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Industry 4.0 Supporting Logistics Towards Smart Ports: Benefits, Challenges and Trends Based on A Systematic Literature Review

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Abstract:

Purpose: The fourth industrial revolution has pushed companies, and even seaports, to adapt the way they operate in order to remain competitive in the marketplace. Thus, ports are going from analog to digital, and are on their way to achieving the status of smart ports. The purpose of this paper is to analyze what is already known about smart ports.

Design/methodology/approach: A systematic literature review was conducted to identify the contributions of Industry 4.0 to seaport logistics (using the PRISMA method), based on studies present in the SCOPUS and Web of Science databases, both at the bibliometric and content level.

Findings: Using this method, it was possible to identify the most used technology of Industry 4.0 in the smart port context, the benefits, and the challenges of the digital transformations in seaports, and the world's smartest port cities. Curiously, from the universe of studies found, few articles are concerned about the impacts of smart ports on the human factor and on the cities and municipalities where the port is located.

Originality/value: This study presents contributions both at the theoretical level (which increases knowledge about the status of some of the ports considered smart), and at the practical level (which aims to help/encourage other ports to start/continue to become increasingly smart).

Keywords: industry 4.0, digital transformation, smart ports, logistics, sustainability

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1. Introduction

Earth has become an urban planet, and according to Wigginton (as cited in Cambra-Fierro & Pérez, 2022), more than half of the world's people now live in cities, and the proportion is growing. Also, new challenges are emerging every day as a result of the change that is continuously taking place which has forced cities to adapt by incorporating current trends for digitalization and adopting smart solutions within the concept of Industry 4.0 to make cities more resilient and efficient (Kolotouchkina, Barroso & Sánchez, 2022). The concept of Industry 4.0 was presented for the first time at the Hannover Fair in 2011 and is the symbol of the Fourth Industrial Revolution (Xu, Xu & Li, 2018). This revolution has brought about a change in the way we live and work, as more needs to be done, in more complex ways, with smaller and smaller budgets (Fiorini & Galloro, 2022). This revolution aims to build intelligent machines, systems, processes, and products, from the combination of Industry 4.0 practices, namely digitization and smart, Internet-based communication and manufacturing technologies (Sun, Solvang, Wang & Wang, 2022). The 12 most important technologies of Industry 4.0, according to Sun et al. (2022), and shared by many other authors, are IoT (Internet of things) (Song, Cui, Vanthienen, Huang & Wang, 2022); cyber-physical systems (CPS) (Min, 2022); big data analytics (Fernández, Santana, Ortega, Trujillo, Suárez, Santana et al., 2017; Yau, Peng, Qadir, Low & Ling, 2020); artificial intelligence (AI) (Cambridge dictionary as cited in Walter, Denter & Kebel, 2022); cloud technologies (Min, 2022); blockchain (Nguyen, Shu-Ling-Chen & Du, 2022; Philipp, 2020); autonomous robots (Sun et al., 2022); unmanned aerial vehicles (UAV) (Koroleva, Sokolov, Makashina & Filatova, 2020; Yang as cited in Sun et al., 2022); additive manufacturing (AM) also known as 3D printing (Pietrewicz, 2019; Wankhede & Vinodh, 2021); augmented reality (AR) (Oh, Park & Kwon, 2016); virtual technologies and simulation (Sun et al., 2022); and cybersecurity (Douaioui, Fri, Mabrouki & Semma, 2018; Kim, Alfouzan & Kim, 2021).

Out of this evolution emerged the concept of the smart city, which despite not having a uniform definition, can be described as an approach that aims to: improve the quality of life of citizens by meeting their needs; provide environmental protection and sustainability; raise public safety; and increase the efficiency of industrial and commercial activities (Kaluarachchi, 2022; Wu, Xiong, Gang & Nyberg, 2013).

The concept of the smart city emerged in 1990, its aims being to use information and communication technologies to develop an integrated, habitable and sustainable city, to respond to six major components: the smart economy, smart environmental practices, smart governance, smart living, smart mobility, and smart people (Bhushan, Khamparia, Sagayam, Sharma, Ahad & Debnath, 2020; Correia & Teixeira, 2022; Kaluarachchi, 2022).

Among the various constituents of smart cities, smart ports stand out, which when integrated with other initiatives (for example, intelligent transportation systems) aim at sustainable economic, environmental, and social development, to improve the competitiveness of cities (Di Vaio & Varriale, 2019; Wu et al., 2013; Yau et al., 2020).

Maritime transportation can be seen as "the backbone of the global supply chain" (Gao, Sun, Rameezdeen & Chow, 2022) and is very relevant in the global economy (De Albuquerque, Machado, De Sa & De Toledo, 2022), since approximately "80% of world trade is transported via maritime logistic" (Idrissi, Haidine, Aqqal & Dahbi, 2022).

With all this responsibility, ports are being guided using a strategy oriented toward the digitalization of processes and are using technologies to increase the efficiency of port activities and services in order to achieve these sustainability goals (Boullauazan, Sys & Vanelslander, 2022; de la Peña-Zarzuelo, Freire-Soeane & López-Bermúdez, 2020). So, with the increasing use of digital technologies that we are facing daily from industries and the world in general, it is no longer a choice for ports to adopt digital solutions as well, with this matter increasingly becoming a focus for researchers (Jović, Tijan, Brčić & Pucihar, 2022; Min, 2022).

In this way, the port community aims to transform the traditional port into a smart port to meet the challenges they face with globalization, including increased port congestion, compliance issues, increased port competitiveness, the need to mitigate environmental impacts, and the need to reintegrate residents and infrastructure near ports (community issues) (Boullauazan et al., 2022; Rajabi, Khodadad-Saryazdi, Belfkih & Duvallet, 2019; SINAY, 2021).

A smart port uses information and communications technology (ICT) to promote the exchange of information between equipment and infrastructure to make decisions in real time and develop various smart applications ranging from smart vessels to smart containers, smart energy, and smart resources, which consequently promotes the increased performance of the supply chain as a whole (Jugović, Sirotić & Poletan-Jugović, 2022; Rajabi et al., 2019; Yau et al., 2020). Min (2022) states that among the key components of a smart port are smart logistics, which consists of handling cargo with automatic cranes, adoption of the port community network, which promotes communication among the stakeholders of a port, and concern for environmental sustainability.

As Fiorini & Galloro (2022) suggest, the COVID-19 pandemic has demonstrated that smart ports already exist and understand the benefits of this digital transformation. However, some ports still operate traditionally, without yet understanding digitalization and, in some cases, how it can be introduced (Fiorini & Galloro, 2022; Philipp as cited in Meyer, Gerlitz & Henesey, 2021). Thus, it is important to study what already exists in the literature on digital transformation in logistics operations at the seaport level, informing not only academics but also practitioners.

This paper is structured as follows: section 2 presents a detailed focus on the objectives and questions that the paper intends to answer; section 3 describes the method used to reach the objectives; section 4 presents the results that were obtained; and, in the end, section 5 presents the discussion, the contributions, the limitations, and future work related to the field under analysis.

2. Objectives and Methods

This paper was designed with the main objective of gaining knowledge of the state of the art of Industry 4.0 contributions to logistics operations in maritime ports by answering the question: "What contributions and challenges of Industry 4.0 are expected to improve logistics towards smart seaports?" To answer this main question, the authors decided to break it down into eight more specific questions as follows:

1. How has the topic progressed over the years?
2. Which are the most influential countries in this field?
3. Which are the most influential journals in this area?
4. Which are the most respected authors in this area?
5. Which is/are the Industry 4.0 technology(ies) that most influence port logistics?
6. What are the benefits and opportunities of digital transformation in ports?
7. What challenges are most often pointed out in this transition?
8. Where and which ports are already applying Industry 4.0 technologies?

To achieve these objectives, a systematic literature review (SLR) was performed, since it can be seen as a method used to identify, collect, and analyze available information from different research on a specific topic, utilizing several techniques to minimize errors and providing high-quality evidence (Snyder, 2019; Tranfield, Denyer & Smart, 2003).

Thus, an SLR was conducted to identify the contributions of Industry 4.0 to seaport logistics and provide an overview of the research to date related to this topic. This SLR was conducted according to the approach described by Snyder (2019) and was divided into four phases: designing the review; conducting the review; analyzing; and writing the review.

First, in the design phase, it was necessary to understand the motivation and the importance of the topic for the academy by identifying the research question. Subsequently, the type of approach and methodology to be used was chosen to arrive at the answer to the question posed. Then, in the phase of conducting the review, the keywords and the inclusion and exclusion criteria were decided upon, to ensure that the selection of the final sample was well performed, utilizing the PRISMA (preferred reporting items for systematic reviews and meta-analysis) methodology. In the third phase, analysis, it was decided how the chosen papers would be analyzed. Finally, in the writing phase, it was decided to prepare the review using the PRISMA methodology, following the guides stated in the reports (Liberati, Altman, Tetzlaff, Mulrow, Gøtzsche, Ioannidis et al., 2009; Moher, Liberati, Tetzlaff &

Altman, 2009). This approach is designed to support systematic reviews and to report "why the review was done, what the authors did, and what they found" (Page, McKenzie, Bossuyt, Boutron, Hoffmann, Mulrow et al., 2021).

2.1. Data Collection

Initially, a search strategy was defined in the scientific databases, SCOPUS and Web of Science. This search took place between December 2022 and January 2023.

The keywords used in the search were divided into three major groups, detailed in each of the columns of Table 1: digital transformation and the whole new era of digitalization and Industry 4.0; logistics operations and the supply chain; and ports. These are the terms used to search within the databases using Boolean operators to link them together ("OR" between lines and "AND" between columns).

Industry 4.0 and terms with the same meaning	Maritime ports and terms with the same meaning	Logistics and terms with the same meaning
Digital transformation	Seaport	Logistic*
Industry 4.0	Maritime terminal	Supply chain
i4.0	Maritime port	Transport*
4th industrial revolution	Container terminal	
Digitali?ation*	Port authority	
fourth industrial revolution	Port city	
Cyber-Physical Production System*		
Internet of thing*		

Table 1. Keywords used in the bibliographic review

In an initial search, 132 titles were found, 115 from Scopus and 17 from Web of Science, 15 of which are present in both databases and are referenced as duplicates (information illustrated in Figure 1).

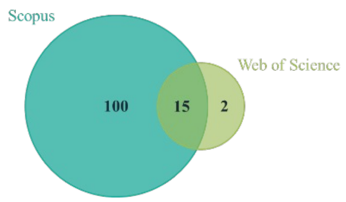

Figure 1. Distribution of the papers found in the databases

The result is 117 articles, to which exclusion criteria were applied, referring to language, publication year, availability (due to lack of funding to read the full article), type of document, and the scope of each document, totaling 24 excluded articles.

The exclusion criteria adopted in the search were as follows:

- Language: other than English;
- Year restriction: before 2011 (articles between 2011 and January 2023 were included);
- Full text of the study not available;
- Type of documents: books, book chapters, and conference reviews (type of documents included: articles, conference paper, AND review)

Taking the above criteria into account, Table 2 shows the final search strategies used in each database, as well as the number of articles obtained in each case.

From this 93, the title and the abstract were read, and studies not focusing on the scope were also excluded. Finally, 82 remain to be read in full, of which 18 were excluded since some of them were not considered relevant and consistent with the research questions under analysis.

Both the screening and eligibility process was conducted jointly by both authors. In cases of differing opinions, detailed discussions were held to reach a consensus, thus ensuring the integrity and accuracy of our review. This collaborative approach ensured a balanced and thorough assessment of the included studies.

Databases	Searching Strategy	Results Obtained
Scopus	TITLE-ABS-KEY (((“digital transformation” OR “industry 4.0” OR “i4.0” OR “4th industrial revolution” OR “digitali?ation*” OR “fourth industrial revolution” OR “cyber-physical production system*” OR “internet of thing*”) AND (“seaport” OR “maritime terminal” OR “maritime port” OR “container terminal” OR “port authority” OR “port city”) AND (“logistic*” OR “supply chain” OR “transport*”))) AND PUBYEAR > 2010 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “cp”) OR LIMIT-TO (DOCTYPE, “re”)) AND (EXCLUDE (PUBSTAGE, “aip”))	91
WoS	TOPIC: ((“Digital Transformation” OR “Industry 4.0” OR “i4.0” OR “4th industrial revolution” OR “Digitali?ation*” OR “fourth industrial revolution” OR “Cyber-Physical Production System*” OR “Internet of thing*”) AND (“Seaport” OR “Maritime Terminal” OR “Maritime Port” OR “Container Terminal” OR “Port Authority” OR “Port City”) AND (“Logistic*” OR “Supply Chain” OR “Transport*”)) AND (PY==(“2023” OR “2022” OR “2021” OR “2020” OR “2019” OR “2018” OR “2017” OR “2016” OR “2015” OR “2014” OR “2013” OR “2012” OR “2011”) AND DT==(“ARTICLE” OR “PROCEEDINGS PAPER” OR “REVIEW”) AND LA==(“ENGLISH”))	2

Table 2. Final search strategy query for each database

To identify additional relevant articles from the reference lists of the primary articles, snowballing (as a search method) was then applied, with eight studies being added this way. All of this information is schematized in Figure 2, developed according to Liberati et al. (2009), Moher et al. (2009), and the PRISMA website (PRISMA, 2020).

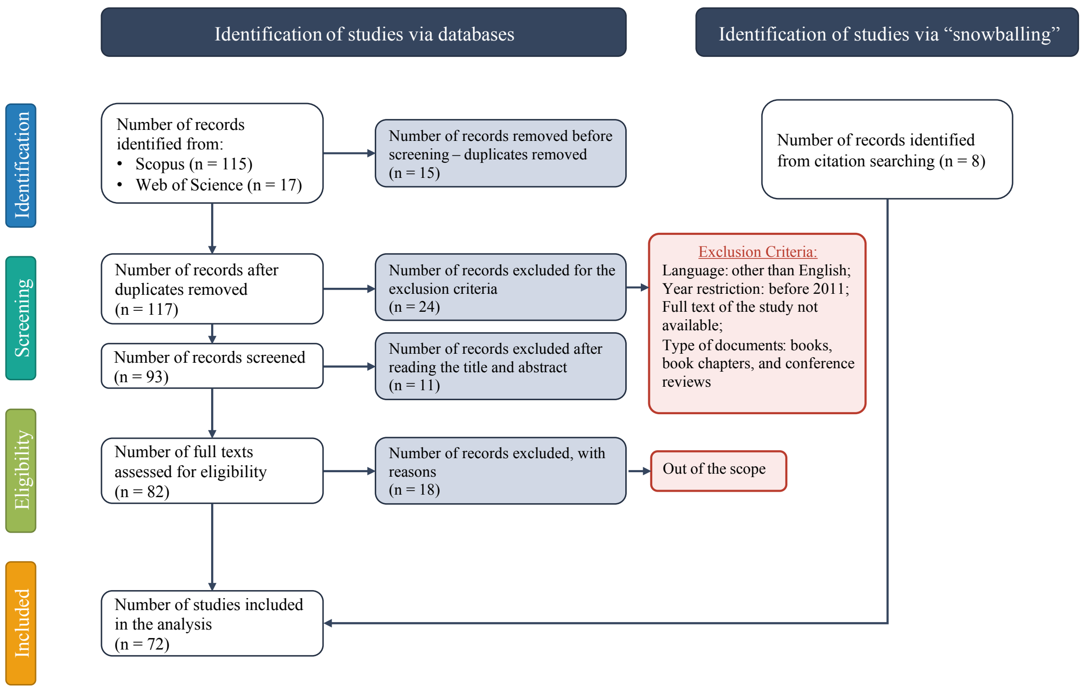

Figure 2. Flowchart of search and selection criteria, based on PRISMA

2.2. Data Analysis

Figure 3 illustrates how the research questions were answered. Research questions 1, 2, 3, and 4 were answered using bibliometric analysis, while questions 5, 6, 7, and 8 were answered by means of content analysis, with a full reading of the article and analysis of the topic to be investigated).

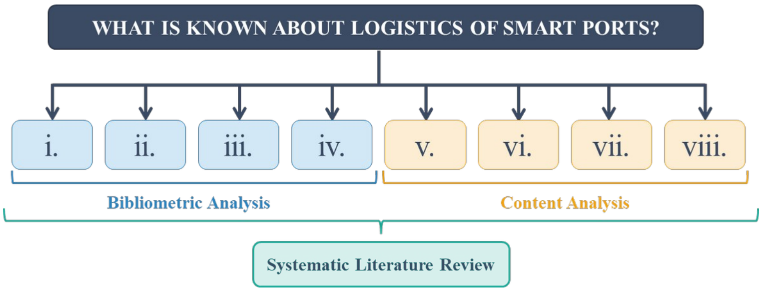

Figure 3. The methodology utilized to analyze and answer the specific questions

3. Results. Systematic Literature Review

In the first phase of analysis, the content of the articles was analyzed with VOSviewer, showing which words were most used in the articles (from the analysis of the titles, abstracts, and authors' keywords).

3.1. General Characteristics of the Study (Bibliometric Analysis)

3.1.1. Analysis of Papers per Year

According to the methodology adopted, only studies published from 2011 onward were selected, since that was the year that the concept of Industry 4.0 emerged.

Figure 4 shows the evolution of the number of papers per year, demonstrating that most studies were published in 2022 (21 papers), followed by the year 2021 (17 papers), and 2020 (16 papers). The gradually growth in the number of publications since 2018 indicates increasing interest from the academic community in the field of digital transformation in seaport logistics.

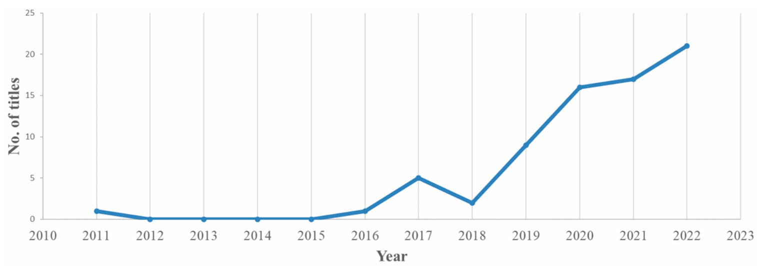

Figure 4. Number of selected articles, per year

3.1.2. Analysis of the Geographical Distribution of the Papers

Figure 5 shows the 20 countries (of a total of 38 countries) with the most publications in the different journals and conferences, among the papers selected (based on the affiliations of every author, rather than solely the first or corresponding author). By analyzing Figure 5, it can be seen that authors with German affiliation are those who have contributed the most (13 articles), followed by Spanish (11 articles) and Italian (9 articles). The first study published among the selected authors was in 2011 by a German author, which suggests that they contributed early to the academic community in this field.

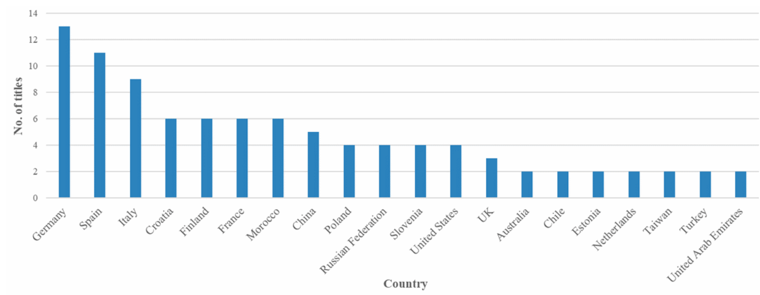

Figure 5. Top 20 countries that contributed to the selected publications

3.1.3. Analysis by Source (Journal or Conference)

Of the total 72 articles included in the analysis, 57 are published in journals and 15 are published in conferences. Table 3 shows the journals that contribute most publications out of the 57. IEEE Access and Research in Transportation Business & Management represent the journals that present the greatest number of papers in this area—the digital transformation of logistics in seaports. While the first publishes multidisciplinary and application-oriented articles (IEEE Xplore, 2023), the second publishes in the field of international transport management, in a wide range of aspects, such as sustainability and logistics, among others (Science Direct, 2022). Concerning conferences, we observed no significant differences between them in terms of the number of publications.

Journal Title	No. of Studies
IEEE Access	4
Research in Transportation Business & Management	3
Sensors	2
Environmental and Climate Technologies	2
Business Process Management Journal	2
Maritime Policy and Management	2
Sustainability Switzerland	2

Table 3. Most active journal, by the number of publications, from the selected ones

3.1.4. Analysis of Most respected Authors and Most Cited Papers

Some of the papers selected for analysis are by more than one author, constituting cooperative work among peers. Table 4 shows the names and data of the most productive and published authors in the universe under analysis, and the respective number of studies. Jović M., Palau C. E., Tijan E., Voß S., and Heilig L. constitute the most influential authors, having carried out joint work with different peers. For example, as presented above, Heilig L and Voß S. are two of the co-authors of the most cited article among the 72 selected.

Author's Name	No. of Studies	Author Data
Jović M.	4	Institute of Shipping Economics and Logistics, 28359 Bremen, Germany
Palau C.E.	4	Communication Department, Universitat Politècnica de València, 46022 Valencia, Spain
Tijan E.	3	Faculty of Maritime Studies, University of Rijeka, 51000 Rijeka, Croatia
Voß S.	3	Deloitte Touche Tohmatsu, Shanghai, China
Heilig L.	3	Institute of Information Systems, University of Hamburg, Germany

Table 4. Number of studies per author

3.2. Content Analysis

3.2.1. The 12 Most Important Technologies of Industry 4.0 Applied to Seaports

According to de la Peña-Zarzuelo et al. (2020), ports are at the beginning of the fifth generation, marked by the adoption of Industry 4.0 practices, beginning the journey of digital transformation. This digital transformation is undertaken by port stakeholders to overcome challenges such as congestion in ports, the need for faster deliveries, and the growing concern for port sustainability, among others (Boullauazan et al., 2022). To understand the influence of industry 4.0 on the logistics activities of seaports, studies were analyzed according to their integration in the 12 most important technologies of Industry 4.0. These technologies are: IoT (Internet of things); cyber-physical systems (CPS); big data analytics; artificial intelligence (AI); cloud technologies; blockchain; autonomous robots; unmanned aerial vehicles (UAV); additive manufacturing (AM) (3D printing); augmented reality (AR); virtual technologies and simulation; and cybersecurity (Sun et al., 2022).

From the reading and full analysis of the 72 articles included in the study, it could be determined that 12 of them did not refer to any type of the 12 most important technologies, and some conclusions could be drawn from the remaining 60. Appendix A contains a summary of this analysis.

According to the analysis conducted, it can be concluded that the most used and most important technology in Industry 4.0, when applied to the logistics operations of ports, is the Internet of things (IoT), which is present in 82% of the studies selected for analysis, followed by big data analytics with 50%, as can be seen in Figure 6.

An example of the application of the IoT in port logistics is in the case of the port of Hamburg, with the use of sensors to manage ship and vehicle traffic in the port to help managers monitor their movements, thereby reducing carbon emissions and increasing the efficiency of port operations (de la Peña-Zarzuelo et al., 2020).

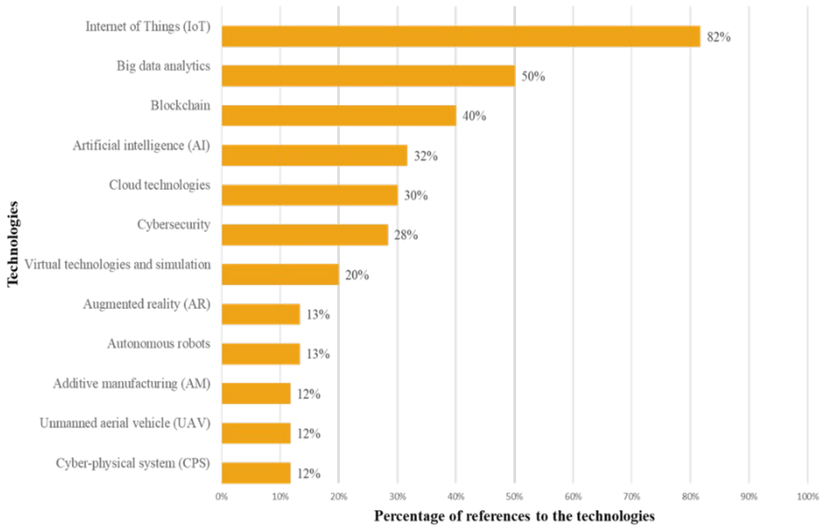

Figure 6. Percentage of references found to the 12 most important technologies of Industry 4.0 in the studies under analysis

In addition to the 12 technologies, applications of other concepts were found, including machine learning (Yan, Wu, Jin, Cao & Wang, 2022); 5G (Wang, Potter, Naim, Vafeas, Mavromatis & Simeonidou, 2022); AGVs (automated guided vehicles) (Watfa & Karmadi, 2019); physical Internet (Fahim, Rezaei, Jayaraman, Poulin, Montreuil & Tavasszy, 2021); digital twins (Agatić & Kolanović, 2020); RFID (radio-frequency identification) (Rajabi et al., 2019); and GPS (global positioning system) (Heilig & Voß, 2017), among others.

The content of the articles was analyzed with VOSviewer, showing which words were most used in the articles (from the analysis of the titles, abstracts, and author's keywords). Figure 7 illustrates the resulting information by means of a map. The size of the circles represents the number of times the words appear throughout the papers (the larger the circle size of the concept, the more often it appears). Thus, the words that appear most frequently are: "Internet of things," "ports and harbors," "digital transformation," "smart port," "supply chain," "sustainable development," "big data" and "digitalization."

As mentioned before, the most predominant technology employed in the digitization of seaport logistics is the Internet of things. This is supported by the VOSviewer visualization in Figure 7, where the significant frequency of the key term "Internet of things" is evident from the sizeable diameter of the circle.

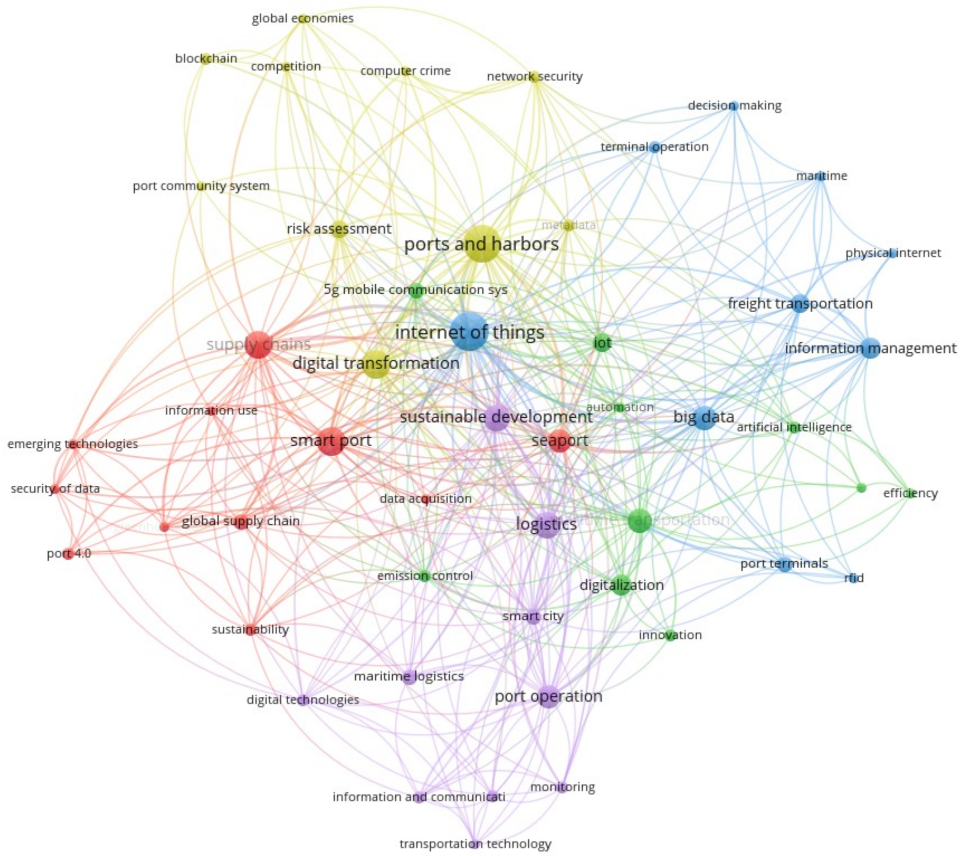

Figure 7. VOSviewer: Result—most frequent keywords

3.2.2. Benefits and Opportunities of Digital Transformation in Seaports

After a literature review, it could be concluded that there is a high number of authors that recognize the importance of digital transformation in seaports. Therefore, the objective of this section is to explain some of the benefits and opportunities found in light of the studies analyzed, grouped in the following table (Table 5).

Benefits and opportunities	Sources
1. Improved efficiency of the logistic chain, operations, and processes; reduced logistic and operation costs of the ports;	Durán, Fernández-Campusano, Carrasco, Vargas & Navarrete, 2021; Tardo, Pagano, Antonelli & Rao, 2022; Min, 2022; Sarkar, Shankar & Kar, 2022; Chuprina, Zahorodnia, Petrenko, Britchenko & Goretskyi, 2022; Paulauskas, Filina-Dawidowicz & Paulauskas, 2021; Costa, Lacalle, Llorente, Le Brun, Ptsikas, de Marco et al., 2021; Tijan, Jović, Aksentijević & Pucihar, 2021; López-Bermúdez, Freire-Seoane, Pais-Montes & Lesta-Casal, 2020; Jović, Kavran, Aksentijevic & Tijan, 2019; Heilig, Schwarze & Voß, 2017; Baştuğ, Arabelen, Vural & Deveci, 2020; Philipp, Prause, Olaniyi & Lemke, 2021; Gonzalez, Koivisto, Mustonen & Keinänen-Toivola, 2021; Kusuma & Tseng, 2020; Yau et al., 2020; M'hand, Boulmakoul, Badir & Lbath, 2019; Ferretti & Schiavone, 2016; Fruth & Teuteberg, 2017; Russo & Musolino, 2021
2. Allows the development of environmental sustainability (some authors state that the level of smart and sustainable port can be simultaneously reached);	Yen, Huang, Lai, Cho & Huang, 2022; Tardo et al., 2022; Philipp et al., 2021; Rajabi et al., 2019; Min, 2022; Di Vaio & Varriale, 2019; Jović, Tijan, Vidmar & Pucihar, 2022; Del Giudice, Di Vaio, Hassan & Palladino, 2022; Costa et al., 2021; Inkinen, Helminen & Saarikoski, 2021; Gonzalez et al., 2021; Kusuma & Tseng, 2020; Lacalle, Llorente & Palau, 2019; Douaioui et al., 2018; Fruth & Teuteberg, 2017; Russo & Musolino, 2021

Benefits and opportunities	Sources
3. Allows for better decision-making based on accessing and processing a large amount of data in real-time and forecasting capability; increased ability to adapt to the constantly changing port environment;	Tardo et al., 2022; Tijan et al., 2021; Min, 2022; Sarkar et al., 2022; Zaychenko, Smirnova, Gorshechnikova & Piminov, 2021; Jović et al., 2019; Heilig, Schwarze et al., 2017; Durán et al., 2021; Di Vaio & Varriale, 2020; Jović, Tijan, Brčić et al., 2022; Fernández et al., 2017; Heilig & Voß, 2017
4. Improved flow of information between the stakeholders;	Tardo et al., 2022; Tijan et al., 2021; Min, 2022; Di Vaio & Varriale, 2019; Jović et al., 2019; Baştuğ et al., 2020; Yau et al., 2020; Sarabia-Jacome, Palau, Esteve & Boronat, 2020; Heilig & Voß, 2017
5. Helps to improve the port's competitiveness;	Rajabi et al., 2019; Boullauazan et al., 2022; Paulauskas et al., 2021; Costa et al., 2021; Jović, 2019; López-Bermúdez et al., 2020; Jović et al., 2019; Heilig, Schwarze et al., 2017; Baştuğ et al., 2020; Lesniewska, Ani, Carr & Watson, 2019; Yau et al., 2020; Heilig, Lalla-Ruiz & Voß, 2017; Russo & Musolino, 2021
6. Improved seaport service quality; improved quality of logistics and transport processes;	Agatić & Kolanović, 2020; Rajabi et al., 2019; Philipp et al., 2021; Gonzalez et al., 2021; Kusuma & Tseng, 2020
7. Improved usage of labor, resources, and space;	Min, 2022; Del Giudice et al., 2022; Zaychenko et al., 2021; Philipp et al., 2021; Al-Kaderi, Koulali & Rida, 2019
8. Enables customer service customization, and efficiency in response time; enables customer retention (loyalty);	Zaychenko et al., 2021; Rajabi et al., 2019; Baştuğ et al., 2020; Di Vaio & Varriale, 2020; Kassou, Bourekkadi, El-Imrani, Boulaksili, Aharouay, Ourdi et al., 2021; Min, 2022
9. Development of qualified workers and new job positions;	Zaychenko et al., 2021; Rajabi et al., 2019; Tijan et al., 2021
10. Enabled reduction of human errors.	Inkinen et al., 2021; Yu, Murray, Fang, Liu, Peng, Solgi et al., 2022; Min, 2022

Table 5. Benefits and opportunities of digital transformation in seaports

3.2.3. Challenges of Digital Transformation in Seaports

Each of the seaports faces different problems, and the digital transformation can be a long and challenging process (Jović et al., 2019; Mazzarino, Braidotti, Cociancich, Bottin, La-Monaca, Bertagna et al., 2019). Table 6 presents some barriers to the implementation of digital technologies faced by seaports, found in the previously selected studies.

Challenges	Sources
1. Increasing risk of cyber-attacks due to the growing use of new technologies;	Tijan et al., 2021; Min, 2022; Nguyen et al., 2022; Lesniewska et al., 2019; Chuprina et al., 2022; Costa et al., 2021; Zaychenko et al., 2021; de la Peña-Zarzuelo et al., 2020; Rajabi et al., 2019; Heilig, Schwarze et al., 2017; Durán et al., 2021; De Albuquerque et al., 2022; Jović, Tijan, Brčić et al., 2022; Inkinen et al., 2021; Gunes, Kayisoglu & Bolat, 2021; Yau et al., 2020; Fabarius as cited in Fruth & Teuteberg, 2017
2. Challenge of connectivity and data sharing between different stakeholders, due to the existence of heterogeneous and incompatible information systems;	Tijan et al., 2021; de la Peña-Zarzuelo et al., 2020; Kumar as cited in Jović, Tijan, Brčić et al., 2022; Acciaro & Sys, 2020; Costa et al., 2021; Duvallet et al. as cited in Rajabi et al., 2019; Heilig, Schwarze et al., 2017
3. High investment in and implementation costs of these technologies and workers who know how to use them;	Tijan et al., 2021; Di Vaio & Varriale, 2019; de la Peña-Zarzuelo et al., 2020; Min, 2022; Rajabi et al., 2019
4. High risks concerning the implementation of emerging technologies and the uncertain return on investment;	Tijan et al., 2021; Min, 2022; Heilig, Schwarze et al., 2017

Challenges	Sources
5. Lack of understanding of what should be digitized first;	Tijan et al., 2021
6. Lack of digitally skilled labor and qualified labor (needed to train the employees);	Tijan et al., 2021; Di Vaio & Varriale, 2019; Boullauazan et al., 2022; Zaychenko et al., 2021; Henesey, Lizneva, Philipp, Meyer & Gerlitz, 2020; Heilig, Lalla-Ruiz et al., 2017; Sarkar et al., 2022
7. Resistance by employees and managers to change;	Tijan et al., 2021; Rajabi et al., 2019; Inkinen et al., 2021; Heilig, Lalla-Ruiz et al., 2017; Heilig, Schwarze et al., 2017
8. Government policies in countries that are not open to innovation; sometimes the laws themselves require paper to exchange data;	Molavi, Lim & Race, 2020; Jović, 2019
9. Stakeholders can refuse to share information and adjust their processes to ensure the smooth functioning of digital technologies;	Boullauazan et al., 2022; Acciaro & Sys, 2020
10. Lack of understanding of which technologies are appropriate to use;	Tardo et al., 2022; Karaś, 2020
11. Reducing the need for manpower, as the skills needed by workers are taken over by automated equipment;	Bright as citted in Min, 2022; Zaychenko et al., 2021; Rajabi et al., 2019; Berg & Hauer as cited in Fruth & Teuteberg, 2017
12. Possible failure in technological equipment.	Zaychenko et al., 2021; Nguyen et al., 2022; Inkinen et al., 2021

Table 6. Challenges of digital transformation in seaports

3.2.4. World's Smartest Port Cities

Although digital transformation is almost a requirement for ports to move forward nowadays, it should be noted that each port is a specific house, with its own characteristics. This makes it normal for the level of digitalization to vary between different ports, as this depends on the size of the port, its traditions, the type of cargo that is handled, and so on (Paulauskas et al., 2021).

Furthermore, it is important for a port to feel the need to become "smarter" through the need to better understand and adapt to market requirements and develop integration with stakeholders (such as the cities where they are located and the port logistics operators), and not just due to the pressure they feel through benchmarking with smart port models (Henríquez, Martínez de Osés & Martínez-Marín, 2022).

The concept of "smartness" in the seaport field is defined by some authors as the level of intelligence of a given port, that is, a smart port has a high level of "smartness," and each port has its own level of "smartness" according to its own needs and characteristics. This "smartness" is linked to the amount of technology adopted by the port, the quality of customer service (market satisfaction at the port level), and the improvement of the economic, social, and environmental area (Gao et al., 2022; Henríquez et al., 2022; Rajabi et al., 2019).

Among the studies analyzed it was found that several authors suggest that port cities are considered leaders in the digitalization of their logistics (the smartest port cities with a high level of "smartness") (Henríquez et al., 2022; Molavi et al., 2020). D'Amico, Szopik-Depczyńska, Dembińska and Ioppolo (2021) mention that some of the leading ports in intelligent logistics are: Rotterdam, Amsterdam, Los Angeles, Antwerp, Montreal, Hamburg, Hainan, Valencia, Stockholm, and Singapore. Chuprina et al. (2022) highlighted the ports of Rotterdam, Qingdao, Singapore, Busan, Xiamen, Shanghai, Antwerp, Hamburg, Tilbury, and Long Beach. Henríquez et al. (2022) emphasize the smart ports considered as benchmarks, such as Singapore, Hamburg, and Rotterdam. The ports of Hamburg and Singapore are also underlined as smart ports by Rajabi et al. (2019) and Di Vaio & Varriale (2019). Baştuğ et al. (2020) pointed out the 10 most innovative ports, namely: Rotterdam, Felixstowe, Singapore, Hamburg, Busan, Le Havre, Hong Kong, Shanghai, Barcelona, and Jebel Ali.

4. Discussion and Conclusion

Nowadays it is essential to adapt to the context in which we live, and digitalization is one aspect of that adaptation. Digital transformation is increasingly essential for ports, leveraging them to another level of competitive advantage, which can be corroborated by the growing number of publications in the literature since 2018.

As stated by D'Amico et al. (2021), the integration of smart technologies with the physical infrastructures of the port and its surroundings is capable of leveraging the logistics of port cities, and several technology companies are investing in port cities, such as IBM, Cisco, Huawei, SAP, etc.

These conclusions allow us to assess the importance of this study conducted on Industry 4.0 technologies in port logistics. After the analysis, it could be understood that the most used technology for the digitalization of seaport logistics is the Internet of things. The same conclusion could be arrived at from the VOSviewer map in Figure 7, since the frequency of the key term for the "Internet of things" is comparable (large diameter of the circle). Ferretti & Schiavone also present the same conclusion, stating that "Transportation and logistics are one of the main domains of application for IoT" (Atzori as cited in Ferretti & Schiavone, 2016). Additionally, the frequency for the key term "big data" is also comparable to the others, which leads us to conclude that, as in the graphic of Figure 6, it is the second most used technology in this field.

This study presents some impacts of digitalization on seaports. Of the benefits found, those that are most referenced are the increased efficiency of the logistic chain, the reduced environmental impact, and the increased competitiveness, among others. This section (Benefits and Opportunities of Digital Transformation in Seaports) fills the gap stated by Boullauazan et al. (2022) about the benefits of making the port smart, to inform port stakeholders and encourage them to grow to another level.

As concerns challenges, the most referenced one is vulnerability to cyber-attack that a port presents after adopting digital technologies. This section (Challenges of digital transformation in seaports) fills the gap stated by Molavi (2020) about the lack of exploitation of the challenges of digital transformation. However, curiously, from this universe of studies found, few articles are concerned about the impacts of smart ports on the human factor and on the cities and municipalities where the port is located, which is also a gap stated by Molavi (2020).

This study contributes alongside the studies by Tijan et al. (2021) and D'Amico et al. (2021) on the impacts of smart ports and the digital transformation occurring in ports.

To conclude this study, Table 7 shows the main findings for each of the eight research questions.

To answer the main question of this article "What contributions and challenges of Industry 4.0 are expected to improve logistics towards smart seaports?", a systematic literature review was performed, through which it was possible to ascertain that this is an important and fashionable topic nowadays that presents not only advantages but also challenges and that there are various ports that are already considered as smart ports. Thus, this paper presents two contributions, theoretical and practical, which can help both academia and practitioners:

1. Theoretical—which consists of increasing knowledge and clarification of the impacts of digital transformation in seaports;
2. Practical—which aims to encourage other ports to become smart.

This study presents some limitations, as it bases the results presented only on the evidence of the literature. Although it is our intention that the review process should be systematic and impartial, the process of choosing the studies to be included and the respective interpretation of their results can be susceptible to bias, which constitutes a limitation. In addition, the literature is constantly changing, and this is a constantly evolving topic, so a systematic literature review can quickly lose its topicality. As future work, the intention is to investigate the practical context of the ports that are already considered smart, and, consequently, analyze and go into more detail about the impacts of smart ports on the human factor and on the cities and municipalities where the port is located.

Question	Findings
i. How has the topic progressed over the years?	The trend shows an ascending trajectory in the volume of studies since 2018. This upsurge in academic publications indicates intensifying curiosity and focus within the scholarly circle on the digital transformation within the sphere of port logistics. Furthermore, technological advancements may also play a significant role in this trend and its progression.
ii. Which are the most influential countries in this field?	Analysis of the studies showed that authors with German affiliations have contributed the most, followed by Spanish and Italian authors. The first article published among the selected authors dates from 2011 and is by a German author, indicating Germany's early contribution to the academic community in this field, perhaps because it was the country where the concept of Industry 4.0 first emerged.
iii. Which are the most influential journals in this area?	IEEE Access and Research in Transportation Business & Management are the journals that present the greatest number of papers in this area of the digital transformation of logistics in seaports.
iv. Which are the most respected authors in this area?	Jović M., Palau C. E., Tijan E., Voß S., and Heilig L. constitute the most influential authors, having carried out joint work with different peers.
v. Which is/are the Industry 4.0 technology(ies) that most influence port logistics?	The Internet of things (IoT) stands out as the predominant and most significant technology in Industry 4.0 applied to port logistics, featuring in 82% of the studies analyzed, while big data analytics appears in 50% of the cases.
vi. What are the benefits and opportunities of digital transformation in ports?	Digital transformation in maritime ports offers numerous benefits and opportunities. 1. It improves the efficiency of the logistics chain and operational processes, significantly reducing costs; 2. It enhances decision-making capacity through access to large volumes of data and processing of it in real time; 3. It improves the flow of information between stakeholders; 4. It increases the competitiveness of ports; 5. It raises the quality of services provided; 6. It optimises the use of labor, resources, and space; 7. It personalizes customer service; 8. It reduces human error; 9. It promotes the development of skilled workers and the creation of new professional positions, contributing to social sustainability; and 10. It strengthens environmental sustainability by transforming the port into a smart port.
vii. What challenges are the most pointed out in this transition?	The digital transformation of maritime ports faces multiple challenges, for example: 1. Increased risk of cyber-attacks with the adoption of new technologies; 2. Connectivity and data sharing issues due to incompatible information systems, complicating system integration; 3. High investment and implementation costs of new technologies; 4. The need to train skilled workers to use these technologies; 5. Risks associated with adopting emerging technologies and uncertain financial returns; 6. Resistance to change from employees and managers; 7. Government policies that do not favor innovation in maritime ports; 8. Reluctance of stakeholders to share information and adjust processes; 9. Uncertainty about which technologies to apply; and 10. Possibility of technological equipment failure.
viii. Where and which ports are already applying Industry 4.0 technologies?	Some of the ports mentioned in the studies analyzed that are leaders in smart logistics are: Rotterdam, Amsterdam, Los Angeles, Antwerp, Montreal, Hamburg, Hainan, Valencia, Stockholm, Qingdao, Tilbury, Shanghai, Barcelona, Felixstowe, Busan, Le Havre, Hong Kong, Jebel Ali and Singapore.

Table 7. Findings for each of the eight research questions

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Annex

Annex A - Analysis of which of the 12 most important technologies are mentioned in each of the studies (cont.).

Sources / I4.0 Technologies	Internet of things	Cyber-physical system (cps)	Big data analytics	Artificial intelligence	Cloud technologies	Blockchain
(Yan et al., 2022)				x		
(Jackiva, Brauner, Vesjolijs & Petrovs, 2022)	x		x	x	x	x
(Nguyen et al., 2022)				x		x
(Min, 2022)	x	x	x	x	x	x
(Henríquez et al., 2022)	x		x	x	x	x
(Yu et al., 2022)	x	x		x		
(Song et al., 2022)	x					
(Jović, Tijan, Brčić et al., 2022)	x			x		x
(Gao et al., 2022)	x		x	x	x	
(De Albuquerque et al., 2022)		x				
(Wang et al., 2022)					x	
(Tardo et al., 2022)	x					x
(Yen et al., 2022)	x		x	x	x	
(Idrissi et al., 2022)	x					
(Zhu & Du, 2022)	x		x			
(Chuprina et al., 2022)	x		x	x		x
(Barasti, Troscia, Lattuca, Tardo, Barsanti & Pagano, 2022)	x				x	
(Imeri, Agoulmine, Khadraoui & Khadraoui, 2021)	x		x			x
(Haidine, Ait-Allal, Aqqal & Dahbi, 2021)	x					
(Inkinen et al., 2021)	x		x	x		x
(Paulauskas et al., 2021)	x		x	x	x	x
(Costa et al., 2021)	x		x	x		
(Fahim, An, Rezaei, Pang, Montreuil & Tavasszy, 2021)						x
(Vano, Lacalle, Molina & Palau, 2021)	x		x			
(D'Amico et al., 2021)	x		x	x	x	x
(Gunes et al., 2021)		x				
(Gonzalez et al., 2021)						
(Fahim, Rezaei et al., 2021)	x		x	x		x
(Tesse, Baldauf, Schirmer, Drews & Saxe, 2021)	x					
(Philipp et al., 2021)	x					
(de la Peña-Zarzuelo et al., 2020)	x	X	x	x	x	x
(Koroleva, Sokolov, Makashina & Filatova, 2020)	x		x			

Sources	I4.0 Technologies	Internet of things	Cyber-physical system (cps)	Big data analytics	Artificial intelligence	Cloud technologies	Blockchain
(Philipp, 2020)							x
(Cho & Lee, 2020)						x	
(Kusuma & Tseng, 2020)		x					
(Tsiulin, Reinau, Hilmola, Goryaev & Karam, 2020)		x					x
(Henesey et al., 2020)		x					x
(Agatić & Kolanović, 2020)		x			x	x	x
(Yau et al., 2020)		x	x	x			x
(Sarabia-Jacome et al., 2020)				x			
(Koroleva et al., 2019)		x			x		
(Al-Kaderi et al., 2019)		x		x			
(Jović et al., 2019)		x					
(Rajabi et al., 2019)		x		x		x	
(Lesniewska et al., 2019)		x					
(Lacalle et al., 2019)		x				x	
(Watfa & Karmadi, 2019)		x					
(Fernández, Suárez, Trujillo, Domínguez & Santana, 2018)		x		x			
(Fernández et al., 2017)		x		x			
(Ferretti & Schiavone, 2016)		x					
(Shi, Tao & Voß, 2011)		x					
(Baştuğ et al., 2020)		x	x	x		x	
(Durán et al., 2021)		x		x			x
(Kassou et al., 2021)							x
(Heilig & Voß, 2017)		x		x		x	
(Douaioui et al., 2018)		x		x			
(Tijan et al., 2021)		x		x		x	x
(Di Vaio & Varriale, 2019)		x		x			x
(Fruth & Teuteberg, 2017)		x		x		x	
(Russo & Musolino, 2021)		x		x	x		x

Annex A - Analysis of which of the 12 most important technologies are mentioned in each of the studies.

Sources	I4.0 Technologies	Autonomous robots	Unmanned aerial vehicle (uav)	Additive manufacturing (am)	Augmented reality (ar)	Virtual technologies & simulation	Cyber security
(Yan et al., 2022)							
(Jackiva et al., 2022)						x	x
(Nguyen et al., 2022)						x	x
(Min, 2022)		x					x

Sources	I4.0 Technologies	Autonomous robots	Unmanned aerial vehicle (uav)	Additive manufacturing (am)	Augmented reality (ar)	Virtual technologies & simulation	Cyber security
(Henríquez et al., 2022)						x	
(Yu et al., 2022)							
(Song et al., 2022)							
(Jović, Tijan, Brčić et al., 2022)				x			x
(Gao et al., 2022)							
(De Albuquerque et al., 2022)							x
(Wang et al., 2022)						x	
(Tardo et al., 2022)							x
(Yen et al., 2022)							
(Idrissi et al., 2022)		x					
(Zhu & Du, 2022)							
(Chuprina et al., 2022)		x		x	x		x
(Barasti et al., 2022)					x		
(Imeri et al., 2021)							
(Haidine et al., 2021)			x				
(Inkinen et al., 2021)		x					x
(Paulauskas et al., 2021)		x	x		x		
(Costa et al., 2021)							x
(Fahim, An et al., 2021)							
(Vano et al., 2021)						x	
(D'Amico et al., 2021)		x	x	x	x		x
(Gunes et al., 2021)							x
(Gonzalez et al., 2021)							
(Fahim, Rezaei et al., 2021)							
(Tesse et al., 2021)						x	
(Philipp et al., 2021)							
(de la Peña-Zarzuelo et al., 2020)		x	x	x	x	x	x
(Koroleva et al., 2020)			x				
(Philipp, 2020)							
(Cho & Lee, 2020)						x	
(Kusuma & Tseng, 2020)							
(Tsiulin et al., 2020)							
(Henesey et al., 2020)							
(Agatić & Kolanović, 2020)				x	x		
(Yau et al., 2020)						x	x
(Sarabia-Jacome et al., 2020)							
(Koroleva et al., 2019)			x	x	x		
(Al-Kaderi et al., 2019)							
(Jović et al., 2019)							

Sources	I4.0 Technologies	Autonomous robots	Unmanned aerial vehicle (uav)	Additive manufacturing (am)	Augmented reality (ar)	Virtual technologies & simulation	Cyber security
(Rajabi et al., 2019)							
(Lesniewska et al., 2019)							x
(Lacalle et al., 2019)						x	
(Watfa & Karmadi, 2019)							
(Fernández et al., 2018)							
(Fernández et al., 2017)							
(Ferretti & Schiavone, 2016)							
(Shi et al., 2011)							
(Baştuğ et al., 2020)		x	x	x	x	x	x
(Durán et al., 2021)							
(Kassou et al., 2021)							
(Heilig & Voß, 2017)							
(Douaioui et al., 2018)							x
(Tijan et al., 2021)							
(Di Vaio & Varriale, 2019)							x
(Fruth & Teuteberg, 2017)						x	
(Russo & Musolino, 2021)							