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DIGITAL TWINS IN THE RETAIL INDUSTRY: A SYSTEMATIC LITERATURE REVIEW

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Abstract

Digital Twin (DT) is considered the most modern simulation method when it comes to tightly connect the real and virtual worlds to produce accurate simulation models of constant use to aid stakeholders in decision making. This method has been used more intensively in the manufacturing sector, but its use has spread to other sectors of great relevance in the economy, such as the retail industry. The contribution of this article to existing research is to present a Systematic Literature Review (SLR) addressing the state-of-the-art of the potential use of Digital Twins (DTs) to support decision making in the retail field. The main findings illustrate a considerable appearance of case studies applied directly in the sector, a strong investment in research focused on supply chains, an extensive use of simulation models and sensors, however, that mostly make use of secondary data and are not completely autonomous. Summary tables of the main benefits, opportunities and challenges in applying DTs in the retail sector are also presented.

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Key Words: Digital Twin, Cyber-Physical System, Simulation, Retail

1. INTRODUCTION

Simulation modelling has evolved over the years. It has established in the literature as a method with well-defined steps, with emphasis on the design, implementation, and analysis stages [1, 2]. Furthermore, it has also changed from simulation models of limited lifetime and that do not use any kind of automated data exchange between the physical and virtual worlds, to more dynamic approaches of constant use in which data can flow between physical and virtual systems in real or near-real time [3]. This new simulation modelling paradigm is called DT.

There is a wide range of areas that can benefit from it [4-6]. Retailing is an example of field that, thanks to the Internet of Things (IoT) ascension, now can take advantage of technologies capable of generating useful real-time data to feed essential analytical tools and dynamic simulation models. It consequently facilitates the creation of DTs, that can strategically help retailers in a more constant and realistic way to improve the management and performance of its daily operations [4, 7].

The use of simulation to support the various operations present in the retail sector is already a reality [8, 9]. However, despite being one of the most important areas in terms of both revenue and actors involved in the supply chain [10], to the best of our knowledge, there is a lack of significant overview available in the existing literature that aims to present a general panorama about the use of DTs aimed at the retail industry and that can serve as a basis for future scholars and professionals interested in developing DT solutions to this sector.

Therefore, this study aims to contribute to the existing literature by presenting a SLR addressing the state-of-the-art of the potential use of DTs to support decisions in the retail industry. The novelty of this study lies in trying to answer several research questions (RQs) that seek to cover key-elements related to this topic of research, such as the types of works found so far about this subject (concepts, reviews or case studies), which retail operations have been taking advantage of this approach, what are the input data, time frame updating and the degree of autonomy of the practical solutions found, which key technologies have enabled the application of DTs, and what are the main benefits, opportunities and challenges of applying DTs in the retail industry.

The rest of this article is organized as follows: Section 2 gives details about the research method used in this study. Section 3 presents the findings and search to answer the proposed RQs. Finally, in Section 4, conclusions and future directions are presented by the authors.

2. RESEARCH METHOD

The method applied in this paper was the SLR. This article was structured according to the following four stages suggested by Oliveira et al. [11] to conduct a SLR: (i) Planning (development of the research protocol), (ii) Searching/Screening (selection and study quality assessment), (iii) Analysis/Synthesis (treatment and analysis of data), and (iv) Presentation (reporting and highlighting of the findings).

2.1 Planning

Initially, an exploratory search on the theme of research was conducted using the Scopus database. The search was conducted on 21st June 2024 and included the strategic keyword ‘Digital Twin’ followed by the logical operator ‘AND’ and the keyword ‘Retail’, respectively. The title, abstract and keywords of the results were analysed by the authors.

Despite the contributions of the works found in this exploratory research, it was observed that there is a lack of studies that discuss the state-of-the-art about the use of DTs aimed at the retail sector in a broader way, not presenting aspects such as: categorization of the works exploring this concept so far; retail operations that have been used it; technologies that have allowed its deployment; what are the data sources, time frame updating and the degree of autonomy used by the practical solutions; the benefits, opportunities and challenges for retailers. The purpose of this SLR is to seek answering these questions to provide a credible theoretical update to scholars and professionals that aim to improve retail operations by using modern technological approaches, such as DTs.

Given the aforementioned gaps, the following RQs were formulated:

RQ1: What types of works have been found so far about this subject? (Concepts, Reviews or Case Studies).

RQ2: Which retail operations have been taking advantage of this approach?

RQ3: What key technologies have enabled the application of DTs in the retail sector?

RQ4: What are the input data, time frame updating and the degree of autonomy of the solutions found?

RQ5: What are the main benefits, opportunities and challenges of applying DTs in the retail industry?

2.2 Search/screening

In this stage the first step was to identify and select the research databases. Therefore, three strategic databases were included in this study: Scopus, Web of Science, and IEEE Xplore. According to the study performed by dos Santos et al. [5], other different nomenclatures can be used to refer to approaches very similar to DTs such as ‘Cyber-physical System’, ‘Real-time Simulation’, ‘Near Real-time Simulation’, ‘Symbiotic Simulation’, ‘Online Simulation’, ‘Data-driven Simulation’ and ‘Semi-physical Simulation’.

Therefore, the 'OR' Boolean operator was used to obtain all possible combinations among the 'Digital Twin' and the terms, followed by the logical operator 'AND', and the keyword 'retail*'. The '*' symbol is a wildcard that allows the search of variable keywords that are based in a root word, such as 'retailer', 'retailing' and so on. Fig. 1 summarises the steps performed in the Planning followed by the Searching/Screening stages. In the end of the Screening stage, 65 unique articles were selected for full-text reading.

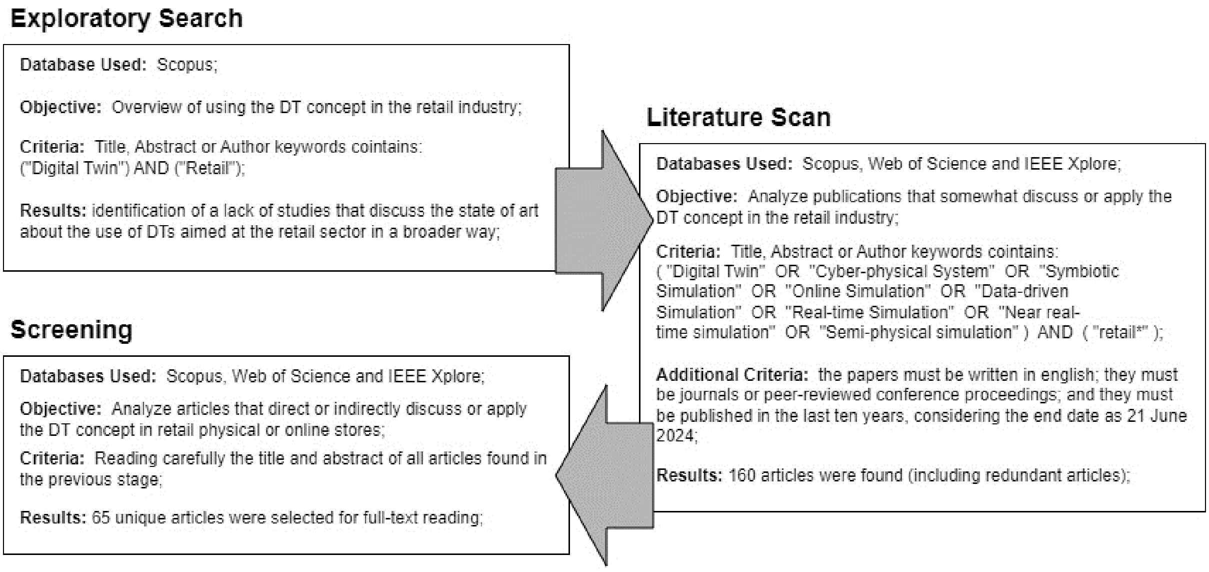

Figure 1: Steps performed in the Planning and Searching/Screening stages.

2.3 Analysis/synthesis

We conducted an analysis and synthesis of the findings using a Microsoft Excel spreadsheet. This facilitated the extraction of information from the reviewed papers, with each paper systematically recorded in the spreadsheet alongside responses to the RQs. Subsequently, we employed descriptive statistics to analyse the data.

Finally, to answer the raised RQs, the next section will present the findings and discussions for each of them in sequence.

3. FINDINGS AND DISCUSSION (PRESENTATION)

3.1 Types of works

Regarding the types of works found about the application of DTs in the retail sector, we noted that there are already practical attempts to do it. Among the researched articles, 37 of them or about 57 % already tried to do it someway. Theoretical Studies (Concept) were found in 18 articles or about 28 %, and Literature Reviews comprehend 10 articles or about 15 % of the total, as shown in Fig. 2. This study seeks to present a general overview of the potential application of DTs in the retail sector, while the Literature Reviews found discuss its use in specific retail operations.

Most of the articles (46 papers or about 71 % of the total) discuss or talk about solutions that directly impact retail spaces, such as physical and online stores. Another 19 papers or about 29 % discuss about how their proposals can indirectly impact retail spaces, as presented in Fig. 3. Once the retail is the last step in a supply chain process from supplier to consumer, the application of DTs in stages that precede retail can also positively impact this industry.

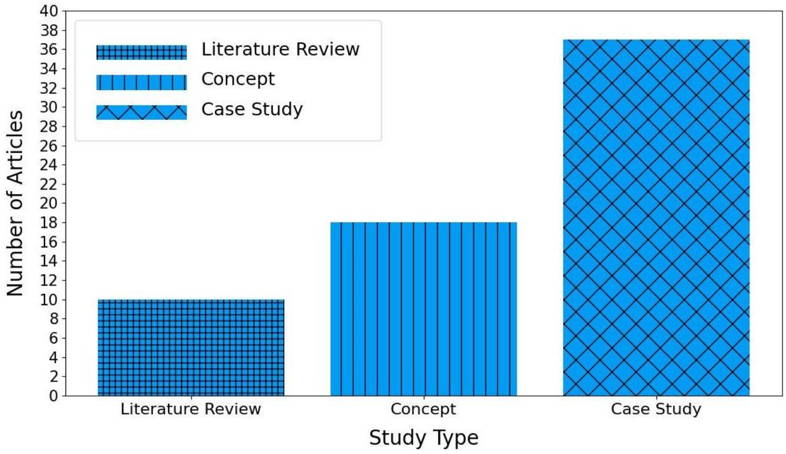

Figure 2: Types of studies found in the SLR.

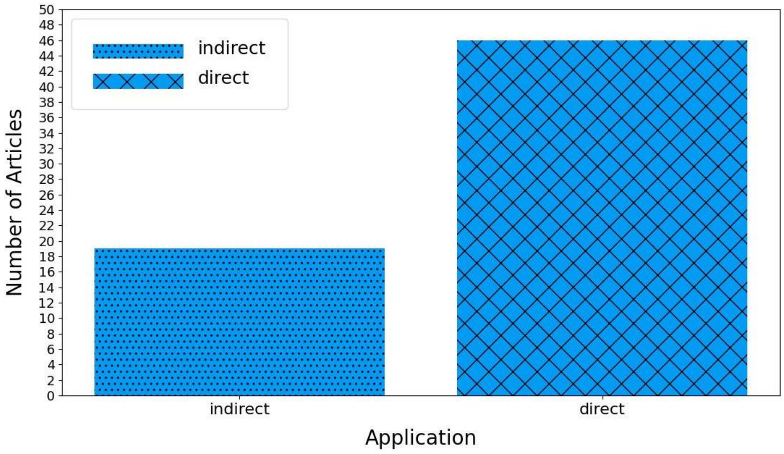

Figure 3: Direct or indirect application of the studies in the retail industry.

3.2 Retail operations

Among the articles analysed, the authors identified 8 different operations in the retail industry in which DTs have been discussed/applied, as depicted in Fig. 4. It is possible to notice that operations related to the Digital Transformation of the retail, Customer Behaviour Prediction and Supply Chain are those that are making the most use of it.

DTs are digitally transforming retail shops and taking them to another level. As example, the French supermarket chain Intermarché developed a DT of their store. This enabled them to access real-time stock information and perform experiments with various store layouts, evaluating their effectiveness before actual implementation [12]. Brick and Mortar (B&M) retailers have started to implement intelligent service innovations within their stores as a strategic move to recapture the market share that was lost to online competitors. Emerging trends in the retail sector, exemplified by the appearance of concepts like the ‘Amazon Go’ store, indicate a profound shift in conventional B&M establishments, transitioning them into intelligent retail spaces [13].

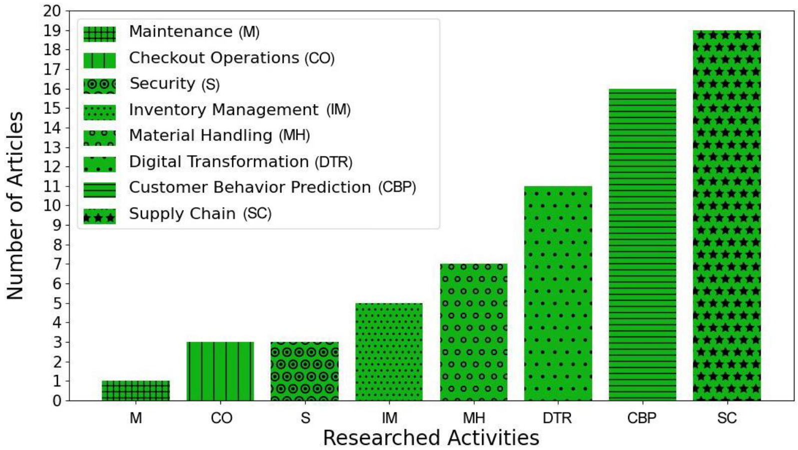

Figure 4: Most popular researched activities in the retail industry that have explored the use of DTs.

A deep understanding of consumer behaviour is essential for retailers to create tailored suggestions in focused marketing efforts, enhance their services, and predict customer preferences [14]. According to Barnes [15], sentiment analysis, body movements monitoring, ambient sound recognition, and image identification are some key approaches that can generate useful data to be analysed, aiming captivating, and maintaining customers engagement. Immersive shopping experiences can integrate real-time data visualization tools and consumer behaviour data to create DT solutions capable of attracting and retaining customers [16].

Modern businesses within each supply chain do not operate independently, rather, they collaborate to create a broader system [17]. Retailers, manufacturers, and suppliers need to establish a network connection and employ current situation data, including information of raw material and parts procurement, customer demands, and manufacturing conditions, to operate efficiently and effectively [18]. Several studies found sought to tackle this issue by proposing conceptual and practical solutions. For example, Maheshwari and Kamble [19] employ a dynamic simulation approach to increase the visibility of inventory operations among the various stakeholders by using a paradigm called Supply Chain Digital Twins (SCDT).

Some authors have explored the idea of the so-called Virtual Supply Chain (VSC) to better integrate retailers, manufacturers, and suppliers. According to Matsuda et al. [18], VSC is the basis for constructing a Cyber-physical System (CPS) for a smart supply chain. Upon implementing a VSC, it becomes possible to simulate the behaviour and its impact on individual enterprises as well as the collective behaviour of the entire supply chain simultaneously.

It was also noted a strong investment in research related of controlling and monitoring the perishability of fresh food throughout its supply chain pipeline. Defraeye et al. [20] identify many advantages of how the supply chain of fresh horticultural produce can benefit from DTs and cite an important concept called Physics-based Digital Twins (PBDT). Works developed by Shoji et al. [21] and Shrivastava et al. [22] are practical examples that have applied the PBDT approach to control the hygrothermal conditions of vegetables and fresh fruits along its cold chain from post-harvest to retailer.

3.3 Key technologies

Throughout the reading of the 37 case studies found in this research, the main concepts, hardware, and software resources directly used by the authors to propose DT related solutions were listed to have a general overview about which key technologies have enabled the application of the DT paradigm in the retail industry so far. The words/expressions used by each work were organized into three columns (concepts, hardware, and software) and after reading all the articles, the package *wordcloud* of the Python language was used to generate the word clouds depicted by Figs. 5, 6 and 7.

Fig. 5 illustrates the main concepts used by the authors. Simulation stands out as the most cited concept along the articles. This is justified by the fact that it is an important element for building DTs and can be used as an output forecast and a decision-making support tool for the management. Most of the practical works employed Data Analysis and Statistical Analysis to extract meaningful insights from the data. The large amount of data available to feed DTs have also stimulated the use of Artificial Intelligence (AI) techniques.

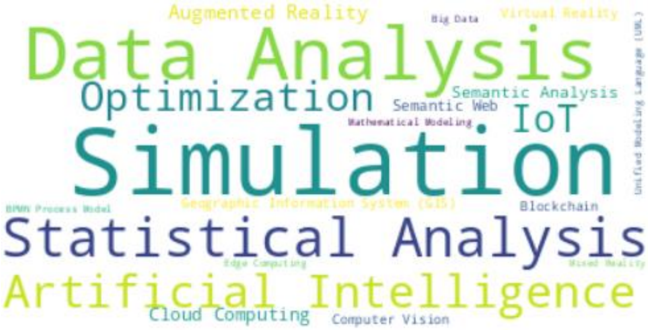

Figure 5: Most popular concepts related to the implementation of DTs in the retail industry.

Fig. 6 depicts the most popular hardware employed by the authors. Among the devices, sensors of different types assume the protagonism in generating useful data for the systems. Some authors also mention the intense use of sensors to give support to DTs solutions but without specifying them. Many retailers have implemented item-level tagging of their physical assets. Among the prevailing identification technology available, the Radio Frequency Identification (RFID) stands out. Owing to the popularization of cameras and drastic improvements in image recognition technologies, object tracking is also becoming of strategic use to retailers.

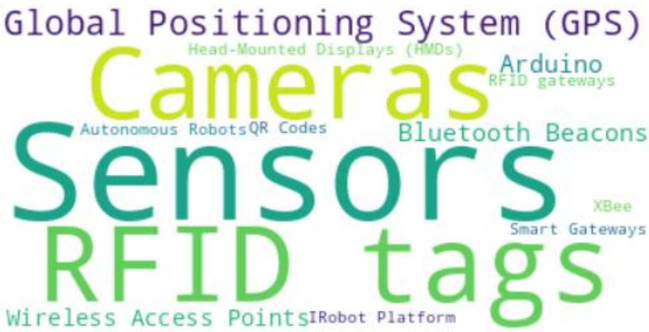

Figure 6: Most popular hardware related to the implementation of DTs in the retail industry.

Regarding the software used by the authors in practical applications, they are quite heterogeneous, as illustrated by Fig. 7. Even so, as expected, it is possible to observe a greater presence of simulation tools such as COMSOL Multiphysics, AnyLogic and Netlogo. Classic but very useful mathematical tools like Excel and MATLAB are also present. Java and R were the most used programming languages.

Figure 7: Most popular software related to the implementation of DTs in the retail industry.

3.4 Input data, time frame updating and degree of autonomy

Fig. 8 presents the distinct types of data sources used by the case studies found in this research. Most of the data used by the authors are secondary. The main secondary sources are datasets that store past sensor data, inventory levels, customer transactions and/or customer location/navigation data. Real-time data come from sensors, cameras, databases and/or platforms. Simulated are the least used. The simulated data were prepared by the authors themselves by using classic tools such as MATLAB, Excel, and R Programming Language. As can be noted, DT is a purely data-driven system that can use different data sources to accurately map entities or processes from the real world into the virtual world.

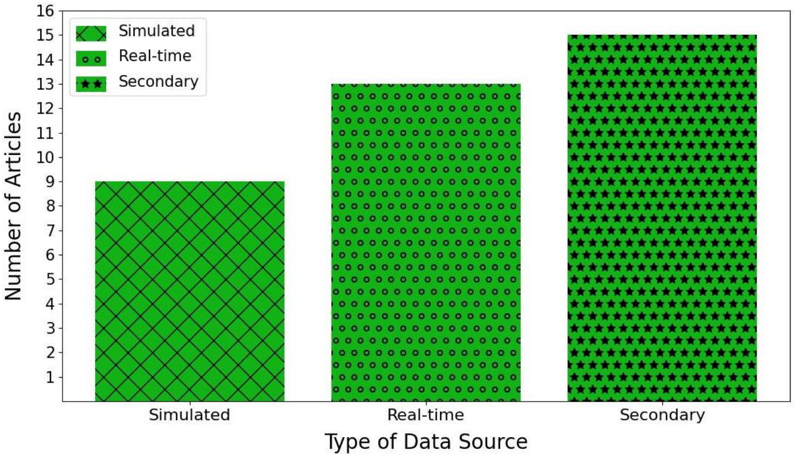

Figure 8: Types of data used in the case studies.

Results show that the time frame in which a DT is updated does not need to be in real-time. It is in synergy with what is stated by Wright and Davidson [23]. Among the case studies analysed, about 49 % do not use real-time updating. It varies according to the need for making decisions. The other 51 % of the case studies, the time interval is in real or near real-time.

The level of autonomy in a DT correlates with its ability to command actions either directly within the physical system (resulting in full autonomy, without human intervention) or provide suggestions for actions [5]. Among the case studies analysed, only 16 % are fully autonomous.

3.5 Benefits, opportunities and challenges of applying DTs in the retail industry

Although the adoption of DTs in retail is in its early stages compared to the manufacturing sector, it was possible to identify many benefits, opportunities and challenges of applying DTs in this industry, both in practical applications and theoretical explorations. Tables I and II provide a summary of these findings.

Table I: Summary of the main benefits and opportunities related to the use of DTs in the retail industry.

Benefits and Opportunities
• The magnitude of data generated by online platforms and sensors are strategically suitable to feed simulation and data analytics platforms to obtain useful information to predict customer behaviour in retail (Cyber-physical behaviour) and help management in logistics [7, 12, 14, 24-26]; • The fresh food transportation and distribution can be considered an emerging cyberphysical-human system with substantial advances. DTs have enabled the identification of where and how much the fresh food lose their quality in a supply chain. It also offers the possibility to calculate the remaining shelf life of the products in the retail [20-22, 27]; • Facilitates the creation of VSC. By using this approach, behaviour and its effect on each enterprise and total behaviour of the supply chain can be simulated at the same time when an order in the retailer side is made [17, 18]; • Offers a way to try different options to improve operations in retail and grocery stores, such as checkout operations [28, 29]; • Allows retail decision makers to create early warning systems and make the best utilization of resources in urban last-mile operations, such as reducing the number of vehicles utilized, costs and obtain better accuracy in the estimated time of arrival to each customer [30]; • Create systems that take advantage of learning procedures by using AI to self-adjust themselves to meet stakeholders’ goals in mutually beneficial situations [13, 25, 29-31]; • Tracking customer engagement with products within physical retail stores has been monitored. Through the utilization of IoT platforms and specific sensors, these actions can be better recorded, reported, and predicted [7, 14, 25]; • B&M fashion retailers are encountering growing competition from e-commerce businesses. Ubiquitous retail systems have the potential to enhance the appeal of these stores and mitigate the cost disadvantages associated with maintaining stationary retail locations [13, 28]; • Supply Chain Digital Twin (SCDT) represents an emerging research topic in manufacturing modelling, management, and control of the SC once it helps evaluate, predict, and optimize system behaviour in physical and virtual directions [19, 32]; • Traditional retail stores can be revitalized by integrating IoT technology, effectively creating omnichannel shopping experiences. This means leveraging multiple channels to cater to the needs of the customer, ultimately providing a seamless shopping experience [25, 33].

Table II: Summary of the main challenges related to the use of DT in the retail industry.

Challenges
• As the interaction between Physical and Cyber increase, then the physical systems are more prone to the security vulnerabilities [24, 34]; • Analysing large amounts of data can be complex and time-consuming. It is important to employ sophisticated statistical and machine learning techniques to extract meaningful insights from the data [26, 30]; • In terms of autonomy, most DT adaptations still necessitate and rely on human involvement to effectively make changes in the physical system [31]; • Companies are generally reluctant to adopt digital technologies due to a high degree of heterogeneity and prior perceptions [19]; • Autonomous operation of CPS requires an interdisciplinary and cross-layer approach due to the coupling between cyber and physical components [35]; • Develop studies that deal with multiple store operations decisions, multiple themes, and products [7]; • Develop adaptable solutions once every supply chain comprises a different combination of unit operations, and every shipment encounters unique logistic and environmental boundary conditions [22].

4. CONCLUSION

It was observed that despite the DT approach still in its early years, most of the works found in this research are case studies that someway tried to apply this concept to seek reach better results in a series of operations present in the retail. Among these operations, customer behaviour prediction and supply chain stand out as the most established in literature, clearly illustrating the need to understand customer actions in ever greater detail and the importance of creating increasingly precise and predictable supply chains. However, the research also identified that the application of the DT concept in other important operations is still limited, thus opening a range of research opportunities.

It was noted that almost every feature or application of DTs can be traced back to data, i.e., data is both the foundation and fuel of it. This is justified by the fact that Simulation, Data Analysis, Statistical Analysis and AI were the most used concepts by the case studies. Sensors of different natures, cameras, RFID tags and GPS are the main sources of data among the case studies. It clearly shows how the use of these devices have also become popular and strategic in the retail industry. The software resources used by the authors in practical applications are quite heterogeneous. It illustrates that there are no specific applications to create a DT, the most important thing is providing a model of constant use, that tightly connect the physical and virtual worlds, and that precisely represent the physical system in its virtual counterpart. It was noted that simulation tools can facilitate this process.

The connection between these worlds does not need to be necessarily in real-time. Practically half of the case studies do not use real-time updating, and most of them lies on past data sources. Most practical solutions are also not fully autonomous, i.e., they still require human participation to make final decisions.

Many benefits, opportunities and challenges are also presented. Among the benefits and opportunities, the high availability of data produced nowadays stands out, once this has increasingly facilitated the creation of solutions based on DTs. The increasing use of AI techniques in DT based solutions has also generated great interest, as it has helped to create increasingly independent and autonomous systems. Security vulnerability and the analysis of large amount of data were the main challenges raised by the authors when it comes to create DT solutions to retail.

The contribution of this work is to provide a significant overview that can support scholars and professionals in future research. For future works, to have an even broader panorama of the potential use of DTs in the retail industry, we additionally recommend examining alternative research sources, such as patents and registered products.

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