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SIMULATION AND DIGITAL TWINS TO SUPPORT REVERSE LOGISTICS DECISIONS: A REVIEW

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Abstract
Researchers believe that Industry 4.0 is the new industrial revolution. In this case, we highlight the critical role of decision support tools, such as Simulation and Digital Twins (DT) models, that might help decision-making in strategic decisions in the industry. Additionally, Green Supply Chain is a theme that has been widespread due to all the issues involving pollution and tax breaks that some government offers to industries. Furthermore, enterprises worldwide are becoming more aware of environmental issues. In this subject, an area that has been emerging but is not significantly addressed in the literature is Reverse Logistics (RL). Thus, this work aims to analyse how Simulation and DT are helping RL in the Industry 4.0 context, answering some questions that may support future researchers to begin their studies in the area.
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Key Words: Reverse Logistics, Green Supply Chain, Industry 4.0, Digital Twins, Simulation

1. INTRODUCTION

Simulation models have been widely used during the last years to support decisions in several areas, such as manufacturing, healthcare, and logistics [1]. On the other hand, the use of Digital Twin (DT) models tends to be an evolution of the Simulation models, and although it is a relatively new concept, the research on this theme has been increasing since 2016 [2]. Digital Twins (DTs) may be defined as replicas of a physical entity [3], and it is also commonly defined as a virtual mapping of a physical product, including properties and structures defined in the development of the product and the current usage settings information of it [4]. Additionally, they can cover a complete process life cycle of products, from design to operations, including the continuous development process.

Another area that has become a recent research object is the Circular Economy (CE) [5]. According to Zou et al. [5], this is related to recycling waste products, which helps companies to reduce costs and increase profits, lowering emissions of poisonous gases and improving environmental protection. Intending to recover these wasted products, Reverse Logistics (RLs) models are also being used.

According to Riedelsheimer et al. [6], the discussion about CE combined with DTs has not been investigated. In this way, this work seeks to join these mentioned areas (Simulation, DT, and RL/CE), performing a review to show what are the works that have been done using these themes, and answer some Research Questions (RQs) such as:

- What is the main difference between Simulation and Digital Twins applied in Reverse Logistics?
- Is Simulation used in Reverse Logistics?
- Is DT a technology used in Reverse logistics?

Thereby this paper presents four sections besides this introduction. Section 2 describes the databases used for the research, the keywords, and the papers' exclusion criteria. Section 3 defines the themes, and some works are shown to identify in what subjects (manufacturing, products, logistics) they are being used. Section 4 shows the answers to the proposed research questions, and finally, section 5 presents the conclusion of the analysis and possible gaps that can be addressed in the future.

2. DATABASE

This section aims to show the search and exclusion criteria of the papers composing this work's core, showing how many articles were found in whole and how many remained after the screening phase.

To implement a literature review, a protocol is necessary. In this work, we follow the four steps suggested by Do Amaral et al. [7]: (i) planning of objectives, (ii) searching and screening, (iii) analysis of the results, and (iv) presenting the results and conclusions.

2.1 Planning

The elaboration of this paper is based on two databases known to be the most complete ones used in reviews [8], Scopus and Web of Science (WoS). Additionally, the data from both bases are easily summarised by RStudio® software, which performs some of the analysis in this work. Another justification for using only these two databases is cited by Mongeon and Paul-Hus [9]. The authors say that both databases are the most used for analysis and reviews.

This work does not apply any filter related to the publication year of the paper since the DT area is relatively new and not so much used in Circular Economy (CE), and few works were published before 2015.

To make the data collection in the mentioned bases only results with open access and in the English language were used since this is the most used language by the world scientific community. Some filters, such as only papers in engineering, computer science, and mathematics, were applied to help restrict the results. At first, a search was performed using only the search string:

("green supply chain management" or "reverse logistics" or "circular economy") and ("digital twins" or "simulation").

With this search string, the results were 665 papers found in Scopus and 555 in WoS, and they were inserted in RStudio for a preliminary analysis of the word cloud, and other keywords were found. After these new results, another search was performed in the databases using these new words, thus creating another search string:

("sustainable development" or "life cycle" or "recycling" or "green supply chain management" or "reverse logistics" or "circular economy") and ("digital twins" or "simulation" or "computer simulation").

2.2 Searching and screening

Using the search string shown in subsection 2.1, a large number of papers were found:

- 6834 papers in Scopus,
- 1948 papers in WoS.

Aiming to evaluate the relevant works for this research, the title, abstract, and keywords were read following a criterion, and the papers that did not possess it were discarded:

- Works that include Digital Twin, Simulation, Circular Economy, and Reverse Logistics.

After reading the title and abstracts, we verified that some papers were duplicates, which means they were found in both databases. After disposing of all the duplicated documents and those not interesting for the study, a smaller amount of work was left in the search: 132 articles were left in the Scopus database and only 18 in the WoS database. Some papers seemed relevant for this work when reading the abstract but were not helpful after carefully reading it entirely and, therefore, were also discarded. After the analysis of the relevant works, among all the selected ones, the remaining was:

- 79 documents in the Scopus database,
- 10 documents in the WoS database.

Thus, the initial search, which had more than 8000 papers, resulted in 89 relevant documents for the proposed theme, and Fig. 1 shows a resume of the research carried out for this work.

The following section brings some definitions and papers written in Simulation, DTs, and RL.

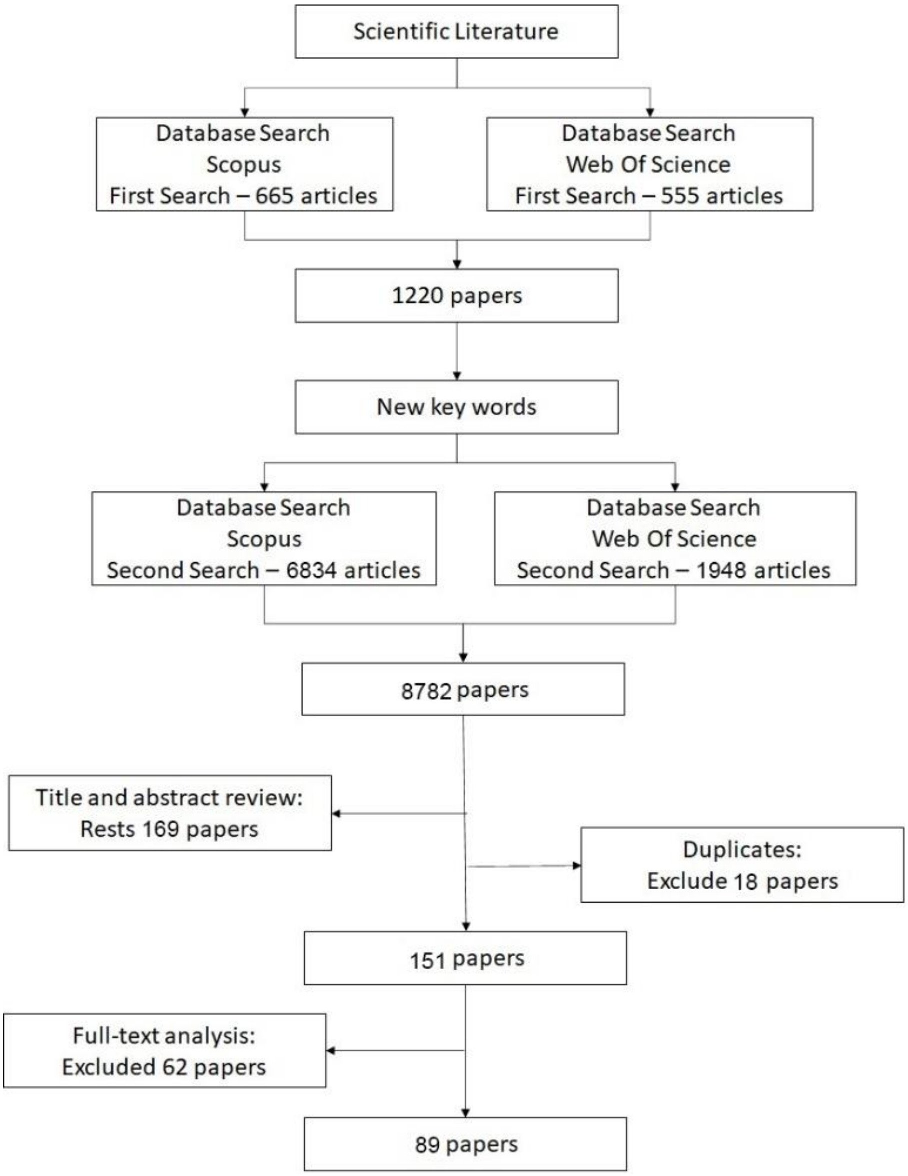

Figure 1: Resume of the research done in this work.

2.3 Analysis

The analysis of the papers was carried out using Mendeley® software. With this software, it is possible to make annotations and highlight the essential parts of the documents, making it easier to perform future evaluations related to the RQs. Then it was only necessary to create an MS Excel® Spreadsheet to define and analyse all the highlighted parts of the works that were read.

2.4 Presentation of the results

The results are discussed in section 3, where each subsection corresponds to a RQ. Tables and graphics were used to summarise the results and help their interpretation. Therefore, this paper shows the importance of the evolution of Simulation and DTs in RL over the years and some perspectives on this approach.

3. DEFINITIONS AND RELATED WORKS

The focus of this paper is a review of the use of Simulation and DTs in RL, and this chapter shows some definitions of these subjects addressed in this paper.

3.1 Digital Twin

Digital Twins are often defined as digital replicas of components, products, services, and processes that contain the structure of the physical assets and can be used to predict and optimise the performance of the product, process, or industry. Qamsane et al. [10] write that the interest in Digital Twin has been increasing since 2016 in the literature, as shown in Fig. 2. In 2018, DTs were in the top ten of strategic technology and may reach a 15-billion-dollar investment by 2023 [11]. Moreover, DT has been cited as the most significant technology trend disrupting engineering and design in 2020 [12].

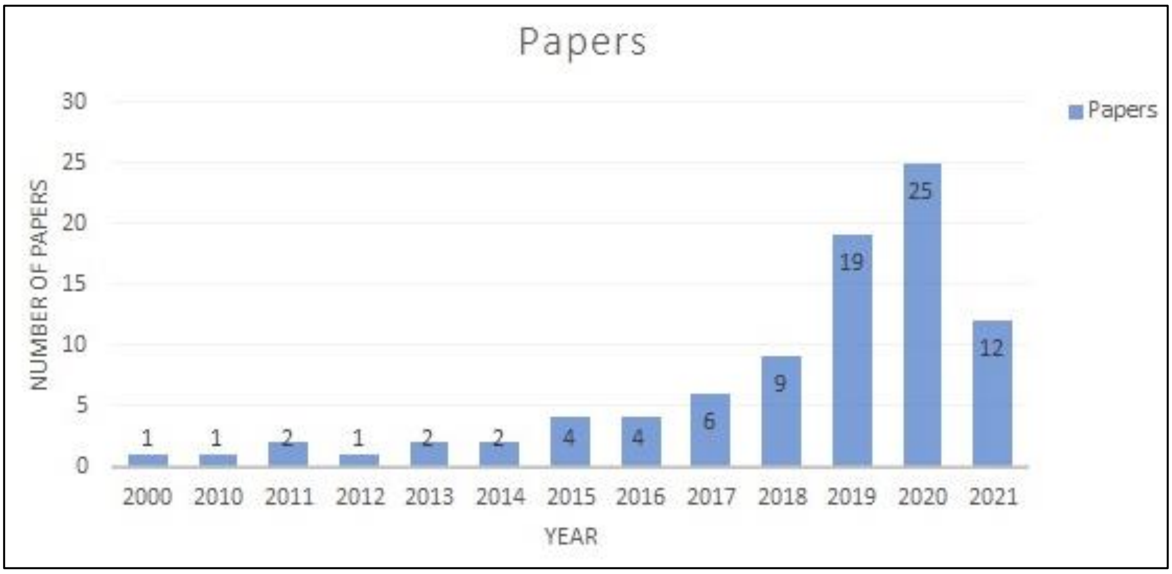

Figure 2: Papers published over the years.

The National Aeronautics and Space Administration (NASA) created one of the first DTs found in literature in the Apollo program as a hardware twin [13]. According to the authors, NASA developed an identical vehicle to the one sent to space that could mirror all conditions of its twin in orbit. This way, Earth engineers could help astronauts to solve problems and maintain the vehicle working.

The main difference between the NASA definition and the one used nowadays is that the first only applies to vehicles or physical replicas of physical entities. Still, today with the advancing of technologies, a new definition must be coined. Some authors now describe Digital Twin as a "virtual replica of a physical entity" [3, 10]. This entity may be a tool, a product, a process, or even the whole factory. Although some authors defend that the DTs must work in real-time [14], Malik and Bilberg [13] show that DTs do not have to use real-time communication.

Although there are some advantages of using DT, they are vague, and only a few cases can be found in published works [2]:

- DT can provide more customer participation and interaction, providing mass individualization [15].
- DT is location and time-independent; it means that it is possible to simulate a product behaviour at any time and any place [16].
- DT allows reduced experimentation with real products, reducing costs and time in production [16].

A DT has mainly two entities, the physical and the virtual ones, Li et al. [17] call them layers and describe their DT as a two-layer framework. Although this description is not incorrect, the most used and cited today is the five-layer method, and the authors describe its layers as five entities: Physical, Virtual, Data, Connections, and Services.

The Physical layer is the asset that will be twinned; the Virtual one is the replica of the Physical entity; Data is the data collected from the Physical entity that will be simulated in the Virtual one; Connections update the Virtual layer with data from the Data layer and returns the feedback from Virtual to Physical one. Finally, Services is the interface that allows stakeholders to see all the data and help the decision-making process [15]. Fig. 3 shows the data flow of the five-layer model of a DT.

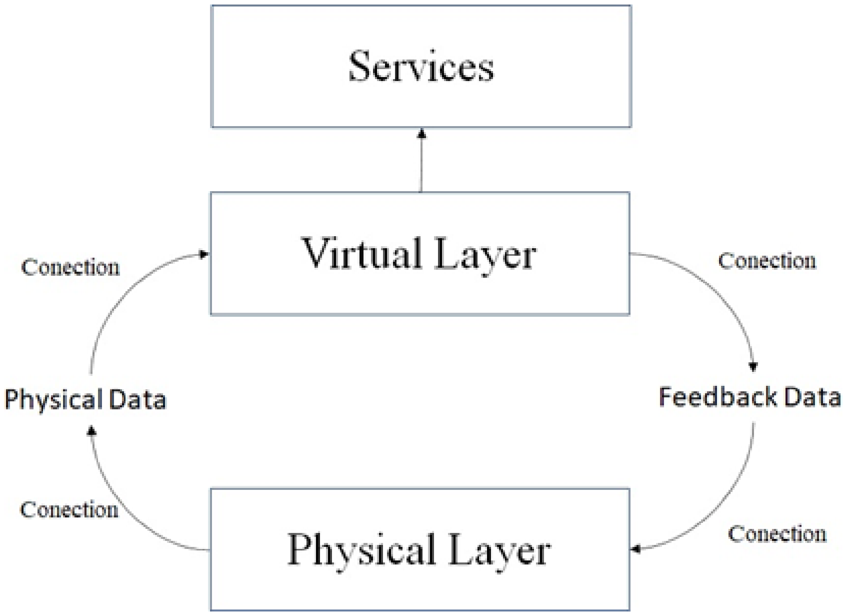

Figure 3: Five-layer DT model.

3.2 Reverse Logistics

Sustainability is an area that has been growing very fast [18], and Closed Loop Supply Chain (CLSC) is the term used to describe the whole cycle of recycling wasted products, allowing to reduce not only costs and emission of poisonous gases but also increasing profits [4]. According to Canella et al. [19], one part of the CLSC is the RL, in which the manufacturer or final client returns the goods.

Straka et al. [20] describe RL as all the operations necessary to recycle products, including their collection with the final user and remanufacturing or reusing components. According to the authors, the RL's acceptance is high but has received minimal attention.

Despite the growth of this area nowadays, Chiang et al. [21] write that most enterprises used to be focused on Forward Logistics (FL) because RL was often considered a nonprofitable activity. The authors also say that a problem that still makes RL less used is that it is more complex than FL. One obstacle that makes RL more difficult is that it is necessary to predict the return rate of wasted products to make plans. However, academia and industries still do not know how to predict it due to uncertainty about returned products' number and quality.

DT is a subject not widely addressed with RL in the literature. 89 articles were read in this review, and none combined these two areas in a study. Although DTs are not used in RL, Simulation is already used in Logistics, and Lopes et al. [22] describe one advantage from using these two areas combined: it provides a way to forecast the impacts of the decisions in complex logistics problems.

The following subsection answers the RQs proposed in this paper.

4. RESULTS

This section shows the results found through paper analysis that help answer the questions proposed in section 1. After analysing the papers in the search for answers, some gaps were found that can help future research. However, they will not be addressed in this section. Some of them will be cited in Section 5 as suggestions for future work.

A. RQ 1: What are the main differences between Simulation and Digital Twins applied in RL problems?

There are some differences between Simulation and DT, and before showing them, it is necessary to differentiate a Simulation from a DT [23]. According to Lindegren et al. [24], Simulation is a computer model that imitates a system to help study it without changing the physical system. On the other hand, as described in 3.1, a DT is a virtual replica of a system that exchanges information with the physical system.

Although it is possible to use Simulation as one part of the DT [25], Schleich et al. [26] write that the DT is not a complete model but a set of process, data, and Simulation models, contributing to the assumption above that a DT is composed of a Simulation model. Another difference is that the DT uses Artificial Intelligence (AI) and continuous data exchange between models, while Simulation models do not necessarily [27].

In addition, Kuehn [25] writes about the advantage of using DT with Simulation and DT with AI. The author says that when using Simulation, the DT can test some alternatives outside the physical world before these alternatives are applied, avoiding problems. Otherwise, it is possible to create advanced models using DT with AI.

In conclusion, as Schleich et al. [26] described in their paper, the DT is the next generation of modelling, Simulation, and optimisation, which means that a DT can unite all these tools in one, capable of exchanging information among them to help the decision-making process.

B. RQ 2: Is Simulation used in Reverse Logistics?

Braun et al. [28] describe that RL and Closed Loop Supply Chain (CLSC) are areas not significantly addressed in the literature and are also not widely used with Simulation. Although Simulation is used in several areas, it is not particularly related to RL and CLSC. This research shows that from 89 papers read, only 9 use Simulation in the context of RL.

Table I shows the articles using Simulation and RL or CLSC describing authors, titles and a brief resume.

C. RQ 3: Is DT a technology used in Reverse logistics?

The analysis of the 89 papers used in this work revealed no study which relates DT with RL, and a short review of the most relevant papers is shown in this subsection.

Some papers are theoretical and do not implement or create any DT or solve any practical problem. For example, the work of Tekinerdogan and Verdouw [3] shows some digital model patterns that can be considered a DT but do not implement nor cites RL, just define these patterns. Another paper that fits in this category is in the work of Qamsane et al. [10], which introduces a DT development solution as a generic procedure so that it is possible to analyse and develop DTs for manufacturing processes but not for remanufacturing.

Khajavi et al. [11] study the expansion of DTs in the Lifecycle of buildings and explore the benefits and shortcomings of implementing DTs but do not cite RL. Czwick and Anderl [16] deal with Cyber-Physical twins' definitions and conceptions and discuss their benefits. Golda et al. [23] describe the possibilities of using a Virtual Reality application to model and simulate production and Forward Logistics processes in different product life cycle management aspects.

Schleich et al. [26] propose a reference model based on the skin model shape concept (a paradigm for geometric modelling) that serves as a DT of a physical product for design and manufacture. Its model, representation, implementation, and application along the product lifecycle are approached.

Matskul et al. [29] show a practical problem of optimizing the operation of a cold supply logistics network. Finally, the last theoretical work is by Umeda [30]. This paper proposes a modelling, Simulation, and analysis methodology in a supply chain with RL flows and discusses two reverse supply chain types, PUSH-type and PULL-type, but does not address DTs.

Although there are some theoretical papers, most of them are practical. It is possible to highlight some of the most important ones, such as Detzner and Eigner [4], that create DT elements for a problem's root cause and quality monitoring. It also suggests a data structure that allows data analysis. Zou et al. [5] use game theory to explore decision-making in a shared revenue model. Moyne et al. [12] create a framework capable of approaching aspects such as reusability, interoperability, maintainability, extensibility, and autonomy in a DT.

Other papers use practical studies in the laboratory; work from Rocca et al. [31] is an example. This work shows how technologies based on Industry 4.0 may support Circular Economy (CE) practices, virtually testing a WEEE disassembly factory through dedicated simulation tools. Moreno et al. studied enablers of CE [32].

The DT is not only used in manufacturing problems but it can be used in several different areas. Riedelsheimer et al. [6] use DTs to help the user in the clothing area. The DT shows all the processes, from creating clothes to cleaning and discarding. Malik and Bilberg [13] developed a framework that supports design, construction and control for Human-machine cooperation. The authors also use Simulation to create a collaborative work environment between man and machine.

Other areas in that DTs can also be used are maintenance and performance measures. Rajesh et al. [14] describe a DT that supports automotive brake predictive maintenance, which is vital for security issues.

Pandian and Abdul-Kader [33] use Simulation and RL but do not approach DT solutions. The authors use Agent-Based Simulation to measure the performance of a RL company. Another work that uses Simulation and RL is from Straka et al. [20], which uses Simulation (but not DT) and RL to separate concrete waste to be transformed into raw materials or reusable resources.

Braun et al. [28] and Matskul et al. [29] present the last two papers that use Simulation. In the first one, the authors make a use case for a company which uses deterministic simulations to show that it is crucial to raise material efficiency. Still, it is necessary to make more efforts to return waste and used products to the economic cycle. In the second work, the authors create an optimisation model for the cost of a logistic network in cold alimentary products. Although it uses Simulation, the software used in MS Excel® means that authors do not use proper simulation software to calculate route costs.

Table I: Articles that combine Simulation and Reverse Logistics.

Authors	Title	Resume
Braun, Kleine-Moellhoff, Reichenberger, Seiter	Case study analysing potentials to improve material efficiency in manufacturing supply chains, considering circular economy aspects	Checks the material efficiency of a sample manufacturing along its supply chain and evaluates waste recovery. It uses Simulation to determine material efficiency [28].
Matskul, Kovalyov, Saiensus	Optimisation of the cold supply chain logistics network with an environmental dimension	Creates a mathematical model that helps the logistics of refrigerated trucks. Use Simulation to calculate transport costs and routes from the environmental perspective [29].
Umeda	Simulation analysis of supply chain systems with reverse logistics	The paper proposes simulation model methodologies in Supply Chain and RL [30].
Golda, Kampa, Paprocka	The application of virtual reality systems as support of digital manufacturing and logistics	The paper shows methods of creating virtual reality applications to model and simulate logistics processes. Creates simulations for logistics and shows examples [23].
Straka, Khouri, Paška, Buša, Puškaš	Environmental assessment of total waste recycling based on principles of logistics and computer simulation design	Use logistics, modelling, and Simulation to separate waste so that raw materials and other resources can be reused [20].
Rocca, Rosa, Sassanelli, Fumagalli, Terzi	Integrating virtual reality and digital twin in circular economy practices: laboratory application case	Introduces a laboratory application case demonstrating how technologies based on Industry 4.0 may support Circular Economy practices and test the configuration plant that disassembles electronic waste using simulation tools [31].
Moreno, Court, Wright, Charnley	Opportunities for redistributed manufacturing and digital intelligence as enablers of a circular economy	This paper shows if Discrete Event Simulation (DES) can be used in circular scenarios to determine traditional economic values. In the study, Simulation also evaluates the effect of CE in a supply chain [32].
Pandian, Abdul-Kader	Performance evaluation of reverse logistics enterprise – an agent-based simulation approach	Measure the performance of the RL using a model of Agent-Based Simulation. The agents (collectors, remanufacturing, recycler, etc.) act independently [33].
Tako, Robinson	The application of discrete event simulation and system dynamics in the logistics and supply chain context	Review Discrete Event Simulation and System Dynamics to find out which is the most used to tackle Logistics and Supply Chain Management. It shows that from 127 papers read, only 7 approach the RL [34].

The only work closest to the two themes approached in this work is from Wang and Wang [35]. The authors show a DT-based system to support the manufacture and remanufacture operations in the product's life cycle, but their work focuses on these two operations in a CLSC and does not address the RL's collection part.

5. CONCLUSIONS

This paper aims to show some critical topics in the research about Simulation, and DT applied in RL problems and shows that these two areas are not widely approached in combination in the recent literature by answering some research questions.

Section 2 introduced a protocol intending to select the papers that served as a base for this research. This section showed the keywords, search strings and inclusion and exclusion criteria. So it was possible to select 8782 papers on Scopus and Web of Science databases that culminated in the 89 papers used in this work after applying all criteria.

Section 3 explained the terms Simulation, DT and RL used in this work. Section 4 described all bibliometric analyses performed in this work and answered the research question in Section 1.

This paper's main question is whether any work combines Simulation and DT models with RL. By reading the articles selected in Section 2, it was possible to demonstrate that in the literature reviewed, no paper approaches these areas combined.

Through this review, some future research ideas and gaps were found, and some problems were encountered. Barricelli et al. [27] show some issues and challenges in several areas, they are described in Table II.

Although these challenges are essential and must be addressed, one problem mentioned by the same authors is the most important, the creation of DT in which users can easily interact. According to the authors, most developers are only concerned about creating the DT and do not create proper documentation from the process beginning, which could be easily solved with well-developed documentation of the whole process.

Czwick and Anderl [16] describe two DT problems that could be addressed. The first one is that DTs usually represent the characteristics of the products but not external influences, and the second one is a problem with the feedback from the virtual to the physical asset. It is necessary to create constant communication between both so that it would be possible to exchange information.

Chadegani et al. [8] developed a solution for manufacturing systems but wrote that a framework that can create a universal infrastructure capable of attending some DT capabilities such as scalability, verification, validation, and maintainability is necessary.

Table II: Issues and challenges pointed out by Barricelli et al. [27].

Areas	Issues and challenges	Solution
Ethical	Personal medical records	Clinical trials Anonymous data Use only with patients' consent
Security and privacy	Hacker attacks	Create security solutions to prevent data from being seen by unauthorised person
Cost of development	Costs with software and hardware	Open repositories for research purposes with some DT experimental models
Government regulations	Validation must be created to assure the credibility of models in Biology	Define regulations for virtualisation of human beings
Technical limitations	Needs devices that do not offer reliable data Slow internet connections Large amounts of data make it difficult to visualise them	Needs improvement of hardware that are limited nowadays

Finally, Widok et al. [18] suggest combining different sustainability perspectives to create a single model.

Since in this paper, we focus on DT and Simulation at the same time, it is suggested for future works, to explore these two themes separately in RL problems.

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