Industry 4.0 Technologies and Sustainable Warehousing: A Systematic Literature Review

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Abstract

Warehouse is a significant component of logistics network. Automated warehousing positively influences environmental, social, and economic aspects of sustainability. In recent years, the literature has seen substantial growth in studies at the nexus of Industry 4.0 technologies and sustainability warehouse management. In the light of growing research on the topic, this study aims to consolidate the existing knowledge base, focus of research, methodological development, gaps, and opportunities for more impactful future research in the area. A widely accepted systematic literature review methodology was employed on a sample of 36 peer-reviewed articles retrieved from the two large databases: Scopus and EBSCOHost. The analysis revealed several interesting findings, including the positive association between Industry 4.0 technologies and warehouse sustainability; shortage of empirical research on the topic; imbalance amid studies on three main aspects of warehouse sustainability; limited application of some Industry 4.0 technologies; and disproportion in scholarly focus between warehouse activities. To the best of our knowledge, this is the first systematic literature review at the intersection of Industry 4.0 technologies and sustainable warehousing. Theoretically, this review expands the existing knowledge base and opens several avenues for more fruitful future research, thus proving a sound premise to advance the field of research. From a practical standpoint, our review integrates scattered literature in one place, thereby help improve practitioners' understanding of various Industry 4.0 technologies and their significance for sustainable warehouse operations.

Keywords
Industry 4.0 technologies, Sustainability, Warehousing, Logistics, Systematic Review.

1. Introduction
The term Industry 4.0, also known as Fourth Industry Revolution, was first coined in Germany in 2011, referring to fully automated and interconnected technologies of the 21st century. The frequently discussed Industry 4.0 technologies include the Internet of Things (IoT), sensors, cloud computing, big data analytics, robotics, cyber-physical systems, artificial intelligence, among others (Ali 2019; Ali and Gölgeci 2019). These technologies have tremendous potential to increase operational efficiency and reduce operational wastes (Kamble et al. 2020; Ali et al. 2021). As such, a mounting interest of scholars and practitioners can be seen in Industry 4.0 technologies to deal with the challenges of sustainable business operations.

Among other business functions, logistics systems have been facing significant challenges associated with sustainable practices. Within the last ten years, due to the significant impact that logistics activities have on modern business operations, sustainability is one of the top aspects that have been attracting a large variety of audiences from researchers to practitioners (Ali and Gurd 2020; Mohan Kumar et al. 2017). Abbasi and Nilsson (2016) claim

that many positive socio-economic effects are generated through logistics activities such as satisfying human demands, developing infrastructures, raising employment rate through new jobs creating, mitigating poverty, hunger and crime rates, and generally increasing human living standards and wealth. Nevertheless, logistics activities are also criticised as one of the main causes of greenhouse gas emissions and environmental pollution in global supply chains (Ries et al. 2017). Thus, to maximise the efficiency and effectiveness of logistics, their negative impact on the surrounding environment and societies should be carefully addressed (Abbasi and Nilsson 2016). Moreover, there is a remarkable increment in the number of uncertainties in modern business: unpredictable climate change, economic crisis, pandemic leading to business closure, raw material price fluctuation; cooperating with the high pressure toward the environment (Mohan Kumar et al. 2017). These rising pressures, which originate from not only the public media, new enacting governmental regulations but also from competitors in building the 21st century's competitive advantage, have constructed a playground for sustainable logistics.

Over the last decade, warehousing, one of the significant components within the logistics network, has received substantial attention in terms of sustainability initiatives. Sustainable warehousing can be defined as an approach of maximising the efficiency and effectiveness of warehouse operations by utilising organisational and technological solutions, so that firm's financial objectives can be reached while environmental and social impacts are mitigated (Malinowska et al. 2018). Sustainable warehousing is indispensable to enhance a firm's brand image and public awareness, improve international benchmarking, ensure adherence to local government policies and regulation, and most importantly, satisfy the increasing public pressure for socially and environmentally friendly business operations (Mohan Kumar et al. 2017; Winkelhaus and Grosse 2020). Prior research emphasise that the success of sustainability warehousing lies in the wide spectrum of direct and indirect benefits across all three sustainability pillars: economic, environmental, and social (Mostafa et al. 2019).

Recently, Industry 4.0 technologies have emerged as a game-changing factor to effectively achieve sustainable warehousing (Ding et al. 2020; Lee et al. 2018; Mostafa et al. 2019). Industry 4.0 technologies have been entirely transforming the nature of global business activities and contributed to the formation of a digital, connected, and shared market (Ali and Aboelmaged 2021; Kayikci 2018). Taking into account the warehousing industry, Lee et al. (2018) state that warehouse management is experiencing a fast-paced transition stage due to the influence of Industry 4.0. For instance, Industry 4.0 can help increase customer satisfaction through real-time information tracking and more accurate data, which, as a result, provides better synchronisation of warehouse operations (Lee et al. 2018). IoT-connected sensors, for example, constantly transmit and receive information on order picking, loading, shipping, etc. In such a connected system, there are fewer chances of errors and waste. Likewise, automated robots help move warehouse materials more efficiently. Cloud computing generates a pool of big data that can be used for rational decision-making (Habib and Chimsom 2019). Additionally, when embedding RFID with IoT, it records a decent rise in the reliability and accuracy rate of warehouse processes, thus improving the decision-making process (Mostafa et al. 2019; Natanaree and Sriyos 2014; J. Zhao et al. 2019). Industry 4.0 technologies can also provide multiple social benefits to warehouses such as improved workers' safety, better product quality, reduction in business cost and thereby cheaper products for consumers (Mostafa et al. 2019; Trab et al. 2017). Moreover, IoT systems can be used to control environmental conditions within warehouses through automatic sensors, which results in a remarkable drop in the level of greenhouse gas emission from warehouse activities (Ding et al. 2020; Mostafa et al. 2019). Indeed, the penetration of Industry 4.0 technologies has been entirely transforming the traditional warehousing industry.

Given the connection between Industry 4.0 and sustainable warehouse management, growth in literature at the intersection of these two concepts has been recorded over the last decade. In light of growing literature, it is indispensable to consolidate the existing literature, explore the recent trends, focus of research, gaps and opportunities for more impactful research on the area. Even though the prior literature offers some insightful reviews, such as the work of Mostafa et al. (2019) and Ding et al. (2020), there is no evidence of a comprehensive and up-to-date review at the intersection of Industry 4.0 and sustainable warehousing. Therefore, this study aims to fill this knowledge gap by undertaking a systematic literature review approach. The formation of the research question is essential to conduct a study more systematically and logically (Ali and Gölgeci 2019; Gölgeci et al., 2021)). As such, this study builds upon the three key research questions:

1. What are the current state-of-the-art, recent developments and gaps in the literature on Industry 4.0 technologies and sustainable warehousing?
2. What is the methodological development of the area?

3. What are the fruitful avenues for future research on the topic?

This paper is structured in six sections. After the introduction in section 1, Section 2 outlines the review methodology used for the systematic literature review. Section 3 provides descriptive statistics of the sampled articles. Section 4 presents the discussion. Section 5 provides future research avenues, while Section 6 derives conclusions and contributions.

2. Review Methodology

We used the systematic literature review methodology (Tranfield et al. 2003). which has been increasingly recommended to identify, collect and classify related studies in a more structured, nuanced, transparent and reproducible manner (Kable et al. 2012; Rhoades 2011). Systematic literature review, also sometimes called descriptive literature review, has gain popularity due to its ability to map intellectual knowledge base on a particular topic (Wong 2021). It is considered the most effective method to advance scientific knowledge (Tranfield et al. 2003). Indeed, the systematic review can help researchers systematically organise the available literature related to a given research topic (Peričić and Tanveer 2019). Moreover, through analysing the extant literature, the systematic review will reveal possible literature gaps which need to be addressed by further research to strengthen this discipline of study (Kamble et al. 2020; Peričić and Tanveer 2019). Another benefit of the systematic review is to eliminate research questions where extant literature suffices to answer, thus avoiding unnecessary further research (Chalmers and Glasziou 2009).

We chose two large scientific databases—EBSCOhost and Scopus—to identify and collect the maximum number of articles on the topic. Then, based on the main review objective, which is to understand how various Industry 4.0 technologies are being used to achieve the three pillars of sustainability in warehousing management, two sets of keywords for searching were defined below.

- *Group A* includes general terms such as warehousing, warehouse management and warehouse operations.
- *Group B* includes specific terms related to Industry 4.0 technologies that can be used in warehouse management such as Industry 4.0, Cyber-physical systems, RFID - Radio frequency identification, RTLS - Real-time location systems, Internet of things, Internet of services, Big data, Data mining, AR - Artificial reality, VR - Virtual reality, Blockchain and Cloud technology.

The running queries included a keyword from Group A combined with a keyword in Group B. As a result, EBSCOhost and Scopus provided 629 and 380 articles respectively in response to initial hits. The search engine was limited to the English language and peer-reviewed articles published during the past 10 years 2010 to 2020. The selection of the past 10 years is attributed to the increasing momentum of research around the topic. Following past reviews in the field (Ali and Gölgeci 2019; Tang and Nurmaya Musa 2011), we have excluded reviews, book chapters, trade reports, newsletters and conference papers to ensure a better quality of findings.

The articles to be considered suitable for this review should focus on warehouse operations and their linkage with Industry 4.0 technologies. As such, the articles that discussed warehousing operations without Industry 4.0 technologies were excluded from our review. Following these inclusion and exclusion criteria, 129 articles from EBSCOhost and 132 articles from Scopus were shortlisted from the initial results. Also, the article content should reflect at least an aspect of sustainability. This has reduced the number of qualified articles down to 37 and 40 for EBSCOhost and Scopus respectively. After carefully examining and deleting the duplicates from both databases, 36 articles were finally defined as related to our review purpose. Retrieval of only 36 articles at the nexus of Industry 4.0 technologies and sustainable warehousing shows that this important topic of research is still in its infancy.

3. Descriptive Statistics

3.1. The Trend of Publications Over Time

The searching results show that the number of works on the topic of Industry 4.0 technologies in constructing sustainable warehousing practices is still at an early stage. As can be seen from Figure 1, scholarly attention towards the research topic has gradually increased during the ten years from 2010 to 2020, even though the growth pattern is non-constant. From 2010 to 2011, there was a sharp increase in the progress of research as the number of publications published in 2011 was doubled compared to 2010. From 2011 to 2016, there was a slowdown in the

number of contributions. Especially, there was no publication recorded in 2012 and 2016. However, it is somewhat encouraging to see a noticeably increase in the recent research attention towards that topic where nearly 67 percent of the works (24 out of 36) being undertaken within the last four years of the review period.

From 2016 to 2020, there was a remarkable increase in research which has reached the 10 years peak in 2019. It completely aligns with the continuously increasing focus from scholars, profit and non-profit organisations, and governments on the public pressure for the sustainability movement (Martins et al. 2019; Torabizadeh et al. 2020). Following the trendline, it is projected that the interconnection between Industry 4.0 technologies and sustainable warehousing will receive more academic limelight in the upcoming future.

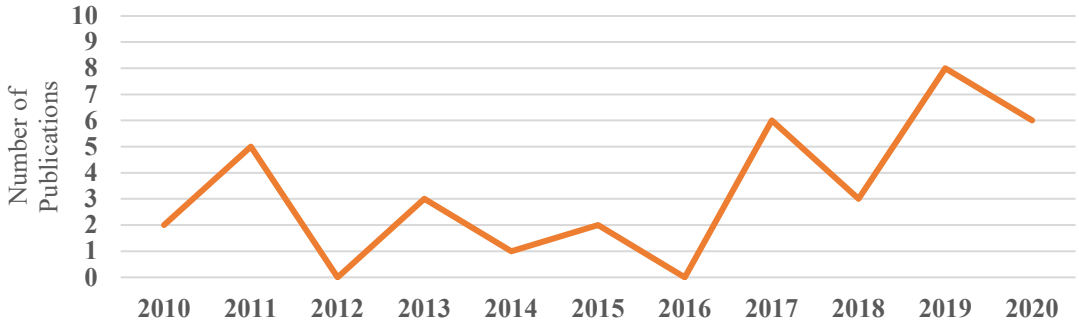

Figure 1. Number of Publications on Industry 4.0 Technologies application on Warehousing per year

3.2. Publication Outlet

Most of the peer-reviewed journals being recorded for this review (21) published one paper related to the relationship between Industry 4.0 technologies and sustainable warehousing (See Table 1). However, several top contributions with more than one publication can be seen in *International Journal of Production Economics* (4), *International Journal of Production Research* (3), *International Journal of RF Technologies* (2), *Expert Systems with Applications* (2), *LogForum* (2) and *Sensors* (2). The fact that those are also the top world-renowned publishing journals certifies the high level of academic concerns towards sustainable warehousing through Industry 4.0 technologies.

Table 1. List of peer-reviewed journals contributing articles to the systematic literature review

Peer-reviewed journal	Number of articles
International Journal of Production Economics	4
International Journal of Production Research	3
International Journal of RF Technologies	2
Expert Systems with Applications	2
LogForum	2
Sensors	2
Applied sciences	1
Assembly Automation	1
Computer-Aided Design & Applications	1
Computers & Industrial Engineering	1
Concurrent Engineering: Research and Applications	1
Decision Support Systems	1
Information Systems Frontiers	1
International Journal of Advanced Manufacturing Technology	1
International Journal of Computer Integrated Manufacturing	1
International Journal of Intelligent Systems	1
International Journal of Logistics Research and Applications	1
Journal of Intelligent Manufacturing	1
Journal of Interdisciplinary Mathematics	1

Journal of Manufacturing Technology Management	1
Management Review Quarterly	1
Netnomics	1
Social Sciences	1
Soft Computing	1
The Visual Computer	1
Transportation Research Part E, Logistics and Transport Review	1
Wireless Networks	1
Total	**36**

3.3. Keywords' Analysis

The frequency of keywords represents the popularity of various research themes in the sampled articles (Ali and Aboelmaged 2020). BibExcel tool has been used to extract the most frequently used keywords among the database of 36 peer-reviewed journal articles. As different authors may use different wordings to express a similar concept, all the keywords have been scanned through and categorised into several main categories for easy analysis. Figure 2 clearly depicts the connection between warehouse management and various Industry 4.0 technologies.

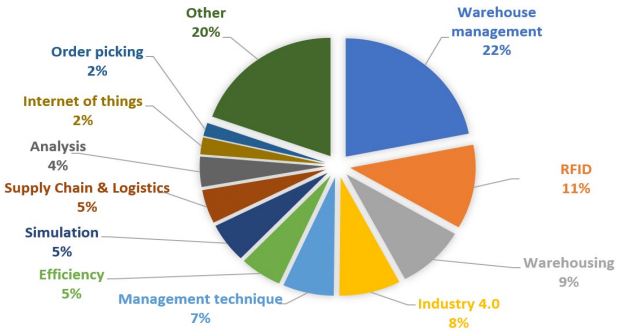

Figure 2. Frequently used keywords

3.4. Methodological Development in the Past Research

When considering the methodology used per article within the review sample. The analysis shows that the highest number of studies (18) have been undertaken through case studies (27.78% with a proposed conceptual framework and 22.22% without it). In addition, 11 of 36 papers (30.56 %) build upon simulation/mathematical modelling without the support of real-world data. Four papers (11.11%) proposed conceptual frameworks without empirical validation. Further, three papers (8.33%) conducted the literature review.

It can be concluded that the extant research on the topic needs more empirical research. In particular, given the new research area, theory-building qualitative research could help expand theoretical knowledge around the topic. There is also a scarcity of survey-based single as well as multi-method studies.

4. Discussions

The following section presents literature on the connection between Industry 4.0 technologies and the three major pillars of sustainability.

4.1. Industry 4.0 and Economic Sustainability

Most studies in our sample have demonstrated that Industry 4.0 technologies can bring a wide range of economic benefits to help warehouses achieve their economic sustainability. Firstly, these technologies directly contribute to the reduction of operational overheads and financial losses as human resources are utilised in more efficient and effective ways (Fosso Wamba and Takeoka Chatfield 2011; Lim et al. 2013; Pacciarelli et al. 2011; W. Zhou et al. 2017). Secondly, the widespread adoption of IoT-supported RFID technology can result in a significant increase in the efficiency level of warehouse operations as well as the utilisation level of warehouse resources (Poon et al. 2011). When comparing the level of efficiency improvement in warehouse operations received from different technologies, Ballestín et al. (2013) claim RFID technology outplays any other ones which require human

intervention. The application of the Lean concept through RFID technology also provides a great reduction in processing time and a significant improvement in warehouse performance (Chen et al. 2013). Other remarkable benefits from the implementation of IoT-connected RFID in warehousing include increasing reliability and accuracy rate of warehouse processes and providing better warehouse visibility for the decision-making process (Mostafa et al. 2019; Natanaree and Sriyos 2014; J. Zhao et al. 2019). Reaidy et al. (2015) demonstrate that the construction of IoT infrastructure will increase warehousing transparency and help warehouse management improve their reactivity and competitiveness in a dynamic and complex environment. Based on that benefit, customer satisfaction level can be boosted through improving order fulfilment rate (Lam et al. 2015; L. Zhou et al. 2020), and minimising the level of substandard products (Lao et al. 2011); which, as a result, strengthens the firm reputation and public image (Mostafa et al. 2019). In another study regarding the economic advantages of Industry 4.0 technologies towards warehousing, Lorenc and Lerher (2020) propose an AR software called Pickup Simulo that can strongly support the decision-making process in warehouse operations. By evaluating potential pickup and product allocation planning in a simulation environment, the software can provide valuable information to warehouse managers on the effectiveness and efficiency of their warehouse strategies, thus mitigating the risk of financial/resources loss when undertaking an ineffective solution (Lorenc and Lerher 2020). Also, working on the topic of AR, the study of Piardi et al. (2019) presents a simulation platform called ARENA for experimenting with advanced interactions between multi-robot systems and virtual elements within a smart warehouse. The construction of warehousing economic sustainability also receives the contribution from upscale Industry 4.0 technologies such as cloud technology and big data technology. According to Z. Zhao et al. (2017), by embedding internet devices to physical forklifts, equipment visibility is significantly improved based on real-time data collection and communication through the cloud service, thus enhancing warehouse picking efficiency and effectiveness as well as reducing inventory level and paperwork tasks. L. Zhou et al. (2020) demonstrate the powerful capability of big data technology in improving picking efficiency and resource allocation strategy compared to traditional strategies, thereby boosting the order fulfillment rate and eventually enhancing customer satisfaction.

4.2. Industry 4.0 and Social Sustainability

Literature has recorded several studies on the societal effect of Industry 4.0 technologies towards warehouse operations, especially for those with a human factor involved. For instance, new systems and models embedded in RFID technology have been introduced to enhance product quality through improving the human-based decision-making process for quality assurance (Lao et al. 2011; Arslan et al. 2021). According to Lao et al. (2011), Industry 4.0 technologies significantly reduces the number of human errors involved, thus minimising the rate of defective goods, ensuring the high quality of products supplying to the market and enhancing customer satisfaction. Besides, Mostafa et al. (2019) claim that IoT can provide great social impacts such as ensuring goods safety, raising product quality and reducing the rate of counterfeiting, fraud or theft. Risk management is another most significant social benefit that industry 4.0 technologies can provide to warehouses. According to Lam et al. (2015), Industry 4.0 technologies contribute to the enhancement of risk management within warehouse operations. In a study about utilising industry 4.0 technologies to improve risk management, Trab et al. (2017) stimulate the implementation of IoT to monitor and mitigate the number of high-risk interactions and dangerous circumstances in warehouse operations. Halawa et al. (2019) illustrate the capability of Industry 4.0 technologies, especially RFID, in providing visibility to identify areas of safety concern and prevent congestion. In turn, this will enhance warehouse safety standards and boost operational efficiency (Halawa et al. 2019). As a result, it is apparent that the application of Industry 4.0 technologies can greatly improve staff safety awareness and mentality, maintain warehouse safety standards and ensure smooth operations (Yuen 2010). Moreover, employee's work intensity can be greatly reduced through the assistance of RFID technology, which eventually releases pressure on human resource allocation (Pacciarelli et al. 2011; Xiao et al. 2017). Further social benefits of those new technologies are mentioned in the systematic literature review including the removal of laborious paper-based tasks (Z. Zhao et al. 2017) and the formation of job training opportunities for new roles and responsibilities (Fosso Wamba and Takeoka Chatfield 2011). Consequently, through those benefits, warehouses can record a significant boost in employees' morality and work efficiency (Lee et al. 2018; Periša et al. 2019).

4.3. Industry 4.0 and Environmental Sustainability

Surprisingly, only a small portion of literature appears on how Industry 4.0 technologies provide solutions to reduce the environmental impacts of warehouse activities. These studies demonstrate that Industry 4.0 technologies contribute to the reduction of energy consumption and the level of the carbon footprint emitted from warehouse activities. For example, Mostafa et al. (2019) present the potential benefits of using automatic sensors (controlled

through an IoT system) in monitoring the heating, ventilation and air conditioning (HVAC) system. In fact, the sensor systems will capture real-time data regarding surrounding environments and then transfer it to the warehouse management systems for processing and converting into useful information and proper actions (Mostafa et al. 2019). Besides, by conducting a literature review analysis on the application of the Internet of things on logistics activities, Ding et al. (2020) state that the use of sensing technologies in monitoring and managing the changes of environmental conditions greatly improves warehousing security and transparency. Furthermore, Industry 4.0 technologies can minimise unexpected environmental disasters as well as prevent potential environmental risks to warehouses. Indeed, by enhancing the responsiveness of the warehouse management system, Industry 4.0 technologies can ensure the immediate triggering of the decision-making process to decrease the preventive action time when unexpected events occur (Trab et al. 2017). That benefit can be seen through the study of Trab et al. (2017) which has proposed an IoT conceptual model of communicating warehouse objects to effectively monitor, mitigate or even prevent environmental disasters in warehouse operations. In conclusion, even though with limited contribution, Industry 4.0 technologies can provide many potential solutions to target the environmental sustainability of warehousing.

5. Knowledge Gaps and Avenues for Future Research

Based on the review of literature on Industry 4.0 and sustainable warehousing, we have identified several knowledge gaps which provide opportunities for more impactful research on the topic.

5.1. Imbalance in Scholar Attention Toward Each Sustainability Aspect

A high volume of studies from the systematic literature review has demonstrated that Industry 4.0 technologies can provide substantial economic advantages to warehouses. These advantages include: enhancing warehouse efficiency (Ballestín et al. 2013; Lee et al. 2018), mitigating operational costs (Fosso Wamba and Takeoka Chatfield 2011; Lim et al. 2013), raising customer satisfaction level and increasing the competitive advantage (Lam et al. 2015; Mostafa et al. 2019; L. Zhou et al. 2020). The fact is that those advantages directly manipulate the financials of the warehouse operations, which self-explains why this aspect becomes the most popularly discussed topic for global researchers.

As such, this is surprising because the systematic literature review shows that the social aspect is mentioned half as much as the economic aspect. Our systematic literature review shows that the social aspect is mentioned half as much as the economic aspect. Nonetheless, the social influence of Industry 4.0 technologies holds the same importance as the economic benefits in constructing a sustainable warehouse model. It is evident through many significant benefits toward human factor such as reducing employee's work intensity (Pacciarelli et al. 2011; Xiao et al. 2017), strengthening staffs' safety awareness and warehouse risk management (Halawa et al. 2019; Lam et al. 2015; Trab et al. 2017; Yuen et al. 2010), removing laborious paper-based tasks (Z. Zhao et al. 2017) and boosting employees' morality and work efficiency (Lee et al. 2018; Periša et al. 2019).

Among the three pillars of sustainability, the environmental aspect garners the least attention from researchers and practitioners. It raises the question of whether the importance of this aspect has been underestimated or overlooked. Indeed, researchers pay the least attention to the environmental impact of warehouse activities (Ries et al. 2017) even though those activities contribute a large percentage of greenhouse gas emissions within a supply chain (Fichtinger et al. 2015). Nevertheless, our review has recorded some interesting recent studies on the environmental benefits of Industry 4.0 technologies. One of them is the work of Mostafa et al. (2019) that emphasises its potential in reducing the level of carbon footprint emanating from warehouse activities. In another studying regarding the assistance of Industry 4.0 technologies, Evangelista et al. (2017) also recognise its great help to warehouse management in releasing pressure on green initiatives investment. The presence of recent studies supports our argument on the significance of and need for more research including the connection between various Industry 4.0 technologies and the environmental aspect of warehouse operations. Our argument is in line with Strandhagen et al. (2017) who claim that the significant impact of Industry 4.0 technologies on the triple bottom line of sustainability should be considered as interrelated effects as they do not target a single aspect only. Instead of limiting the research scope to only one or two aspects, it is better to conduct compound research that can capture all three types of benefits.

In a nutshell, both social and environmental aspects should be recorded as holding the same importance level as economic. Therefore, there exists a need in enriching literature on warehousing sustainability facilitating by Industry

4.0 technologies. Further research should be conducted in this important area to obtain more real-world evidence to verify the practical as well as potential social and environmental impacts of those technologies which are surprisingly being underestimated. The full picture of warehousing sustainability will only be achieved if that unexpected imbalance is completely corrected.

5.2. Shortage of Empirical Studies

Our systematic literature review has shown two main methodologies used by a majority of studies. The first methodology is studying and analysing conceptual frameworks which will be supported by simulation experiments, for example, Chen et al. (2013), Lao et al. (2011), Piardi et al. (2019), Poon et al. (2011), Yuen et al. (2010), etc. Another popularly used methodology is case study research to back up conceptual frameworks. See for example: Choy et al. (2017), Lee et al. (2018) and Lorenc and Lerher (2020). Indeed, it is undeniable the powerful ability of both simulation experiments and case studies in visualising the practicality of a research topic. Simulation experiments play their best role in theoretically testing the effectiveness of the proposed research initiatives. For instance, after presenting a reengineered warehouse model with the integration of the Lean concept and RFID technology, Chen et al. (2013) use real simulation scenarios to test if processing time is reduced in any warehousing stages. Alternatively, L. Zhou et al. (2020) apply a computational simulation model in testing the order picking speed and order picking efficiency of their proposed strategy of warehouse inventory allocation. Furthermore, case studies have been popularly used as an effective tool in obtaining an in-depth understanding of a phenomenon in its real-life settings whose aspects have not yet been fully investigated (Yin 2009). One of the best examples demonstrating the effectiveness of case studies is the work of Choy et al. (2017). By using a case study of a machine manufacturing company, all the positive testing outcome received from the pilot test has verified the practicality of the proposed RFID-storage assignment system (Choy et al. 2017). Another study using the case study method is the work of Oner et al. (2018) in implementing a proposed roadmap for an RFID integrated warehouse management system in a Turkish textile company. Together, these studies showed the effectiveness of the two aforementioned methodologies in this research area.

Nevertheless, the use of simulation experiments or case studies will affect the generalisation possibility of the research. According to Dube and Pare (2003) and Yin (2009), these research methods can cast a doubt on the representativeness or uniqueness of the study, which, and as a result, fails the prerequisite for generalising the study result. The most effective solution for this issue is to perform cross-case comparisons (Eisenhardt 1989), as well as to collect more information widely within the studied category (Z. He et al. 2017). Therefore, it emphasises the need for obtaining more real-world evidence for the generalisation purpose.

5.3. Limitations of Industry 4.0 Technologies Being Applied

It is not surprising that Industry 4.0 technologies have been widely adopted in many industries nowadays (Arslan et al., 2021). The reason lies in its fascinating capability in collecting and generating a large volume of real-time data that can be used to improve productivity at many operational levels (Bosman et al. 2019). However, the systematic literature review has recorded an unexpected limitation on the number of Industry 4.0 technologies being discussed.

Indeed, there is a huge academic interest in the application of Industry 4.0 technologies into the warehouse environment. RFID connect IoT can be considered as not only the most popularly used Industry 4.0 technology in warehousing but also the most significant technology of the 21st-century information economy. Its presence as well as penetration throughout all warehouse operations have strongly proved the empirical effect that RFID can bring to the warehousing industry and the entire supply chain (Chen et al. 2013; Lim et al. 2013; Liu et al. 2019). Besides, other IoT-supported devices are also receiving the academic spotlight. The works of Trab et al. (2017), Lee et al. (2018), Mostafa et al. (2019) and Periša et al. (2019) have demonstrated a surge of interest in the use of the Internet of Things to build transformational solutions for the contemporary global economy (Xu et al. 2018).

However, there is a noticeable limitation on scholars' works on several cutting-edge technologies such as big data analytics, blockchain, virtual reality and cloud technology. It spontaneously raises a big question mark as the practicality of those technologies in logistics and supply chains has been verified throughout the literature. For instance, Winkelhaus and Grosse (2020) conceptualise the importance of Big Data analytics in facilitating the digitalisation of Logistics or Logistics 4.0. In another study, Yew et al. (2016) state that virtual reality enables the placing of virtualised computational objects in a real environment, which can be used in designing products, simplifying maintenance tasks, maintaining product quality or employee training (Elia et al. 2016). In the case of

blockchain, it can be considered as one of the most critical Industry 4.0 technologies. Blockchain plays its best role in providing a secure, trustful, transparent and immutable solution for information sharing throughout all operation stages (Ghobakhloo 2018; Karunarathna et al. 2019). Finally, cloud technology is another notable Industry 4.0 technology that is rarely discussed in the literature of warehousing. According to Xu et al. (2018), cloud technology allows the delivery of computing resources and solutions (databases servers, decision-making tools, etc.) over the Internet or the Cloud. It will consequently construct a flexible platform for sharing and collaborating between geographically separated resources and capabilities (W. He and Xu 2015). In general, the most reasonable explanation for the appearance of big data analytics, virtual reality, blockchain and cloud technology at the bottom of the ranking is because they are new rising technologies. It can also be implied that there are more opportunities for empirical research on those promising but unexplored fields.

In summary, literature has revealed a limitation in the number of studies contributing to each type of Industry 4.0 technology being applied to warehouses. Theoretically, each of those technologies can greatly provide positive impacts to the achievement of sustainability warehousing. A comprehensive understanding of the impacts of all key Industry 4.0 technologies on warehouse operations will then need to be achieved to increase the implementation success rate and to enhance warehouse performance when applying those technologies. Therefore, further research on the application of all those technologies in warehousing will then be required not only to retest the practicality and suitability of popularly adopted technologies but also to explore the potential effects of those newly rising ones. To be specific, case study research is recommended as the best fit due to its strengths in obtaining an in-depth understanding of a phenomenon in its real-life settings whose aspects have not yet been fully investigated (Yin 2009). The research result will promisingly provide valuable insights to warehouse managers to select the most appropriate Industry 4.0 technologies for their warehouses.

5.4. Unbalance Focus Between Warehouse Activities

The fact is that Industry 4.0 technologies can penetrate all warehouse activities including receiving, put-away, storage, order picking, dispatching and other general use. However, the systematic literature review is witnessing an unbalanced focus on the impact of those technologies on different warehouse activities. At the moment, most of the headlines are for storage and order picking while other activities are underrepresented.

There is no surprise for storage to be at the top attention for researchers and scholars as the core mission of warehouses is no other than inventory management. Indeed, storage or inventory control can be considered the most important activity of warehouse operations. This activity has a huge impact on warehouse space utilisation and controls the operational efficiency when performing other activities such as order picking (Chen et al. 2013). Besides, in the case of order picking, this activity has attracted a high number of academic concerns which is aligned with the works of Chiang et al. (2011), Latif and Shin (2019) and Yener and Yazgan (2019). The reason lies in the necessity to increase the efficiency of the most repeated, laborious and costly task within warehouse operations (Chiang et al. 2011; Latif and Shin 2019). Moreover, the effectiveness and efficiency of order picking can also impact the customer satisfaction level of the warehouse as well as its related supply chain linkages (Yener and Yazgan 2019).

However, it is questionable why other warehouse activities besides storage and order picking have limited playgrounds for Industry 4.0 technologies although the potential benefits of these technologies to those activities have been recorded in literature multiple times. For example, RFID and the internet of things are the two most popularly used technologies for receiving and dispatching. The application of those two technologies has removed the bottleneck in the traditional warehouse model where cargo receiving and despatching are heavily delayed due to unmatched goods conditions and status (Chen et al. 2013). Chen et al. (2013) state that, with the assistance from RFID, the in/out goods flow within the warehouse can now be fully controlled through digital tags embedded in the goods. Furthermore, all their associated data can be collected and shared on a real-time basis within an Internet of Things integrated warehouse management system (Chen et al. 2013; Mostafa et al. 2019). According to Chen et al. (2013), a significant reduction in processing time has also been recorded when applying RFID processes in those activities. Besides, it is said that warehouses can play the role of the value-adding center through providing services such as labeling, marking, testing, packing and packaging, assembling, cross-docking, maintenance, recycling, along with others (Bank and Murphy 2013; Lim et al. 2013). It therefore expands the boundaries to which level Industry 4.0 technologies can support warehouse activities. For instance, Yuen et al. (2010) present the initiative of a full-immersive virtual reality simulation system for training warehouse staff to prevent possible accidents when using forklifts as well as how to deal with these adverse situations. In another study, Xiao et al. (2017) promote the use of

RFID in reducing work intensity and processing time for inward and outward goods inspection, which as a result releases cost pressure and maximises staff productivity. Another evidence of the benefits of industry 4.0 technology on warehouse value-adding activities is the smart wristband from the work of Periša et al. (2019). Indeed, that big advancement gives great help in optimising the warehouse processes, increasing warehouse traceability level and enabling people of any disability degree to efficiently perform their work tasks (Periša et al. 2019). Therefore, it is clear that Industry 4.0 technologies can be beneficial to every warehouse activity.

It is evident that the application of Industry 4.0 technologies in warehousing will significantly enhance warehouse performance. Each warehouse activity is supposed to receive certain levels of benefit when integrating Industry 4.0 technologies into its operations. However, the imbalance in the number of studies contributing to different warehouse activities has questioned whether those benefits are practical in those least mentioned activities. Therefore, it urges for an update on the practical impacts that warehouses are receiving from Industry 4.0 technologies.

6. Conclusions and Contributions

This paper aimed to review the literature on the interconnection between Industry 4.0 technologies and sustainable warehousing by conducting a systematic literature review. Accordingly, 36 articles were thoroughly analysed to delineate the literature and summarise the available knowledge in this field of study. The systematic literature review has clarified the importance level of Industry 4.0 technologies in constructing warehousing sustainability in terms of economic, social and environmental perspectives. We find that a chain reaction of substantial benefits is triggered to facilitate the achievement of sustainability objectives when implementing Industry 4.0 technologies into the warehouse environment. The review results also shed the light on future research recommendations (RR) to fully explore all the unveiled knowledge in this area of study.

- RR1: Further research needs to be conducted to verify the practical as well as potential social and environmental impacts of Industry 4.0 technologies on warehouse operations. These two types of impacts are surprisingly receiving far less scholarly attention compared to economic impacts.
- RR2: From a methodological point of view, research methodologies being used currently cannot provide enough evidence to generalise the research result. Thus, multiple case study research to perform a comparison between the real world and the extant literature is recommended to fill the literature gap.
- RR3: As there is a limitation in the number of studies contributing to each type of Industry 4.0 technology being applied to warehouses, further case study research is required to obtain a comprehensive understanding of all the key popularly adopted technologies as well as new rising ones.
- RR4: In terms of warehousing activities, most of the studies focus on the two main warehouse activities (storage and order picking). Therefore, further research needs to be conducted to verify the practical and potential benefits that Industry 4.0 technologies can provide to other warehouse activities.

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Dr. Imran Ali is currently a Lecturer (Assistant Professor) in Operations and Innovation Management at the School of Business and Law in Central Queensland University, Australia. Dr. Imran also serves as a 'Food Systems Expert' at the FAO of the United Nations to develop resilient food systems in the developing and developed countries of the world. He holds a Ph.D. in Business Management (logistics and supply chain management) from the University of South Australia. His current research focuses on supply chain risk and resilience, Industry 4.0, climate change, sustainable global supply chains. Dr. Imran's research has been featured in several good-quality journals and conference proceedings such as *Production Planning and Control, Supply Chain Management: An International Journal, International Journal of Physical Distribution and Logistics Management,* and *Academy of Management Best Paper Proceedings,* among others.