The Role of Human Factor in Sustainable Warehousing with a Logistics 5.0 perspective: a conceptual framework

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Abstract: Companies have been facing increasing pressures to adopt sustainable practices in their supply chains, with logistics nodes playing a crucial role in this regard. Characterised by increasing complexity, they have been experiencing a fast technological transformation to cope with today's ever-rising challenges. The rapid advancement of technologies related to the Logistics 4.0 paradigm, and quickly evolving towards the Logistics 5.0 concept, are expected to facilitate the sustainable transition. In such transition, the role of manpower is still central in warehousing tasks, with human-technology interaction representing a significant challenge. Studies on human factor, human-technology interaction, and social sustainability at warehouses are emerging but are still under investigated. Besides, the intertwined implications of considering these topics simultaneously with the other sustainability perspectives (i.e., economic and environmental) have captured rising interest from both academia and industry, but research in this regard is still scarce. Few recent reviews aim at providing a more structured understanding of the overall topic. However, previous contributions often consider a single activity, such as picking, or specific technologies, such as automated and robotized systems, or tackle one facet of human centricity and focus essentially on the operative level. Still, an overall picture of how these elements should be considered in the design and management of sustainable warehousing from a holistic perspective is missing. The present paper addresses this gap by providing a state of the art about the role of human factors in sustainable warehousing design, in the light of the Logistics 5.0 paradigm. A conceptual framework is proposed based on a Systematic combining approach coupling a PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses)-based literature review and an empirical analysis. Research limitations are discussed, and future research directions are outlined.

Keywords: Warehousing; Human-Factor; Logistics 5.0; Sustainability; Systematic combining approach.

1. Introduction

In recent years, companies have been facing increasing pressure due to several emerging trends, including the diffusion of e-commerce, increased market competition and important sustainability requirements. The diffusion of e-commerce, for instance, offering convenience, variety, and personalized shopping experiences, has reshaped consumer expectations, and set a new standard for expected service level. Besides, the extreme business competition has made it necessary for companies to respond promptly and efficiently to customer requests (Kumar et al., 2023). Lastly, companies have been facing increasing pressure to adopt economic, environmental, and social sustainable practices in their supply chain (Martins and Pato, 2019). This has strongly affected activities in company warehouses, which represent a key component for the company due to their impact on logistics costs and on customer service. The increasing complexity of warehousing activities pushed companies to look at automation and technological innovation to support operations at their logistics facilities (Modica et al., 2023). However, increased adoption of automation and digital technologies does not imply the complete substitution of human operators. Instead, it is combined with the crucial presence of manpower, which can guarantee the required flexibility, a capability that is still hard to replicate with automated systems in a cost-effective way (Grosse et al., 2015). Simultaneously, warehouse workforce is put under significant physical and psychological stress (Boysen et al., 2019) and companies are experiencing workforce shortage in warehouses. Therefore, due to several concurrent causes, Human Factor (HF) in warehouse management is becoming more and more important, also given the new challenges from increased human-technology interaction (HTI) (Perotti et al., 2022a). Human factor and human-technology interaction are now considered key for operational outcomes of warehouses (Grosse, 2024). This fits into the broader context where Logistics 5.0 (L5.0) paradigm is emerging as a key component of Industry 5.0. The Industry 5.0 concept emerged as a value-driven industrial revolution, with societal goals, in contrast with Industry 4.0, which essentially focuses on digitalization and efficiency (Xu et al., 2021). Industry 5.0 aims to extend the concept of Industry 4.0 by giving a central role to human workers and their well-being considering not only economic or technological factors but also environmental and social dimensions (European Commission, 2022). Despite the growing recognition of the need to address human factor alongside technological advancement for holistic sustainable development, academic literature does not explore extensively this aspect, especially in relation to warehousing. HTI in warehouses represents an important field to be investigated (Ali and Phan, 2022), and how it can affect warehouse configuration and therefore its economic, environmental, and social sustainability is still unclear

(Grosse et al., 2023). Few recent reviews have been developed for a more structured understanding of the subject (e.g., De Lombaert et al., 2023; Grosse, 2024; Lorson et al., 2023). However, previous contributions often consider a single activity, such as picking, or specific technologies, such as automated and robotized systems, or tackle one facet of human centricity, with a focus essentially on the operative level. Still, an overall picture of how these elements should be considered in the design and management of sustainable warehousing from a holistic perspective is missing. This work aims at addressing this gap by proposing a state of the art about the role of human factors in sustainable warehousing design in light of the L5.0 paradigm. In line with the objective of this work, the following research questions (RQs) have been defined. **RQ1:** Which is the state of the art related to human-centric warehousing considering the L5.0 paradigm? **RQ2:** What are the main research areas that need to be further explored when it comes to the role of the human factor to support the design of sustainable warehouses?

To address these objectives, a conceptual framework is proposed based on a Systematic combining approach which couples a PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses)-based literature review and an empirical analysis on technology adopters. An outline of the investigated topic is provided by integrating academic studies and empirical cases in a framework that incorporates the various elements of L5.0 in warehousing and highlights the main research gaps.

The remainder of this document is structured as follows. Section 2 presents the methodology adopted. Section 3 illustrates the findings and Section 4 discusses the proposed framework and the emerging research gaps. Conclusions are presented in Section 5.

2. Methodology

A systematic combining approach (Kirkeby, 1994) has been applied to build a framework describing the role and the intertwined relationship between human factor and technologies at warehouses, in the light of the emerging L5.0 paradigm. The systematic combining approach is based on abductive logic, and it is characterized by the combination of empirical observations and theoretical models. This interchange allows the development of a framework which is continually adjusted with insights gained from real-world data (Dubois and Gadde, 2002). In this study, the theoretical contribution is offered by means of a PRISMA-based systematic literature review, whereas the empirical lens addresses real-world business cases - technology users (e.g., Logistics Service Providers (LSPs), manufacturers, retailers) - that have been examined based on secondary sources (e.g., company reports and websites, practitioners' journal papers). The research methodology is presented in (Figure 1). First theoretical knowledge is acquired in a structured way from academic literature, and it is used to develop the initial framework. Then, empirical information is collected from secondary sources reporting real-world insights, which are used to adjust the framework, by confirming or enlarging and enriching its structure.

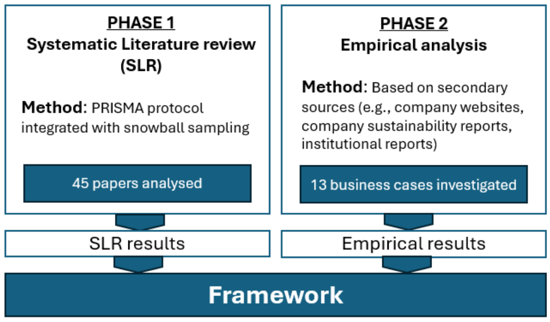

Figure 1: Research methodology

As per the first phase, the systematic review is considered the most rigorous approach to collect papers and synthetize all the relevant data present in academic literature that answer to a research question (Snyder, 2019). Therefore, a systematic review is performed to obtain a reliable, reproducible, and complete overview of the state of the art about L5.0 and HTI in warehousing. To support the achievement of this objective the guidelines based on the PRISMA methodology have been followed for paper identification and selection. Besides, the sample of papers obtained has been extended with the inclusion of papers found through a backward search, in line with (Miklautsch and Woschank (2022). The paper selection process is reported in Figure 2.

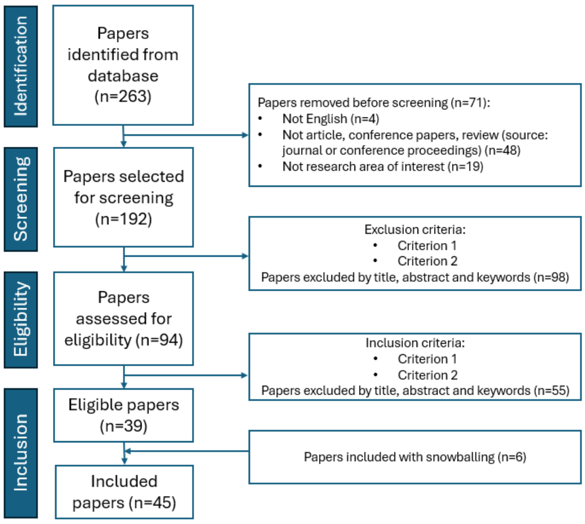

Figure 2: Paper selection according to PRISMA protocol

Coherently with the defined review objective and approach, a search strategy to locate relevant literature is formulated through the identification of appropriate search terms and databases to explore. The selected database to locate the papers for the literature review is Scopus, as the largest repository of high-quality, peer-reviewed papers, in line with Kar et al. (2022), and one of the most used databases available online. Moreover, a research string of keywords is defined to compose a thorough query to be searched in the database. To this extent, a set of keywords combining warehousing and related activities, L5.0 paradigm, technologies, and human factor is defined based on the keywords most used in this field. Besides, the set of keywords and the final string underwent several adjustments to obtain a concise, complete, and meaningful query that could be thorough and effective for the objective of the work. Warehouse-related keywords include a list of warehousing activities, as defined in (Perotti et al., 2022b), to admit papers focused on a specific warehousing activity not mentioning warehouses. These keywords are linked through an AND operator with a set of keywords related to 5.0 paradigms. This choice has been set coherently with the aim of obtaining a complete overview of the topic while setting the boundaries of the research to the warehousing arena, which is the designed unit of analysis. An alternative set of keywords, distinct from those strictly tied to 5.0 paradigm, has been proposed. This supplementary set of keywords combines terms related to human factors with those indicating technologies associated with the 4.0 paradigm. This measure ensures the inclusion of papers relevant to the research topic that may not explicitly mention the 5.0 paradigm. The search string used to identify the first sample is the following:

TITLE-ABS-KEY ((("warehous" OR "receiving" OR "storage" OR "put-away" OR "putaway" OR "picking" OR "shipping" OR "material handling") AND ("operations" OR "logistics")) AND (("logistics 5.0" OR "industry 5.0" OR "warehouse 5.0" OR "human-tech" OR "assistive device" OR "cobot" OR "collaborative robot" OR "robot-human" OR "human-robot") OR (("logistics 4.0" OR "industry 4.0" OR "warehouse 4.0" OR "smart logistics") AND ("human factor" OR "human cent*" OR "socio technic*" OR "sociotechnic*"))))*

The first sample obtained from Scopus through the search of the selected query is composed of 263 papers, retrieved in February 2024 and updated until April. Then, according to the PRISMA protocol, two screening steps were performed. The first screening required the definition of timeframe, subject and typology of the papers to be selected. To keep the sample exhaustive, no constraints in terms of timeframe were applied. However, to ensure high quality of the sample, the search was limited to peer-reviewed journals and conference proceedings, the language was restricted to English, and the research areas of interest were limited to Engineering, Computer Science, Social Science, Decision Science, and Business, Management, and Accounting. These settings led to the reduction of the initial sample to 192 papers, which underwent the second screening process. The second screening step required defining the basic criteria for screening the papers collected and performing the selection of papers accordingly, by reading title, abstract and keywords of each paper. The basic exclusion criteria were identified and summarized as follows:

- Papers not related to warehousing (e.g., papers related to data warehouses, data storage);
- Papers not involving the role of human factor or HTI but focusing on pure technology.

As a result of this screening phase, 98 papers were excluded from the previous sample, thus leaving 94 papers adapt for the full-text screening. In this third step, papers were further filtered based on full-text reading, according to the eligibility hereinafter reported, and in line with the exclusion criteria above defined. The following eligibility criteria have been set:

- Papers discussing HTI in warehouses.
- Papers discussing L5.0 in warehouses.
- Papers focusing on HF and related challenges, opportunities, and solutions in warehouses.

This procedure led to the identification of a final sample of 39 relevant papers. Lastly, 6 more papers have been added to the sample through the snowballing approach, adopted to overcome the limitation of a systematic review and the adoption of a single database for paper search, thus leading to a sample of 45 papers which were subject to in-depth review. The entire procedure was performed independently by three researchers to ensure reproducibility and minimize biases in the criteria definition and paper selection.

As per the empirical analysis, 13 Italian business cases have been analysed to understand the state of the art about the main technological solutions adopted, and their application area. Information has been collected in March 2024 from secondary sources (e.g. company websites, company sustainability reports, institutional reports) reporting real-world insights and has been used to adjust the framework. The analysed pool of companies has been selected balancing the quality and availability of information, and the quantity and variety of cases, to provide valuable insights about companies implementing human-centric solutions in their warehousing processes.

3. Findings

3.1 Academic literature: descriptive analysis

Papers distribution over time (Figure 3) shows that no relevant papers on the topic were published before 2013. The number of publications has experienced rapid and constant growth since 2020, in conjunction with the increased interest in both sustainability topics and L5.0 paradigm. The trend stemming from this analysis shows the current importance of the topic and suggests a further growth of contributions in the coming years.

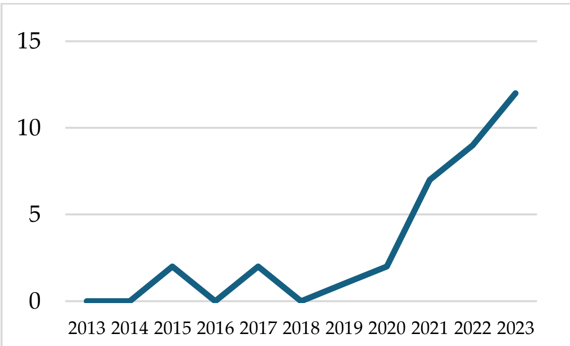

Figure 3: Paper distribution over time

3.2 Academic literature: content-wise analysis

A thorough analysis of the selected papers has been conducted to comprehend the current state of the art related to human-centric warehousing and to address the defined RQs. The SLR results have led to the identification of four main research streams, corresponding to four possible approaches to consider a human-centric warehouse with a L5.0 perspective:

1. Focusing on human factor and technologies fostering human well-being;
2. Focusing on human-technology interaction;

3. Integrating human perspective into system management policies;
4. Focusing on the design of collaborative or interface technologies.

The first stream focuses on the human factor by addressing technologies fostering human well-being and assessing impacts on the human factor. Studies of this kind are various, spanning from the physical to the mental human dimension and from automated to digital technologies, although technologies supporting human physical dimensions in order picking are the most investigated topic. These studies usually observe a positive impact of supportive technologies on the physical dimension of human operators, instead, recorded impacts on mental or psychosocial dimensions lead to less unanimous conclusions. For example, Schmalz et al. (2022) and Jakobsen et al. (2023) examine the physical impacts on human operators of a passive shoulder exoskeleton (PSE), the former, and of a back-support exoskeleton, the latter, in manual material handling in warehouses. Both results indicate a beneficial reduction in physical load for human operators. Jakobsen et al. (2023) also investigate their acceptance. However, low adoption of PSE hinders conclusions on the suitability of exoskeletons for the logistics sector which is still uncertain and presents many challenges. Loske and Klumpp (2020) tackle the mental dimension of the human factor, specifically the employees learning curve, by comparing learning curves in manual pick-by-voice and semi-automated order picking. The results suggest that automating human tasks accelerates the individual learning progress in human-robot picking systems. Berx et al. (2021) assess the impact of working with Autonomous Mobile Robots (AMRs) on logistics operators through a case study and surveys. Results indicate that, in general, the AMR is not seen as a threat, either for safety or for job loss.

The second research stream focuses on human-technology interaction. It investigates warehouse configurations and processes looking at the best combination of technologies and human operators with a greater concern for performances and efficiency and a minor attention to the impact on humans. Also in this case, physical technological solutions (e.g., robots, AGVs, AMRs) supporting order picking are the most investigated and they are usually associated with performance benefits. For example, Koreis et al. (2023) study hybrid order picking systems, where an AMR automatically follows pickers in their travel direction and humans and robots share the same objectives. A model to estimate the impact of this AMR setting on task performance, measured in travel and picking time, is applied and a significant reduction in picking task with respect to manually steered industrial trucks is recorded. One of the fundamental aspects to be defined for a human-robot collaborative order-picking system is the system configuration, i.e., the respective role of the human and the robot partners. The role of robots can be designed to be either leading (active) or following (passive) (Azadeh et al., 2019). Pasparakis et al. (2023) study the long-term effect of human-robot collaboration on job satisfaction and core self-evaluation of the human factor, in two alternative configurations: the human leading and the human following the robot. Differently, Chen and Li (2024) tackle the storage location assignment (SLA) problem to enhance order-picking efficiency. While many studies focus on robot retrieval efficiency, this study emphasizes human-robot collaboration in Robotic Mobile Fulfilment Systems (RMFS), by considering proxies of human behavioural factors, such as storage levels and product characteristics, to optimize item assignment and improve overall efficiency. In conclusion, many studies investigate different warehouse technologies and the possible system configurations associated (Azadeh et al., 2019), however, they rarely integrate the impact on human factor in their evaluations and often focus on system performances. When the human factor is considered, no standard metrics are adopted and usually proxies for selected human dimensions are chosen. Still, a clear understanding of how to assess this kind of impacts in a structured way is missing.

The third research stream focuses on the integration of human perspective into system management policies, trying to identify policies and measures to be applied for improving performances. To this aim, some papers propose machine learning algorithms that match operators' characteristics with the most suitable task to reduce task processing time. Matusiak et al. (2017) propose an algorithm that performs order batching, routing, and job assignment for order picking, considering pickers' skills, thus minimizing total order processing time. Other papers investigate the introduction of collaborative order-picking robots and their impact on human operators and propose measures to facilitate this transition. For example, Lambrechts et al. (2021) study human aspects such as resistance to change, organizational culture, communication on change, and leadership, thus unveiling the importance of planning the implementation process, the importance of leadership, and the need to focus on reskilling and upskilling of logistics professionals. While Pasparakis et al. (2023) measure job satisfaction, self-esteem, and self-efficacy through surveys, showing that the introduction of collaborative robotics increases pickers job satisfaction. Rieder et al. (2021), instead, introduce a model assessing the additional training costs to be sustained for the implementation of an automated order-picking system, along with the savings generated by the system over time.

The fourth research stream focuses on the design of collaborative or interface technologies to enhance human-robot cooperation in proximity while ensuring safety. Therefore, these studies aim to establish a human-robot cooperation aiding system that facilitates working at close distance, thus improving both safety and efficiency. Studies in this domain propose various methods for object tracking, primarily leveraging deep learning and detection algorithms, to identify and monitor moving entities like humans and goods within smart logistics warehouses (Xie and Yao, 2023). Some research explores the use of augmented reality/mixed reality technologies to enhance interaction between cobots and human operators. Artificial intelligence algorithms and physical patterns in work environments are utilized to enable robots to understand operator intentions and operators to comprehend robot status (Owaki et al., 2023). Additionally, effective manipulation relies on the real-time integration and interpretation of manual gestures, a topic explored in the literature through several approaches such as hand gesture recognition algorithms (Bose et al., 2023).

In conclusion, contributions on the topic are diverse. The theme has been approached with different methodologies and various perspectives, often with a specific focus on picking or on specific technologies, and, predominantly at the operational level. Concurrently, few reviews have been recently developed for a more structured understanding of the subject. However, these contributions often consider a single activity, such as order picking (e.g., De Lombaert et al., 2023; Grosse, 2024), or specific technologies, such as automated and robotized systems (e.g. Lorson et al., 2023), and focus essentially on the operative level (e.g., Lorson et al., 2023)(e.g., Lorson et al., 2023). Still, an overall picture of how these elements should be considered in the design and management of sustainable warehousing from a holistic perspective is missing.

3.3 Discussion of empirical results

A summary of the business cases considered for the analysis is reported Table 1. The main technologies adopted, along with their scope and role, are identified. For confidentiality reasons, company names are not disclosed.

Table 1: Features of the business cases analysed

Business cases	Technology	Technology role	Activity
[1][2] 3PLs [3] food retailer	Voice picking	Support (informative level)	Picking
[4] 3PL for food retailer	Exoskeleton	Support (physical level)	Picking
[5] 3PL	AMR (Autonomous Mobile Robots)	Substitution (Physical and decisional level)	Picking
[6] e-commerce retailer [7] retailer of sports apparel and accessories	RMFS (Robotic Mobile Fulfilment System)	Substitution (information, physical and decisional level)	Picking
[8] 3PL in pharma sector	Palletizer cobots	Support (physical level)	Picking
[9] fashion manufacturer	AVSRS (Autonomous Vehicle Storage and Retrieval System)	Substitution (information, physical and decisional level)	Put away and picking
[10][11] fashion manufactures [12][13] retailers of spare parts for household appliances	RCSRS (Robotic Compact Storage and Retrieval System)	Substitution (information, physical and decisional level)	Put away and picking

In line with academic contributions (Winkelhaus et al., 2021; Ito et al., 2021), results show that technologies can be implemented with a supportive or substitutive role, at different levels (informative, physical, decisional). Among the analysed cases, solutions that support picking activity at informative level, such as voice picking (business cases [1][2],[3]) or that allow human substitution at physical level thus benefitting physical fatigue such as AMR (autonomous mobile robots) (business case [5]), are more common and more successfully adopted. Differently, exoskeletons providing physical support during picking activity are still difficult to find. Just one pilot project emerged (business cases [4]), however, there are still some challenges in their implementation since exoskeletons provide strong benefits for stationary activities but significant limitations during movement. This result is also reflected in academic literature (Ashta et al., 2023). Most of the described technologies are characterized not only by significant benefits for the human operator but also by a high degree of operational flexibility and they are often proposed by 3PLs. At the same time, several substitutive and highly automated technologies have been found to be quite diffused and well consolidated, such as Autonomous Vehicle Storage and Retrieval System (AVSRS) (business case [9]) and Robotic compact storage and retrieval system (RCSRS) (business cases [10][11][12][13]). These systems provide human substitution at information, physical and decisional levels. Their implementation is usually driven by efficiency objectives in high-volume warehouses. It also aims at improving human well-being when applied to refrigerated warehouse areas.

4. Discussion

4.1 RQ1 and proposed framework

In line with the final aim of this paper, this section proposes a comprehensive framework describing the main aspects of human-centric warehousing in light of the L5.0 paradigm (Figure 5). This framework aims at summarizing the current theoretical and empirical state of the art on the topic. Its development is based on a systematic combining approach, considering the results of the conducted SLR and empirical analysis, along with the definition of Industry 5.0 provided by the European Commission (2021).

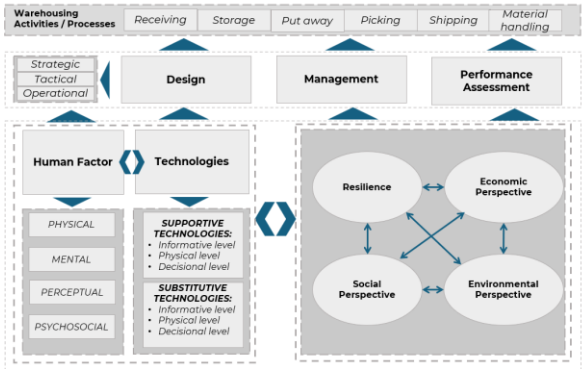

Figure 5: Human-centric Warehousing Framework

The resulting framework of human-centric warehousing encompasses all the different aspects to be considered when adopting this new perspective, based on the academic and empirical state of the art. The first key aspect is represented by technologies, that need to be considered in light of their relationship with the human operator. In this regard, technologies can have a substitutive or supportive role, at informative, physical, or decisional level (Grosse, 2024). For a human-centric warehouse, it is fundamental to be aware of the human component. The human factor, present in warehouse alongside technologies, is composed of four main dimensions: physical, mental, perceptual, and psychosocial (De Lombaert et al., 2023; Grosse, 2024). Different settings of human factor and technologies interactions can generate different warehouse configurations, which need to be evaluated with a holistic perspective. So, resilience, social sustainability (e.g., human well-being and safety), environmental sustainability (e.g., effects of GW practices and energy efficiency) and economic sustainability (e.g., investment costs, operating costs, efficiency) need to be considered together (European Commission, 2021). Last, this consideration should be done for each warehousing activity and with the aim of supporting warehouse design, management, and performance measurement at operational, tactical, and strategic levels (De Lombaert et al., 2023). In this regard, three possible areas of intervention emerged to implement a human-centric warehouse: implementing technologies to encourage and improve operators' well-being; acting on process design by leveraging human-technology interaction; integrating the human perspective into the definition and application of system management policies.

4.2 RQ2: Research gaps and future research agenda

The aspects analysed in the previous section are characterized by significant knowledge gaps. On one hand, resilience (Zhai et al., 2022) and environmental sustainability (Liu et al., 2022) are marginally tacked in relation to human-centric warehouse, while social sustainability is investigated deeper (Jakobsen et al., 2023), and economic sustainability is the most studied in relation to human-centric warehousing (Koreis et al., 2023; Kumar et al., 2023; Rieder et al., 2021). However, the different dimensions are usually studied separately, and joint effects and trade-offs of specific human-centric-oriented actions are largely neglected. On the other hand, different actions to implement a human-centric warehouse lack in-depth analyses and require further investigation. Additionally, there is a lack of a comprehensive overview of possible areas of interventions and actions for implementing and developing a human-centric warehouse in line with the Logistics 5.0 paradigm. While some papers propose actions related to specific aspects of the paradigm, there is no classification of these actions, and of their linkages with warehouse performances and the human factor. Moreover, the existing contributions resort to proxies and unstructured methods to measure the impacts on operators. It is still difficult to find standard metrics to assess impacts in this context. For example, distance travelled is used as a proxy of human fatigue (Koreis et al., 2023), while surveys are used to assess job satisfaction (Pasparakis et al., 2023). Additionally, also specific technologies aiming at supporting human factor require further investigation. For example, studies on exoskeleton applications in the logistics field are not exhaustive and there is still the need to understand their suitability and their impact on different human dimensions as well as on warehouse performances (Schmalz et al., 2022; Jakobsen et al., 2023). Analytical models, quantitative analysis, and empirical studies are fragmented and present several limitations, such as strong assumptions or applications to a limited sample, within a limited time horizon, or under controlled conditions. Moreover, several works tackle only picking activity, which is the most complex and surely needs to be further investigated, while other activities are under-investigated. Lastly, existing literature mainly focuses on the operative level, leaving a significant research gap in terms of tactical and strategic analysis (Lorson et al., 2023). Warehouse design, management, and performance measurement are not performed according to the presented holistic perspective but usually follow efficiency objectives. The lack of decision-support models emerges, meaning that tools that could support warehousing design, management, and performance measurement with a L5.0 perspective need to be investigated. In conclusion, many and diverse research gaps emerged, paving the way for several future research streams that need to be addressed to contribute to human-centric warehousing with a L5.0 perspective.

5. Conclusions

In a context where the market is fast changing and highly demanding and sustainability goals are crucial, logistics, and particularly warehouses, are under significant pressure and play a crucial role in value chains. Automation and technologies are largely leveraged in warehousing to face these challenges, while human operators still play a crucial role by guaranteeing a high degree of flexibility which is fundamental in warehousing activities. The role of human-technology interaction becomes crucial in this context, also in light of the emerging L5.0 paradigm, as it can impact, on one hand, social sustainability and human well-being, on the other hand, the overall performances of warehouse activities and, if well designed, can be leveraged to improve them. However, the topic is still novel and fragmented. This paper offers a study on human-centric warehousing in light of the L5.0 perspective, based on a systematic combing approach. A conceptual framework is eventually proposed as a lens for the understanding of the overall subject, and research gaps and future research fields emerging from the analysis are pointed out. The main elements to be considered are highlighted, i.e., warehousing activities, human factor and technologies, and different sustainability and resilience goals, along with different managerial levels and perspectives. This work offers both academic and managerial contributions. From an academic perspective, an overall understanding of an emerging and fragmented topic is provided in a structured way through the proposed framework, also highlighting the current academic and empirical state of the art on the topic, along with research gaps and a possible future research agenda. From a managerial perspective, guidelines that can support practitioners in understanding the main elements of L5.0 are provided, along with empirical insights. Despite the relevance of the provided contributions, this work presents some limitations. First, papers location strategy (e.g., relying on a single database) and selection criteria adopted to conduct the SLR could have led to the elimination of relevant contributions, despite the effort to be complete. Then, the empirical analysis is based on secondary sources, it is limited to the Italian landscape and only 13 business cases have been considered. Future research could target the research gaps highlighted before to further enrich and detail the framework, with the aim of supporting a sustainable design and management of warehouses.

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the quality of the research produced and funds specific development projects.

References

Ali, I., & Phan, H. M. (2022). Industry 4.0 technologies and sustainable warehousing: A systematic literature review and future research agenda. *The International Journal of Logistics Management*, 33(2)

Ashta, G., Finco, S., Battini, D., & Persona, A. (2023). Investigating the efficiency of a passive back-support exoskeleton in manual picking tasks. In *Proocedings Summer School Francesco Turco*.

Azadeh, K., Roy, D., & De Koster, R. (2019). Design, modeling, and analysis of vertical robotic storage and retrieval systems. *Transportation Science*, 53(5), 1213-1234.

Berx, N., Pintelon, L., & Decré, W. (2021, March). Psychosocial impact of collaborating with an autonomous mobile robot: Results of an exploratory case study. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction* .

Bose, S. R., Kumar, V. S., & Sreekar, C. (2023). In-situ enhanced anchor-free deep CNN framework for a high-speed human-machine interaction. *Engineering Applications of Artificial Intelligence*, 126, 106980.

Boysen, N., De Koster, R., & Weidinger, F. (2019). Warehousing in the e-commerce era: A survey. *European Journal of Operational Research*, *277*(2), 396-411.

Chen, Y., & Li, Y. (2024). Storage Location Assignment for Improving Human–Robot Collaborative Order-Picking Efficiency in Robotic Mobile Fulfillment Systems. *Sustainability*, *16*(5), 1742.

De Lombaert, T., Braekers, K., De Koster, R., & Ramaekers, K. (2023). In pursuit of humanised order picking planning: methodological review, literature classification and input from practice. *International Journal of Production Research*, *61*(10).

Dubois, A., & Gadde, L. E. (2002). Systematic combining: an abductive approach to case research. *Journal of business research*, *55*(7), 553-560.

European Commission, Directorate-General for Research and Innovation, Breque, M., De Nul, L., Petridis, A., Industry 5.0 – Towards a sustainable, human-centric and resilient European industry, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/308407

Grosse, E. H., Sgarbossa, F., Berlin, C., & Neumann, W. P. (2023). Human-centric production and logistics system design and management: transitioning from Industry 4.0 to Industry 5.0. *International Journal of Production Research*, *61*(22), 7749-7759.

Grosse, E. H. (2024). Application of supportive and substitutive technologies in manual warehouse order picking: a content analysis. *International Journal of Production Research*, *62*(3), 685-704.

Grosse, E. H., Glock, C. H., Jaber, M. Y., & Neumann, W. P. (2015). Incorporating human factors in order picking planning models: framework and research opportunities. *International Journal of Production Research*, *53*(3), 695-717.

Ito, A., Ylipää, T., Gullander, P., Bokrantz, J., Centerholt, V., & Skoogh, A. (2021). Dealing with resistance to the use of Industry 4.0 technologies in production disturbance management. *Journal of Manufacturing Technology Management*, *32*(9), 285-303.

Jakobsen, L. S., de Zee, M., Samani, A., Desbrosses, K., & Madeleine, P. (2023). Biomechanical changes, acceptance, and usability of a passive shoulder exoskeleton in manual material handling. A field study. *Applied Ergonomics*, *113*, 104104.

Kar, A. K., Choudhary, S. K., & Singh, V. K. (2022). How can artificial intelligence impact sustainability: A systematic literature review. *Journal of Cleaner Production*, *376*, 134120.

Kirkeby, O. F. (1994). Abduktion. *Andersen. H, ed., Videnskabsteori og metodelaere, Fredriksberg: Samfundslitteratur*, 122-152.

Koreis, J., Loske, D., & Klumpp, M. (2023). Together, we travel: empirical insights on human-robot collaborative order picking for retail warehousing. *The International Journal of Logistics Management*.

Kumar, S., Sheu, J. B., & Kundu, T. (2023). Planning a parts-to-picker order picking system with consideration of the impact of perceived workload. *Transportation Research Part E: Logistics and Transportation Review*, *173*, 103088.

Lambrechts, W., Klaver, J. S., Koudijzer, L., & Semeijn, J. (2021). Human factors influencing the implementation of cobots in high volume distribution centres. *Logistics*, *5*(2), 32.

Liu, D., Kaisar, E. I., Yang, Y., & Yan, P. (2022). Physical Internet-enabled E-grocery delivery Network: A load-dependent two-echelon vehicle routing problem with mixed vehicles. *International Journal of Production Economics*, *254*, 108632.

Lorson, F., Fügener, A., & Hübner, A. (2023). New team mates in the warehouse: Human interactions with automated and robotized systems. *IISE Transactions*, *55*(5), 536-553.

Loske, D., & Klumpp, M. (2020). Smart and efficient: Learning curves in manual and human-robot order picking systems. *IFAC-PapersOnLine*, *53*(2), 10255-10260.

Martins, C. L., & Pato, M. V. (2019). Supply chain sustainability: A tertiary literature review. *Journal of cleaner production*, *225*, 995-1016.

Matusiak, M., De Koster, R., & Saarinen, J. (2017). Utilizing individual picker skills to improve order batching in a warehouse. *European Journal of Operational Research*, *263*(3), 888-899.

Modica, T., Colicchia, C., Tappia, E., & Melacini, M. (2023). Empowering freight transportation through Logistics 4.0: a maturity model for value creation. *Production Planning & Control*, *34*(12).

Miklautsch, P., & Woschank, M. (2022). A framework of measures to mitigate greenhouse gas emissions in freight transport: systematic literature review from a Manufacturer's perspective. *Journal of Cleaner Production*, *366*, 132883.

Owaki, K., Techasarntikul, N., & Shimonishi, H. (2023, October). Human Behavior Analysis in Human-Robot Cooperation with AR Glasses. In *2023 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (pp. 20-28). IEEE.

Pasparakis, A., De Vries, J., & De Koster, R. (2023). Assessing the impact of human–robot collaborative order picking systems on warehouse workers. *International Journal of Production Research*, *61*(22).

Perotti, S., Santacruz, R. F. B., Bremer, P., & Beer, J. E. (2022a). Logistics 4.0 in warehousing: a conceptual framework of influencing factors, benefits and barriers. *The International Journal of Logistics Management*, *33*(5), 193-220.

Perotti, S., Prataviera, L. B., & Melacini, M. (2022b). Assessing the environmental impact of logistics sites through CO2eq footprint computation. Business Strategy and the Environment, 31(4).

Rieder, M., Bonini, M., Verbeet, R., Urru, A., Bartneck, N., & Echelmeyer, W. (2021, December). Evaluation of human-robot order picking systems considering the evolution of object detection. In *2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 1-8). IEEE.

Schmalz, T., Colienne, A., Bywater, E., Fritzsche, L., Gärtner, C., Bellmann, M., ... & Ernst, M. (2022). A passive back-support exoskeleton for manual materials handling: reduction of low back loading and metabolic effort during repetitive lifting. *IISE transactions on occupational ergonomics and human factors*, *10*(1), 7-20.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of business research*, *104*, 333-339.

Winkelhaus, S., Grosse, E. H., & Morana, S. (2021). Towards a conceptualisation of Order Picking 4.0. *Computers & Industrial Engineering*, *159*, 107511.

Xie, T., & Yao, X. (2023). Smart Logistics Warehouse Moving-Object Tracking Based on YOLOv5 and DeepSORT. *Applied Sciences*, *13*(17), 9895.

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of manufacturing systems*, *61*, 530-535.

Zhai, D., Wang, C., Cao, H., Garg, S., Hassan, M. M., & AlQahtani, S. A. (2022). Deep neural network based UAV deployment and dynamic power control for 6G-Envisioned intelligent warehouse logistics system. *Future Generation Computer Systems*, *137*, 164-172.