufacturing companies to collect and analyse customer and market data to produce personalised products efficiently and flexibly at low volume with high quality and fair price. This, in turn, will increase customer satisfaction and retention rate (Fatorachian & Kazemi, 2018b; Kiel et al., 2017b; Müller et al., 2018b; Sader et al., 2019b).

4.5.8. *Competitive advantage*

Digital technologies will enable manufacturing companies to gain immense knowledge from various sources, either inside or outside. This knowledge will promote manufacturing companies' innovation capabilities to find new ways of creating values via innovative products and new service features (Weking et al., 2020). Additionally, and as mentioned before, Industry 4.0 provides a chance for manufacturing companies to produce customised products, improve process efficiency, reduce manufacturing costs, increase product quality, increase customer satisfaction and retention rate, and enhance information sharing and collaboration. All these gains will provide manufacturing companies with the opportunity to have a competitive advantage and outperform competitors (Horváth & Szabó, 2019; Kiel et al., 2017b; Müller et al., 2018b; Rejikumar et al., 2019a).

4.6. *Industry 4.0 implementation challenges*

The transition towards Industry 4.0 is a complex and complicated process that contains many obstacles. For manufacturing companies to realise the previously stated benefits, they must deal with the challenges that may hinder Industry 4.0. This section will highlight most of the barriers related to the adoption of Industry 4.0.

4.6.1. *Availability of the required skills*

One of the main challenges for implementing Industry 4.0 is the availability of employees with the required skills and knowledge to use the new technologies. The implementation of industry 4.0 will change the current ways of working and create new ways. This change will significantly impact the employees to fit the changed circumstances (Dhanpat et al., 2020; Horváth & Szabó, 2019; Ing et al., 2019; Kamble, Gunasekaran, & Sharma, 2018a; Moktadir et al., 2018b; Müller et al., 2018b).

Although automation will perform most of the jobs and tasks inside manufacturing companies, the role of employees cannot be ignored during the implementation of Industry 4.0. They can facilitate or hinder the successful implementation of Industry 4.0 (Horváth & Szabó, 2019).

Manufacturing companies should develop the technical skills of the current employees and personal and social skills (Müller et al., 2018b). Improving these skills will be a crucial challenge for human resources management. The human resources management should develop suitable training programs for the current employees. Additionally, the human resources department should ensure that any new employee must have the required skills (Kamble, Gunasekaran, & Sharma, 2018b; Konur et al., 2021; Oesterreich & Teuteberg, 2016b).

4.6.2. Risk of data security

Industry 4.0 involves exchanging and sharing a huge volume of data and information between the manufacturing company and other external partners, posing cyber-security and data protection issues (Kamble, Gunasekaran, & Sharma, 2018b; Kiel et al., 2017b; Oesterreich & Teuteberg, 2016b; Sasiain et al., 2020).

According to Ing *et al*., (2019), most manufacturing companies are not paying the required attention to develop a robust security system during the implementation of Industry 4.0. Thus, they may be subject to the risk of cyber-attacks, industrial spying, unauthorised access, process manipulation, and losing their data. Therefore, one of the critical challenges for manufacturing companies is developing solid systems to protect their data against cyber-security threats (Horváth & Szabó, 2019; Kiel et al., 2017b; Kovacs, 2018; Luthra & Mangla, 2018; Moktadir et al., 2018b).

4.6.3. Huge capital investment

The transition towards Industry 4.0 requires a significant initial capital expenditure for developing manufacturing companies' capabilities in terms of technological infrastructure, training, and education, as well as consultancy services costs (Ing et al., 2019; Kamble, Gunasekaran, & Sharma, 2018b; Moktadir et al., 2018b; Oesterreich & Teuteberg, 2016b).

Not all manufacturing companies have the necessary financial resources for Industry 4.0 implementation, which is considered a significant adoption barrier (Horváth & Szabó, 2019; Luthra & Mangla, 2018).

4.6.4. Resistance to change

One of the factors that can hinder Industry 4.0 is employees' acceptance of new technologies. Employees resist using new technologies because of their fear to lose their jobs as a result of the intensive use of automation (Horváth & Szabó, 2019; Kamble, Gunasekaran, & Sharma, 2018b; Kiel et al., 2017b; Kovaitė et al., 2020; Luthra & Mangla, 2018; Müller et al., 2018b). Kovacs (2018) mentioned that "about 47% and 54% of jobs in the United States and Europe" can be lost due to automation.

Thus, manufacturing companies must deal with employees' apprehensions by enhancing their trust in the potential benefits they can achieve from Industry 4.0 and helping them feel ownership over performance improvement (Müller et al., 2018b; Oesterreich & Teuteberg, 2016b).

4.6.5. *Unclear implementation strategy*

The transition towards Industry 4.0 is considered a strategic decision that needs a solid strategic vision, mission, and plans for the successful transformation (Luthra & Mangla, 2018; Moktadir et al., 2018b). Some manufacturing companies struggle to explain their Industry 4.0 strategy to their employees, leading to implementation failure.

4.6.6. *Underestimating the benefits of Industry 4.0*

(Sunil Luthra & Mangla, 2018), (Horváth & Szabó, 2019), (Kamble, Gunasekaran, & Sharma, 2018), and (Oesterreich & Teuteberg, 2016), mentioned that one of the challenges of implementing Industry 4.0 related to the lack of clear understanding of the expected implications from the adoption of Industry 4.0. To encounter this challenge, manufacturing companies should develop feasibility studies demonstrating the cost-benefit expectations from investing in Industry 4.0 (Horváth & Szabó, 2019).

4.6.7. *Lack of knowledge management system*

The absence of a knowledge management system that can store, retrieve, and process the collected data from various sources is one of the Industry 4.0 implementation barriers. Manufacturing companies need to develop a knowledge management system to enhance collaboration and integrate data in a real-time manner (Ing et al., 2019; Kamble, Gunasekaran, & Sharma, 2018b; Oesterreich & Teuteberg, 2016b).

4.6.8. *Poor technological infrastructure and internet-based networks*

Poor technological infrastructure and internet-based networks are critical barriers to Industry 4.0. The implementation of Industry 4.0 needs rapid and reliable internet connectivity and access (Kamble, Gunasekaran, & Sharma, 2018b; Luthra & Mangla, 2018; Moktadir et al., 2018b; Oesterreich & Teuteberg, 2016b).

4.6.9. *Lack of integration and collaboration*

One of the most critical barriers for implementing Industry 4.0 is establishing a flexible platform that can integrate various systems and subsystems within and across the manufacturing companies' boundaries. There is a need for collaboration among the supply chain partner to achieve synchronisation and compatibility of different technologies and methods for better communication (Horváth & Szabó, 2019; Ing et al., 2019; Kamble, Gunasekaran, & Sharma, 2018b; Kiel et al., 2017b).

4.6.10. *Legal issues*

Legal issues related to data privacy, security, and protection must be considered during the implementation of Industry 4.0. manufacturing companies need to have rigid privacy rules and standards to protect private information and data (Kamble, Gunasekaran, & Sharma, 2018b; Luthra & Mangla, 2018).

4.6.11. *Lack of standards and reference architectures*

(Oesterreich & Teuteberg, 2016) and (Kamble, Gunasekaran, & Sharma, 2018), mentioned that one of the inhibitory factors for implementing Industry 4.0 is the lack of standards and reference architectures. The reference architecture represents the roadmap that can be followed to implement Industry 4.0 in an organised manner.

5. Conclusions, implications of the study and future research directions

5.1 Implications of the Study

Nowadays, the business world is more complex and dynamic, characterised by severe competition, technological innovation, and uncertain market demands. Manufacturing companies strive to improve their capabilities to provide more customised products and services that meet customers' demands in a better way, on time, at a fair price, and with high quality. No doubt that Industry 4.0 is crucial for any manufacturer to understand its business and technological dimensions to implement it in a competitive and sustainable way successfully (Chari et al., 2022; Intalar et al., 2021; Tay et al., 2021).

Industry 4.0 is a continuously evolving definition as technology and management practices evolve. Thus, the need for an updated review of this phenomenon is crucially needed over time(Calabrese et al., 2022; Dixit et al., 2022; Yilmaz et al., 2022). From an academic perspective, the significant implication of this study is to provide a solid and constructive analysis of the most profound literature that exists in this field that applies to the manufacturing industry. It helps to bridge the gap of better understanding Industry 4.0 definition, enablers, implementation, and assessment for the manufacturing industry. Moreover, the paper provides a guideline for any manufacturing organisation that needs to assess their readiness for industry 4.0 technologies and how the technology-management mix of this phenomenon can be blended together to ensure the continuity of this development.

From a practical perspective, no doubt that the way manufacturing organisation work dramatically changes after the Covid-19 pandemic and the need for further digital transformation initiatives to cope with the new business environment. this research provides valuable insights into the key enablers and pillars of Industry 4.0 successful implementation in the manufacturing industry, including the vital digital technologies currently used by successful manufacturing firms. Moreover, by addressing the challenges of implementing Industry 4.0, this paper allows manufacturing firms to address these challenges innovatively and systematically. This will enable manufacturers to understand Industry 4.0 better and ensure its technological and managerial aspects are implemented efficiently.

Through the systematic review, this study denotes a limited number of literature studies on the field of industry 4.0. This study updates and extends the currently available literature studies and demonstrates Industry 4.0 current trends. Moreover, this study covers both the technological aspects besides the managerial and organisational aspects of Industry 4.0, where most of the previous studies focused mainly on the technical side.

5.2 Conclusion

Industry 4.0 is one initiative that provides manufacturing companies with opportunities to increase productivity, efficiency, and responsiveness to changing customers' demands, enabling them to increase revenues and achieve a competitive advantage. As the importance of Industry 4.0 has expanded since its introduction in 2011, the contributions of researchers and practitioners in this topic have expanded.

Thus, this study investigates recent academic researchers on Industry 4.0 phenomenon by performing a comprehensive literature review on the most relevant publications using appropriate research methodology.

The systematic review indicates that industry 4.0 is still an immature topic that needs an approved and unique definition among researchers, although there have been increasing publications covering this topic in the last few years. This review highlights the main features and principles characterising Industry 4.0

from other initiatives, such as system integration, decentralisation, interoperability, virtualisation, and real-time capacity.

Throughout the review, it is evident that modern technology is one of the critical enablers for the successful implementation of Industry 4.0. This study discussed the essential technologies according to their popularity, such as the Internet of Things (IoT), Cyber-Physical Systems (CPS), and cloud computing. However, modern technology is central to this new paradigm. This review indicates that Industry 4.0 is not only a matter of technology. Organisational and managerial aspects should be considered during the transition towards Industry 4.0. Manufacturing companies' endeavours towards Industry 4.0 will only be worthwhile by investigating their organisational and managerial capabilities.

The study determines the extensive opportunities that Industry 4.0 offers for manufacturing companies. The implementation of Industry 4.0 is expected to provide many benefits for manufacturing companies in terms of improved operations efficiency and productivity, flexibility, and decision-making and meeting customers' demands better, which will lead to revenue gains. However, for manufacturing companies to realise these benefits, they have to overcome some barriers. These barriers are high implementation cost, unqualified employees, data insecurity, and resistance to change.

To sum up, this study provides a comprehensive view of a dynamic and rapidly changing concept that is crucially important to the manufacturing industry. Industry 4.0 phenomenon was investigated through a systematic approach to identify the main technological, organisational, and managerial enablers that are fundamental for its implementation, as well as to determine the expected benefits and barriers of adopting this approach in different fields and organisations.

5.3 Future Research

According to the outcomes of this study and the nature of Industry 4.0, rooms for future research were identified. First, future research studies should develop a practical and comprehensive strategic framework that can be used by manufacturing companies intended to implement this new approach. This framework must be realistic and clarify all the steps that must be followed to implement Industry 4.0 according to a specific timeframe. The framework should be tailored according to different aspects like industry type and company size. Also, most previous research focused mainly on the manufacturing sector, with little attention paid to the service sector. Thus, future studies can determine how Industry 4.0 can be implemented in the service sector.

Second, another attractive avenue for future research is the relationship between sustainability variables, like circular economy and Industry 4.0, where this area is still immature, and further research is required. Future research studies should also address how other improvement initiatives like lean manufacturing, six sigma, and agile manufacturing can be integrated and work with Industry 4.0, where few studies covered this area.

Third, implementing Industry 4.0 on the financial performance of organisations should gain more attention. More research is required to investigate how Industry 4.0 can impact companies' economic indicators such as return on equity (ROE), return on investment (ROI), and customer acquisition ratio.

Finally, the review highlights that the main concentration of the previous studies was on developed countries, with little concern about developing countries. This represents another area of interest for future research to determine how different environments can impact the successful implementation of Industry 4.0.

The main limitation of this study is selecting only the Scopus database to collect the relevant publications. Therefore, some journals in other databases have yet to be considered. Future review studies may combine other databases like Web of Science (WoS) and Science Direct with the Scopus database. Another limitation of this study is related to the exclusion and inclusion criteria. Only articles written in English were considered in this study, and any publications in other languages were excluded. The study can be enhanced by taking into account more languages.

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