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Augmented Reality as Extended Cognition for Logistics Decisions

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Abstract

Decision-making is lined with cognitive biases. Due to the limitations of our cognitive system, it is influenced by several contextual or even demanding aspects of the environment where the decision is made. Logistic decisions are also influenced by cognitive biases; therefore, the application of data-driven decision support systems is already the subject of studies. Nevertheless, although cognitive biases are often investigated and defined, the lack of an organizing principle is detectable. The present paper is a first attempt to fill the gap resulting from the absence of a taxonomy of cognitive biases. This research paper aims to highlight the importance of Augmented Reality (AR) in logistic decisions, and also to accentuate the application of AR in the process that filters cognitive biases.

Keywords: augmented reality, cognitive bias, logistics, decision-making process, taxonomy

INTRODUCTION

Investigating human behaviour is one of the most significant and perhaps one of the most important challenges of our time. We make decisions several times every day (Baron, 2006), both in our private lives and in our workplaces. In many cases, logistical decisions are supported by machines (Adriana et al., 2022), so we can talk about human-machine communication. However, humans also enter data into machines, therefore cognitive biases may already appear in the programming phase.

In this publication, we analyse the decision situations in logistics processes. We have chosen this discipline due to its hectic aspect. It is also a field where new decisions have to be made daily (Choudhary and Shankar, 2013) under time pressure, which the literature defines as "fast" decisions (Kahneman, 2011). In addition, logistics strategies and the design of the logistics environment take more time, therefore "slow" decisions (Kahneman, 2011) also appear.

To understand cognitive biases in logistics decisions, we use the Sibony (2020) classification based on strategic business decisions. In the present paper, we also describe the procurement field and a logistics example to highlight the situations in which cognitive biases may occur.

Kahneman (2011) defines two types of thinking systems that result in systematic errors and fallacies of thinking, called cognitive biases. System 1 refers to fast, automatic thinking that enables quick responses, which, in turn, are essential for complex decision-making for adaptive behaviour in challenging environments (Preisz, 2019). Alternately, system 2 represents slow thinking, where the cognitive process is data-driven and more analytical (Kahneman, 2011). Slow thinking improves decision-making by enabling the elaboration of a certain problem; however, it presumes accessibility to the necessary rules for solving the problem and the recognition of the application of that rule (Kahneman, 2000; Lawson, Larrick & Soll, 2020). Therefore, the system 2 process could be limited and an expert system would be needed to enhance reflective thinking.

Considering the characteristics of data-driven, analytical thinking, the benefits of AR in the decision-making process enables reflective thinking. It can also support and promote the operation by maximizing the effort due to the experience of the experts that it is based on (Zhang, Wang, Zhang, Xiao & Ren, 2022).

In philosophy, the extended mind/ cognition refers to the interaction between cognitive processes and the environment where behaviour appears (Clark and Chalmers, 1998; Wheeler, 2010), which also contains social interactions (Krueger, 2011). Therefore, the environment serves the role of the non-neural scaffolding of the cognitive processes that includes socio/ cultural practices as well (Kirschhoff, 2012; Krueger, 2011). Considering the claims that cognitive systems are spatially extended (Silberstein and Chemero, 2020) augmented reality serves the purpose of the extension of spatial sense-making through human-computer- interaction (Çöltekin et al., 2020).

Although the use of Augmented Reality (AR) in the decision-making process might enhance reflective thinking, and could serve as an extension of human cognition, an important aspect of the quality of the human-machine interaction has been emphasized by Mohammadi & Taylor (2021) in data-driven decision-making; that is the process of decision-making is influenced by both the characteristics of the decision-making and the quality of the data-driven model.

In order to understand the knowledge background, we conducted a literature analysis to map the direction of the articles written on the topic we are researching. Our investigation covers the use of Augmented Reality (Blümel, 2013) in the logistics field (Ginters et al. 2020) that is a technical tool to support human decision-making.

1. Cognitive biases in decision-making

Since corporate decisions are very similar to logistical decisions, to understand the cognitive biases in decision-making, we use the Sibony (2020) classification based on corporate strategic decisions, which is briefly described in Table 1.

Table 1: Classification of cognitive biases

Storytelling trap	To know a story that has an impact on costs and processes. Instinctively recalling information from memory that supports a given decision situation.
Confirmation bias	In a specific situation, focus on the information that confirms the current views of a situation and supports the decision.
Attribution error	Success or failure is attributed to one person in the company performing or not performing well.
Halo effect	Copying the work of a successful expert to ensure that the strategy they use will work.
Anchoring	A professional evaluate information as an "anchor". For example, the annual budget plan does not put in a process that is needed.
Commitment	Due to an already-made decision, no change is made even though the process is inadequate.
Status quo bias	Maintaining the status quo in the decision-making process. Fear of wasting the energy invested so far.
Loss aversion	The fear of loss has a significant impact on decisions.
Uncertainty aversion	Avoiding risky situations for fear of uncertainties.
Hindsight bias	The same event is judged differently before and after the event.

Adapted from Sibony (2020)

In order to understand the cognitive biases involved in decisions in the logistics domain, we will first describe the procurement area, and then a procurement example.

The role of the purchaser is usually to provide the resources necessary for the company to operate according to the 6Rs (Altendorfer-Kaiser, 2015), that is, to provide the right product, at the right time, in the right place, in the right quantity, of the right quality, and at the right price. However, the purchasing department does not only mean the purchase of materials and services that are essential for the production process, but also the management of the related organizational tasks (Liu et al., 2022). Purchasing is an area where the number of decisions per day is quite high and often of great importance, both in terms of price and product quality, which also affects the company's performance indicators (Choudhary and Shankar, 2013). In addition, monitoring the inventory level is the responsibility of the purchaser as well.

The following example clarifies how cognitive biases can appear in the field of purchasing:

A purchaser places a regular order 2 weeks in advance rather than at the specified time because they fear that a stock shortage will occur due to an unexpected event (e.g. supplier delays or production problems). In this case, loss aversion bias (Földesi and Botzheim, 2010) appears.

At the same time as placing the order, it is also necessary to examine the storage capacity, that is, if the products arrive 2 weeks early, how the storage can be managed. When loaded into Augmented Reality, the data can be used to investigate the possible location of warehouse capacity (Zywicki and Bun, 2021) and storage (Zhaojia et al. 2022) at that moment and also for the time when the product is likely to arrive. Hence, uncertainty aversion (Sibony, 2020) in the purchaser can be avoided by using AR.

2. AR as the extended cognition of the generalist

According to the Cambridge Dictionary, the definition of the generalist is "…someone who has a range of skills and knowledge…", "…offering a range of products or services…" (Cambridge Advanced Learner's Dictionary & Thesaurus, 2005); therefore, the term generalist refers to someone with broad domain experience (Landrum & Mills, 2015). On the other hand, specialists focus on a narrow area in depth and the two extremes are connected on a continuum (Waller & Anderson, 2019).

The taxonomy presented earlier integrates generalist-specialist definitions together with the continuum of physical-augmented realities, offering an organizational principle for cognitive biases. The taxonomy reveals the alteration between cognitive biases depending on the generalist-specialist dimensions' interaction with the continuum of reality, through the dynamical change of slow and fast thinking.

Augmented reality decelerates fast thinking, complementing the errors of system 1 in decision-making. The application of AR in decision-making facilitates system 1 thinking in certain conditions, and fallacies of system 2 are filtered. However, the usage of AR does not result in the elimination of cognitive biases since augmented reality is highly affected by the quality, characteristics, and aspects of data.

Reflective thinking is supported by AR due to its data-driven nature, therefore the deployment of AR not only scaffolds slow thinking but even narrows in-depth alternatives for the generalist decision-maker. It also regulates systematic errors of the specialist decision-maker by expanding alternatives through different domains.

3. A knowledge background validation to examine the relationship between logistics, AR, and decision-making

To understand the relevance of our research direction, we examined the knowledge background in order to analyse the relationship between logistics, AR, and the decision-making process.

In this research, we present a trend in the use of Augmented Reality in the field of logistics in decision-making, considering the cognitive biases that arise in the decision-making process. To understand the knowledge background related to this topic, we conducted a search in the ScienceDirect database. In the database, we first searched for the terms "logistics" and "augmented reality", to which were added the keywords "decision making" and "bias". In order to obtain more relevant results, we further narrowed the search by adding the words "context", "expertise" and "industry 4.0", as well as "extended", "cognition", "mind" and "cognitive bias", to focus the search on publications related to logistics decision making.

Table 2. Summaries of results on ScienceDirect on 6 February 2023.

SEARCH NAME	KEYWORDS / RESULT SCIENCEDIRECT						TOTAL
LOGandAR	**logistics**	**"augmented reality"**					**1844**
Last 5 years (2018-2023)							1530
LOGandARandDM	**logistics**	**"augmented reality"**	**"decision making"**				**1208**
Last 5 years (2018-2023)							1045
LOGandARandDMandBIAS	**logistics**	**"augmented reality"**	**"decision making"**	**bias**			**309**
Last 5 years (2018-2023)							276
LOGandARandDMandBIASandCO	**logistics**	**"augmented reality"**	**"decision making"**	**bias**	**context**		**286**
Last 5 years (2018-2023)							257
LOGandARandDMandBIASandIND4	**logistics**	**"augmented reality"**	**"decision making"**	**bias**	**"industry 4.0"**		**154**
Last 5 years (2018-2023)							150
LOGandARandDMandBIASandEXP	**logistics**	**"augmented reality"**	**"decision making"**	**bias**	**expertise**		**124**
Last 5 years (2018-2023)							108
LOGandARandDMandCOGBIAS	**logistics**	**"augmented reality"**	**"decision making"**	**"cognitive bias"**			**12**
Last 5 years (2018-2023)							10
LOGandARandDMandBIASandMIND	**logistics**	**"augmented reality"**	**"decision making"**	**bias**	**extended**	**mind**	**84**
Last 5 years (2018-2023)							62
Filtered by field of expertise (2018-2023)							*50*
LOGandARandDMandBIASandCOGN	**logistics**	**"augmented reality"**	**"decision making"**	**bias**	**extended**	**cognition**	**41**
Last 5 years (2018-2023)							31
Filtered by field of expertise (2018-2023)							*23*

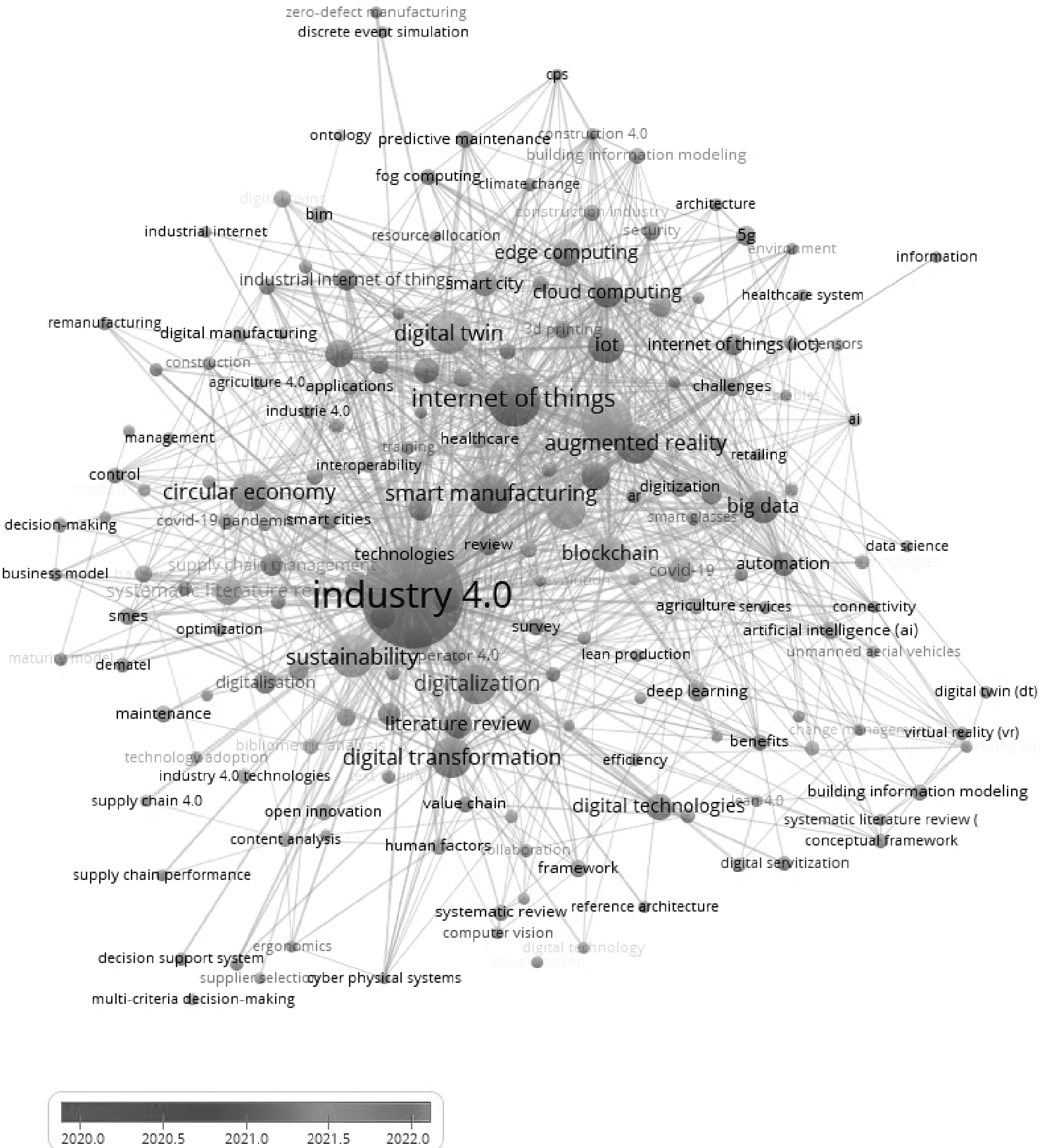
Table 2 shows the results obtained for the keywords given, for all fields of study, in the ScienceDirect database. The results obtained have been further narrowed down to show the trend over the last 5 years (2018-2023). The search for the keywords logistics AND "augmented reality" AND "decision making" yielded 1045 results, narrowed down to the interval 2018-2023.

In the second step, by using VOSViewer, we examine the associations of keywords appearing in the publications for the last 5 years (2018-2023). The analysis was made by VOSViewer with basic settings based on a ScienceDirect search on 6 February 2023. Keywords: logistics AND "augmented reality" AND "decision making". The minimum number of occurrences of a keyword: 4. The analysis shows the direction of articles written in recent years for these keywords.

Based on the results obtained, it can be seen in Figure 1 that Industry 4.0 is prominent among the keywords and is also directly related to the keywords Augmented Reality and Extended Reality. In addition, sustainability and circular economy also appear, which leads us to conclude that professionals have recognized the importance of sustainability for the development of Industry 4.0 systems, and have therefore focused on these aspects in the decision-making process.

The first few pages of the search results highlighted 4 relevant literature papers on the use of Augmented Reality in logistics decision-making. Lagorio et al. (2022) based their paper on a preliminary analysis and provide insight into the main benefits and challenges of implementing AR in logistics. The paper analyses the three logistics activities most affected by the implementation of AR (warehousing, transportation, and training), focusing on the benefits of support and complementation for operators, as well as the drawbacks, technical barriers, and human barriers observed during practice and experimentation. Plakas et al. (2022) in their paper, after a brief overview of AR in manufacturing and logistics, present a real-life AR-Smart Glasses application supporting one of the most repetitive, error-prone, and costly warehouse logistics processes: order picking. The AR system is implemented in a real production environment and integrated into the commission-picking process of a distribution centre operated by a large telecom operator. This paper describes the functionalities of the developed AR system and highlights details of the experiences and lessons learned during the pilot implementation.

Figure 1. Overlay Visualisation by VOSViewer from the research results of keywords: logistics AND "augmented reality" AND "decision making"



At the end of the paper, it is concluded that augmented reality applications in warehouse logistics are still in their infancy. Therefore, a 6-month trial is planned where, in addition to capturing and monitoring critical values for picking performance indicators such as time, picker utilization, and % of picking errors, the pilot project will also introduce gamification features in the AR system for picking. These evaluate whether gamification improves picking performance and increases system acceptance among warehouse workers. Cirulis & Ginters (2013) use augmented reality (AR) to reduce the error rate and decision time of item picking in warehouses. Augmented Reality (AR) offers a key technology to solve these problems by enabling decision-making based on computer-generated visualizations and 3D model projections. In the conclusion, it was supposed that item picking time can be reduced in human-operated warehouses using AR. The article by Mohammed et al. (2022) discusses the increasing pressure on supply chain managers to consider multiple demands in their decision-making processes. They have not yet found a supplier selection and order allocation system in which all needs can be integrated. AR is emerging as an option.

The search was further narrowed down to logistics AND "augmented reality" AND "decision making" AND bias, with 276 results for the period 2018-2023. In a review of the publications, we found that Industry 4.0 is prominent here and that several publications directly mention Augmented Reality.

In the next step, we extended the filtering with the word "context" and created a keyword map. The figure 2 analysis was made by VOSViewer with basic settings based on a ScienceDirect search on 6 February 2023. Keywords: logistics AND "augmented reality" AND "decision making" AND bias AND context. The minimum number of occurrences of a keyword: 4.

Figure 2. Overlay Visualisation by VOSViewer from the research results of keywords: logistics AND "augmented reality" AND "decision making" AND bias AND context

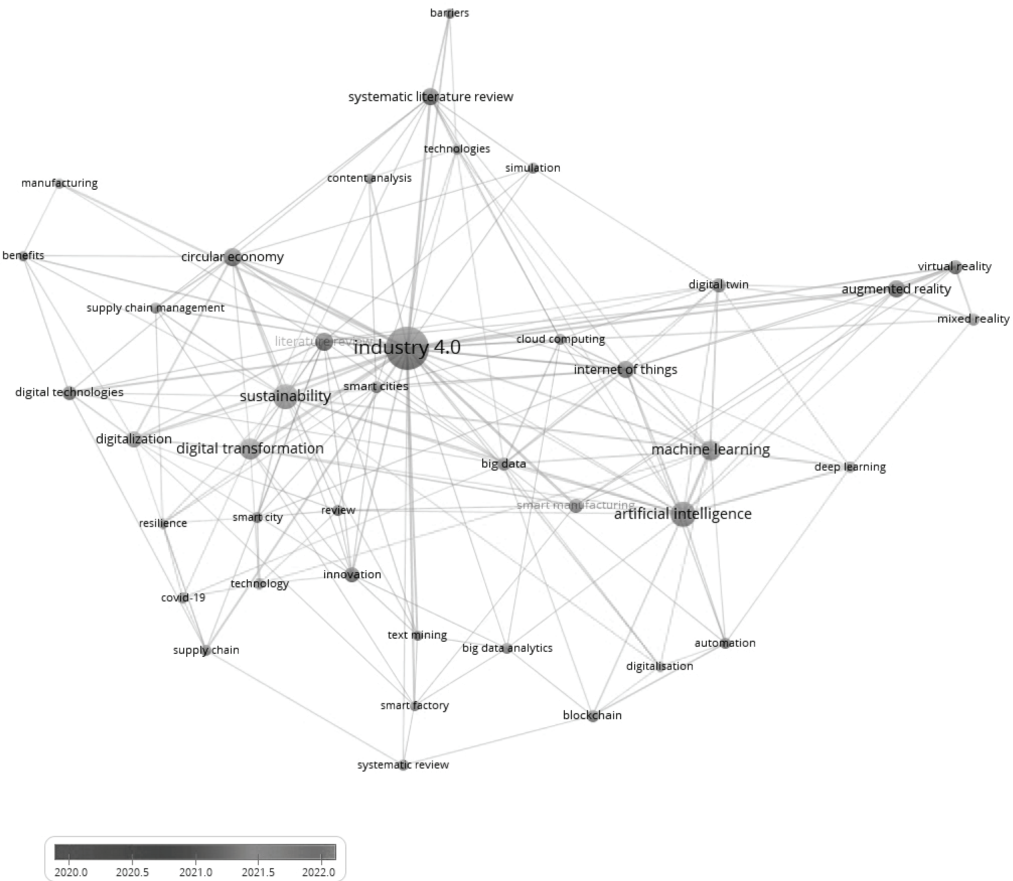
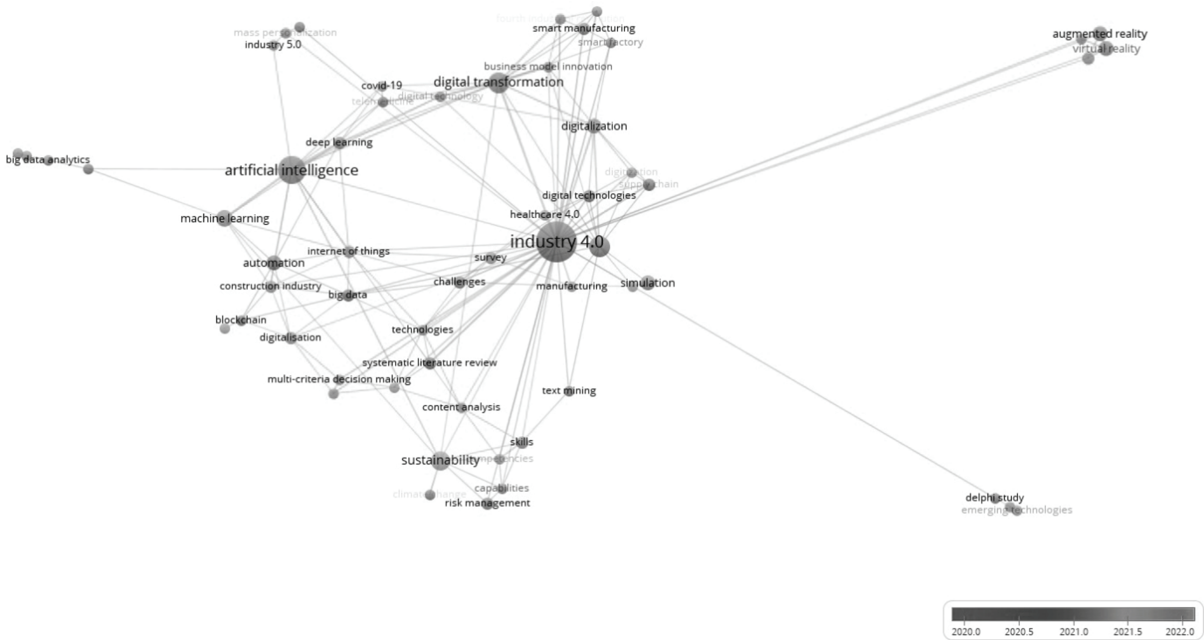


Figure 2 shows that when expanding with the keyword "context", the relationship between Industry 4.0, the decision-making environment and the importance of using decision-support tools is clearly visible. The keywords referring to this are artificial intelligence, as can be seen in Figure 2, played a central role in 2022. Moreover, other decision support systems by machines emerged, such as augmented reality, virtual reality, mixed reality, big data, and digital twins.

An extended search using the word "industry 4.0" resulted in one relevant article that explores the potential of using eye-tracking technology (Kessler and Arlinghaus, 2021) in manufacturing and logistics, in the form of a systematic literature review. It also outlines future research opportunities for the application of eye-tracking technology in manufacturing and logistics.

Figure 3. Overlay Visualisation by VOSViewer from the research results of keywords: logistics AND "augmented reality" AND "decision making" AND bias AND expertise



The word "expertise" has been added to the filtering and creation of a keywords map. The figure 3 analysis was made by VOSViewer with basic settings based on a ScienceDirect search on 6 February 2023. Keywords: logistics AND "augmented reality" AND "decision making" AND bias AND expertise. The minimum number of occurrences of a keyword: 2.

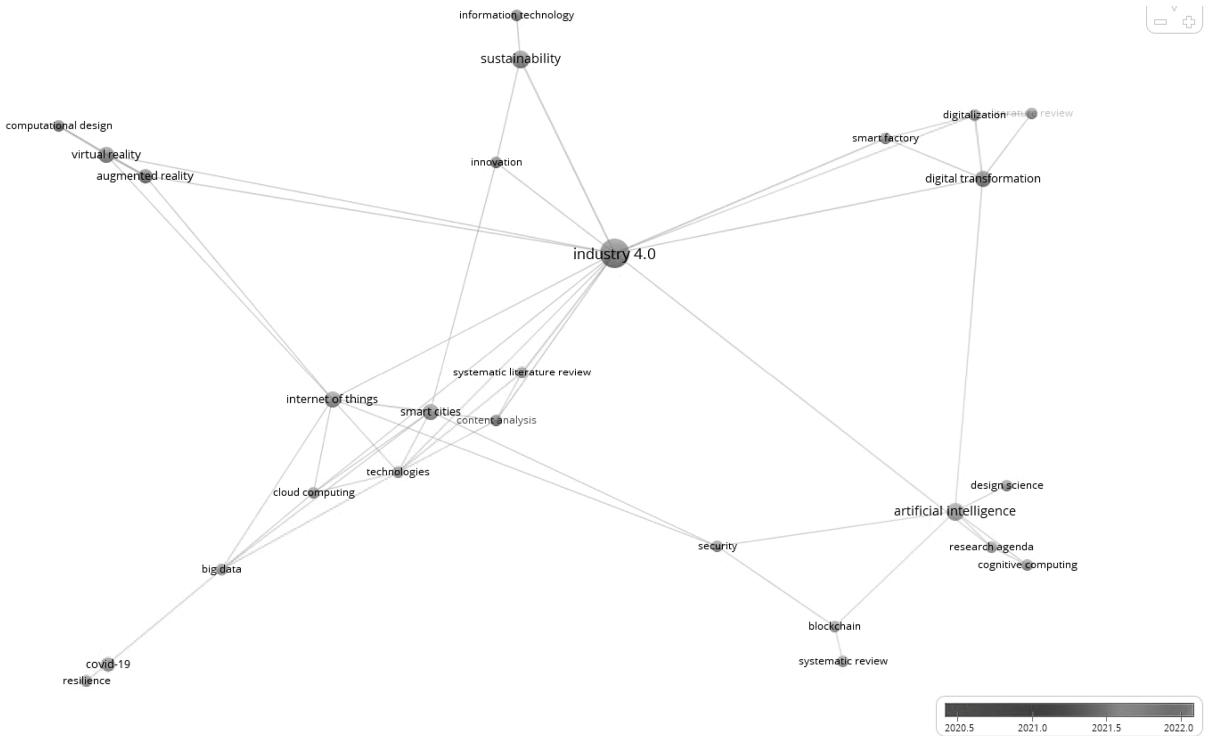
An extended search with the word "expertise" found one relevant publication dealing with augmented reality technologies (Kessler et al., 2022), such as virtual reality, augmented reality, and mixed reality, which support Industry 4.0 in different environments. This systematic review focuses on the analysis of the essence and application of augmented reality and reports on evaluations collected between 2011 and 2022, classified and characterized in the proposed taxonomy. Furthermore, the application areas of augmented reality in Industry 4.0 are described. We plotted the resulting hits on a VosViewer keyword map (Figure 3), where we set the minimum number of occurrences to 2 due to the small number of hits, to provide a clear indication of the current direction of research based on the keyword associations. (The minimum number of occurrences: this parameter is used to specify the minimum number of occurrences that a term should have in the co-occurrence map of terms.)

From the keyword analysis in Figure 3, it can be seen that the decision processes supported by the technology also appear here, which points to the importance of using different decision-support techniques to eliminate the cognitive biases that appear in the case of expert knowledge.

When narrowing down the search using the keyword "cognitive bias", a total of 12 results were obtained. Looking through the publications, one relevant article we highlight analyses the management of risks within buyer-supplier relationships at different steps that require human decision-making. However, research shows that human decisions are often biased, which can negatively affect risk management. The publication by Burger, Kessler, and Arlinghaus (2021) combines a systematic literature review on the state of development and cognitive biases of buyer-supplier relationships in Industry 4.0 with the practical experience from discussions with experts. Our examples from practice reveal that cognitive biases have a strong influence on process, governance, and collaboration risks in the buyer-supplier relationship. Another relevant paper (Kessler et al. 2022) explores the risk factors of digital technologies in industrial operations, examining whether this is useful or harmful for Industry 4.0.

For the knowledge background analysis, we further narrowed down the publications filtered on ScienceDirect by discipline in order to obtain the most relevant results. Accordingly, we expanded the keywords already provided with the words "extended", plus "cognition" and "mind", which have been narrowed down by field to the last 5 years (2018-2023), and by field to only publications in the following areas: Business, Management, and Accounting; Decision Sciences; Engineering; Psychology and Environmental Science.

Figure 4. Overlay Visualisation by VOSViewer from the research results of keywords: logistics AND "augmented reality" AND "decision making" AND bias AND mind



Thus, by specialising the search with "extended" and "mind", 50 results were obtained. By reviewing the results, we found that about one-third of the publications were written about Industry 4.0, with several of these publications being systematic literature reviews on various Industry 4.0 technologies. The publication by Singh, Payal, and Bharti (2019) analysed the use of the Internet of Things (IoT) and Big Data in relation to industrial domains. The publication of Ancillai et al. (2023) pointed out that digital technologies (e.g. Industry 4.0, Internet of Things, cloud computing, big data, blockchain, etc) fundamentally affect the activities and processes of companies, leading to changes in the value creation, value delivery, and value capture mechanisms of companies. Therefore, this paper conducts a systematic literature review to collect and synthesize existing knowledge on the subject.

We created a keyword diagram for the expansion with the word "mind". The figure 4 analysis was made by VOSViewer with basic settings based on a ScienceDirect search on 6 February 2023. Keywords: logistics AND "augmented reality" AND "decision making" AND bias AND mind. The minimum number of occurrences of a keyword: 2.

Analysing Figure 4, we can see that the keyword Industry 4.0 is directly related to the digital technologies used today, which means that our keywords are relevant. (In the analysis, the minimum number of occurrences was also set to 2 due to the small number of hits.)

In the following, we added the keywords "extended" and "cognition" to the keywords and only examined these fields: Engineering, Business, Management and Accounting, Decision Sciences, Environmental Science, and Psychology, resulting in a total of 23 hits. In reviewing the results, it was found that most of the publications are about the use of AR or digital decision-support tools in different disciplines, such as sustainability, commerce, health, etc. The publication by Neumann et al. (2020) explores the role of humans in the Industry 4.0 environment and their summary describes that current research on Industry 4.0 technologies and implementation has largely ignored humans in Industry 4.0 so far. In other words, the alignment of humans and digitalization is essential for the effective operation of Industry 4.0.

Based on the knowledge background described above, it can be seen that the publications on AR as extended cognition for logistics decisions are mainly oriented toward industry (Blümel, 2013). Thus, based on this, we assume that practitioners have recognized that the use of AR can support logistics decisions (Ginters et al. 2020) and we assume that it can also be used to identify cognitive biases.

4. Conceptual model and taxonomy for the classification of cognitive biases in inventory decisions

Previous study results claim that several cognitive biases are frequently confused (Cosette, 2014) highlighting the need for an organizing principle. In order to characterize cognitive biases, we propose a taxonomy that integrates the classification of heuristics and biases proposed by Baron (2006) as well as Sibony (2020).

The definition of cognitive biases has been defined in many different ways. Rolf Dobelli (2013) defined cognitive biases as systematic deviations from logical and rational thinking and behaviour. In everyday understanding, the word “bias” has a negative connotation and meaning, suggesting that distortion is wrong; therefore, in the present publication, the term refers to a consistent cognitive deviation.

Cognitive biases are fallacies in the thinking process that influence decision-making. One of the major factors that induce cognitive biases is due to decision- maker cognitive characteristics such as awareness or lack of conscious awareness (Thirsk, Panchuk, Stahlke & Hagtvedt, 2022), memory capacity (Wiers, Gladwin, Hofman, Salemik & Ridderinkhof, 2013), previous experiences, and beliefs (Bataille, Brannon, Teas & Gawronski, 2022). Consequently, the importance of the environment, where the decision is made, is also indisputable. Task-irrelevant information can influence even expert decision-makers causing errors in reasoning (Curley, Munro, Lages, McLean & Murray, 2020).

Table 3: Taxonomy of cognitive biases through the Dimensions of memory and Context

		Memory	
		Generalist	**Specialist**
Context	**Fast thinking**	1 - Attribution error	2 - Storytelling trap
	Slow thinking	3 - Halo effect	4 - Confirmation bias

Taking together the multifarious study results from the literature, the present paper aims at proposing a two-dimensional taxonomy of cognitive biases, where different cognitive biases can be placed on the dimensions of knowledge, experience, cognitive aspects of the decision maker (Memory) and the environment of the decision maker (Context), where the decision is made (Table 3). The dimension of Memory is divided into Generalist and Specialist, and at the same time the dimension of Context is also distinguished into two parts: one part where the contextual signals are dominant, that promote Slow thinking, the other part characterized by the influence of the lack of signal perception. Therefore, the contextual features promote Fast thinking. Cognitive biases can be placed in the intersection of the two-dimension.

Table 4: Cognitive biases when AR is introduced as Slow thinking in the taxonomy

		Memory	
		Generalist	**Specialist**
Context	**Physical Reality (Thinking fast)**	1 - Anchoring	2 - Commitment escalation
	AR (Thinking slow)	3 - Hindsight bias	4 - Status quo bias

As previously mentioned in this paper, AR might serve the role of extended cognition, as, due to the data-driven nature of AR, it promotes slow, analytical thinking that facilitates decision-making. Although AR promotes reflective thinking that yields improvement in decision-making, the evanescence of cognitive biases from the process remains unfeasible. Therefore, we integrated AR in the Context dimension in the taxonomy (Table 4). AR in the context of cognitive bias serves as a promoter of multiple-domain use through the extension of alternatives.

CONCLUSION

The purpose of this paper was to analyse and understand the background knowledge of cognitive biases in logistical decision-making, at the same time as proposing an organizing principle of the cognitive biases that were previously categorized by Sibony (2020). Since AR is frequently used in decision-making, we categorized it as extended cognition.

Including generalist- specialist, and slow-fast thinking terms in the taxonomy, our organizing principle consists of two dimensions, where the generalist-specialist dimension represents Memory, the experience related continuum, and the other dimension of the taxonomy is defined by the slow-fast thinking continuum, as the characteristics of Context. The contextual aspect, the environment, where decision-making takes place, can facilitate and also inhibit the process through cognitive biases.

To understand the cognitive biases in logistical decision-making, we examined background knowledge, by reviewing publications on the topic of ScienceDirect. We chose the Sibony clustering as a starting point and then presented a logistical example, highlighting the biases that can be involved in purchasing decisions and how the use of AR can support them.

During the literature review, we found that AR is often used in logistics decision-making. In order to understand the knowledge background on the applicability of AR in logistics decision-making, we examined the publications available on ScienceDirect filtered by different keywords, with a focus on the last 5 years.

The knowledge background analysis showed the significance of technology included in the decision-making process, such as different machine systems (IoT, AI, Digital Twin, Big Data) and decision-making support systems, which are also shown in the figures, that promote the extended mind approach. It also strengthens the importance of the inclusion of context in decision-making.

It can also be highlighted that AR plays an important role in expertise in the context of decision-making, emphasizing that cognitive biases are equally present in expertise, which can be "remediated", filtered, and even altered by the technique.

The examination of the background knowledge revealed that the inclusion of AR in logistical decision-making is supported in the literature, henceforward the integration of AR in the proposed taxonomy would be essential for a comprehensive understanding of the alteration of different cognitive biases. In the current paper, we evaluate AR as an extension of cognition that promotes slow decisions of both generalist and specialist decision-makers.

As the conclusion of the background knowledge examination, we established that cognitive bias is not always objectional; on the contrary, in many cases, it prevents problems in the company. According to our interpretations, the concept of controlled cognitive bias in logistical decisions might serve as an advantage as well, and lead to beneficial outcomes.

We can also conclude that the application of AR is supported on the generalist-specialist continuum, altering emerged cognitive biases in decision-making. Our initiative of the taxonomy of cognitive biases offers a new perspective on the comprehension of cognitive errors.

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