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Review

How Digital Twin Concept Supports Internal Transport Systems?—Literature Review

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Abstract: In the Industry 4.0 era, the Digital Twin has become one of the most promising enabling technologies supporting material flow. Although the literature on the Digital Twin is becoming relatively well explored, including a certain number of review papers, the context of the Digital Twins application in internal transport systems has not been investigated so far. This paper thoroughly reviews the research on the Digital Twins applied in internal transport systems concerning major research trends within this research area and identification of future research directions. It provides clarification of various definitions related to the Digital Twin concept, including misconceptions such as a digital shadow, a digital model, and a digital mirror. Additionally, the relationships between terms such as material handling, material flow, and intralogistics in the context of internal transport systems coupled with the Digital Twin are explained. This paper's contribution to the current state of the art of the Digital Twins is three-fold: (1) recognition of the most influential and high-impact journals, papers, and researchers; (2) identification of the major research trends related to the Digital Twins applications in internal transport systems, and (3) presentation of future research agendas in investigating Digital Twins applied for internal transport systems.

Keywords: digital twin; material flow; material handling; internal transport; intralogistics; internal logistics

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1. Introduction

The concept of Digital Twins (DT) attracts continuously increasing attention and gains importance in recent years, both in academia and industry [1]. The DT technology has great research potential as the number of publications per year is still increasing, with 2343 publications including "digital twin" in their titles, according to the Scopus database (checked online on 28 July 2021). The interest rate in DT technology had dramatically changed in 2019 when 492 papers were published, and the upward trend continues.

The implementation and development of the DT seem to be promising, especially in the area of Industry 4.0 and for more technology-dependent societies [2,3]. Anticipating the semantic aspect of this term considered further in this article, it is worth noting that the DT is a technology, which, based on data derived from different sources, develops a digital representation of products, processes, machines, or components [4]. Alongside means of automation and data exchange in manufacturing technologies, including Internet of Things (IoT), cloud computing, Cyber-Physical Systems (CPS), big data and analytics, and simulation and augmented reality, this technology fits into the concept of innovations within the Industry 4.0 [5–7].

Although the DT concept is characterized by a short-period history, several review papers within this research area have already been published. The search for English language DT review publications in Scopus and Web of Science databases based on searching the following keywords *"Digital Twin*" AND "review" OR "state of art*" OR "current state"* allowed 38 relevant records to be identified. This set of publications is composed of papers published from 2001 to 2021 and included three papers published in 2021 [8–10]. The content-based analysis of these publications is referred to below in order to present the current state of knowledge related to the DT concept. Although the DT concept is present in the literature since the 2000s, the first review on this topic was developed in 2016, namely [11]. This review covered 38 articles published in the period of 2001–2016 and provided the first systematization of the DT literature in the manufacturing industry. Another summary paper published in 2017 [12] covered the DTs' role within Industry 4.0 with an overview of existing definitions of the DT developed until 2016. For the next years, growth in the number of review papers was observed, yet the highest increase was noted in 2020 when 55% of all reviews on DT were published. This trend may be a consequence of the numerous subject areas of DT application, such as manufacturing [13–15], maintenance [16,17], and supply chain [18,19], including the remanufacturing supply chain [8], construction industry [9], and agriculture [20]. Moreover, many publications present a cross-industry overview of contemporary DT applications [21–24]. Interestingly, more than 50% of all identified review papers focus strongly on manufacturing applications [13–15,17,25]. This may be a consequence of the fact that many machines and products within the manufacturing industry have sufficient prerequisites to use DT, for example, owing to the connection of production machines to IT systems.

All in all, it may be stated that DT is a frequently used term recognized in the scientific and trade literature, which is applied diversely along with different subject areas. Although there are several literature reviews on the DT concept within different application areas, and some of them provide the foundations of the DT definition, none of them relates to the DT application in the internal transport systems (understood collectively with internal logistics or intralogistics, etc.) and its inherent material flow. This paper aims to focus on this research gap. The major objective of this study is to answer a general question serving as a title of this paper, namely: how the Digital Twin concept supports internal transport systems? Thus, the paper presents an overview of the academic research on the DT applied in internal transport systems of which inherent attributes are flows of materials and accompanying information. The study is focused on the inquiry of main research trends within this research area and the identification of future research directions. In this paper, the existing literature on DT applied in internal transport systems is reviewed to map the research stream. Additionally, the most substantial contributions to the advances of research in this field of study are identified. Thus, the contribution of this paper toward the existing body of knowledge on DT is three-fold: (1) recognition of the most influential and high-impact journals, papers, and authors; (2) identification of the major research trends related to DT applications in internal transport systems; and (3) presentation of future research agendas in investigating of DT applied for material flow within internal transport systems.

The research presented in this paper is devoted to answering four following research questions (RQ):

- RQ1: What sources, papers, and authors influence the research on DT applied in internal transport systems the most often?
- RQ2: What is the main research focus related to DT applied in internal transport systems?
- RQ3: What might be the future field of interest in investigating DT applications for material flow within internal transport systems?
- RQ4: What is the role of optimization in the research focused on DT when the material flow within internal transport systems is considered?

The paper presents answers to the research questions raised above through the use of bibliometric analysis, including the evolution of publications; general citation structure;

citations analysis of authors, publications, and sources; performance-based analysis of sources; productivity of researchers; and graphical mapping allowing to visualize co-occurrence networks of citations, researchers, countries (affiliations), and keywords.

This paper is organized as follows. Firstly, the theoretical background of the paper is presented along with the most relevant definitions, including material flow, material handling, intralogistics, and DT within the context of Industry 4.0. Then, the research methodology is described, followed by research results of general bibliometric analysis and graphical mapping of the studied research area. Finally, concluding the comments, answers to the research questions together with the entitled question, and additionally, research limitations are described.

2. Area Definition

The basic function of a production company is to manufacture products and distribute them for a specific purpose and in a specific way. This function is performed in the production and logistics systems and includes the following main types of logistics activities:

- Material flow control—situational and managerial approach to material flow (operational approach). Material flow control requires the use of simulation methods. This is especially important when the efficiency of the production system is influenced by the arrangement of the sequence of products to be manufactured. Some authors focus on the relation between simulation and emulation in the context of DT [26,27];
- Material flow conversion—engineering approach to technology (engineering approach). In the case of the material flow conversion in an object, one can mention complex mathematical models that describe the behavior of a real (physical) object or the transformation process with high accuracy; this is the so-called computational approach. Today, a DT is typically a virtual model of a real (physical) object or a process that can be defined by an inherently complex mathematical model [28,29].

There are two concepts associated with these activities: material flow and material handling.

Material flow is related to the external and internal transport of raw materials, precast parts, parts, components, integrated objects, and end products. Material flow can be described by three main elementary subjects: products, processes, and resources [30]. A product is understood as any material object, which states changes during a particular production process, and which is the result of such a production process (a material, a work piece, a part, a product). In general, plant/factory processes include production, transport, quality control and testing, maintenance and repair processes, etc. Resources, however, include all production facilities of a particular enterprise (equipment, technological equipment, production infrastructure, human resources, transport and storage equipment, information infrastructure, etc.) [31].

On the other hand, material handling is the movement, protection, storage and control of materials and products during production, storage, distribution, consumption, and disposal; therefore, it is mostly associated with internal transport and internal logistics. As a process, material handling includes a wide variety of manual, semi-automatic, and automated equipment and systems, which support logistics and maintain supply chains' functioning [32].

The flow of material in time and space is realized by means of transport. Transport refers to the movement of freight and people from one place (point of origin) to another (point of destination) and various means, devices, and equipment, which support such movement. Inside a factory or a warehouse, material flow is carried out by means of handling: lifting devices and transport devices, such as trolleys and conveyors [33]. Continuous advancements of mechanics, electronics, automation, and IT expanded the means of transport and means of handling from fundamental trolleys to complex automated guided vehicles (AGV). The last one, coupled with autonomous mobile robots (AMR), supports the creation of Intelligent Transport Systems (ITS) for internal plant or logistics facilities' applications (typically, ITS is considered along with road transport—the authors' premises are commented further in this paper).

The development of internal ITS along with the development of monitoring, communication, and planning systems (including digital technologies in enterprises) resulted in combining production and logistics systems in one complex system and the introduction of the concept of intralogistics. The term intralogistics is well-known, especially in the German-based industries, as many scientific articles were affiliated in renowned German universities, e.g., [34–36]. This term is defined by the Intralogistics Forum Verband Deutscher Maschinen- und Anlagenbau (VDMA) [36] as "organization, control, execution and optimization of the flow of materials and information inside a plant, as well as handling of goods in industrial, distribution and public sector facilities". Although this term appeared in 2008, there are papers that present the developments in intralogistics since the 1950s [34]. These contributions are presented in Table 1.

Table 1. History and development of intralogistics. Source: own elaboration based on [34].

Period of Time	Features
2010—Industry 4.0 Idea and Implementation	Cobots (collaborative robots), Big Data, Clouds Computing, IoT, Smart Sensors, MicroElectroMechanical System (MEMS), Artificial Intelligence (AI), DT, 3D Printing
2000–2010—Supply Chain Management, E-Commerce	Internet, Pick-by-voice, Wireless Local Area Network WLAN, Radio-Frequency Identification (RFID), Digital Factory
1990–2000—Globalization, Outsourcing	Commissioning robotics, Data networks, Bus systems, Logistics control post, Inventory Management (standardized software)
1980–1990—Flexible Production line, Just In Time	Auto picking equipment, Sorting Systems, Barcodes/Scanner, CAD-Systems, Data transmission, Mobile terminals, Pick by light, Inventory Management (personal Computers), Simulation systems
1970–1980—Distribution Technology	Electric monorails systems, AGVs, Automated Storage and Retrieval System (AS/RS), Microcontrollers, Inventory Management (process computer)
1960–1970—Storage Technology	Rack feeder, High rack storage, Automatic systems, Very Narrow Aisle (VNA) trucks, Inventory Management (punch cards)
1950–1960—Production	Palettes, Forklift, Stacking Cranes

In the case of the abovementioned material flow control as a situational approach, one of the instruments for the implementation of this approach is intelligent internal transport. Hence, there is a need to analyze the literature concerning Intelligent Internal Transport Systems supporting material flow in the context of DT consider the following points of view:

- Visionary approach—where authors describe visions and needs of DT, however, without detailed references to practice—these visions are most often described in the context of the entire supply chain;
- Object approach (object/process related to the conversion in an object)—associated with manufacturing and CPS;
- Process approach (focus on situational and managerial approach)—associated with material handling and information management;
- DT versus simulation (DES—Discrete Event Simulation and ABS—Agent-Based Simulation);
- DT versus emulation (where real simulation model is connected to real elements of a system);
- DT versus MES/APS and WMS (MES—Manufacturing Execution System, APS—Advanced Planning System, WMS—Warehouse Management System—existing real-time IT systems);
- Other, e.g., optimization.

The emergence of technologies related to Industry 4.0 has a significant impact here. Industry 4.0 is defined as a general term associated with various digital concepts such as IoT, CPS, Big Data, Data Analytics, DT, Digital Shadow, Human-Robot Collaboration (HRC), etc. [37]. These concepts promise new potentials for production planning and control. The essence of Industry 4.0 is the decision-making autonomy of cooperating CPS. Therefore, the following features of a smart factory can be distinguished:

- Interoperability—objects, machines, and people need to be able to communicate with each other via the Internet and, in particular, IoT;
- Virtualization—everything physical must have a virtual equivalent (model);
- Autonomy—the ability of CPS to work autonomously, opening the way to mass personalization of products, providing a flexible production environment facilitating innovation;
- Work in real time—a smart factory must collect data in real time, aggregate them, analyze and make decisions in accordance with new arrangements; intelligent objects must detect faults and reallocate tasks to machines;
- Customer orientation—people and intelligent machines must be able to communicate effectively in order to produce personalized products based on customer specifications;
- Modularity—owing to modularity, intelligent factories will be able to quickly and smoothly adapt to seasonal changes and market trends.

A special role of systems' optimization and personalization should be underlined here. A smart factory consists of thousands of intelligent devices able to self-optimize production, which will lead to almost zero downtime. This is especially important in industries using very expensive production equipment. The ability to continuously use the means of production enables to increase a company's profitability. Customization enables the creation of a flexible, customer-oriented market, helping to meet human needs quickly and efficiently. It also reduces the distance between a producer and a customer, as their communication takes a direct manner. This, in turn, accelerates production and delivery. The features of the smart factory (as the object of engineering activities), namely Interoperability, Virtualization, Autonomy, and Work in real time, are currently implemented by the IoT and DT.

Moreover, the positive correlation between Lean manufacturing and Industry 4.0 should also be mentioned [38], in particular when the management (engineering) of the production process is discussed in the context of material flow control and material flow conversion. Many authors indicate the great impact of lean production tools on the DTs application, notably the case of Value Stream Mapping [39], considering the fact that simulation methods are also based on methods derived from lean manufacturing [40,41].

The synergy of using digital twins in internal transport systems and manufacturing systems is visible on the one hand in the formulation of the intralogistics concept, which was already mentioned in the paper, and in the works of authors emphasizing the need and vision of such synergy [42,43].

The objective of engineering activities is to define the objects and principles of material flow transformation in the "product-process-resource" system. The digital model of these objects is a static model, and it is created as part of technical equipment and modernization of a company's facility, as well as during technological preparation of production.

Production plans and work schedules, quantitative material flow rates, resource availability, capacity, and operational parameters in a given period determine operational activities. During operational activities, data on the current state of material flow, the state of workplaces, etc., are collected. They form a digital, dynamic data model.

The terms such as (1) digital, static model and (2) digital, dynamic model are discussed and defined in the literature as a digital model, either digital shadow or DT. Many authors focus primarily on real-time work and the flow between a real and a digital object, introducing the concepts of digital model (manual data flow), digital shadow (manual and automatic data flow), and DT (only automatic data flow). A digital model is a digitalized version of an actual or planned object. The coupling of a digital model and a physical object is not interconnected by any automatic data exchange [44]. A digital shadow is defined as a digital version of an object that is characterized by a one-direction impact between a physical and a digital object. A change in any state of a physical object is reflected in a digital model of a physical object, while the reverse situation does not occur [44]. In the case of DT, an impact between a physical object and its digital reflection is mutual. Once a change in any state in a physical object occurs, it automatically leads to a change in a digital object. The opposite interconnection occurs as well [44].

However, it is challenging to present an unambiguous definition of DT at the moment [13,45]. On the one hand, different authors quote the definition of Michael Grieves [46], who is the founder of the DT term (i.e., "[t]he DT concept [. . .] contains three main parts: a) physical products in Real Space, b) virtual products in Virtual Space, and c) the [two-direction] connections of data and information that ties the virtual and real products together"). On the other hand, different publications contain authors' own definitions, as it was, for example, mentioned in [47], where a classification of the definitions of DT was also presented.

Most DT definitions underline a bi-directional link between the digital and physical objects and describe the DT that processes data. While most DT are described as being physically related to their counterparts, only some mention the DT as being independent [48]. It seems that most authors describe the DT as an identical equivalent of its physical counterpart, whereas only a few refer to them as only partially identical [47].

3. Materials and Methods

The research presented in the paper is based on bibliometric tools and techniques, namely, bibliometric performance analysis and graphic mapping (conducted in VOSviewer: version 1.6.15, Nees Jan van Eck and Ludo Waltman, Melbourne, Leiden, the Netherlands) [49]. In the paper, bibliometrics is used to statistically analyze publications, authors, sources, and countries in order to identify main research trends related to DT applied in internal transport systems. Apart from general statistical calculations, indicator-based analysis is used based on the ratio i_j developed as Equations (1)–(3) adopted from the study of Marczewska and Kostrzewski [50]:

$$i_J = c_J^{\Sigma} / p_J^{\Sigma};\ j \in \boldsymbol{J},\ \boldsymbol{J} = \{j : j = \overline{1, J}\} \tag{1}$$

$$c_J^{\Sigma} = \sum\nolimits_1^J c_j;\ j \in \boldsymbol{J},\ \boldsymbol{J} = \{j : j = \overline{1, J}\} \tag{2}$$

$$p_J^{\Sigma} = \sum\nolimits_1^J p_j;\ j \in \boldsymbol{J},\ \boldsymbol{J} = \{j : j = \overline{1, J}\} \tag{3}$$

where:

- $\boldsymbol{J}$—set of all analyzed sources;
- i_j—ratio of influence of an analyzed research topic computed for j-th source;
- c_j—number of citations for an analyzed research topic in j-th source;
- p_j—number of publications in an analyzed research topic in j-th source;
- c_J^{Σ}—total number of citations for an analyzed research topic in all J analyzed sources;
- i_j^c—ratio of citations for an analyzed research topic in j-th source and a total number of citations in all J analyzed sources;
- p_J^{Σ}—total number of publications in an analyzed research topic in all J analyzed sources;
- i_j^p—ratio of publications in an analyzed research topic in j-th source and a total number of publications in all J analyzed sources.

The graphical mapping is used in this paper to construct and visualize co-occurrence networks of citations, researchers, countries (affiliations), and keywords. One of the most notable objectives of science mapping is to present relations between analyzed elements, such as papers, keywords, authors, etc. [51]. It combines classification and visualization of the analyzed elements [52]. In this paper, such an approach is applied to support general bibliometric analysis and indicator-based analysis. It adds value to the paper as, apart from indicating the most important contributions to the state of the art on the subject matter, it presents interrelations between analyzed elements, i.e., citations, researchers, countries (affiliations), and keywords and extracts more holistic conclusions.

The graphical mapping presented in the paper is partly based on co-citation analysis understood as the frequency of two or more elements (such as documents, authors, or journals) being cited together [53–55]. Precisely, the analysis presented below uses authors' co-citation analysis which not only allows identifying the most important authors in the researched field yet also presents their joint appearance in reference lists of other publications. On the one hand, it is proved to be a reliable method of evaluating scientists and specific research fields, whereas on the other hand, since citations are long-lasting, newer publications and relatively young authors will not be visible in such an analysis right straightaway [51].

The analysis was conducted based on the four-step research procedure, including study design, data collection, data cleaning, and reporting research results. The research procedure is presented in Figure 1.

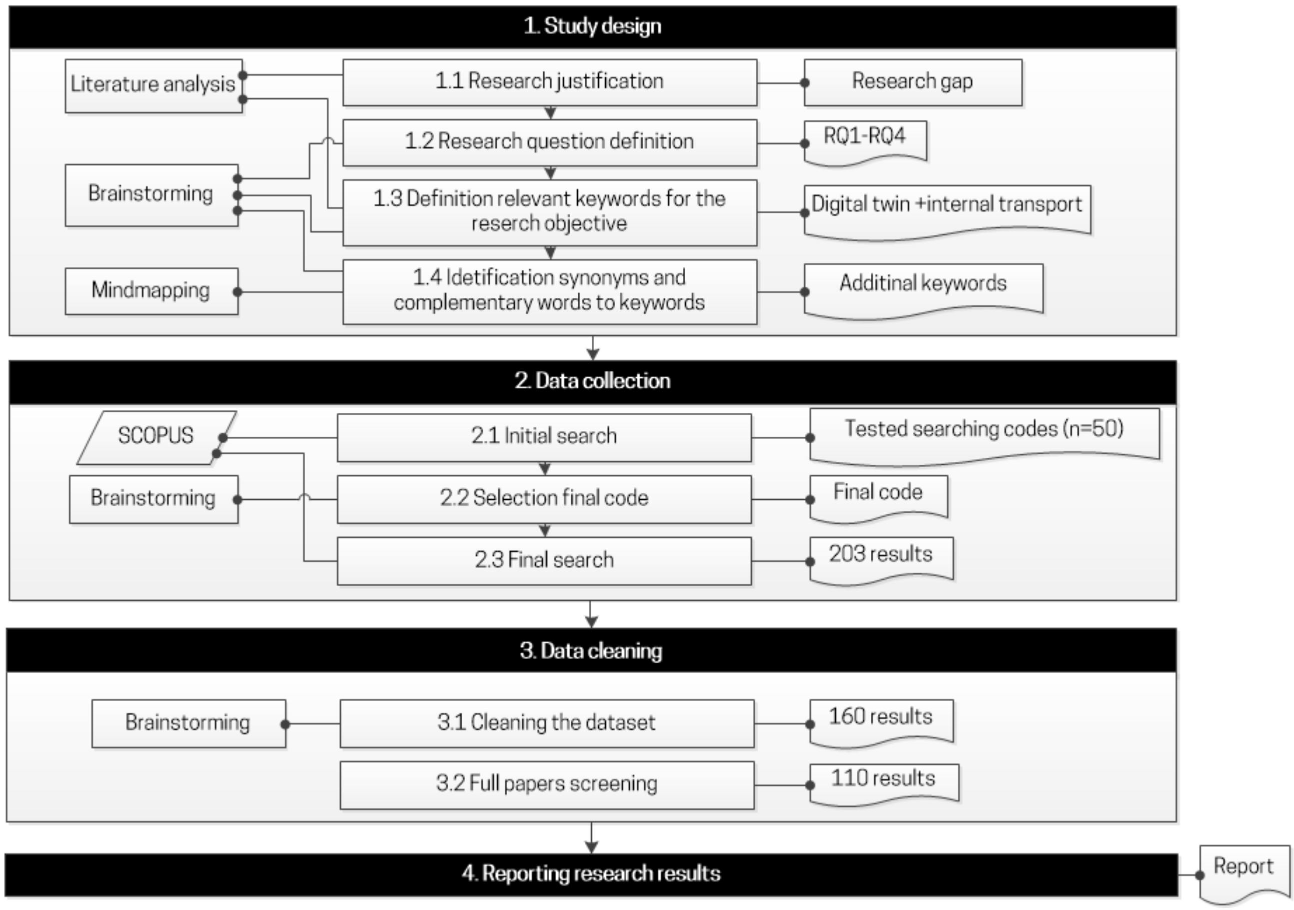

Figure 1. Research procedure. Source: own elaboration.

3.1. Study Design

The study design—a planning stage—resulted in research gap identification. The research gap was identified owing to the initial literature review, which was based on the analyses of review papers related to the DT concept and its interrelations with other concepts. The results of this analysis were briefly presented in the introductory section of the paper. As the research gap was identified, the authors of this paper have defined RQs, presented in the introduction. Considering the major objective of this paper and previous steps within the first research stage, the study was limited to DT supporting material flow applied in internal transport systems. This required specifying various applicable keywords, including foremostly three aspects: DT, material flow, and internal transport systems. These keywords were applied in the Scopus database in order to obtain bibliometric data for further analysis (stage 2 of the research procedure presented in Figure 1). The Scopus database was chosen by the authors of this paper over Web of

Science Core Collection (WoS); nevertheless, both databases are comparable in terms of content and accessibility.

3.2. Data Collection

The data analyzed in this paper come from the Scopus database. Each author of the paper performed an initial search individually to test previously defined keywords and searching codes. Consequently, 50 tests were obtained and resulted in the definition of the final searching code, which was applied in the Scopus database on 18 February 2021 (please note that the asterisk at the end of a keyword ensures the inclusion of the term in both singular and plural forms and its derivatives):

TITLE-ABS-KEY ((((digital AND (twin)) AND (((material*) AND handling*) OR (* internal *AND* transport* *))) OR ((digital AND (twin*) AND (intralogistic*) OR (internal* AND *transport*))) OR (digital AND (twin*) AND (internal AND ((logistic*) OR (internal* AND *transport*)))) OR (digital AND (twin*) AND ((logistic*) OR (internal* AND *transport*))))) OR TITLE-ABS-KEY ((((digital AND (shadow*)) AND (((material*) AND handling*) OR (internal AND transport*))) OR ((digital AND (shadow*) AND (intralogistic*) OR (internal AND transport*))) OR (digital AND (shadow*) AND (internal AND ((logistic*) OR (internal AND transport*)))) OR (digital AND (shadow*) AND ((logistic*) OR (internal AND transport*))))) OR TITLE-ABS-KEY ((((digital AND (mirror*)) AND (((material*) AND handling*) OR (internal AND transport*))) OR ((digital AND (mirror*) AND (intralogistic*) OR (internal AND transport*))) OR (digital AND (mirror*) AND (internal AND ((logistic*) OR (internal AND transport*)))) OR (digital AND (mirror*) AND ((logistic*) OR (internal AND transport*)))))*

As a result, 203 records were obtained.

3.3. Data Cleaning

The set of 203 publications extracted from the Scopus database required further investigation and limitation considering, among others, the timeframe, source type, stage of publication, and language (Figure 2).

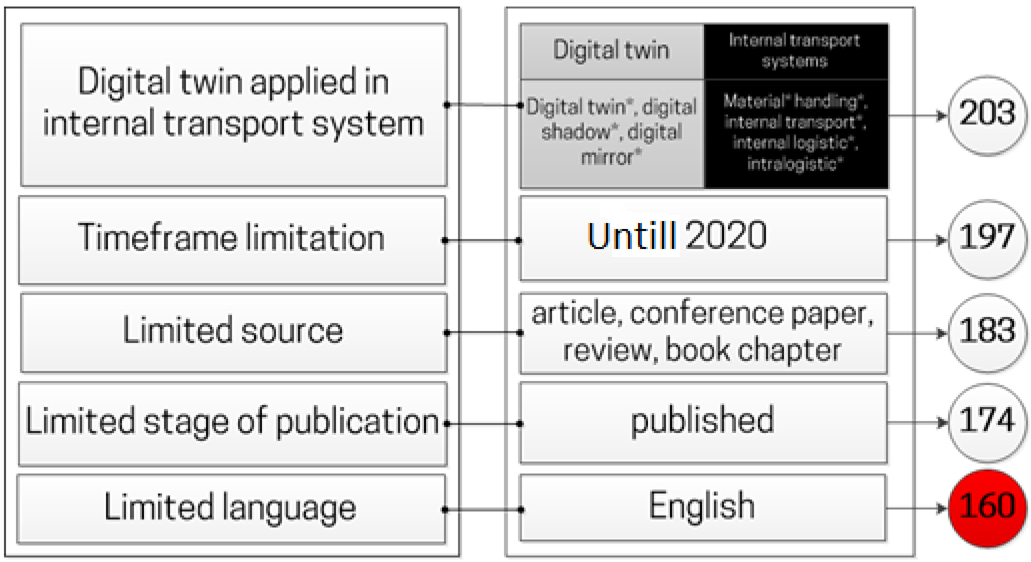

Figure 2. Scopus searching process. Source: own elaboration.

The searching process was limited to publications released until the end of 2020, as the final searching was performed on 18 February 2021. As a consequence, six records published in 2021 were excluded. The dynamics of scientific research on the DT concept in internal transport (material flow) determined over time is provided in Figure 3. According to the keywords applied in the Scopus database, there were 197 publications announced on the DT, digital shadows, and digital mirrors since 1976. However, the origins of the DT concept derived from the 2000s when the idea of a real (physical) space/object and virtual (digital) one connected through data and information flow was introduced by Michael Grieves in the context of product lifecycle management [24]. Namely, the concept was introduced in 2003 [46], therefore considering the stages in the DT research development proposed in [25], it should be considered that there are no significant publications before 2003 (Figure 3). This was also further proved by abstract analysis during the screening stage of the research procedure. Thus, the publications from the period of 1976–2002 were excluded from the research sample during the screening process.

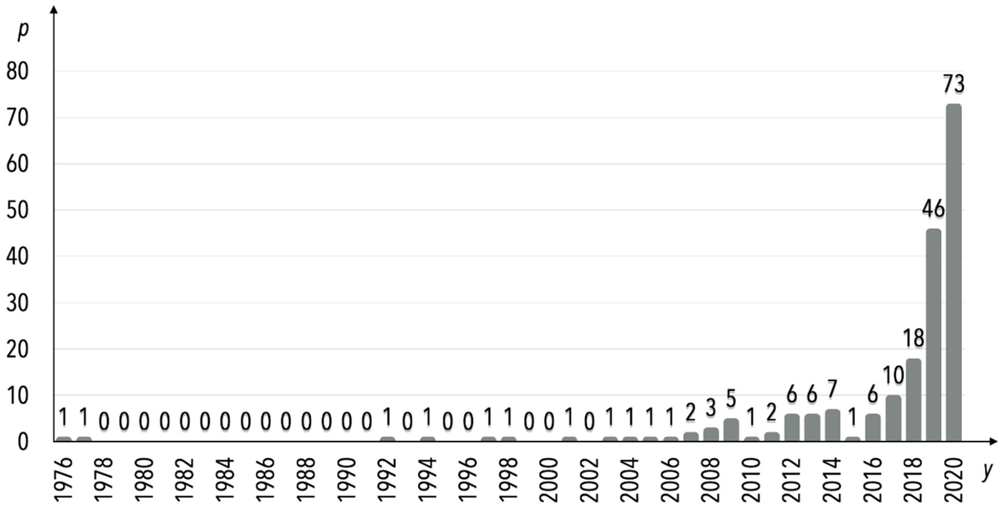

Figure 3. Evolution of publications on DT (including digital shadows, digital mirrors), 1976–2020 (n = 197). Source: own elaboration based on Scopus.

The first publication directly related to the DT applied in internal transport systems, and consequently connected to material flow, was published in December 2012 [56], after NASA formalized the definition of the DT in April 2012 [57]. It introduced a discrete-event simulation-based decision supporting system that had to automatically mirror the real state of a material flow system of a production system in a digital model. The source of data for a digital model was MES and programmable logic controllers (PLC) [22]. Since then, more efforts were devoted to DT research and consequently to DT applications in internal transport systems. As it can be observed in Figure 3, until 2016, there were only a few publications on the analyzed topic per year. Between 2017 and 2018, there was a slight increase in the publication number. However, the vast majority of all relevant publications were released during the last 2 years (more than 70% of all papers). It should also be underlined here that the authors of [25] perceived the rapid development of various digital-alike technologies such as IoT, sensor technology, big data analytics, and simulation technologies, which, among others, contributed to the rise of the DT interest between 2003 and 2011 [25]. Looking at the annual increase in publication number, it can be expected that this trend will intensify further in the years to come.

Most analyzed publications were classified as articles, conference papers, reviews, and book chapters; thus, these references were of the author's interest, resulting in a sample of 183 publications. As this study should represent the actual state of the knowledge on DT applied in internal transport systems and consequently connected to material flow, it was required to take into consideration already published papers. After excluding articles in the press, only 174 records were obtained, and 160 of them were published in English. This set of 160 publications was screened in order to exclude publications that were not associated with the DT applied in internal transport systems.

The papers were screened based on abstracts and keywords. The publications included in the final research sample had to relate directly to the DT concept applied in internal logistics (understood as well as intralogistics or material flow). Interestingly, 31.25% of publications were excluded from the final research sample due to their irrelevance. One hundred and ten publications constituted a final research sample. The vast majority of them (95.45%) were conference papers (66.36%; 73 publications) and articles (29.09%; 32 publications). Book chapters accounted for 2.72% (3 publications; see Appendix A). The reviews (2 publications) published in journals constituted less than 2%.

All these publications were released in conference proceedings (45.63%), journals (43.13%), books (9.38%), and trade journals (1.86%). It is noteworthy that certain publications' sources are treated as book chapters or conference proceedings in particular years and journals in other years. For this reason, some publications issued in the same source are treated as conference papers, and others as articles.

Last but not least, the research was not limited to any specific subject area as the authors intended to identify the most relevant subject areas covering the DT concept applied in internal transport systems. The top two subject areas related to the research on DT applied in internal transport systems are Engineering (accounting for 58.2% of these publications listed in Scopus database) and Computer Science (covering almost 50%).

Among subject areas listed in Figure 4, there are also publications assigned to other subject areas, such as Mathematics; Decision Sciences; Business; Management and Accounting; Economics, Econometrics, and Finance. This is related to the fact that some fraternal concepts are closely related to the DT concept (e.g., digital shadow, digital model, etc.). Consequently, the DT concept appears in different subject areas in various contexts. For example, the context of medical research, including research on people and animals, appears in subject areas such as Medicine, Biochemistry, Genetics and Molecular Biology, and Agricultural and Biological Sciences. In Social Sciences, there is a "twin" context understood in relation to human twins. The "digital" context appears in the papers assigned to subject areas such as Materials Science, Energy, Environmental Science, Physics and Astronomy, Earth and Planetary Sciences, Chemistry, and Chemical Engineering. The above-listed subject areas, other than Engineering and Computer Science, are less important in the body of knowledge on the DT applied in internal transport systems and account for a small percentage share of all these publications. Based on the above mentioned, it becomes clear that the DT is a term applied diversely along with the different scientific disciplines and subject areas. This conclusion is also supported by [25], in which authors claimed that research on the DT is related to technological advancement in many areas.

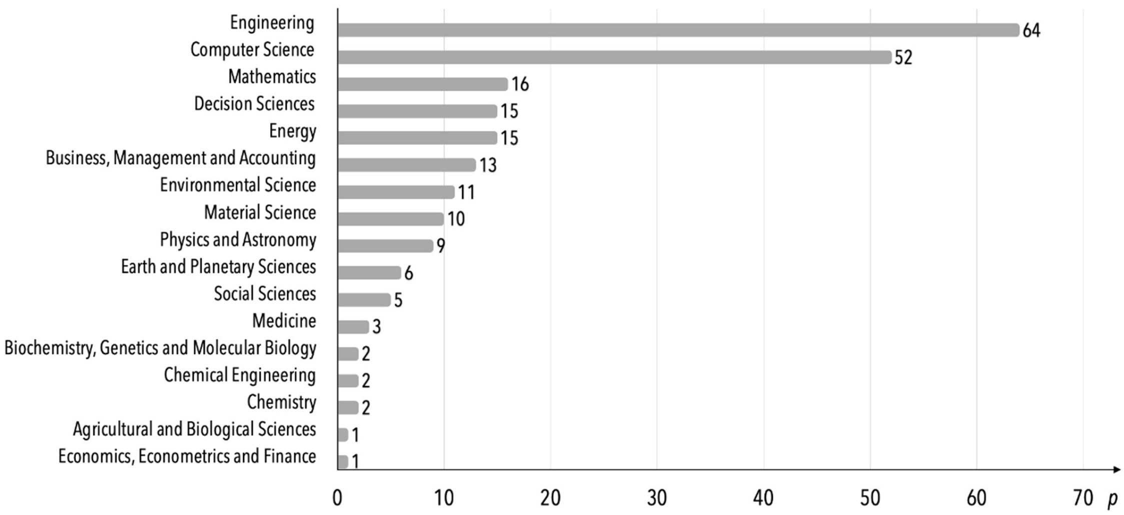

Figure 4. Number of publications on the DT applied in internal transport systems (including digital shadows and digital mirrors) according to subject area, 2003–2020 (n = 110). Source: own elaboration based on Scopus.

4. Results

This paper focuses on the DT applied in internal transport systems. This section of the paper presents the main results of the bibliometric analysis of this research area supported by graphical mapping.

4.1. Bibliometric Analysis

As mentioned earlier, the concept of the DT applied in internal transport systems gains importance over time, especially in recent years. The dynamics of the publications on the topic over time are presented in Figure 5. It is noteworthy that recently, i.e., in the period of 2019–2020, enormous growth in publication number occurred.

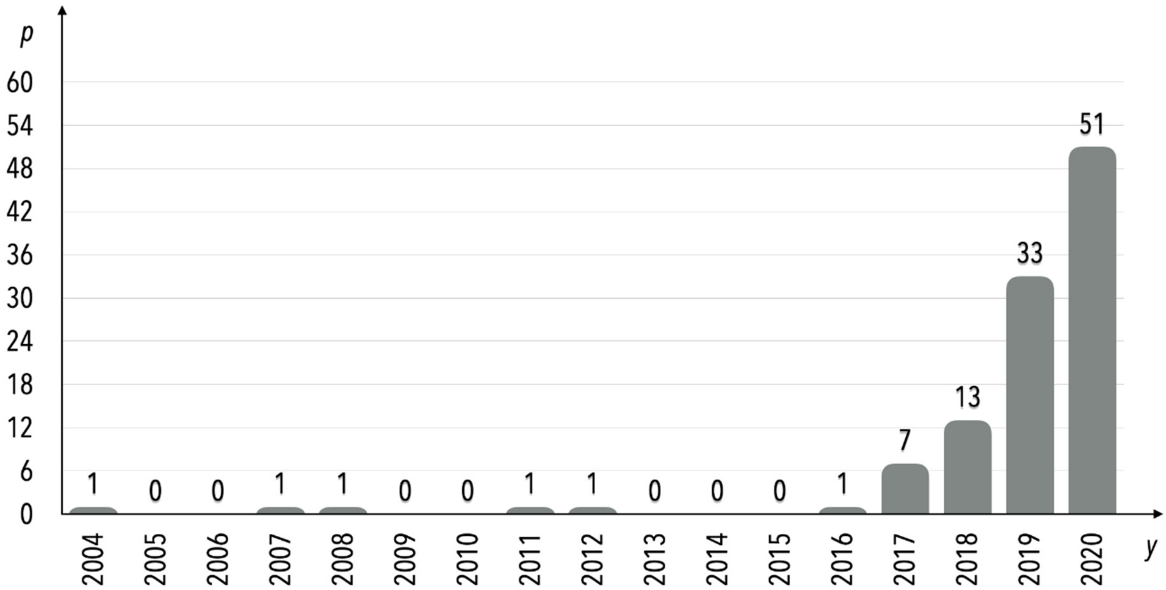

Figure 5. Evolution of publications on DT applied in internal transport systems literature (including digital shadows and digital mirrors, as DT are called by selected authors), 2004–2020 ($n = 110$). Source: own elaboration based on Scopus database.

The vast majority of publications on the DT in internal transport systems are conference papers (i.e., 73 papers; 66.36% of all publications). This may be due to the practical context of research on the DT applied in internal transport systems and the fact that conferences are usually platforms for sharing practical experience. Almost 20% of all conference publications were prepared for Institute of Electrical and Electronics Engineers (IEEE) conferences. This might be the result of the IEEE conferences' focus, which is related to technology advancements. The IEEE conferences address worldwide concerns on technology as the IEEE's major purpose is to foster technological innovation and excellence for the benefit of humanity. The IEEE proceedings cover all relevant technical developments, while the DT is a promising technology of Industry 4.0. Another important publisher of conference papers on the analyzed topic (publishing around 8% of all conference publications) is "*Procedia Manufacturing*", currently noted as the journal of Elsevier publisher. "*Procedia Manufacturing*" publishes papers from conferences on all important topics in the field of manufacturing engineering, including DT. "*IFIP Advances in Information and Communication Technology*" is the conference proceeding, which stands out as well with regards to the number of publications on the DT applied in internal transport systems (7% of all conference publications). It is issued by Springer publisher, assigned to the top three disciplines: Computer Science, Engineering, and Business and Management.

30.91% of all publications (including review papers) on the DT applied in internal transport systems are published in journals (34 papers). "*Robotics and Computer Integrated Manufacturing*" seems to be the most popular one, publishing 8.82% of all publications on the analyzed topic. This journal is devoted to disseminating knowledge on the application of research on the development of new manufacturing technologies and innovative manufacturing strategies concerning modeling, simulation, and DT. Moreover, the IEEE journals are of high importance, as they also publish 8.82% of all publications in journals within the research topic of this study.

Book chapters are not common when it comes to publications on the DT applied in internal transport systems (these stand for 2.73% of all sources).

The list of all publications presented per source type is included in Appendix A.

In order to measure the impact of the publications on the DT applied in internal transport systems, a citation analysis was conducted. To map the overall citation structure of analyzed records, publications were classified into nine groups based on the obtained number of citations. The general citation structure is presented in Table 2.

Table 2. General citation structure of publications on the DT applied in internal transport systems. Source: own elaboration based on data from the Scopus database.

Number of Citations	Number of Papers	Percentage of References
>60	0	0.0%
51–60	1	0.9%
41–50	0	0.0%
31–40	1	0.9%
21–30	1	0.9%
11–20	10	9.1%
6–10	9	8.18%
1–5	38	34.56%
0	50	45.46%

The vast majority of papers were cited five times or less (80.02%). Only one paper (less than 1%) has received more than 50 citations. It can be assumed that the paper has received so many citations due to the practical context of research presented as it is related to the application of DT technology within the ESB Logistics Learning Factory [58]. The numbers of citations of individual papers are relatively low; however, it is not surprising considering the small overall number of publications related to the topic and its dynamics (Figure 5). Nevertheless, it can be predicted that in the near future, the citation rate of these publications will grow since the research topic is quite new as the DT is cutting-edge technology, and it has recently become a research subject of many scholars and practitioners.

The citation analysis of sources publishing papers on the DT applied in internal transport systems leads to conclusions that there are several most cited sources. The top 12 sources, along with their citations, are listed in Table 3. All other sources, which are not presented in the table, were cited less than 10 times. "*Procedia Manufacturing*", with 6 papers and 58 citations, is ranked first among most cited and main publishing sources. This is also the second most popular conference proceedings (currently journal) with many publications on the analyzed topic. Three of the top seven sources (proceedings and journals) ranked by the number of publications are listed among the top five most highly cited sources. "*Robotics and Computer Integrated Manufacturing*" journal with 40 citations is the second most frequently cited source.

The "*International Journal of Computer Integrated Manufacturing*" has a similar citation number as the "*Robotics and Computer Integrated Manufacturing*" journal, with only two papers covering the research topic. It is noteworthy that the most often cited journals are related to computer science and cover the technology context of research. It is not surprising since DT is digital and coding-based technology. Moreover, these journals are highly ranked worldwide. The fourth most cited source is "*Procedia CIRP*" (classified as conference proceedings), with three publications and 20 citations. The impact of source citations differs per source due to its number of publications. The more citations per source with fewer publications, the stronger the impact of these citations. With this in mind, in order to identify high impact sources publishing research on the DT applied in internal transport systems, indicator-based analysis was conducted based on the ratio i_j developed as Equations (1)–(3) (see: Section 3. Materials and methods) adopted from the study of Marczewska and Kostrzewski [50].

Table 3. Most cited sources in DT research area in the Scopus database. Source: own elaboration based on data from the Scopus database.

Rank	Source Title	Cited by Total
1	*Procedia Manufacturing*	58
2	*Robotics and Computer-Integrated Manufacturing*	40
3	*International Journal of Computer Integrated Manufacturing*	38
4	*Procedia CIRP*	20
5	*Proceedings—2018 Global Smart Industry Conference, GloSIC 2018*	20
6	*58th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 2017*	14
7	*Proceedings of the Summer School Francesco Turco*	14
8	*International Journal of Computer Applications in Technology*	13
9	*Resources, Conservation and Recycling*	13
10	*Foundations and Trends in Technology, Information and Operations Management*	12
11	*International Journal of Design and Nature and Ecodynamics*	12
12	*Proceedings—IEEE 16th International Conference on Industrial Informatics, INDIN 2018*	10

The calculated ratio per source is presented in Table 4. Furthermore, in the equations, the following parameters are used that were not included in Table 4, namely $c_{\bar{J}}^{\Sigma} = 416$ and $p_{\bar{J}}^{\Sigma} = 110$.

Table 4. High impact sources of publications on the DT applied in internal transport systems (NA—not analyzed). Source: own elaboration based on data from the Scopus database.

j	Source Title	c_j	p_j	i_j^c	i_j^p	i_j	$SNIP_j$	SJR_j	Scopus Coverage Years
1	*Proceedings—2018 Global Smart Industry Conference, GloSIC 2018*	20	1	0.048	0.009	5.333	NA	NA	NA
2	*International Journal of Computer Integrated Manufacturing*	38	2	0.091	0.018	5.024	1.444	0.658	1988-present
3	*58th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 2017*	14	1	0.034	0.009	3.778	NA	NA	NA
4	*International Journal of Computer Applications in Technology*	13	1	0.031	0.009	3.438	0.768	2.58	1976, 1988–2020
5	*Resources, Conservation and Recycling*	13	1	0.031	0.009	3.438	2.215	2.584	1988-present
6	*Foundations and Trends in Technology, Information and Operations Management*	12	1	0.029	0.009	3.173	0.308	0.346	2005, 2007–2014, 2016–2020
7	*International Journal of Design and Nature and Ecodynamics*	12	1	0.029	0.009	3.173	0.327	0.165	2008-present
8	*Proceedings—IEEE 16th International Conference on Industrial Informatics, INDIN 2018*	10	1	0.024	0.009	2.667	NA	NA	NA
9	*Procedia Manufacturing*	58	6	0.139	0.054	2.556	0.990	0.516	2015–2020
10	*Robotics and Computer-Integrated Manufacturing*	40	5	0.096	0.045	2.115	2.994	1.795	1984–1994, 1996-present
11	*Proceedings of the Summer School Francesco Turco*	14	2	0.034	0.018	1.889	NA	NA	NA
12	*Procedia CIRP*	20	3	0.048	0.027	1.763	1.144	0.728	2012 -2020

Following the calculations, the top three sources representing the greatest impact in the research on the DT in internal transport systems are "*Proceedings—2018 Global Smart Industry Conference, GloSIC 2018*", "*International Journal of Computer Integrated Manufacturing*" and "*58th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 2017*". Considering journals solely, the top three titles are: "*International Journal of Computer Integrated Manufacturing*" and ex aequo "*International Journal of Computer Applications in Technology*" and "*Resources, Conservation and Recycling*". This analysis proves that the highest impact is computed for the source with the highest numbers of citations and relatively few publications.

In addition, the authors have examined if there is any relationship between the elaborated ratio of influence and bibliographic indicators computed directly in the Scopus database, e.g., Source Normalized Impact per Paper (SNIP), dedicated for measurement the contextual citation influence by weighting citations on the basis of the total number of citations in a subject area using Scopus data [59] and SCImago Journal Rank (SJR), which measures weighted citations obtained by a serialized source title [50,59]. SNIP 2019 (Source Normalized Impact per Paper in 2019; computed on 6 May 2020) and SJR 2019 (SCImago Journal Rank per 2019; computed on 6 May 2020) are presented in Table 4 (SNIP and SJR are computed for a series type of sources only; therefore, some parts of this table are noted as NA—not analyzed). No strong correlations were observed. The Pearson correlation coefficient between a set of data for i_j and $SNIP_j$ is equal to $r\left(i_j; SNIP_j\right) = 0.158$ (slight, almost no relation) and between a set of data for i_j and SJR_j is equal to $r\left(i_j; SJR_j\right) = 0.554$ (moderate correlation; substantial relation). Considering the above-mentioned values, it can be concluded that such a ratio of influence could be satisfactorily used for quantitative and qualitative evaluations of publications because there is an ongoing debate on the indicators that assess journal quality [50].

Most cited publications (with more than five citations) on the DT applied in internal transport systems are presented in Table 5.

Interestingly, all these papers focus on a specific topic related to the DT, and there is no review paper among them. This additionally proves that there is a research gap, which this paper tries to address.

The set of publications presented in Table 5 contains 12 articles and 9 conference papers. The vast majority of works were published from 2016 onwards. Taking into account results presented in Figure 5, this is not surprising as the high growth rate in publication number has been noted since 2017. Only one paper among these publications was published in 2011 [60], which coincided with Industry 4.0 term's releasing. Surprisingly, it has a relatively low number of citations.

The most well-known research piece is a paper [58], published in 2017 in "*Procedia Manufacturing*"—the frequently quoted source within the research scope (Table 3). The top four most often cited papers represent the sources with the greatest impact on the research of the DT in internal transport. This confirms the relationship between widely recognizable journals and most cited papers.

The results presented above in Table 5 could be supplemented with the analysis of researchers publishing contributions on the DT applied in internal transport systems (Tables 6 and 7).

Table 7 helps to identify the most influential researchers, and Table 6 helps to identify the most productive ones. Zhong R.Y. is the most influential (according to the number of citations; Table 6) and productive (according to the number of publications; Table 7) researcher exploring the DT applied in internal transport systems. Two of three publications written by Zhong R.Y. were released in 2020 and represent a growing researcher's interest. It may be noted that in time these publications can attract more attention from academia and practitioners as they are directly focused on the DT applied in internal transport.

Kodym O., Wiktorsson M., and Kavka L. also published three papers on this topic analyzed. Nevertheless, their publications have not received any citations yet. Such a performance is rather not surprising, as the DT applications are very limited in internal transport systems so far. This corresponds to the relatively insignificant number of documents per researcher publishing contribution to this specific research area (Table 6).

Table 5. Most cited publications on the DT applied in internal transport systems (A—article, CP—conference paper). Source: own elaboration based on data from the Scopus database.

Rank	Reference	Number of Citations	Year	Contributions' Type	Rank	Reference	Number of Citations	Year	Contributions' Type	Rank	Reference	Number of Citations	Year	Contributions' Type
1	[58]	58	2017	A	8	[61]	14	2019	A	15	[62]	9	2016	CP
2	[63]	38	2019	A	9	[64]	13	2017	A	16	[65]	9	2017	CP
3	[66]	26	2020	A	10	[67]	13	2019	A	17	[68]	9	2020	A
4	[69]	20	2018	CP	11	[60]	12	2011	A	18	[70]	8	2019	CP
5	[71]	20	2018	CP	12	[2]	12	2018	A	19	[72]	8	2018	CP
6	[73]	14	2017	CP	13	[74]	10	2018	CP	20	[75]	7	2019	A
7	[76]	14	2017	CP	14	[77]	9	2019	A	21	[4]	6	2020	A

Table 6. Most cited authors elaborating on the DT applied in internal transport systems. Source: own elaboration based on data from the Scopus database.

Researcher	Number of Works	Number of Citations	Researcher	Number of Works	Number of Citations
Zhong R.Y.	3	35	Marmolejo-Saucedo J.A.	2	1
Kuehn W.	2	13	Constantinescu C.	2	1
Defraeye T.	2	13	Zafarzadeh M.	2	0
Choi S.	2	13	Wiktorsson M.	3	0
Zeidler F.	2	11	Nikishechkin P.A.	2	0
Venkatapathy A.K.R.	2	11	Neroni M.	2	0
Harrison R.	2	11	Mezzogori D.	2	0
Bayhan H.	2	11	Li Y.	2	0
Huang G.Q.	2	9	Kodym O.	3	0
Korth B.	2	8	Khilji W.A.	2	0
Varga P.	2	7	Kavka L.	3	0
Skokan R.	2	6	Jeong Y.	2	0
Grznar P.	2	6	Hauge J.B.	2	0
Fusko M.	2	6	Dolgov V.A.	2	0
			Bertolini M.	2	0

Table 7. Most productive authors publishing contributions on the DT applied in internal transport systems. (considering the total number of publications per author). Source: own elaboration based on data from the Scopus database.

Researcher	Number of Works	Number of Citations	Researcher	Number of Works	Number of Citations
Zhong R.Y.	3	35	Fusko M.	2	6
Wiktorsson M.	3	0	Skokan R.	2	6
Kavka L.	3	0	Dolgov V.A.	2	0
Kodym O.	3	0	Grznar P.	2	6
Hauge J.B.	2	0	Nikishechkin P.A.	2	0
Jeong Y.	2	0	Huang G.Q.	2	9
Khilji W.A.	2	0	Choi S.	2	13
Li Y.	2	0	Constantinescu C.	2	1
Zafarzadeh M.	2	0	Defraeye T.	2	13
Bayhan H.	2	11	Harrison R.	2	11
Bertolini M.	2	0	Korth B.	2	8
Mezzogori D.	2	0	Kuehn W.	2	13
Neroni M.	2	0	Marmolejo-Saucedo J.A.	2	1
Venkatapathy A.K.R.	2	11	Varga P.	2	7
Zeidler F.	2	11			

4.2. Graphical Mapping

The research related to authors of publications on the DT in internal transport systems can be supplemented by mapping interrelations between their bibliometric data, namely the co-citation of the authors (Figure 6).

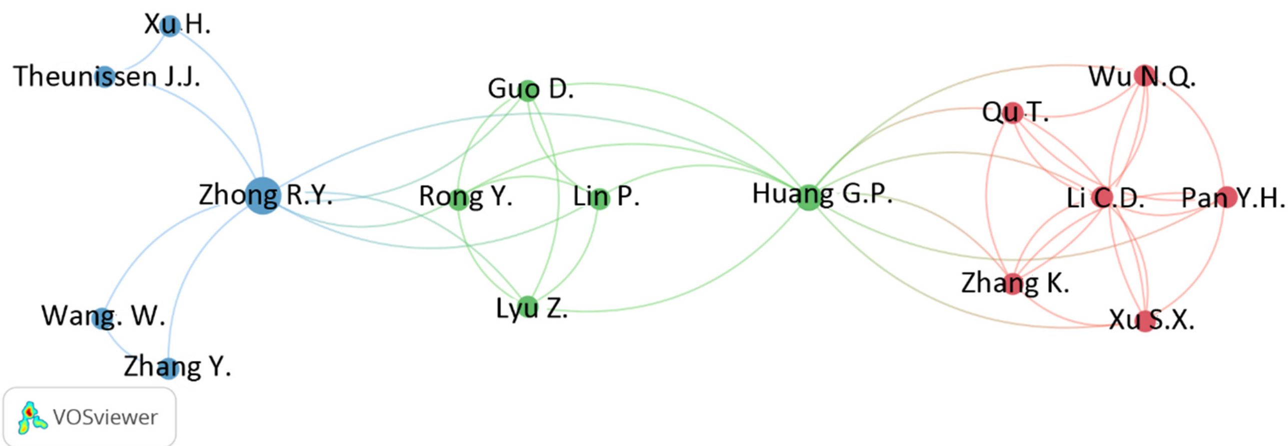

Figure 6. Co-citation of researchers cited in DT' research. Data source: Scopus database. Visualization: VOSviewer software [49], 2004–2020 (n = 110), visualized without additional limitations.

Since there are not many authors with high numbers of publications in the researched area, while computing a co-citation graph, all authors with even only one publication were included. Figure 6 confirms that Zhong R.Y., with the highest productivity and highest citations number, has the widest network of co-citations. This conclusion is not surprising. Further analysis of Figure 6 allowed us to state that other relevant authors who carry out research on the DT applications in internal transport are also Li Y. and Huang G.Q., as there are certain links between them.

Interesting conclusions can be drawn based on co-citations of researchers cited in the DT research when the minimum number of publications of an author is equal to two (Figure 7).

This proves that these authors cooperate within co-working groups. These results were confirmed by the analysis of the link strength between the authors (Table 8).

Interestingly, looking at co-citations between authors with three or more publications (Table 9), a strong link between Kavka L. and Kodym O. can be identified. This is because these two authors have prepared together publications on DT applied in internal transport systems [78–80]. However, Zhong R.Y. as the most productive and most cited researcher, is not quoted by other most productive researchers (Table 7). These results were confirmed by the analysis of the link strength presented in Table 9.

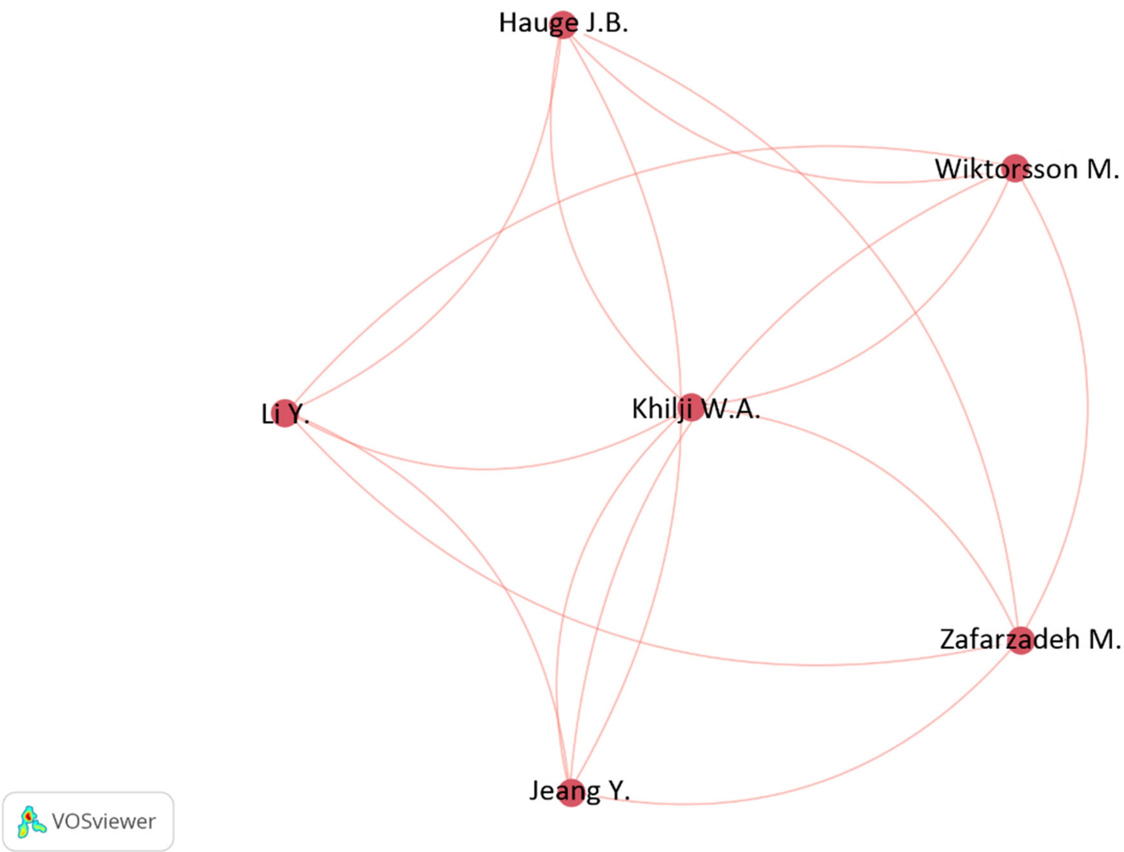

Figure 7. Co-citation of researchers cited in DT research when minimum number of publications of an author is equal to 2. Data source: Scopus database. Visualization: VOSviewer software [49], 2004–2020 (n = 110), visualized with the following limitation: minimum number of publications of an author is equal to 2.

Table 8. Most productive researchers when minimum number of publications of an author is equal to 2. Source: own elaboration based on data from the Scopus database and computation from the VOSviewer software.

Researcher	Number of Documents	Number of Citations	Total Link Strength	Researcher	Number of Documents	Number of Citations	Total Link Strength
Hauge J.B.	2	0	10	Skokan R.	2	6	3
Jeong Y.	2	0	10	Dolgov V.A.	2	0	2
Khilji W.A.	2	0	10	Grznar P.	2	6	2
Li Y.	2	0	10	Nikishechkin P.A.	2	0	2
Wiktorsson M.	3	0	10	Huang G.Q.	2	9	1
Zafarzadeh M.	2	0	10	Zhong R.Y.	3	35	1
Bayhan H.	2	11	4	Choi S.	2	13	0
Bertolini M.	2	0	4	Constantinescu C.	2	1	0
Mezzogori D.	2	0	4	Defraeye T.	2	13	0
Neroni M.	2	0	4	Harrison R.	2	11	0
Venkatapathy A.K.R.	2	11	4	Korth B.	2	8	0
Zeidler F.	2	11	4	Kuehn W.	2	13	0
Fusko M.	2	6	3	Marmolejo-Saucedo J.A.	2	1	0
Kavka L.	3	0	3				
Kodym O.	3	0	3	Varga P.	2	7	0

Co-citation analysis confirms that there may be seen a sort of cooperation between authors, foremostly when they are co-authors of the same publication. However, in the vast majority of publications, there is rather limited cooperation in terms of mutual quotation. This may also result from the small total number of publications on the DT applied in internal transport systems.

The popularity of research on the DT applied in internal transport systems is visible in a relatively small group of countries (listed in Table 10), based on affiliations of scholars.

Table 9. Most productive researchers when minimum number of publications of an author is equal to 3. Source: own elaboration based on data from the Scopus database and computation from the VOSviewer software.

Researcher	Number of Documents	Number of Citations	Total Link Strength
Kavka L.	3	0	3
Kodym O.	3	0	3
Wiktorsson M.	3	0	0
Zhong. R.Y.	3	35	0

Table 10. Bibliographic coupling of countries publishing contributions on the DT applied in internal transport systems. Source: own elaboration based on data from the Scopus database and calculations from the VOSviewer software.

Country	Number of Documents	Number of Citations	Total Link Strength
Germany	30	172	4
Switzerland	5	17	3
United States of America	17	71	2
China	7	44	1
Czech Republic	5	1	1
Italy	6	22	1
Russian Federation	8	22	1
South Korea	6	22	1

Bibliographic coupling analysis with a threshold of a minimum of five publications per country and no limitations with regards to citation number (a minimum number of citations of a country was set as zero) concludes that the countries presented in Table 10 can be treated as most productive ones when research on the DT applied in internal transport systems are considered. According to the analysis, the most productive researchers were affiliated with organizations located in Germany, not only based on total link strength but also looking at the total number of papers published and the total number of citations (Table 10, Figure 8).

Figure 8. Bibliographic coupling of countries that publish in DT research. Data source: Scopus database. Visualization: VOSviewer software [49], 2004–2020 (n = 110), visualized without additional limitations.

This is not a surprising conclusion as the DT is a technology complementary to Industry 4.0, which originated from Germany. Additionally, the term "intralogistics" is widely used in particular in the German industry. Nevertheless, there is no leading research center in Germany focused on the analyzed topic. Not surprisingly, the USA, China, and South Korea are listed among the most productive countries with regards to research on DT. Interestingly, a strong presence of European countries was noted (i.e., Germany, Switzerland, the Czech Republic, Italy), and this leads to the conclusion that researchers from these countries are becoming significantly involved in the studies on DT applied in internal transport systems.

The bibliometric analysis presented above can be supplemented with the analysis of co-occurrence of keywords on the DT applied in internal transport systems (Figure 9). Its aim was to identify the most popular topics and research trends within this field of study. There were 1146 keywords associated with all publications on the DT applied in internal transport systems (setting a minimum number of occurrences of a keyword to four). As it can be expected, among the most popular keywords, "Digital Twin" in various forms takes the lead. Moreover, "Industry 4.0" is also one of the most popular keywords in this research area. The thematic focus of the keywords listed in publications on DT applied in internal transport systems forms six clusters (Figure 9):

- Cluster C1 (red): related to DT and supply chain;
- Cluster C2 (green): related to DT and manufacturing and CPS;
- Cluster C3 (blue): related to DT and simulation and optimization and logistics;
- Cluster C4 (yellow): related to DT and information management;
- Cluster C5 (purple): related to material handling and DT;
- Cluster C6 (light blue): related to DT and Industry 4.0.

With reference to Figure 9, the leading keywords pay attention to Industry 4.0 and its enabling technologies, including the IoT, simulation, CPS, or Big Data, as DT is also included within this concept. DT is used in logistics, supply chains, and in manufacturing. Moreover, the information management context is relevant in DT as there is an information exchange between real (physical) objects and their virtual representation, as was described in Section 2. In addition, in DT, there is a relevant role of automation also related to the information flow. It is noteworthy to consider these research results (Figure 9) to define the future research agenda for research on the DT in internal transport systems.

Figure 9 presents the topic clusters of DT research between 2004 and 2011. The detail of this clustering is given as follows.

Apart from DT, C1 relates to the following keywords:

- "decision making" (this keyword together with DT covers the period between 2018 and present);
- "supply chain" and "industrial management" (these two keywords together with DT cover the period between 2016 and present);
- "investment", "production control", "product control", and "ships" (these four keywords together with DT cover the period between 2004 and the present).

In the case of C2, it relates to the following keywords together with DT:

- "smart manufacturing" (this keyword together with DT covers the period between 2019 and present);
- "embedded systems" (this keyword together with DT covers the period between 2018 and present);
- "interoperability", "smart factory", "cyber physical system", "cyber physical systems (cps)", "flow control", and "smart factory" (these six keywords together with DT cover the period between 2017 and present);
- "manufacture" (this keyword together with DT covers the period between 2011 and present).

Hence, strengthened interest between DT, manufacturing, and CPS occurred especially by 2017.

The pairs of DT and the following keywords are consolidated in C3:

- "decision support systems" and "artificial intelligence" (these two keywords together with DT cover the period between 2019 and present);
- "optimization", "logistics process", and "simulation" (these three keywords together with DT cover the period between 2018 and present);
- "logistics" (this keyword together with DT covers the period between 2011 and present).

As it can be observed based on the abovementioned list, simulation and optimization, as common and efficient methods applied in logistics, have gained importance in the context of DT relatively recently.

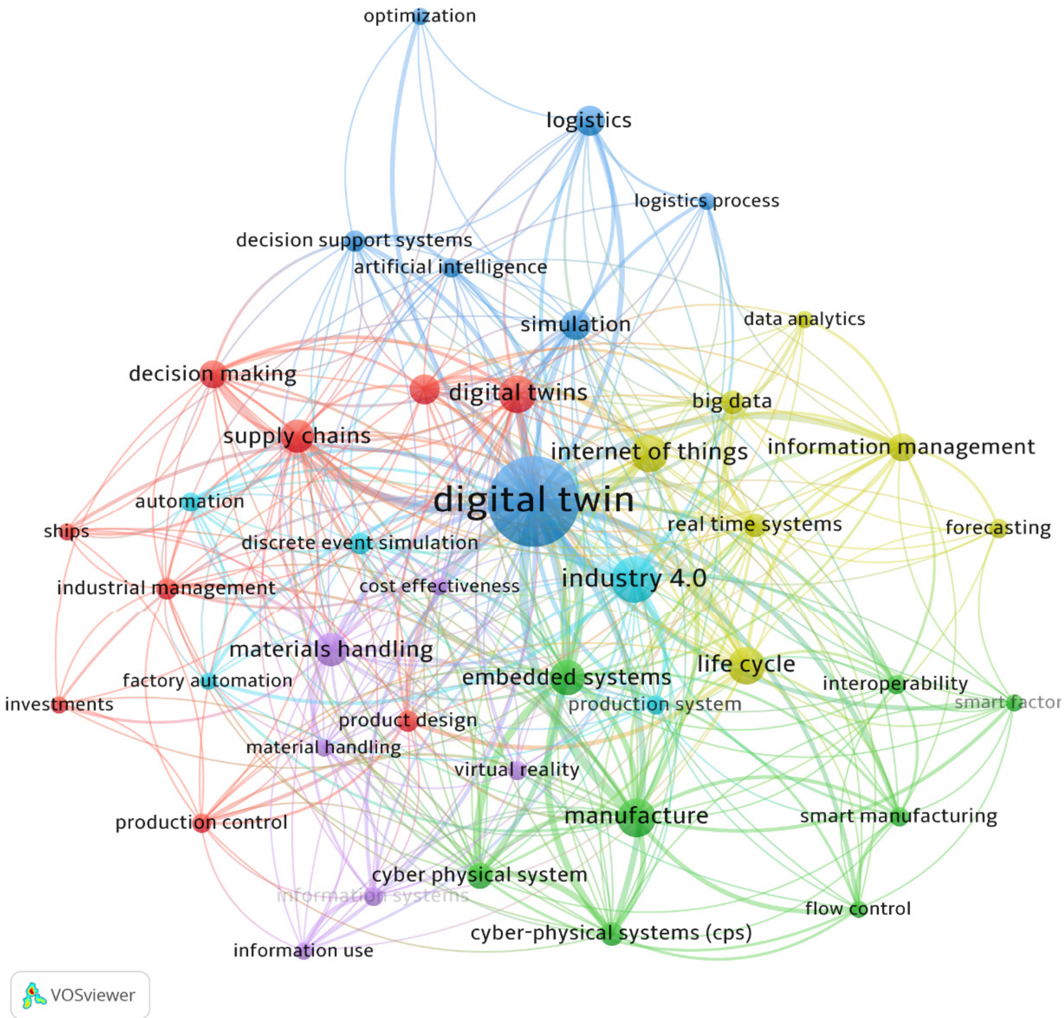

Figure 9. Co-occurrence of coupled keywords (the researchers' keywords with database's accompanied keywords) of publications released in DT research when a particular keyword occurs a minimum of four times. Data source: Scopus database. Visualization: VOSviewer software [49], 2004–2020 (*n* = 110), visualized without additional limitations.

In the case of C4, the following keywords relate together with DT to the management of information:

- "life cycle" (this keyword together with DT covers the period between 2019 and present);
- "data analytics" and "information management" (these two keywords together with DT cover the period between 2018 and present);
- "big data" and "real time systems" (these two keywords together with DT cover the period between 2017 and present);
- "internet of things" (this keyword together with DT covers the period between 2011 and present);
- "forecasting" (this keyword together with DT covers the period between 2007 and present).

It should be underlined here that the IoT presence in this cluster is not without significance. As one of the technological approaches, IoT is applied both for data collection, its processing, and autonomous support of decision-making processes in the systems described in this paper. Special interest in the management of such data and information is certainly significant in the high-quality operations of DT and especially their physical representatives.

The pairs of the DT and the following keywords are consolidated in C5, which considers DT and material handling:

- "information systems" and "information use" (these two keywords together with DT cover the period between 2018 and present);
- "virtual reality" (this keyword together with DT covers the period between 2017 and present);
- "materials handling" and "materials handling" (these two keywords together with DT cover the period between 2004 and present);
- "cost effectiveness" (this keyword, together with DT, covers the period between 1998 and present).

The pairs of DT and the following keywords are consolidated in C6, which considers DT and selected aspects of Industry 4.0:

- "discrete event simulation" and "factory automation" (these two keywords together with DT cover the period between 2019 and present);
- "automation" (this keyword together with DT covers the period between 2018 and present);
- "Industry 4.0" (this keyword together with DT covers the period between 2016 and present);
- "production system" (this keyword together with DT covers the period between 2012 and present).

The bibliometric analysis is worth enriching by the main approaches that the researchers take into consideration in their publications. Digital systems (models) are built to remove errors in real (physical) systems, anticipate obstacles, or better respond to disturbances caused by accidental events. Optimization, forecasting, or machine learning can be applied to all DT-based systems, i.e., digital twins, digital shadows, and digital models, where the application of such methodologies can support decision making (Table 11).

This feedback does occur in DT, and all the results are listed in Table 11, which presents the analysis of a pool of publications selected from the sample of 110 documents. The selection criterion was the application of optimization, forecasting, or machine learning to the digital twin, shadow, or model considered in the review. The number of 34 publications (30.91%) met the selection criterion. In 10% of the selected publications, the presented approach is very general. Certain proposals for specific solutions can be found in 19.09% of publications, whereas in 1.82% of publications, the case studies are presented.

Regarding the research areas of the publications, 21.82% of applications concern the area of manufacturing, 7.27% in the transport area, and 11.82% in the supply chain research field (Table 11). Some publications can be related to more than one application area. Based on Table 11, it can be concluded that some researchers developed their own software—it was presented in 6.36% of publications. The other researchers applied professional software. In 21.82% of cases, DT were running in real time. In one case, the authors expected that their DT preceded the actions of the physical object twin so that the production could be interfered with in the event of problems revealed by the DT.

Table 11. Optimization, forecasting, and machine learning in DT research area in the Scopus database. Source: own elaboration based on data from the Scopus database.

No.	Reference	The Scope Work			Subject Area			Digital			Work in Real Time	Applied Methods			Original Software
		Specific Application	Case Study	Discussion of the Issues	Manufacturing	Transportation	Supply Chain	Twin	Shadow	Model		Optimization	Machine Learning	Forecasting	
1	[81]	X			X			X					X		
2	[82]	X				X	X	X			X	X			X
3	[83]	X			X			X		X	X	X			
4	[84]		X		X		X	X			X	X			X
5	[68]	X			X			X			X	X	X		
6	[85]	X			X		X		X		X	X		X	X
7	[66]		X		X			X			X	X		X	X
8	[86]	X				X	X	X			X	X			
9	[87]	X			X				X			X	X		
10	[88]	X			X		X	X			X	X			
11	[89]	X					X	X			X	X			
12	[90]			X			X	X				X			
13	[91]	X			X		X	X			X	X			
14	[92]	X			X			X				X			
15	[26]			X	X			X			X	X			
16	[93]			X	X			X		X	X	X	X	X	
17	[94]	X			X			X				X	X	X	
18	[95]			X	X		X	X				X		X	
19	[96]	X				X	X	X			X	X		X	
20	[97]			X	X			X				X		X	
21	[98]			X	X		X	X				X			
22	[99]	X				X	X	X			X	X		X	X
23	[100]	X					X	X				X			
24	[101]			X	X			X				X	X		
25	[63]			X	X			X			X	X			
26	[102]	X			X			X			X	X	X	X	X
27	[80]			X	X			X			X	X			
28	[103]	X			X			X			X	X			
29	[104]				X	X		X			X	X		X	
30	[74]	X				X		X			X	X		X	
31	[105]	X				X		X			X	X			
32	[72]	X			X			X			X			X	X
33	[65]			X	X			X			X		X	X	
34	[71]	X		X		X		X			X	X			
in total		21	2	11	24	8	13	32	2	2	24	31	8	13	7

5. Discussion

The analysis presented in this paper on the DT applied in internal transport systems leads to several interesting conclusions given below as answers to research questions RQ1–RQ4 outlined in the Introduction.

In the RQ1, the focus was emphasized on the sources, papers, and researchers, which were identified as the most prominent in research on the DT applied in internal transport systems. The total number of publications within the research scope seems to be limited; however, an increase in the popularity of the topic was recently observed (Figure 4).

In line with the rising interest in Industry 4.0 and increasing need for internal transport improvements, in particular in rapidly changing working environment—e.g., including pandemic situation caused by COVID-19—DT technology seems to be, among other technologies, a suitable solution. As the topic of the COVID-19 pandemic brought up attention, it is worth noting several contexts of the mentioned changes in the working environment (outside the mainstream of this paper). The paper [106] provides a detailed analysis of efforts in the production of personal protective equipment in manufacturing plants and informal production spaces organized by the community in response to the COVID-19 pandemic in the United States. Manufacturing-assisted plants are more responsive and resilient and will be able to survive unpredictable changes such as the COVID-19 pandemic. In the paper [107], the authors mentioned that during the COVID-19 pandemic, the costly physical launch of a new production system is hampered by various sanitary constraints. The authors of paper [108] proposed a remote semi-physical launch based on DTs for flow-type intelligent production systems with open architecture. The proposed approach was verified based on a case study. To respond to urgent public needs such as the COVID-19, it is imperative to respond quickly to the production of emergency materials. Next-generation information technology represented by cloud computing, IoT, big data, AI, etc., is developing rapidly and can be widely used in such situations [109].

The technology context of DT and its interrelation with Industry 4.0 technology proves that sometimes practice comes before theory. The technologies centered around the concept of Industry 4.0 were applied and tested in factories often before their popularity as research topics. Thus, in the future, the total number of publications within the research scope should increase. However, considering the existing publications on the DT in internal transport systems, it may be noted that conference papers prevail over articles published in journals. Nearly two-thirds of analyzed publications were conference papers. This confirms that the topic is relatively new as conferences tend to be knowledge-sharing events, on which scholars usually present initial research results before they are published in journals or as comprehensive books. Conference publications prepared for IEEE conferences have played a predominant role within this research scope as they focus on technology advancements. Moreover, "*Procedia Manufacturing*", previously indexed as a conference proceeding and currently as a journal, is a popular source publishing research on the DT in internal transport systems. Additionally, "*Procedia Manufacturing*" published the most frequently quoted paper related to the analyzed research topic: [58] was cited almost 60 times (in the time of data source analysis). Interestingly, other papers on the DT in internal transport systems are characterized by rather low citation indexes. Most of them have not been cited so far or have less than five citations. Since the research topic is rather novel, and DT is cutting-edge technology, these statistics will certainly increase in the future.

Apart from conference proceedings, there are also relevant journals publishing works on the DT in internal transport systems. Among them, "*Robotics and Computer-Integrated Manufacturing*" and "*International Journal of Computer Integrated Manufacturing*" take the leading role with relatively high overall citation numbers. It is important to note that the most cited journals are related to computer science, and they address the technology-related contexts of DT.

Considering the above facts, the researchers interested in the DT in internal transport systems should carefully consider where to publish their research in order to make it visible and quotable.

Regarding the researchers, Zhong R.Y. is the most influential (according to the number of citations) and productive (according to the number of publications) [66,68,110]. Moreover, Zhong R.Y. has the widest network of co-citations. Kodym O., Wiktorsson M., and Kavka L. also published a substantial number of papers connected to the DT applied in internal transport systems, although without any citations indexed in the database yet. It is noteworthy that researchers who conduct research on the DT applied in internal transport systems try to prepare an in-depth analysis of the topic, as they co-author several publications. This proves that the topic is attractive, in particular starting from many misconceptions (such as digital model, digital shadow, digital mirror) of DT and various applications. Kavka L. and Kodym O. represent the same University, and their papers may be characterized by the same keywords, including transportation, logistics, and supply chains' Industry 4.0 technologies, including DT, modeling, etc. Wiktorsson M. and Zhong R.Y. frequently include decision making, automation, and various Industry 4.0 technologies in their work, i.e., DT, RFID, IoT in the context of decision-making problems in the manufacturing industry, often automotive. Considering the above-mentioned facts, it may be noticed that the most influential topic (based on the topic Field-Weighted Citation Impact in Scopus) is Industry 4.0, as DT is a technology of Industry 4.0.

Additionally, co-citation analysis proves that there is low cooperation between authors, primarily when they are co-authors. Furthermore, it is worth pointing out that the greatest research impact is noticed in European countries what may be a consequence of origin on the Industry 4.0 concept. However, no research center has a leading role in addressing the DT applied in internal transport systems.

The RQ2 was focused on the main research trends related to the DT concept applied in internal transport systems. Contemporary research on the DT applied in internal transport systems tends to focus on a few trends. These research trends include the so-called visionary approach in case of which various researchers describe visions and requirements of DTs (this approach seem to be quite popular in current research considerations), whereas other researchers focus on either process approach (concentrated on situational and managerial approach) or object/process related to the conversion in this object. The process approach is continuously associated with material handling, material flow, and information management, and a DT versus simulation (DES—Discrete Event Simulation and ABS—Agent-Based Simulation), whereas the object/process approach is associated with manufacturing and CPS. Another trend considers a DT versus emulation (where a real simulation model is connected to real elements of the system). The subsequent trend is DT versus systems such as MES/APS and WMS (MES—Manufacturing Execution System, APS—Advanced Planning System, WMS—Warehouse Management System, existing real-time IT systems). Engaging optimization methods to continuously improve a DT is also an important trend.

As a result of analysis of keywords associated with the publications on the DT applied in the internal transport system, six broad thematic clusters were formed: (C1) DT and supply chain, (C2) DT and manufacturing and CPS, (C3) DT and simulation and optimization and logistics, (C4) DT and information management, (C5) material handling and DT, (C6) DT and Industry 4.0. On the one hand, these research results (clusters) serve as a supplement to research trends, as it is provided in Table 12 (left column). On the other hand, these research results were the basis to answer RQ3 and determine future research agendas presented, along with sample research questions, in Table 12 (right column). These future research agendas should focus on finding answers to questions suggested in Table 12, listed according to current research trends described in the previous paragraph. The future research directions that are presented in Table 12 result from the analysis described in this paper. Nevertheless, it is not an exhaustive list of issues related to a DT applied in internal transport systems. Transport is an activity that does not add value to a process, and as a consequence, continuous needs to improve processes with the DT, as cutting-edge technology, are expected.

The in-depth literature review also focused on optimization in the DT context, as one of the current research trends suggested. Answering RQ4, it can be stated that optimization, forecasting, and machine learning find their place primarily in DTs, which are built to improve the performance of a physical object and to react right in case of disturbances caused by random events. In such cases, it is important that the optimization gives answers as quickly as possible and of the highest possible quality.

In detail, it should be implemented as follows: A particular DT is constructed to improve the performance of an actual object. The coupled solution is supported by optimization, forecasting, or machine learning, wherever it is necessary. The real, physical object provides up-to-date data and receives the necessary decision parameters computed in a DT. In case of random events unforeseen by a DT, the optimization receives new data and provides new parameters to a DT as soon as possible. A DT functions if the designers foreordained and considered random events that may occur. In some publications, the emphasis was focused on forecasting instead of optimization. The ideal solution would consist of a combination of forecasting and optimization in a DT. All tools are supported by AI methods, especially when a lot of data are held.

Last but not least, considering all the above, it is necessary to explicitly answer a general question serving as a title of this paper, namely: How Digital Twin concept supports internal transport systems?

The main conclusion in this respect is the interpretation of the DT's reference to the terms of an object and a process. The DT, in the vast majority of definitions, is associated with a real (physical) object; only then an association with a process/service appears. It should be borne in mind that while the association of a DT with a real (physical) object is quite natural and evident, the association to a process is not so obvious. It is easier to comprehend considering the operating process associated with an object. In such a case, a strong inseparability (a strong connection) occurs between an object and a process, to be straightforward: a process is carried out by this object. In the case of material flow control (situational and managerial approach), the matter is more sophisticated because a process is an abstract term. A process is defined as a logically ordered sequence of activities carried out for a specific purpose. If a process is attributed to a unit of material flow that represents this process, the question arises whether one can consider it as one process or as many processes as there are units under material flow. To follow the sample situation of such kind: the case of Volkswagen Caddy in the automotive industry can be considered. The company declares that it produces 150,000 different cars (no cars are identical) [111]. Different vehicles cannot result from the same process, so it may be noticed that the company realizes 150,000 distinct processes. Thus, hypothetically considering, 150,000 DTs must be built in that case.

On the other hand, a process is characterized by its dynamics, which means it is carried out over time and depends on it. The question is: how to show these dynamics in a DT? Should a twin process be treated as an inherited process of the reference ones? It is essential to separate cycles in processes, identify them and define conditions (e.g., decision points), in which given cycles are triggered to build twin cycles, configure them depending on the practical necessities. A properly constructed DT corresponds online with an actual system. This correspondence is supported by software of various classes as MES, APS, and WMS mentioned before. These types of software, linked to a particular DT, assure the performance and monitoring of dynamics in an actual system. Consequently, the influence of the scale of the process (e.g., measured by the number of transport operations performed) on the digital twin designing is also an open question worth considering in future research.

Table 12. Future research directions related to the DTs applied in internal transport systems. Source: own elaboration.

Research Trend	Thematic Cluster	Research Questions
Visionary approach—where authors describe visions and needs of DTs	(C1)	1. What impact can the research related to DT have on the development of the Industry 4.0 concept in the context of the supply chain? 2. What kind of further, yet unexplored, considerations of new concepts of a DT or applications of a DT in industrial spheres can be expected? 3. How can the issues of a DT be transformed in relation to the application of augmented reality?
Object approach (object/process related to the conversion)—associated with manufacturing and CPS	(C2)	1. Is there a difference in the methodology for creating a DT for an object and for a process? 2. In which contexts a process in a DT can be treated as an inherited process of the reference process?
Process approach (focus on situational and managerial approach)—associated with material handling and information management	(C4) and (C5)	Will the coordination of processes (logistics) become the subject of research related to the development of DT?
DT versus simulation (DES—Discrete Event Simulation and ABS—Agent-Based Simulation)	(C3)	1. What are the possibilities of DES/ABS-based process simulations becoming an integral part of a DT? 2. How the development of a DT will extend DES/ABS-based process simulations?
DT versus emulation (where real simulation model is connected to real elements of the system)	(C3) and (C5)	1. What are the future concepts (visions) of integrating the aspects of existing twin concepts of digital simulation DES/ABS and emulation into a single coherent approach? 2. What are the beginnings of the concept (vision) integrating the existing concepts of DT with DES/ABS simulation and emulation into one coherent approach? 3. Where does the integration of DT coexisting in real time with real systems lead to?
DT versus MES/APS and WMS (MES—Manufacturing Execution System, APS—Advanced Planning System, WMS—Warehouse Management System, existing real-time IT systems)	(C6)	To what extent are the existing and developed real-time systems represented in the DT concept?
Other—as. e.g., optimization	(C6)	What are the directions of development of online optimization (real time) that can be used in the DT concept?

6. Conclusions

The importance of the topic considered in this paper is undoubtedly relevant considering the current degree of technologies' digitalization, industrial development, and environmental and social challenges. This review paper provides some answers to questions enumerated as RQ1–RQ4 and the essential question implied by the paper's title. While it is worth bearing in mind that the search for answers to such questions is an ongoing process, hence the authors of this paper have suggested several potential research problems included in Table 12.

In line with the RQ1, it may be noted increasing interest in publications on the DT applied in the internal transport system, resulting in numerous conference publications as the practical context of DT is prevailing. DT applied in internal transport systems as a conference topic is the most often considered at the IEEE conferences and other conferences, which includes proceedings in "Procedia Manufacturing". The top-cited paper on the DT application in internal transport systems [58] is published in "*Procedia Manufacturing*". Papers connected to DT applied in internal transport systems are the most often published in the following journals: "*Robotics and Computer-Integrated Manufacturing*" and "*International Journal of Computer Integrated Manufacturing*". Kodym O., Wiktorsson M., Kavka L., and Zhong R.Y. are currently considered representative authors in the case of DT application in internal transport systems. Such information may be useful for the selection of the conference or journal for research results' presentation, which is related to DT application in internal transport.

Considering the RQ2, major aspects related to DT applied in internal transport systems were identified in six thematic clusters based on graphical mapping co-occurrence of coupled keywords including DT: supply chain; manufacturing and CPS; simulation, optimization, and logistics; information management; material handling; Industry 4.0.

In this paper's authors' opinion, these clusters may equally be used in order to define the future field of interest in investigating DT applications for material flow within internal transport systems (RQ3). According to defined clusters, the future research agendas were identified—they are presented in Table 12.

According to the research results, optimization in the DT context is one of the current research agendas. In terms of answering RQ4, the analysis of methods including optimization, forecasting, and machine learning in the DT research area was prepared—it was presented in Table 11. A certain match between DT and optimization, forecasting, and machine learning was observed as DTs are created in order to improve the performance of a physical object, including disturbances in processes (this is an inclusive role of optimization as well).

The research results presented above should be considered, taking into account the limitations of this study, namely: coverage of Scopus database—there might be other interesting contributions to the analyzed topic, which were not indexed in the chosen database; inaccuracies related to citation analysis—high citations indexes do not always relate with high quality of research, thus since the analyzed topic is relatively new, significant publications might not be cited yet.

After the presentation of all the research trends, future research agendas, potential future research questions, and this paper's research limitation, it is worth finalizing this review paper by a newly defined term, which, in an implicit form, runs through the numerous contexts presented in this study. According to the authors, Digital Twins can be treated as a term existing next to an internal transport system. However, when internal transport is considered, the authors believe it requires a definition of the internal intelligent transport system (IITS), especially that it was not found in the reviewed literature, yet certain aspects were found of its applications.

IITS in correspondence to [112] can be defined as an information and communication system aimed at providing services related to various subjects of transport/logistics/production engineering and management (by the subjects the following entities are understood: employees, devices, means of transport, and additional equipment), allowing and ensuring safer, more coordinated, smarter use of internal transport and better information flow between various subjects. These features can be ensured and accomplished through the use of DTs. The authors find this definition as one last potential idea for future research.

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Appendix A

Table A1. Number of publications per source type and number of publications per source. Source: own elaboration based on data from Scopus database.

Source	Number of Works
Conference proceeding	**73**
Procedia Manufacturing	6
IFIP Advances in Information and Communication Technology	5
Lecture Notes in Computer Science including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	2
IEEE International Conference on Emerging Technologies and Factory Automation ETFA	3
IEEE International Conference on Industrial Engineering and Engineering Management	3
International Multidisciplinary Scientific Geo conference Surveying Geology and Mining Ecology Management SGEM	3
IOP Conference Series Materials Science and Engineering	3
Procedia CIRP	3
ASME International Mechanical Engineering Congress and Exposition Proceedings IMECE	2
Proceedings 2020 IEEE International Conference on Engineering Technology and Innovation ICE/ITMC 2020	2
Proceedings of International Conference on Computers and Industrial Engineering CIE	2
Proceedings of The Summer School Francesco Turco	2
Structural Health Monitoring 2019 Enabling Intelligent Life Cycle Health Management for Industry Internet of Things IIOT Proceedings of the 12th International Workshop on Structural Health Monitoring	2
Proceedings of SPIE the International Society for Optical Engineering	1
17th International Industrial Simulation Conference 2019 ISC 2019	1
2018 IEEE 7th World Conference on Photovoltaic Energy Conversion WCPEC 2018 a Joint Conference of 45th IEEE PVSC 28th PVSEC and 34th EU PVSEC	1
International Multi Conference on Industrial Engineering and Modern Technologies FAREASTCON 2020	1
2nd International Conference on Industrial Artificial Intelligence IAI 2020	1
58th AIAA ASCE AHS ASC Structures Structural Dynamics and Materials Conference 2017	1
ACM International Conference Proceeding Series	1
AIAA Propulsion and Energy 2020 Forum	1
American Society of Mechanical Engineers Power Division Publication Power	1
CEUR Workshop Proceedings	1
E3s Web of Conferences	1
IEEE International Conference on Industrial Informatics INDIN	1
IFAC Papers online	1
Interconnected Supply Chains in an Era of Innovation Proceedings of the 8th International Conference on Information Systems Logistics and Supply Chain ILS 2020	1
Modelling and Simulation 2020 The European Simulation and Modelling Conference ESM 2020	1
Proceedings 2018 Global Smart Industry Conference GloSIC 2018	1
Proceedings 2018 IEEE International Conference on Big Data Big Data 2018	1

Table A1. *Cont.*

Source	Number of Works
Conference proceeding	**73**
Proceedings 2019 IEEE International Conference on Engineering Technology And Innovation ICE ITMC 2019	1
Proceedings 2019 IEEE International Conference on Industrial Cyber Physical Systems ICPS 2019	1
Proceedings 2020 International Conference on Cyber Enabled Distributed Computing and Knowledge Discovery CYBERC 2020	1
Proceedings 2020 International Russian Automation Conference RUSAUTOCON 2020	1
Proceedings IEEE 16th International Conference on Industrial Informatics INDIN 2018	1
Proceedings of the 2017 Federated Conference on Computer Science and Information Systems FEDCSIS 2017	1
Proceedings of the 33rd International Business Information Management Association Conference IBIMA 2019 Education Excellence and Innovation Management Through Vision 2020	1
Proceedings of the Annual Offshore Technology Conference	1
Proceedings VRCAI 2019 17th ACM SIGGRAPH International Conference on Virtual Reality Continuum and its Applications in Industry	1
Proceedings Winter Simulation Conference	1
Refrigeration Science and Technology	1
Rina Royal Institution of Naval Architects 19th International Conference on Computer Applications in Shipbuilding ICCAS 2019	1
SPE AAPG SEG Unconventional Resources Technology Conference 2018 URTC 2018	1
Society of Petroleum Engineers Abu Dhabi International Petroleum Exhibition and Conference ADIP 2019	1
Society of Petroleum Engineers SPE Offshore Europe Conference and Exhibition 2019 OE 2019	1
Lecture Notes in Business Information Processing	1
Lecture Notes in Electrical Engineering	1
Transportation Research Procedia	1
Journal	**34**
Robotics and Computer Integrated Manufacturing	3
Applied Sciences Switzerland	2
Communications Scientific Letters of the University of Zilina	2
EAI Endorsed Transactions on Energy Web	2
IEEE Access	2
International Journal of Computer Integrated Manufacturing	2
Sensors Switzerland	2
Sustainability Switzerland	2
Computers in Industry	1
European Semiconductor	1
Foundations and Trends in Technology Information and Operations Management	1
IEEE Transactions on Systems Man and Cybernetics Systems	1
International Journal of Computer Applications in Technology	1
International Journal of Design and Nature and Ecodynamics	1
International Journal of Mathematical Engineering and Management Sciences	1
International Journal of Mechanical Engineering and Robotics Research	1
International Journal of Pavement Research and Technology	1
International Journal of Precision Engineering and Manufacturing Green Technology	1
International Journal of Production Research	1
Journal of Ambient Intelligence and Humanized Computing	1
Logistics Journal	1
Manufacturing Technology	1
Resources Conservation and Recycling	1
Sensors and Actuators a Physical	1
Strojniski Vestnik Journal of Mechanical Engineering	1
Book chapter	**3**
International Series an Operations Research and Management Science	1
Lecture Notes in Networks and Systems	1
Studies in Computational Intelligence	1

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