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ORIGINAL PAPER

DIGITAL TWINS FOR SUSTAINABILITY PURPOSES IN LOGISTICS INDUSTRY: A LITERATURE REVIEW

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ABSTRACT. Background: The concept of digital twins has been gaining popularity in various industries due to its potential to enhance performance, optimise operations, and reduce costs. Digital twins have shown promising results in improving sustainability in the logistics industry by providing a virtual replica of the logistics activities, processes, systems, equipment or machinery, enabling real-time monitoring, promoting collaboration, and integrating with other technologies. Digital twins can, among others, reduce, optimise, and minimise various costs in logistics activities. This paper's purpose was to explore and analyse the current state of research literature on the implementation of digital twins in logistics for sustainability purposes.
Methods: The paper utilises a structured bibliometrics and systematic literature review methodology to answer these questions and follows the PRISMA methodology. Scopus and Web of Science were used to identify previous research on this topic with the search string (sustainab* AND logistic* AND "digital twin*"). Research that included theoretical or practical digital twin applications for increasing logistics' sustainability was analysed from a basic bibliometrics viewpoint and then systematically reviewed to determine and interpret the significance of digital twins' implementation for the sustainability of the logistics industry. An emphasis was given to the means of digital twin implementation, its scope, and the sustainability aspects (environmental, social, and economic) that the research and consequent implementations target.
Results: The main goal was to identify how scientific literature views the potential impact of digital twins on the sustainable development of the logistics industry and to acquaint the reader with a coherent collection of relevant research from the researched field. Among 47 documents, only 18 met the inclusion criteria for further bibliometrics and content analysis. Unfortunately, only a few publications directly presented digital twins' use for increasing sustainable aspects of logistics activities.
Conclusions: The number of publications regarding digital twins in logistics is increasing, but to a large extent they are not concerned with practical implementation. The latter testifies to the degree and extent of literature on digital twins' integration and implementation for sustainability in the logistics industry still being scarce.

Keywords: digital twins, logistics industry, sustainability, sustainable aspects, systematic review

INTRODUCTION

Digital twins are data-based digital models of physical objects [Minerva et al. 2020], processes [Tao and Qi 2019], or systems [Hartmann and Van der Auweraer 2021, Stark et al. 2019] that enable simulations [Barykin et al. 2020] in a virtual environment [Defraeye et al. 2021]. Through logistics, they can be implemented in four constant multitudes of supply chains: products, services, processes, and/or systems [Kajba, Jereb and Obrecht 2023].

Digital Twin technology has been known about for two decades. Nevertheless, its implementation is relatively new in the logistics field [Moshood et al. 2021] and supply chain systems [Kajba, Jereb and Obrecht 2023]. Digital twins enable (a) insight into the past, (b) optimisation of the present, and (c) innovation of future performance through implementation into products, services, machines, processes, systems, and even entire business ecosystems [Lu et al. 2019]. Premised on the latter, their use brings vital benefits that affect the sustainability aspect of logistics operations and achieving

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sustainability goals that include environmental, social, and economic aspects. Thus, further research into this subject matter is crucial to achieving developments and innovations in sustainable logistics operations.

Theoretical background

Digital twins, artificial intelligence, the Internet of Things (IoT), and cloud computing represent a few Industry 4.0 tools that support technological revolution towards accelerated efforts of cyber-physical operations', services' and systems' efficiency optimisation [Akkad et al. 2022]. The consecutive development of sensor technologies, IoT, and big data analytics has led to the inevitable advancement of digital twins, which enable the interlacement of the physical and digital worlds [Tao et al. 2019].

Digital twins are usually presented as three-dimensional replicas of physical objects or systems, where they use real-time data obtained from sensors that monitor the studied objects' or systems' performance, their environment, or even similar digital twins [Barata et al. 2020]. In simple terms, it can be said that the digital twin operates based on mirroring the life of its corresponding physical twin through an integrated multi-physics, multi-scale probabilistic simulation of the physical counterpart [Glaessgen and Stargel 2012]. However, a digital twin is more than just a digital representation or a replica of the physical object [Belfadel et al. 2021] – it is a comprehensive physical and functional representation of the object under study, where all the necessary information within the life cycle for proper processing is provided [Boschert and Rosen 2016]. Dynamic correspondence connects the digital twin platform with models and data, enabling monitoring and synchronising the current state and behaviour of the digital twin with the mirrored physical environment. However, this connection is generally one-way oriented – from the physical world to the digital replicas, which are considered the digital shadow [Kritzinger et al. 2018]. This will be discussed further in a future paper.

A more adept explanation of digital twins' follows. Technology enablers for digital twin construction include modelling, predictive analytics and decision-making methods correlated with lifecycle data, and targeted knowledge with real-time historical and operational data [Belfadel et al. 2023]. A cyber-physical system combines physical devices correlated in virtual cyberspace, using a data transmission network. Each physical device has its cybernetic component, which represents a digital image of the device in question – the latter catalyses digital twin models. The digital twin can thus inspect and control the physical entity in question and transfer data to optimise and integrate the virtual model. The digital twin model represents an exact and current cyber counterpart of a physical product, process or system that adequately reflects all its functionalities, assimilates extensive contextual work data, and is used as infrastructure for planning, network upgrading, and rapid transformation. In contrast to standard simulation design, the digital twin component is not only a visual reproduction of contingencies or a means of reporting results but also a validation tool for a complete lifecycle upgrade solution. [Andronie et al. 2021]

It should be noted that digital twins are not identical twins. The notion of an exact replica is only an idealisation and an aspiration that may never even be achieved [Batty 2018]. In addition, the studied object must be characterised by evolving data, as physical conditions change in parallel with time. Therefore, decisions must be based on evolving data collections rather than the data collections of a time interval, which provides only a snapshot of the situation at the given moment. This way, it is possible to better understand systemic changes over longer time intervals and patterns. And just like datasets, digital twins depend upon dynamic updates associated with simulation models, which evolve based on physical conditions. [Kaur et al. 2020]

Quite a few contributions can be found in the literature in the context of implementing Industry 4.0 tools. Digital twins have been recently acknowledged for support in advanced experimentation, simulation, and decision-making for on-demand logistics operations [Belfadel et al. 2023]. Nonetheless, digital twin frameworks are still being mainly implemented in the context of producing, manufacturing, and shop floor management [Haße et al. 2019, Zhuang et al. 2018], but it is clear that the

existing architectures are too universal to be used in logistics [Haße et al. 2019]. Nevertheless, concrete use cases for implementing such architectures are rare in logistics, even though digital twins' implementation offers significant added value [Hopkins and Hawking 2018].

Logistics facilities can be equipped with comprehensive sensor systems, based on which a digital image of an individual logistics entity is created, which represents a digital twin. [Wohlfeld 2019]. Digital twins facilitate communication between assets, objects, processes, and various systems [Belfadel et al. 2021], while its architecture facilitates the analysis and processing of extensive data collections in real-time [Haße et al. 2019]. Besides data management, digital twins enable behaviour simulations of the studied object or complement the physical object with digital services. Depending on the digital twins' build requirements, the latter includes a three-dimensional build model, structural properties information, component manufacturer information, maintenance intervals information, and other crucial or necessary information. [Gehring and Rüppel 2023] The challenge in digital twins' creation is in the appropriate data structure design, the required data collection and integration, and the appropriate interface creation to use this data [Tao et al. 2019]. Data collection is not the main challenge in logistics – the decisive factor is how this data is processed further to facilitate maximum added value [Belfadel et al. 2021].

Sustainable development of supply chains is based on environmental, societal, and governance aspects [Zhang et al. 2023]. The abbreviation ESG stands for 'E'nvironmental impact of business activities; 'S'ociety deals with, e.g., employee benefits or product liability; and 'G'overnance focuses on corporate norms and risk management [Díaz et al. 2021]. Digital twin technology represents one of the most promising tools for Industry 4.0 realisation [Tao et al. 2019] whilst enabling sustainable performance improvement [Kaewunruen and Lian 2019]. Many authors have researched the usage and/or implementation of digital twins in logistics for sustainable purposes, such as:

- for accuracy and efficiency improvement of sustainable material selection for laptop design [Xiang et al. 2019];
- for sustainable intelligent manufacturing [He and Bai 2021];
- achieving sustainable objectives in the supply chain, such as prediction of operational failures, improvement of product quality, and reduction of downtime [Kamble et al. 2022];
- for obtaining and predicting the information on performance, energy consumption, and costs from the virtual space through simulations [Zhang et al. 2023].

The constantly evolving technology of digital twins thus represents an innovative and competitive solution for providing sustainable logistics services. With the help of IoT, digital twins provide traceability for sustainable logistics [Yang et al. 2022], which emphatically influences a company's sustainability performance [Zhou et al. 2021]. Logistics is a widely dispersed area where there are many opportunities for digital twin implementation, for example, from sustainability evaluation of companies based on ESG [X. Liu et al. 2021], sustainable urban road planning [Jiang et al. 2021], secure information management [Putz et al. 2021], sustainable blockchain-enabled supply chain [Mukherjee et al. 2021], sustainable smart city design [Xia et al. 2022], and many others.

Therefore, the use of digital twins in logistics contributes to a more sustainable operation of logistics systems, as it can reduce the negative impact on the environment, improve the working conditions, and increase the efficiency and competitiveness of the company. Furthermore, it contributes to sustainable development, which is positively perceived by the environment, society, and governance bodies (ESG). Collectively, the use of digital twin technology is important to achieving sustainability objectives in logistics, as it enables better planning and more efficient operations, consequently improving the environmental, social, and economic aspects of logistics operations.

Scope, objectives, and aim

This paper explores how digital twins can enable more sustainable logistics operations. The latter will be done through structured bibliometrics and systematic literature review methodology, where two literature databases (Scopus, Web of Science) will be used to identify research on this topic and obtain suitable literature for further analysis.

Literature that includes theoretical or practical digital twin applications for increasing logistics' sustainability is first analysed from a basic bibliometrics viewpoint. Afterwards, the suitable literature is systematically reviewed to determine and interpret the significance of digital twins' implementation for the sustainability of the logistics industry. An emphasis will be given to the means of digital twin implementation, its scope, and the sustainability aspects (environmental, social, and economic).

The main objectives are:

- to identify how scientific literature views the potential impact of digital twins on the sustainable development of the logistics industry;
- to divide the suitable scientific literature into three sustainability sections: environmental, social, and economic. The latter is based on the digital twins' implementation for enabling sustainability in logistics through the codification process;
- to acquaint the reader with a coherent collection of relevant research from the researched field.

This paper aims to broaden the understanding of digital twins' implementation in logistics, focusing on sustainability aspects. Essentially, the idea of this paper was premised on previous research, where bibliometrics and literature review were conducted for digital twins implementation in transport and energy fields since "transport has an enormous impact on the sustainability of supply chains, which is emphasised through the close correlation between environmental and economic aspects" [Kajba, Jereb and Cvahte Ojsteršek 2023]. The difference emerges in the studied field, which is logistics rather than supply chains, and was encouraged by another study that considered IT trends for modelling investments in supply chains by prioritising digital twins [Kajba, Jereb and Obrecht 2023]. Here, a further examination of the benefits, challenges, and impacts of digital twin technology implementation in logistics was proposed.

Thus, this paper touches upon a crucial topic in today's world: the degree and extent of literature on the integration and implementation of digital twins for sustainability in the logistics sector, where the paper's main contribution can be found in the bibliometric and systematic overview of the respective topic.

METHODOLOGY

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were applied in reporting the procedure and analysis of the presented literature pool where applicable [Page et al. 2021].

Publication search and selection

Web of Science and Scopus were selected as databases for preparing a literature pool for the review since these two databases are recognised as the leading compilations of academic documents [Zhu and Liu 2020]. Web of Science and Scopus have significant overlaps in coverage but vary in some aspects that make using both in the starting phases of literature reviews feasible [Echchakoui 2020, Okagbue et al. 2020]. A Web of Science search in July 2023 returned 30 documents, while the Scopus search with the input parameters of (sustainab* AND logistic* AND "digital twin*") returned 49 documents. After removing duplicates and entries that are not scientific publications, the whole literature pool included 47 individual documents. Two authors scanned the titles and abstracts of the eligible publications to determine whether they were suitable for inclusion in the final literature pool. In cases of disparities between the authors' decisions and where the decision could not be made based on abstracts alone, the whole documents were obtained and checked. The third author was included to make the final verdict for the documents where an inclusion decision could not be made. Overall, 18 documents were

included in the literature pool after the abstract and publications review. The inclusion criteria were as follows:

- the documents present a journal or conference paper or a book or a part of a book (e.g., patents, datasets, software, or methodological explanations were excluded);
- there were no limitations as to the publication year or source;
- the document explicitly addresses at least some aspects of sustainability (e.g., documents that only mention the potential to reduce carbon footprint as part of the final discussion but do not explicitly address it in the research part were excluded);
- the document explicitly addresses digital twin use from a practical or theoretical standpoint in the research part of the contents;
- the research is focused on logistics or at least a subset of logistics activities (i.e., transport, warehousing, city logistics, etc.).

All 18 publications were available in the Scopus base, representing the source for bibliographical information used in the bibliometrics and content analysis. The research methodology process for publication search and further analysis is evident in Figure 1.

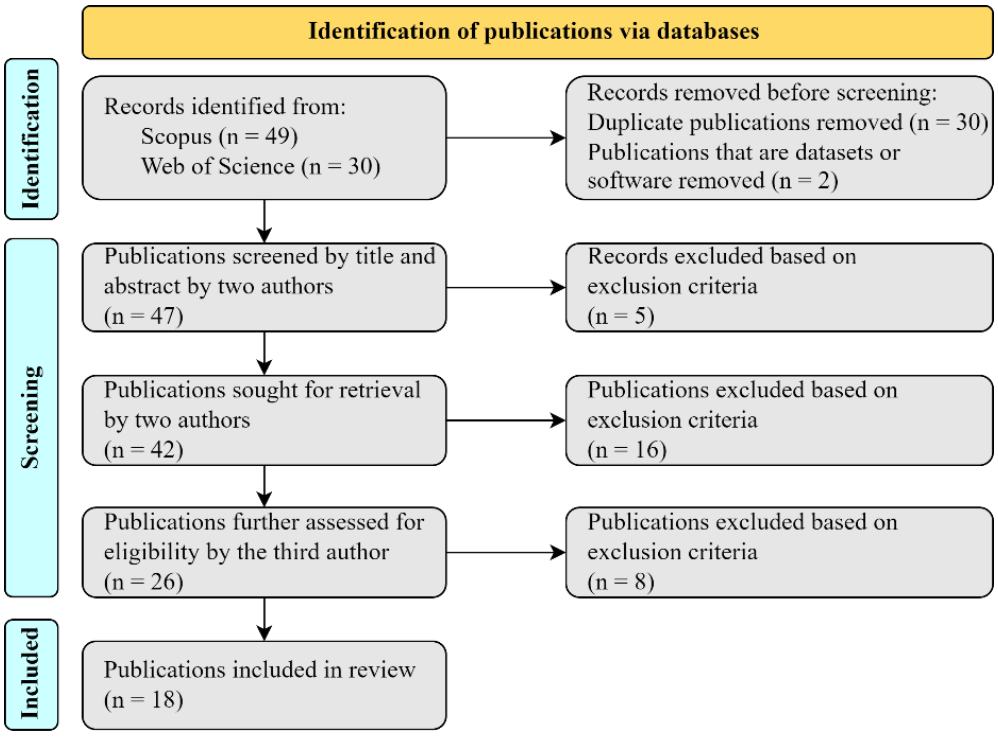

Fig. 1. The research methodology process.
Source: own.

Bibliometric analysis

Bibliometric analysis comprised a descriptive analysis of publication year, sources, and origin countries. Data for these were taken from the bibliographical publication data from Scopus.

Further analysis focused on keywords the authors assigned to their publications and index keywords from Scopus. VOSviewer [van Eck and Waltman 2014] was used to perform a co-citation analysis for the whole pool of keywords to determine which topics are most prominent in researching sustainability and the potential for digital twin use in logistics. Author and index keywords were exported from Scopus for the included 18 publications. Altogether, this gave a pool of 351 keywords. They were scanned for duplicates and synonyms, and a thesaurus was prepared for use in VOSviewer that enabled the

software to combine keywords written differently but sharing a common meaning. E.g., the keywords "supply chain", "supply chains", and "supply chain management" were joined into one keyword group with the name "supply chain management" and were consequently considered by VOSviewer as one keyword. This left 195 keywords to be included in the co-occurrence analysis. Co-occurrence denotes an occurrence of two keywords in a paper, and bibliographic analysis of co-occurrence shows the interconnectedness of keywords in the literature pool, which consequently points to the overarching themes that appear in the analysed literature. VOSviewer prepares a clustering of keywords based on the network of used keywords in the publication pool regarding usage and occurrence in shared publications. The clustering was also a basis for determining the most prevalent topics and publication areas in the researched field.

Content analysis

The publications in the literature pool were analysed in accordance with the research objectives. Firstly, the contents were analysed in accordance with the field of logistics application, sustainable aspects that the presented research considers (environmental, social, economic), the scope of digital twin implementation, and the constant multitudes of supply chain systems [Kajba, Jereb and Obrecht 2023]. Based on the codification of research contents, an in-depth content analysis focused on how digital twins were used in the publications from the literature pool to enable more sustainable logistics operations.

RESULTS

The results present a detailed analysis of publications up to July 2023 that deal with digital twins to increase sustainability in logistics operations. Interestingly, authors frequently seem to think of the sustainability aspect as an umbrella concept but fail to acknowledge how their research results contribute to sustainable logistics operations, e.g., [Trebuna et al. 2022], or sustainability is mentioned as an advantage of digital twin implementation without further explanation [Lam et al. 2023]. Publications like these were excluded from the analysed literature pool due to the lack of focus on the intended fields.

Bibliometric analysis results

In terms of publication years, the first year in which the covered topics appear is 2019, with two publications, and 2020 also follows with two publications. 2021 produced seven publications, 2022 five publications, and two were published in 2023 so far (Figure 2).

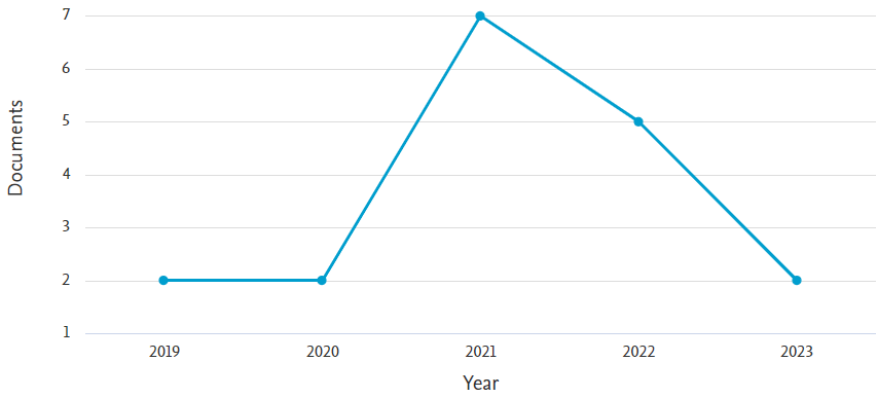

Fig. 2. Quantity of published publications on the topic between 2019 and 2023.
Source: own work.

Regarding author affiliations, China, France, Hungary, and Italy are the most productive countries. Overall, 20 unique countries contributed to the literature pool. Countries with at least two publications are shown in the graph below (Figure 3).

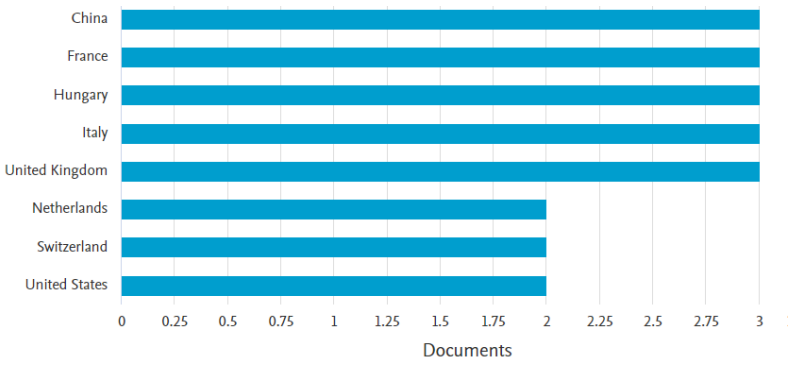

Fig. 3. Quantity of published publications by countries.
Source: own work.

Regarding the publication type, 11 publications are journal articles, and 7 are conference papers. The only source that stands out with three publications in the literature pool is the Journal of Cleaner Production with three publications. In contrast, other sources are unique and have only published one publication in our literature pool.

A deeper analysis of citations and co-citations was hindered by the small number of publications in the literature pool and the relatively young field of research. Therefore, further research into co-citations and coupling was not performed.

Keyword analysis was performed to determine the most prevalent topics in the literature pool. If we set the minimum number of occurrences for a single keyword to 5, only 5 keywords would meet the inclusion criteria – these are "digital twin", "sustainable development", "production logistics", "supply chain management", and "sustainability" – the keywords that are guided by our research objectives. To broaden the scope of keyword co-occurrence analysis, the minimum number of occurrences of a keyword in the literature pool was set to two occurrences among the author and index keywords, which returned 35 unique keywords. The co-occurrence matrix of the keyword pool is shown in Figure 4.

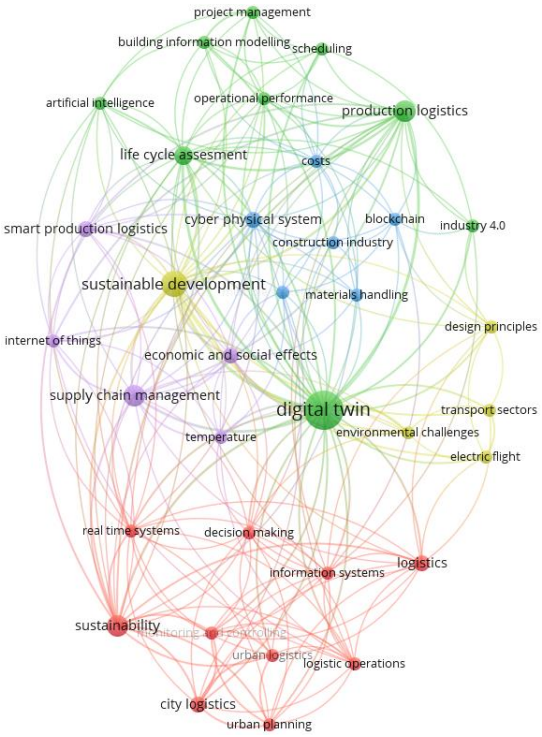

Fig. 4. Co-occurrence matrix of the keyword pool.
Source: own work.

The co-occurrence analysis identified five topical clusters. The green cluster is connected mainly to Industry 4.0 and production logistics with operational performance and project management. The red cluster is focused more on logistics as a holistic topic connected to decision-making and planning. The purple cluster is centred on supply chain management and its economic and social effects with the addition of contemporary technologies such as IoT and smart systems. The yellow cluster is transport-oriented, with an additional focus on sustainable development from an environmental perspective. The blue cluster focuses on digital twins as cyber-physical systems mainly concerning construction and materials handling.

Content analysis results

Since the main focal point of the research is enabling more sustainable logistics, an analysis of which logistics and sustainability aspects are most often covered in the literature from the field was made first. In terms of logistics areas, transport and construction logistics were the predominant fields, with five publications each (Table 1).

Table 1. Quantity of publications regarding application in the logistics field

Field of logistics application	Number of publications
Transport	5
Construction logistics	5
City logistics	3
Production logistics	3
Medical logistics	1
Supply chain management	1

Source: own work.

According to the considered sustainability aspects, the publications were assigned into different groups: environmental, social, and economic. Due to the specifics, one publication can be included in more than one group if it covers more than one field of sustainability (Figure 5). Most publications focused on the environmental aspects of sustainability, often through reducing emissions and energy consumption (e.g. [Akkad et al. 2022] and [Portapas et al. 2021]). Social and economic sustainability were less predominant.

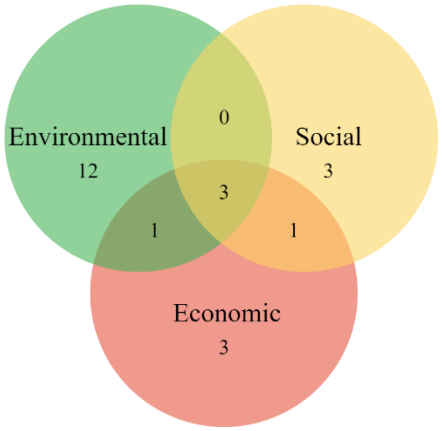

Fig. 5. Quantity of publications regarding sustainability aspects.
Source: own work.

Three publications deal with all three aspects of sustainability as a result of digital twin applications. [Ruperto and Strappini 2021] uses a digital twin of a construction project to overcome the potential logistics and sustainability issues in constructing an office building. Its main goal is to monitor the construction process of the building, ensuring adequate information flows, efficiency, and cost-effectiveness. [Kim et al. 2021] designed a laboratory case study of a digital twin for an automotive manufacturing company that focuses on internal order picking and transport processes. They show that using digital twins for real-time scheduling optimisations based on cyber-physical connections can contribute to all three aspects of the sustainability of an intralogistics process. [Kamble et al. 2022] presents an implementation framework for digital twins in manufacturing supply chains, based on a literature review, as well as the potential for their use in increasing the sustainability of supply chains.

According to the level of digital twin implementation, the publications vary from a conceptual framework to actual implementation descriptions. Consequently, the publications were divided into several groups:

- Conceptual frameworks are publications where the digital twin is described, the basic model or architecture is given, and sometimes even some technical solutions, but no implementation is shown.
- A step further is a use case, where the conceptual framework is also applied to a theoretical or concrete case, but only in terms of a general implementation idea or laboratory experiments.
- The final step in terms of concrete use is an implementation case study, where the developed digital twin is used in practice, and the concrete outcomes are presented in the publication.

Based on this, the publications were divided by implementation level, as shown in Table 2 below. The three most developed publications that address actual implementation cases cover different aspects of sustainability. [Accorsi et al. 2022] used a tailored digital twin to improve the spatial life cycle assessment of secondary food packaging use. They modelled a large-scale transport network and connected it to emissions and fuel consumption in connection to material flows, then used it to determine the environmental impacts of using different reusable plastic containers in comparison to single-use containers. Their concrete results support increased environmental sustainability in logistics through reduced transport emissions and container production and disposal impacts. [Pilati et al. 2021] used a digital twin of a mass vaccination centre for real-time mapping and optimising operator and queue flows. Their results allowed for optimising vaccination efficiency, reducing queues of patients, and resource allocation and optimisation. This contributed towards improving the logistical operation's economic and social sustainability aspects. [Zhao et al. 2022] focuses on economic aspects of sustainable production logistics through utilising IoT devices on mobile resources in the manufacturing system in connection to a digital twin to optimise resource allocation in real-time.

Table 2. Quantity of publications regarding digital twins' implementation level

Digital twin implementation level	Number of publications
Conceptual framework	6
Use case	9
Implementation case study	3

Source: own work.

A part of researching supply chains and logistics is defining the constant multitudes of supply chain systems: products, services, processes, and systems. These present "a consistent part of any and every supply chain system"; furthermore, in themselves, they "form a multitude of other products, services, processes, or systems", which are intercorrelated [Kajba, Jereb and Obrecht 2023] (Table 3).

Table 3. Quantity of publications, divided into constant multitudes of supply chain

Constant multitudes of supply chain systems	Number of publications
Products	2
Services	1
Processes	8
Systems	7

Source: own work.

DISCUSSION

Digital twin use is recommended as a tool for increasing the sustainability of operations in, e.g., freight transport [Dwivedi et al. 2022] and specifically urban freight transport [Golinska-Dawson and Sethanan 2023]; however, both of these publications focus specifically on energy consumption and do not propose concrete roles or implementation procedures for digital twins.

Only a few publications present the use of digital twins to increase sustainable aspects of logistics activities directly. For example, Accorsi et al. [2022] applied a network analysis software-based supply chain digital twin to evaluate input parameters of a life cycle analysis and environmental impact analysis for various packaging alternatives in the food logistics field. Zhao et al. [2022] applied a digital twin to a production facility to track resources, optimise their allocation, and increase efficiency. Publications like these are scarce in today's literature, showing a sizeable potential research gap. The presented publications prove that digital twins can be successfully used in making logistics more sustainable; therefore, we can safely assume that even though the field is currently under-developed, the sole potential of the contemporary modelling and simulation techniques can and will revolutionise the way logistics stakeholders operate and interact with their environments, leading to significant advancements in efficiency, cost-effectiveness, and environmental impact reduction, as well as reducing negative social impacts. As further research and innovation continue to bridge the existing gaps, we can anticipate a future where digital twins become an integral part of strategic decision-making, enabling companies to optimise their supply chains, reduce resource consumption, and create a more sustainable and resilient global logistics network.

A significant limitation to our research is the fact that making various logistics aspects more efficient oftentimes also makes them more sustainable. Still, these effects might not have been explicitly addressed in some publications that were not included in the literature pool. E.g., Gehring and Rüppel [2023] present how using digital twins could optimise the transport and storage of materials in construction projects but does not explicitly address any sustainability factors, and Y. Liu et al. [2021] address a digital twin use case in city delivery and parking management, optimisation of which undoubtedly contributes to sustainability. Nevertheless, this aspect was not explicitly addressed in the paper. Another limitation that is derived from this notion is the search parameters that were used. As said before, many publications focus on using digital twins to improve business operations, reduce emissions, etc., but do not connect these to the broader concept of sustainability. The set search parameters did not recognise these publications as relevant to the present paper.

CONCLUSION

The paper's main contribution is as a bibliometric and systematic overview of digital twins' technology in the logistics industry to enable more sustainable operations. Of the 47 publications in total, 18 met the set criteria and were included in further analysis. With the practical implementation of digital twins' technology in logistics, the paper's first objective was fulfilled, where only three publications described actual digital twins' implementation cases in different sustainability aspects. Regarding the paper's second objective, only three papers in total touched upon all three sustainability aspects, which is a low number in retrospect. The latter testifies to the fact that the number of publications regarding digital twins in logistics is increasing, but to a large extent they are not concerned with practical implementation.

With the bibliometric and systematic overview of the topic, the third objective, and the paper's aim to broaden the understanding of digital twins' implementation in the logistics field, focusing on sustainability aspects was accomplished. This paper's purpose was to explore and analyse the current state of research literature on the implementation of digital twins in logistics industry for sustainability purposes, which was accomplished through the research. Furthermore, as seen from the results, the degree and extent of literature on integrating and implementing digital twins for sustainability in the logistics sector is still scarce. The goal is to facilitate an understanding of the logistics networks' correlations and the outcomes resulting from implementing specific innovations [Belfadel et al. 2021].

New flexible and innovative approaches in supply chain and logistics fields are needed, such as digital twins, to support experiments, simulations, and managerial decisions regarding logistics operations [Belfadel et al. 2021]. Hence, it's advisable to implement data-driven models alongside real-world experiments to predict the consequences of response actions and replicating results, where digital twins can prove valuable [Belfadel et al. 2023]. Playing a significant role, digital twins will be instrumental in forecasting future dynamics [Abideen et al. 2021] by mapping and monitoring various aspects of the supply chain system, including optimum network design, inventory management practices, supply and distribution techniques, logistics integration, outsourcing, and procurement approaches [Zhong et al. 2017].

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