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The Challenges of Augmented Reality in Logistics: A Systematic Literature Review

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ABSTRACT

The proliferation of Industry 4.0 technologies has evoked a new interest in Augmented Reality (AR). Although the concept dates back to several years ago, AR techniques have been identified as a major contributor to logistics activities. The merge of real and virtual objects in logistics scenes could optimize several processes, drive more flexibility, and increase operational efficiencies. However, these benefits do not come without particular challenges. Therefore, the main objective of this paper is to investigate the barriers of AR adoption to logistics. Although AR has gained growing attention in the recent literature, there is a paucity of review research that studies and captures the dynamic nature of this topic. To fill this information gap and respond to the interest of academics and practitioners in AR, we conducted a systematic literature review that provides a timely and up-to-date synthesis of the state of knowledge. Selected 43 papers were classified into three categories of challenges namely, the technical, the organizational, and the ergonomics challenges. The review set to answer the following two questions: (1) What are the factors that inhibit the firm from adopting AR in its logistics processes? and (2) What are the challenges resulting from applying AR to logistics and business processes?

***Keywords*:** Augmented Reality, Industry 4.0, Logistics, Technical Challenges, Organizational Challenges, Ergonomics Challenges

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1. INTRODUCTION

Logistics is a boundary-spanning activity [1]. In the supply chain context, logistics is fundamentally concerned with managing the upstream and downstream relationship with exchange partners to deliver customer value at the least cost to the chain as a whole [2]. An efficient logistics system lies in the proper management of the flow of materials and finished goods from the production line to the customer, and that the right product is delivered to the right customer in the right place at the right time [3]. This implies that logistics is a strategic organizational function that could enable the business to achieve and maintain a competitive advantage. Regardless of its scope, it is crucial to realize that the process of ensuring efficient and cost-effective flows of raw materials and finished goods is critical for successful supply chain management [4]. Today, logistics accounts for a substantial amount of a company's manufacturing costs. As such, the logistics costs represent a significant portion of the overall supply chain costs for a company, often exceeding 10 percent of business turnover [5]. For example, according to Bigness (1995) [6], it is common for US manufacturing firms to spend on logistics more than 30% of the cost of goods sold. This number makes logistics a critical advantage of competitiveness and a potential source of generating more business value. However, this goal can only be achieved through the optimization of logistics processes and the effective utilization of business resources [7]. In this context, the use of modern emerging technologies plays an important role and could affect the practice and significance of logistics management [8]. So far, technologies assist in streamlining several logistics activities and improve the efficiency of business processes.

In recent years, Augmented Reality (AR) has already brought several possibilities to logistics. The concept of AR was initially coined by Tom Caudell - a former Boeing researcher - in 1990 and the augmentation of the real world by virtual elements was tested in several applications in the late 1960s and 1970s [9]. The most widely accepted definition of AR was proposed by Azuma (1997) [10], who posited that AR is a state on reality virtuality continuum that requires the combination of real and augmented objects, the possibility of interacting in real time, and the registration (alignment) of real and virtual objects in a three-dimensional space. Unlike virtual reality which fully immerses the user and cut off from the real-world environment, AR superimposes virtual elements (e.g., objects, scenes, sounds, system hint information etc.) generated by the computer into the real environment, thus improving the realistic scene and the user's perception of the real world [11]. As a result of the evolutionary perspective following the emergence of Industry 4.0 [12], the interest in AR technologies is expected to rise exponentially and to reach USD 108 billion by 2021 and USD 162 billion by 2024 [13]. The industrial applications for AR are extensive. Some developed countries have already begun to explore the potentialities of AR in the future of smart factories [14]. The usefulness of AR has been demonstrated in significantly improving the planning of intralogistics processes [15]. It drives more flexibility in the planning of logistics systems and enables planners to react more efficiently to the market dynamics [16]. For instance, the designers of products would no longer be restrained by physical boundaries as they would have the ability to better visualize and flexibly manipulate three-dimensional product design parameters in real time. In order picking scenarios, warehouse operators equipped with AR devices such as head-mounted displays (HMDs) and smart glasses could benefit from AR visualisation and improved provision of content [17] to reduce dead times caused by looking, for example at a mobile data terminal (MDT), or a paper picking list used in conventional storages [18]. In addition, AR is a quantum leap in manufacturing activities and a key enabler for the smartisation of industrial settings and the next generation of advanced manufacturing. Various benefits cannot be disputed including the support of specific manufacturing tasks by providing the right timing of assembling components and moving materials [19], visually advising and guiding maintenance procedures [20-22], and creating an efficient and intuitive workplace for training and learning [23]. Moreover, applications of AR also include the optimization of transportation activities [24] and the engagement of customers in a pleasurable experiential marketing experience [25].

Although AR offers many opportunities in the field of logistics, the integration of this technology into organizational processes raises numerous issues that challenge its mainstream adoption and render the suitability of AR to business use cases questionable. Research studies highlighting the limitations of AR technologies in logistics are scarce. Most academics who studied AR in the context of logistics focussed on the capabilities of the technology and its implications on business processes while barely discussing the obstacles and complexities that might emerge from the incorporation of AR technologies in the organizational structure. To close this research gap and advance the knowledge in the field of AR, the primary aim of this paper is to investigate the challenges of applying AR to logistics.

The paper expects to answer the following research questions (RQs):

- RQ1: What are the factors that inhibit the firm from adopting AR in its logistics activities?
- RQ2: What are the challenges resulting from applying AR to logistics and business processes?

Aiming at answering these questions, we conduct a systematic literature review (SLR) [26, 27] to identify and analyse relevant publications. To the author' best knowledge, this is the first attempt to make an SLR of the state-of-the-art research and to elicit and comprehensively synthesize the challenges of AR in the context of logistics and supply chain management. We bring relevant insights to scholars and practitioners interested in gaining a deeper understanding of the constraining factors encountered by the firm when considering the adoption of AR solutions. Furthermore, our study identifies gaps in current research and thus advances research directions within the AR domain. The remainder of this paper is structured as follows. In section 2, we introduce the basic concepts of AR and review the potentials of the technology in logistic processes. In section 3, we describe our systematic approach based on [26, 27] to identify and analyse previous literature. Section 4 discloses the results and findings of the review of publications. Section 5 contains a detailed discussion answering the research questions above. The last section summarizes the paper and outlines the theoretical and managerial contribution, the shortcomings of the study, and the potential research directions, which could lead to further investigation and academic attention.

2. AUGMENTED REALITY IN LOGISTICS

2. 1. The concept of augmented reality

AR is an old concept that dates back to early 1900s when the author L. Frank Baum introduced the idea of using electronic glasses that overlay digital data onto the real world [28]. Later in 1950s, the American inventor and cinematographer Morton Heilig tried to expand the field of view given by the cinematic experience from 18% to 100% [29]. He considered the cinema as an activity that would have the ability to draw the viewer into the onscreen activity by taking in all the senses in an effective manner [30]. In 1962, he created a simulator called Sensorama which was designed to make the viewing experience immersive by enhancing the sensorial perception of the reality [31]. Sensorama was a device that gave users the experience of riding a motorcycle through 1950's Brooklyn [32]. After four years later, Ivan Sutherland invented a head-mounted display for merging computer-generated contents with reality [33]. With this invention it was possible to superimpose wireframe drawings of digital content over a real-world environment at real-time frame rates [34]. In 1990, Tom Caudell coined the term augmented reality while working for Boeing to develop an HMD system to help with wiring instruction for planes via the projection of plane schematics on boards at the factory [35]. To further unpack the concept, Milgram & Kishino (1994) [36] provide an effective representation of how reality and virtuality are juxtaposed (see figure 1). The subsequent milestone in the development of the AR field was carried out by Azuma (1997) [10] who is considered as one of the leading scholars in the field of AR technology. In his landmark overview on AR, Azuma (1997) [10] investigated the previous literature surrounding AR applications to medical, manufacturing, visualisation , path planning, entertainment, and military fields. Moreover, in his survey on AR, the author offered a comprehensive and widely accepted definition of AR, explicating the phenomenon as a virtual environment that mixes real and virtual and contains three main characteristics. These include the integration of virtual objects and the real world, the ability to interact with real objects in real time, and the registration of real and virtual elements in three dimensions (3D) [10]. The basis of AR is the possibility to combine the real and virtual objects into a single view.

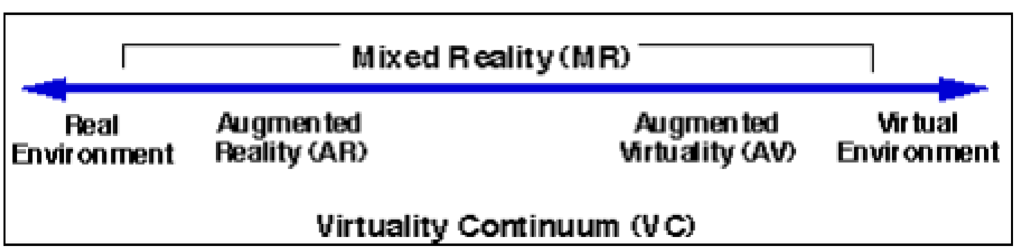

Figure 1. Simplified representation of virtuality-reality continuum [36]

AR differs from virtual reality (VR) which is a system that engages the users in a completely immersive experience within a synthetic environment isolated from the outside world [37]. Similarly, VR is a simulation of the real environment and aims at creating computer-generated virtuality. The term VR is widely used by popular media to depict worlds that only exist in a high-end user-computer interface [38]. This latter involves real-time simulation and interactions through multi-sensory channels (i.e., sight, hearing, touch, smell and taste) [39]. However, AR is a hybrid of virtual and real worlds that does not substitute human involvement but rather enhances the user's perception and ordinary capabilities and make them more useful and operative. The concept of AR should not be confused with mixed reality (MR) which is regarded as the area on the reality-virtuality continuum between reality, the unmodelled real environment, and VR, a pure simulation of the environment [36]. MR is different from AR and VR because the user is already engaged in an immersive experience that combines both virtual and real objects, provides more possibilities for interaction, and layers new strata for perception, learning, experimenting, and collaboration. As argued by Coutrix & Nigay (2006) [40], MR is an interaction paradigm that seeks to smoothly link the physical and data processing (digital) environments. In this paper, while we recognize the importance to clear the confusion surrounding these basic concepts, we will only focus on the study of the AR technologies from the perspective of logistics. AR is an innovative technology [41] that is constantly growing and promises to unlock several opportunities in the business processes. This is discussed in the next section.

2. 2. Possibilities of augmented reality in logistics

Logistics is a primordial part of manufacturing systems and it is a driver for enhancing the performance of the entire system and the effective utilisation of resources [7]. The proliferation of Industry 4.0 technologies challenges the boundaries of logistics which is no longer confined to the mere management of transport and storage of physical goods. Instead, logistics has been broadly extended to the coordination of all phases identified in the course of supply, production and sale of a company and its relation with supply chain partners [42]. To sustain this trend, AR technologies could dramatically revamp the nature and function of the logistics systems.

In the stage of *product planning*, AR plays an important role [43] in the initial conceptualization and development of products and breaks away from the conventional techniques that exhibit limitations in expressing complex and special materials and patterns [44]. The planners can be fully immersed in an unprecedented esthetic designing which is flexible, interactive, and feedback-driven. The increased visualization of AR systems could maximise the legibility of product models through the use of innovative tools such as 3D monitors, virtual caves, and head-mounted glasses [45]. These technologies allow the designer to interact with the virtual world, efficiently manipulate the product prototype, and facilitate the task of triangulating the different views of the product design and the arranging of virtual objects in 3D. For example, Januszka & Moczulski (2010) [45] proposed a system that is based on AR and helps the designer of machinery systems for developing more reliable mobile robots. Ng, Ong, & Nee (2010) [46], Ng et al. (2011) [47], and Luh et al. (2013) [48] developed an AR system to support a more inclusive and participatory design process by directly involving customers. With the fusion of virtual and real objects in the same environment, designers could offer customers with a tool to create, visualise and contextualise objects. It is arguably therefore that AR represents a tool to control the dialogue between the designer, the system and the customer, if included. Previous research confirms that AR techniques improve the perception of designers and provide a deeper understanding of the product development that would be not possible to achieve with the conventional computer-assisted design (CAD) systems [49]. Benefits of applying AR to the product planning and design activities also involve the simplification of the design process, reduction of both time and costs necessary for the development of the product, and the mitigation of possible errors that can occur in further advanced stages.

An initial step for improving the *warehousing activities* lies in the effective design of facility layout [50–53] and the efficient order picking processes [54–56]. In this regard, the capabilities of AR could improve the planning and design of facility layout, which in turn helps to reduce the materials handling time and optimise the operational conditions in terms of productivity, flexibility, and adaptability. The visualisation enabled by AR technologies provides a comprehensive description of the facility layout, the dimensions of the warehouse building, and the space allocations. An example is found in the study of Jiang & Nee (2013) [57] who developed an AR-based tool for enhancing workplace design planning. The proposed system harnesses AR technologies to assess the layout criteria and constraints depending on available existing facilities and to evaluate new facility layout plans. The immersive and intuitive nature of AR motivates Kokkas & Vosniakos (2019) [58] to develop an application to factory layout assessment which allows the user to access and navigate a set of alternative layouts designs containing the actual equipment and the ones to buy in the future.

More relevant to warehousing tasks is the ability of AR techniques to provide superior performance in *order picking processes* [59]. As such, AR could be used to expand the field of view of the order picker, thus ensuring more visibility, flexibility, and guidance. In this context, Guo et al. (2014) [60] noted that displaying the next item to pick on HMD or on a display mounted on the cart outperforms picking using lists or pick-by-light, where the flashing of an LED or small lamps -attached to storage compartments- signals the picking location. The AR-based order picking is tested in the study of Reif & Günthner (2009) [61] who proposed a pick-by-vision system and found that AR enhances information visualisation and increases the performance of order picking processes on a big scale. AR could also relieve the warehouse operator and increase the concentration and attention level during order picking. For example, the pickers equipped with smart glasses could benefit from higher levels of flexibility and convenience by avoiding unnecessary head-movements [62] because the required information related to picking is displayed in the pickers' field of vision. As an illustration, Syncreon is among the first companies to deploy AR glasses in the logistics field and to consequently increase the overall picking performance and reduce the rate of errors [63].

The *manufacturing activities* have witnessed increasingly dynamic transformations and the production processes shift from being dominated by labour-intensive methods to heavily dependent on intelligent systems and new technologies. Here the incorporation of AR in manufacturing tasks is seen to offer scope for the renewal of manufacturing [64, 65]. More specifically, AR applications are not viewed as disparate and decoupled tools for assisting specific manufacturing tasks, but instead as totally fully integrated within the future factory marketplaces [19]. In *assembly*, AR technologies could help to reduce the complexity of the work, the time and costs necessary for assembling the cores to the product, and the intricacies related to the testing and quality inspection of the product. Illustrating this point, the global market leader in the logistics industry DHL has jointly worked with the automotive firm Audi to store and assemble its components [24]. The company leverages an AR system powered by artificial intelligence (AI) to optimise the assembly processes, reduce error rates, and provide intuitive ways to visualise the process and to generate an instruction for controlling each step of the work. In line with these objectives, Wang, Ong, & Nee (2016) [66] suggested a multi-modal AR assembly guidance system based on the captured data of user's behaviour and cognitiveness. The system is set to operationalize just-in-time guidance for the continuous manual assembly tasks. Makris et al. (2016) [67] drew on the intuitiveness of AR and provided a tool to support operators working with industrial robots for the assembly tasks. In the aerospace industry, the augmented assembly was proposed by Caudell & Mizell (1992) [68] to improve the workers' performance of manufacturing activities through the use of HMD technologies. Salonen & Sääski (2008) [69] proposed an AR-based system aimed at enhancing assembly tasks and allowing the worker to see additional graphical information superimposed on his/her view of the real world. Assembling operators can be instructed via graphical instructions, texts, symbols, and other virtual objects during their work. Similarly, Kollatsch et al. (2014) [70] developed an AR system to give dynamic instructions to operators in an assembly line. The outcomes of all these research work put emphasis on the potentials of AR solutions to provide a wide variety of configurations tailored to the workers' needs, overcome different complications in the process, and increase the overall efficiency in assembling activities.

Manufacturing maintenance is another area where AR could unfold its full potential. The interactive and intuitive nature of AR instructions and guides could substitute the long and complex maintenance manuals and documentations. To improve maintenance practices, for instance, Erkoyuncu et al. (2017) [20] proved that a system using a context-aware AR technique could provide adaptive operational support and improve the maintenance efficiency. The proposed system adapts with the available data and the competencies of the technicians without the necessity of having prior AR domain-specific knowledge. Similar to this work is the study of Zhu, Ong, & Nee (2013) [71] who proposed an authorable-context AR system (ACRAS) to assist the maintenance crews. The main goal of the system is to provide technicians with the means to interact with the AR contents actively, to rectify any incorrect AR contents caused by AR developers, and to help maintain and share the accumulated knowledge regarding the maintenance procedures of the equipment with other technicians. A knowledge-based AR for maintenance assistance system is developed in [72] to provide users with maintenance instructions. Considering the use of sensors pre-installed on printer, the proposed system can estimate the relative position of the user's head to the printer, retrieve the corresponding instruction and augment the information in the user's field of view through an HMD. Moreover, AR technologies could significantly simplify the maintenance tasks, ensure increased control of maintenance indicators, minimize costs while maximizing the availability and safety of the equipment. A discussion of these points is presented in work by Buckl et al., (2011) [73] who developed a tool for AR-based maintenance, primarily targeted to small and medium enterprises, to support the creation of AR-based workflows and their execution within a collaborative environment. Driving an elevated sense of collaboration in maintenance activities is another promise of AR. For example, Benbelkacem et al. (2013) [74] introduced an AR system for supporting remote maintenance operations in training and assistance services. The use of AR in the proposed model enables local repairs to view tasks to be performed directly aligned on the real working environment. A combined usage of AR with a wireless sensor network (WSN) and cloud computing is proven feasible for remotely carrying out maintenance through checking the status of the machine tools, calculating their remaining operating time between failures, and identifying the available windows of the machine tools [75].

In *selling and retailing*, AR is recognized as an essential enabler for digital marketing as it allows customers to visualise the surroundings with new digital imagery information [76]. AR enables the dynamic contextualization and real-time modification of context while manipulating users' interests by augmentations and diminishments [77]. As such, the customers may create and modify the geometry of virtual objects and register them to a particular product, so that the desired outcome can be produced by the manufacturer. This approach drives more product customization and responds to the global market trend, which is already shifted towards a higher level of product individualization [78]. Interestingly, the ability to personally design a product prototype and instantly engage in an interactive experience with the design is favourably perceived by customers [48]. For example, Mottura et al. (2003; 2007) [79, 80] developed an innovative shoe shop model where AR-based systems, Magic Mirror and Foot

Glove permit customers to digitally customize shoes, try on customized shoes, and then order their realization. Similar systems based on AR techniques for real-time visualization and customization of shoes were proposed in [48, 81]. The high visualization of AR technologies produces a better presentation of products. This is the reason why the company Audi is conducting a project that incorporates AR glasses in order to help customers configure their dream cars and look at their vehicles from all perspectives and in various surroundings [82]. Therefore, AR resulted in more integration and engagement of customers in the design phase of personalized products, enhancing the customers' perceptions towards the quality of the product and delivering an utterly pleasurable purchase experience.

3. METHODOLOGY

3. 1. Research protocol development

To answer the research questions, we conduct a systematic literature review methodology following the guidelines proposed in [26, 27]. An SLR is driven by a list of specific steps that guarantee the relevance of studies about a particular topic and the minimization of research errors and bias [26, 83]. This approach is used for the present study because of its transparency, completeness, and rigorous nature [84]. Moreover, the author undertook a review procedure which consists of an iterative cycle of identifying appropriate search keywords, surveying the relevant literature, and carrying out the analysis at the end [85]. A review protocol has been developed to define the whole procedures of the conducting stage and set the necessary actions to pursue [86]. Table 1 presents in detail the selection of search databases, the collection of publications, the filtering criteria, and the process of data extraction and synthesis.

Table 1. Research protocol

Research protocol	Details descriptions
Research online databases	Searches were conducted in 5 leading databases which were Scopus, Web of Science Core Collection, IEEE Xplore Digital Library (IEEE), ScienceDirect (Elsevier), and Springer Link (Springer).
Publication types	Only peer-reviewed literature was considered. The search was limited to publications including articles, books, book chapters, and conference proceedings. Apart from ensuring that the research originated from academic sources [87, 88], we intended to extend the literature base and obtain more insights by including besides to articles other publication types.
Language	To enlarge coverage, only publications in English were considered.
Date range	No specific date range was used to conduct the research.
Search fields	Titles, abstracts and keywords

Search keywords	• Scopus: 1st search: TITLE-ABS-KEY ("augmented reality" AND "supply chain*")/ 2nd search: TITLE-ABS-KEY ("augmented reality" AND "logistics") • Web of Science: TS = (("augmented reality" OR "augmented virtual reality" OR "virtual reality") AND ("supply chain*" OR "logistics")) • ScienceDirect: - 1st search: "augmented reality" AND "logistics"/ 2nd search: "augmented reality" AND "supply chain*" • Springer Link: Title: "augmented reality" AND alltext "logistics" • IEEE Xplore Digital Library: 1st search: (("Abstract" : "augmented reality") AND "Abstract" : "logistics")/ 2nd search: (("Abstract" : "augmented reality") AND "Abstract" : "supply chain") The results were organised in a datasheet and redundant publications were eliminated.
Inclusion criteria	Only publications that studied AR applications in the field of logistics were selected.
Exclusion criteria	Publications with a deep and pure technical focus were excluded.
Data extraction and monitoring process	Data extraction and monitoring process was facilitated by the qualitative data analysis software Atlas.ti version 8, which helped in publications classification and categorization.
Data analysis and synthesis	We used a content-analysis approach to address the research questions of the study from prior literature, drawing attention to the main knowledge gaps and future research directions in AR-oriented projects in the field of logistics.

Based on Alexander, Walker, & Naim (2014) and Pereira, Christopher, & Silva (2014) [89, 90]

3.2. Data collection

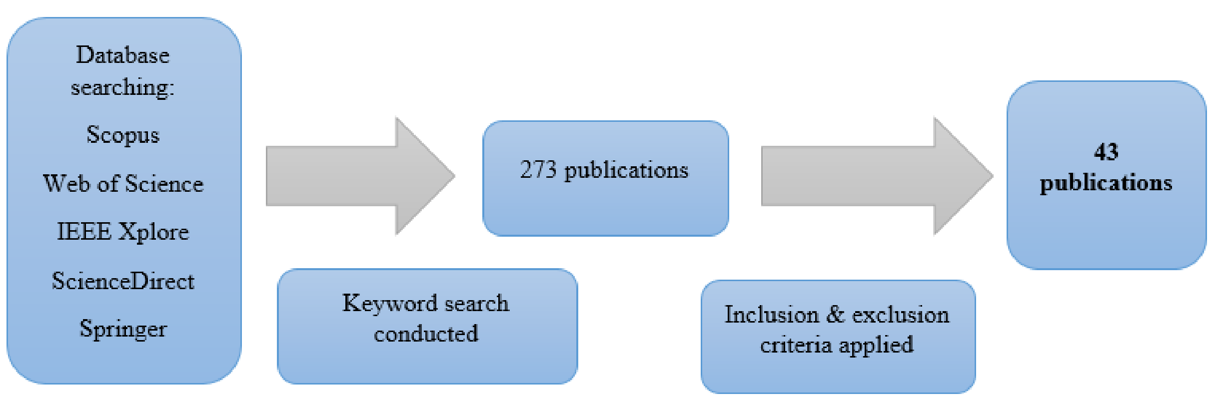

Figure 2. Schematic presentation of data collection

Based on the surveyed scientific databases, the initial search queries resulted in a total of 273 publications. To refine the results further, we removed the redundant papers that existed in the different databases. The publications were analysed according to the inclusion and exclusion criteria mentioned in table 1. The author screened the titles and abstracts for relevance, retaining only 137 publications for full-text reading. A total number of 43 studies were selected for final review. All relevant publications present the barriers to AR adoption in logistics. Figure 2 presents the process of data collection.

4. FINDINGS

4. 1. Publications by year and country

- *Publications by year*

The search was performed on 3 August 2019. Figure 3 presents the number of publications published by year, and derived from the execution of the research protocol. Despite the early existence of AR technologies as mentioned in section 2, papers discussing the challenges of AR in the context of logistics were almost published in this decade. This era corresponds to the emergence of Industry 4.0 which, more precisely, has been initiated in Germany at the Hanover Fair event in 2011, representing the start of the 4th industrial revolution [91]. To embark on the increasing digitization and automation of logistics, producers as well as suppliers are obliged to adapt infrastructure and education to embrace the Industry 4.0 technologies [92]. As a critical component of these technological panoply, a renewed interest in AR technologies has arisen to accelerate the value creation processes, support human performance, and bring the smart factory to a higher degree of operational efficiencies. However, the technological limitations of AR solutions existed prior to the appearance of Industry 4.0 in the corporate value chain and prevented AR to become an effective industrial tool in the past [93]. These challenges continue to prevail and evolve since a remarkable upward trend is observed from the year 2016 to 2019. The number of papers highlighting this fact has increased drastically from 2016 onward. It is observed that 28 out of 43 papers were published in the year 2016-2019, which reflects the scholars' growing attention to the issues hampering AR deployment in logistics.

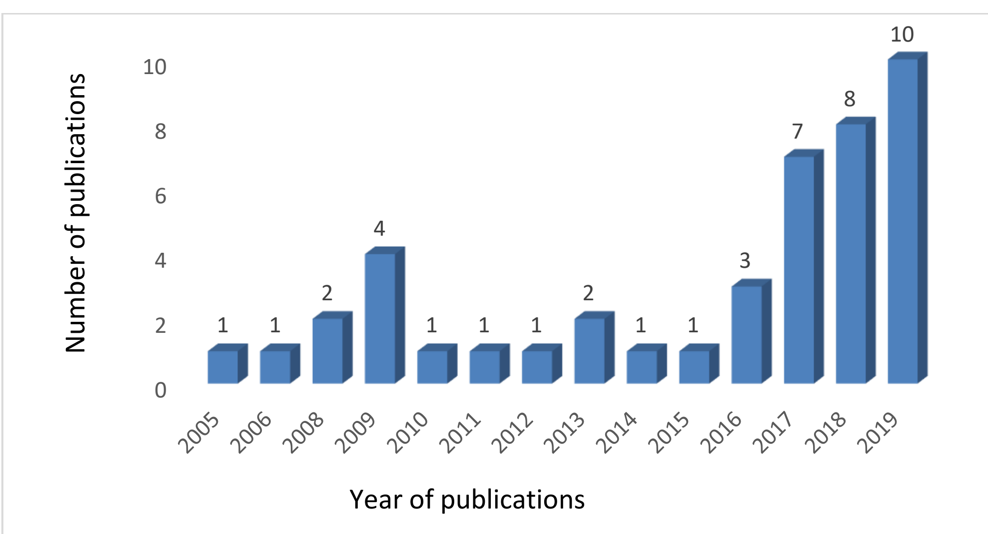

Figure 3. Year-wise publication details

- *Publications by country*

The authors' affiliations with various countries were retrieved, showing that the significant contribution to the AR literature in the context of logistics came from Germany, with 22 papers out of the selected 43 papers. This result is highly expected because Germany is the world's largest intralogistics exporter with EUR 15.8 billion, followed by China and the USA with EUR 13.4 billion and EUR 6.8 billion respectively [94]. Moreover, the manufacturing industry in the country is dominated by large corporations such as Audi, Volkswagen, Leica Microsystems, Siemens AG, to name a few, that devoted enormous investments for the development of their technological infrastructure and innovation capabilities. Moreover, Germany is the cradle of the Industry 4.0 initiative which aims to step further and establish smart industrial units and blend of projects involving the government, private sector, and academia [95]. During this process, new technological innovations such as AR technologies are the biggest auxiliaries. Australia and Italy are next in the list with contributions of six and three papers respectively. In fact, Australia has investigated mobile AR for a number of years [96, 97]. For example, several proofs of concepts went live in Australia and showed promising benefits of applying AR to logistics processes (e.g., order picking) [98]. Researchers benefitted from the thriving research and development activity in Italy, focusing on the application of information technologies and digital solutions in the field of communication and AR [99]. Countries with two relevant publications were namely, Belgium, Brazil, Latvia, New Zealand, UK, USA and India. Finally, the author was only able to locate one paper for each of the remaining countries.

Considering the analysis based on the continent of origin, European researchers were the most attuned to the challenges of AR in logistics, accounting for 70% of the total participations. To a lesser extent, relevant contributions for each of Asia and Oceania represented 22% of the total studies. Scholars from the Americas covered 8% of the studies highlighting the challenges of AR. Unfortunately, we were not able to locate studies from African academic institutions, which emphasizes that developing countries are still suffering from the digital gap and the lack of scholarly and practitioner interest in emerging AR technologies in the logistics activities.

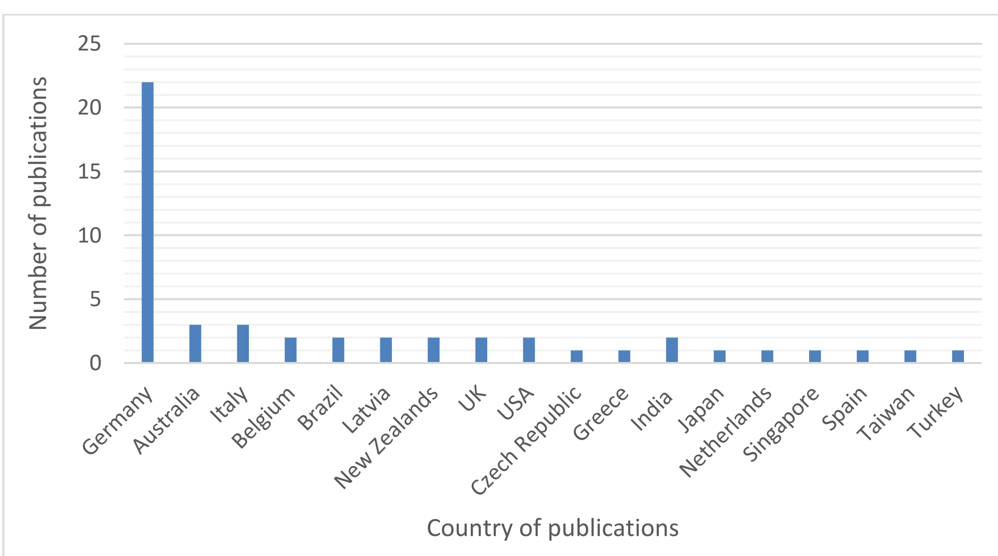

Figure 4. Country-wise publication details

4. 2. The analysis of publications

The selected 43 papers were journal and conference papers, as well as book chapters. Although some conference proceedings are classified as journals according to electronic database search, such as Procedia Computer Science in the ScienceDirect, those papers are still considered as conference papers. Therefore, around 28% of the included papers (12 papers) are identified as journal articles, 56% (24 papers) are categorized as conference papers, and the remaining 16% (7 papers) are book chapters. All the relevant articles were published in leading international journals.

According to the impact factors and journal titles, it was found that ten papers were published in journals with impact factors available in *Journal Citation Report- JCR* (2019). As can be seen in Table 2 each journal only contained a paper that is relevant to this present study except for Visual Reality (Springer). The field under study is not dominated by a single category of journals or disciplines. The content of the 11 journals covers different areas including manufacturing, industrial management, marketing, construction, and computer sciences. The SLR only located one article studying AR technologies in a top supply chain management and logistics journal (i.e., the International Journal of Production Research). This fact points out that AR technologies are still overlooked in the literature of logistics.

Table 2. Journal and number of papers published

Journals	Number of articles	Impact factor (2018)
Journal of the Academy of Marketing Science	1	9.36
Computers in Industry	1	4.769
Automation in Construction	1	4.313
Expert Systems with Applications (Springer)	1	4.292
Business & Information Systems Engineering (Springer)	1	3.6
Journal of Intelligent Manufacturing	1	3.355
International Journal of Production Research	1	3.199
Virtual Reality (Springer)	1	2.906
Computer Graphics Forum	1	2.373
Visual Computer (Springer)	2	1.415
International Journal on Interactive Design and Manufacturing	1	-

4. 3. Categorization of AR studies

To gain a deeper understanding of the challenges of applying AR technologies to logistics, we assigned papers to three main categories, namely, the technical challenges, the organizational challenges, and the ergonomics challenges. To assess these issues in a structured and systematic manner, the selected peer-reviewed publications and the respectively mentioned challenges are presented in the categories matrix in table 3.

Table 3. Categories matrix of the reviewed papers

Authors	The categories of challenges		
	Technical challenges	**Organizational challenges**	**Ergonomics challenges**
Behzadan et al. (2008) [100]	✓		
Berkemeier et al. (2019) [101]	✓	✓	✓
Bernhagen et al. (2019) [102]		✓	✓
Boccaccio et al. (2019) [103]			✓
Bräuer & Mazarakis (2019) [104]			✓
Cantieri et al. (2019) [105]	✓		
Chakraborty & Gupta (2017) [106]		✓	
Cirulis & Ginters (2013) [107]	✓		
Cirulis (2019) [108]	✓	✓	✓
Elbert & Sarnow (2019) [17]		✓	
Elia, Gnoni, & Lanzilotto (2016) [109]	✓	✓	✓
Esengün & İnce (2018) [21]	✓	✓	✓
Friemert et al (2019) [110]			✓
Ginters & Martin-Gutierrez (2013) [107]	✓	✓	
Gross et al. (2018) [112]	✓	✓	✓
Heinz, Dhiman, & Röcker (2018) [113]		✓	
Hilken et al. (2017) [114]	✓	✓	

Hořejší (2015) [115]	✓		
Kokkas & Vosniakos (2019) [58]	✓		
Luh et al. (2013) [48]	✓		
Mueck et al. (2005) [116]	✓		
Murauer & Gehrlicher (2019) [117]	✓	✓	✓
Murauer (2018) [62]	✓		
Murauer (2019) [119]	✓	✓	✓
Murauer, Pflanz, & von Hassel (2018) [62]		✓	✓
Pereira et al. (2016) [120]	✓		
Pierdicca et al. (2017) [121]	✓		
Reif & Günthner (2009) [61]	✓		
Reif & Walch (2008) [16]	✓	✓	✓
Reif et al. (2009) [61]	✓	✓	✓
Reif et al. (2010) [18]		✓	
Renner & Pfeiffer (2017) [123]		✓	
Ro, Brem, & Rauschnabel (2018) [124]	✓		✓
Sarupuri, Lee, & Billinghurst (2016) [125]	✓		✓
Schwerdtfeger et al. (2006) [126]	✓		
Schwerdtfeger et al. (2009) [59]	✓	✓	✓
Schwerdtfeger et al. (2011) [127]	✓	✓	✓
Soete et al., (2015) [128]	✓	✓	✓
Suzuki, Yokono, & Uehira (2009) [129]			✓
Uma (2019) [130]	✓	✓	✓
Vanderroost et al. (2017) [131]	✓	✓	✓
Vogel et al. (2017) [132]	✓		
Wang, Ong, & Nee (2018) [7]	✓		

Our analysis shows that the technical limitations of AR systems in the field of logistics were the most frequently indicated category. Studies that highlighted these key concerns were 32 papers, representing 74.41% of the total reviewed publications. This result suggests that that the fusion of real objects and virtual elements in a logistics environment is still hindered by the lack of appropriate devices, the low accuracy of tracking and registration of AR, and privacy issues etc. This was followed by 23 studies (53.48%) that highlighted the organizational barriers to AR adoption in logistics. Most of these challenges are related to the immaturity of AR technologies, the lack of understanding of this paradigm, the reluctance to change, and the cost probative nature of AR investments in logistics processes. The ergonomics is another equally important area that attracted researchers' interest to investigate the AR implications on the performance of logistics operators, their cognitive abilities, and their physical capabilities. Papers outlining ergonomics issues represented 51.16% of the total contributions to the literature. This suggests that the workers' health is a valuable and sensitive asset that needs to be at the core of concerns while considering the decision to adopt AR in the field of logistics.

Table 4. The distribution of challenges among the papers

	Number of papers	**Percentage**
Technical challenges	32	74.41%
Organizational challenges	23	53.48%
Ergonomics challenges	22	51.16%

5. REVIEW DISCUSSION

5. 1. The technical challenges

Despite their high potentials in logistics, AR technologies still raise several technical issues. According to Uma (2019) [130], object recognition is a key challenge in developing applications using AR. As such, there must be congruence between the virtual and real objects in order to achieve accuracy and high precision in the information display. Moreover, the manipulation of 3D models using AR systems such as in the traditional CAD systems is a complicated task because of the low accuracy of tracking and registration of AR systems [21]. In the 3D model positioning, the marker-based AR systems are not suitable since they operate over a short-distance range in which AR libraries should recognize the marker in video frames and place virtual elements on top of it. A compounding factor is the inability to see those markers due to light glare, light angle, camera rotation, vibration, video camera quality, etc. [107]. Although markerless systems based on the use of sensor data such as GPS coordinates is an appealing option to capture live scenes and support context-aware information delivery, the GPS-based AR tracking systems are only functional where there is a clear line of sight to the sky (i.e., outdoor conditions) [100].

Furthermore, software performance is constrained even with the latest hardware processing capacities [101]. The low performance of AR displays such as cameras does not allow to get a robust tracking of the scenes [121]. For instance, in outdoor logistics settings, AR devices require significant computational power which can respond to the increasing complexity of the modelled scenes, the display motion, and the outdoor industrial and logistics environments (e.g., poor light or open daylight conditions) [7]. Regardless of the algorithm selected, outliners, divergences, the colour scheme and diversity of the environment affect the localization quality and perception accuracy [130]. Thus, more advanced AR systems of environmental interpretation and extended tracking are required to increase the precision of real-time registration and tracking of people in a warehouse environment [107]. Unlike VR applications, the sensing and tracking requirements for AR systems are far more demanding and stringent because virtual elements need to be carefully aligned with objects in the real world. For example, in the study of Luh et al. (2013) [48], the rendering of shoe surfaces does not reflect the environmental lighting unless heavy computation is performed to be able to generate photo-realistic rendering with actual lighting condition. The small misalignments are sufficient to destroy the AR experience [128] and render the product customization process not viable and adaptive. Schwerdtfeger et al., (2009) [59] note that several issues have slowed down the usage of the pick-by-vision AR system. These include the wrong input device, the several system states to click through, the lack of direct back button, and the late display of the aisles to go to, the partial occlusion of the text by the augmentation, and the imperfect guiding by the AR visualisation. In warehouse picking operations, Schwerdtfeger et al. (2006) [126] point out that there is a lack of perfect mobile visualisation and depth perception when using HMDs for picking processes. In their system, subjects frequently picked items one row too high or too low resulting in inaccurate guidance. Esengün & İnce (2018) [21] agreed that the synchronization of the scenes on the views of the participants is a critical issue in the collocated or remote AR environments. It appears that the co-existence and 'collaboration' of real and virtual equipment is a challenging task as it requires high accuracy and real-time processing of different elements combined such as positioning targets on real objects using sensors that signal specific transition events [58]. As a result, a good dynamic registration implies that the user's viewpoint must be tracked at all times so that no jitter (i.e., delay) is noticed between real and virtual objects (Soete et al., 2015) [128].

The biggest problem of harnessing AR technologies in logistics and porting these systems from the research stage into the practical applications is the limited capabilities of hardware components, and particularly, the HMD and the tracking system [61]. The ubiquitous nature of AR applications also necessitates the usage of energy-efficient devices as existing AR devices (e.g., HMDs) use energy-intensive applications that affect the battery longevity [7, 18, 21, 117], development of new standards-based repositories (e.g., data security, interoperability, accuracy of visualisation models etc.), and high-speed internet connection [124]. For example, if the AR system is designed in a way that it allows the logistics operators to walk and move in the augmented world with little physical constraints, then the system should be capable of consistently tracking the user's position and orientation within the environment in order to maintain accuracy. Such system is technically challenging as it requires precise and seamless transition between indoor and outdoor logistics tracking, determination of the most appropriate transition point, and a high level of accuracy of both positioning systems [100]. It is also a critical and challenging task to determine the orientation of a user and there is no best solution despite the promising results of hybrid tracking with visual and inertial sensing [133]. The authoring tools should be developed to facilitate the preparation of digital content, however, the authoring process usually requires the commitment of time and financial resources to produce digital manuals, 3D models of the objects or other types of augmentations [21]. The same goes for advancing near-to-eye applications of microdisplays that require improved parameters, extended features such as full-colour high-brightness, low power, and embedded sensors for user interaction [132].

Privacy is always a critical technical issue that influences the adoption of AR in the logistics domain [101]. It is a major concern that customers confront according to the study of (Hilken et al., 2017) [114]. The authors reported that despite the greater decision comfort because of the spatial presence, this effect is attenuated by customers' worries about being aware of the privacy practices associated with AR-based service augmentation. Image recognition and spatial tracking functionalities enabled by AR will help to record the personal data and retrieve information about consumers from their social media accounts (e.g., Facebook, Twitter, Amazon, LinkedIn etc.) and these constitute a pronounced threat on their privacy [130]. For example, the new entry of Google Glass into the AR market experience failure and the reason may have been concerns about potential privacy intrusions [134]. As a consequence, Google withdrew their product from the market in 2015. These issues underline the importance of creating privacy-by-design AR devices with functionalities that match the usage context in order to avoid unnecessary consumer privacy violations. Logistics and service managers may consider AR technologies with privacy-preserving options and should ensure a clear and conspicuous disclosure of how AR-based service augmentation makes use of customer information (e.g., to assure customers upfront that facial recognition in a virtual mirror only serves fitting purposes and that no images are saved) [114].

5. 2. The organizational challenges

While AR devices embodied the next step for improving logistics performance in industrial applications, their real-world use is still not very wide. In this regard, research by Chakraborty & Gupta (2017) [106] has shown that none of the respondents were aware of the concept of AR, indicating that marketers need to make the customers more aware of this technology. In a similar vein, a systematic literature review reported that the deployment of AR technologies, and specifically AR glasses-based systems, is still limited to discussions in practice-oriented specialist magazines [101,135]. For instance, AR glasses are still encountering barriers in diffusion and concerns about devices' impact on users, organisations, and society [136]. The proportion of HMDs used in the industry is still rather low to non-existent despite the popularity of touch-based systems in everyday life as well as in the industrial environment [113]. As such, they were not commercially available [102] and often designed for research purposes. The lack of maturity of AR technologies results in increased uncertainty about their applicability to logistics activities. For example, although Schwerdtfeger et al., (2009) [59] found that the pick-by-vision AR system was slightly better than the paper list, the authors believe that this improvement is not sufficiently significant to justify industrial wide-scale adoption. Renner & Pfeiffer (2017) [123] asserted that making a grounded decision on the specific AR device and the particular guidance techniques to choose for a specific logistics scenario is difficult, considering the diverse characteristics of AR devices and the lack of experience in the industry.

Technology acceptance denotes the success of implementation in terms of the intention to use the evaluated technology from organizational and individual levels [41]. Acceptance has been confirmed as a key driver for the adoption of AR [101] and it reflects the capability of this technology in addressing more utilitarian needs and wants. However, beneficial use cases for the diffusion of AR products are still scarce [101]. Reif & Walch (2008) [16] posit that AR-based order picking might cause several problems that could lead to lower acceptance among logistics operators. Reif et al. (2009) [59], Reif & Günthner (2009) [61], and Reif et al. (2010) [18] found that some workers dislike the use of AR devices such as HMDs, despite the readiness of many to work with these tools for one day or even longer for evaluation purposes. Hilken et al. (2017) [114] put that customers might be less prone to use AR-based service augmentation and rely on their mental imagery. Moreover, firms willing to invest in AR in their logistics activities and to provide AR experience for their customers have to secure the 3D product models of all their SKUs (i.e., stock keeping units) which is cost-prohibitive [137]. Considering the economic feasibility, some AR apps might be expensive to implement [130] and devices are increasingly difficult to integrate since they require an assessment of positive (or negative) impacts on the processes where they will be adopted [17,109]. The compatibility of hardware and authoring platforms could make the construction of AR systems more cumbersome and expensive [111]. Therefore, it is important to consider making affordable AR devices which will enable fast growth of AR applications in the logistics field.

5. 3. The ergonomics challenges

The increasing digitization of logistics and business processes has caused modern ergonomics to evolve very dynamically. Over the years approach focusing on ergonomics has changed because of the proliferation of smart factory tools, virtual reality, augmented reality, and sensory systems [138]. The standard for ergonomics sets parameters for the working conditions to the psychological characteristics of workers in order to provide comfort, safety, and efficient performance [139]. Although AR devices (e.g., Hololens, smart glasses) have enhanced ergonomics as the user has both hands free when executing applications and those devices are wireless, several challenges lay ahead in the logistics field. For example Schwerdtfeger et al., (2009) [59] and Schwerdtfeger et al. (2011) [127] report that the while the overall strain did not significantly vary between paper list and pick-by-vision AR-based system, a higher strain for the users' eyes was generated by the use of AR. Reif & Walch, (2008) [16] consider that the biggest shortcoming of the AR-based order picking is the non-ergonomically designed HMD. When using HMDs on forklifts, serious labour safety accidents might occur because most of the purchasable HMDs limit the field of view [18, 122].

The labour safety will be influenced negatively if the worker's field of view is occluded by too much virtual information. Potential concerns are expected due to the addictive AR devices usage behavior [124]. As such, the overreliance on AR technologies will make workers miss out what is really in front of them [130]. The fusion of real-world objects with the virtual elements might lead to a virtual mess that will be too demanding to endure in the long run. Not only that, this situation could cause confusion [129], visual fatigue, and low concentration performance levels [62]. These issues are confirmed in the study of Gross et al., (2018) [112] who noted that that the use of display information devices significantly increases the cognitive workload of drivers. According to the authors, the use of smart glasses in logistics may cause distractions, musculoskeletal problems that could become chronic if exposed for a longer period of time, and serious accidents. Similarly Friemert et al. (2019) [110] reported that a significant higher strain for the eyes is likely to happen while working with the data glasses. Negative impacts include dazzle, blurred vision, and frequent errors with the positioning of components in the order picking [117]. Therefore, it is imperative to develop AR technologies that help display the right amount of information, conveniently assist logistics workers in their operations, and have ergonomics options that are easily adaptable to different logistical contexts.

6. CONCLUSIONS

This work is aimed at investigating the challenges of AR technologies in logistics by performing an SLR on selected publications through an appropriate review methodology. Forty-three (43) publications were thoroughly analysed for this purpose. The results of the SLR indicate that the technical challenges of AR are the most critical inhibiting factors for the adoption of these technologies in logistics. Several technical problems have been reported in the literature. These include the difficulty to attain higher levels of accuracy in the superimposition of computer-generated contents over real-world logistics scenes and the limited capabilities of AR devices in terms of performance, computational power, and the real-time processing of data. AR devices are challenged to live up to the ubiquitous logistics environment for which energy-saving applications, high connectivity, interoperability, suitable tools for virtual content authoring, and privacy-preserving features are required. Within the publications, organizational barriers to AR adoption include the immaturity level of AR technologies, the increasing uncertainty regarding their effective applicability to logistics activities, and the incompetence of workers to handle AR devices with diverse characteristics. Such issues along with other financial considerations could inhibit the acceptance and implementation of AR solutions in logistics. Furthermore, several ergonomics challenges have been discussed in the selected publications such as the increased strain on the workers, serious labour safety and health issues, and the lack of concentration. Overall, the categorization of AR challenges identified from the SLR was a contribution to the growing body of knowledge concerning AR technologies.

The literature reveals that previous publications on AR have majorly focussed on the technical challenges indicating a greater need for advancing more sophisticated AR devices that respond to logistics processes and use cases. The lack of literature on these challenges was identified in the literature, and hence the present study makes a considerable theoretical contribution to the literature in the form of a detailed SLR on the current developments of AR in the field of logistics. We propose a comprehensive categorization based on the findings of the literature ranking in order of importance the challenges of AR in logistics (i.e., technical, organizational, and ergonomics challenges). Future research works may investigate other challenges that influence the adoption of AR in logistics on the level of process integration. This will help to understand how the other organizational functions and business processes will be reshaped by AR implementations. Further, This study identified challenges that are not exhaustive. That said, the AR issues were almost focussed on indoor logistics processes (e.g., order picking) while little to no studies investigate the barriers of AR integration into outdoor logistics processes (e.g., transportation and last-mile delivery). The results of the SLR in the form of the challenges categorization is one of the initial attempts to contribute to the theory of AR in the context of logistics. It suggested that although the technology is still at the early stage and the respective body of knowledge is just starting to emerge, further research work is needed to address and solve the issues of AR in logistics. Practitioners, managers and policymakers in the field of logistics may be required to pay more attention to these challenges and develop a technology road map for AR. They may have to follow objective assessments and guidelines for potential trade-offs and decisions of AR applications to logistics and other equally critical organizational processes.

The findings of the SLR will allow practitioners in the field of logistics to gain a deeper understanding of the challenges that hinder the AR adoption in logistics business processes.

The study identified that technical challenges should be a starting point for more innovative and effective AR solutions. The practitioners will undoubtedly recognize the critical role of this emerging technology to enhance the performance of the entire logistics system. The study identifies that the leverage of AR in logistics is possible unless the proposed AR solutions consider the ubiquity of the emerging factories and the smartness of warehouse management in terms of JIT (Just-In-Time) logistics, automatic inventory checking, and real-time statuses of stock and position. The practitioners can have clear ideas on the challenges that may be encountered while applying AR, thus making necessary measures to overcome process-related problems and ensure sustainable working conditions for their workers.

Our work is not without limitations. The selection of search databases might overlook articles that might be relevant to the scope of the study. Therefore, review studies in the future may consider the use of popular databases such as Google Scholar and EBSCOhost. The findings of this paper are also limited to the categorized challenges and the selected number of publications. Further research is needed to give comprehensive coverage of the various AR inhibitors in logistics (e.g., social challenges). The theoretical inferences of the present study should be validated by future studies using other methodological approaches such as expert interviews and empirical research.

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