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Towards Digital Twins Development and Implementation to Support Sustainability – Systematic Literature Review

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Abstract
Digital twin (DT) is a solution for presenting reality in a virtual world. DTs have been discussed in the literature only recently. The aim of this work is to review and analyse literature connected to DTs. Under a systematic literature review the authors searched databases for the information how DTs can support organization operations and how they can support sustainability of companies. A literature review was performed according to a developed research methodology, which covers research questions and keywords identification, selection criteria and results analysis. Databases, such as Web of Science, Scopus and Science Direct, were searched. The titles, abstracts and keywords were searched for works related to digital twins, sustainable development and manufacturing processes. Moreover, the search was focused on real-time monitoring, data, decision-making etc. The keywords used in the searching process are specified in the methodology. Afterwards, quantitate and qualitative analysis were performed taking into account number of publication, year of publications, type of publication, based on keywords and available information concerning the papers. Deeper analysis was performed on available full texts of the papers. The main goal of this paper was to assess how much the specified problem is discussed in literature in the context of production organizations and real-time and what kind of topics are present in publications to indicate future research needs.

Keywords
digital twin, sustainable development, systematic literature review.

Introduction

For many years Sustainable Development (SD) has been one of the fundamental objectives of the European Union. SD Goals have been established to promote prosperity while protecting the planet (Sustainable Development Goals, 2021). Two goals, namely Goal 9 – Industry, innovation and infrastructure and Goal 12 – Responsible consumption and production are very closely connected with digital twins (DTs) which can be introduced to the industry to support sustainability of companies.

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Digital twin (DT) is relatively new solution and has been discussed in the literature only recently, although, one of the first publication with the words "digital twin" is from 1994 and concerns a DT of an arterial phantom. DT can be an important innovation for many companies and can enhance a physical infrastructure with its digital copy i.e. DT. DT can be used for many purposes, i.e. to predict and to prevent problems, to optimize process, to validate process etc. with the use of simulations (Latif & Starly, 2020). In any case, DT safe resources, because all operations are realized virtually.

The aim of this work is to review and analyse literature connected to DTs. The authors wanted to check whether DTs are discussed in conjunction with SD in manufacturing organizations context. Moreover, the topics related to DT and SD discussed in the publications are interesting.

The next section of this paper presents an introduction to DTs. Section 3 describes research goals and methodology. In the section 4 data analysis as well

as discussion are presented. The last section includes conclusions and future research.

Digital twins

DT presents a reality in a virtual world. DT can be e.g. a digital alter ego, a digital copy of a machine or a whole system. DTs have a future in many areas, and this topic is increasingly being discussed in the literature (Kritzinger et al., 2018).

DT is an element of intelligent factory and allows to sense remotely, ensures real-time monitoring as well as controls of devices composed into a cyber-physical system (Lee et al., 2015; Negri et al., 2017). Intelligent manufacturing developments can be divided into three stages: Stage 1 – initial development stage (1987–1997), Stage 2 – the stable development stage (1998–2012) and Stage 3 – the rapid development stage (since 2013) (Yan & Li, 2020). DTs together with Internet of Things (IoT), Big Data and Cloud Manufacturing as well as Cyber-Physical System (CPS) have been developed since 2013 and are recognized as new enabling technologies for intelligent manufacturing supporting smart prediction, evaluation, optimization and decision-making (Yan & Li, 2020).

In the work (Grieves & Vickers, 2016) Digital Twin is defined as "is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level." Moreover, the authors define two types of DTs:

- Digital Twin Prototype (DTP) which describes the prototypical physical object with a set of information needed to describe and then produce a physical version of the virtual one.
- Digital Twin Instance (DTI) which describes a specific corresponding physical object to which a DT is linked throughout the life of that physical object.

DTs need a Digital Twin Environment (DTE) i.e. integrated, multi-domain physics application space for operating on DTs.

DTs can support manufacturing companies in the areas such as:

- production planning and control (Rosen et al., 2015; Biesinger et al., 2019; Zhuang et al., 2018),
- maintenance (Aivaliotis et al., 2019; Barthelmey et al., 2019),
- layout planning (Nåfors et al., 2020) etc.

This enables to safe resources, to prevent wastes, to optimize effort, therefore support sustainability. The sustainability is analysed taking into account three aspects: economical aspect, ecological aspect and social aspect. Opportunities which can support Industry 4.0 (I4.0) for sustainable manufacturing are presented in the work (Stock & Seliger, 2016). Among them there are no DTs yet. Therefore, it is worth to discuss how DTs can support sustainability in the mentioned three aspects.

Research questions and methodology

In the study the following research questions were identified:

RQ1: How much sustainable development (SD) and digital twins (DT) are discussed in the literature in context of manufacturing organizations?

RQ2: Which are the topics mostly discussed in conjunction with sustainable development (SD) and digital twins (DT) in context of manufacturing organizations?

The work methodology consists of the following activities: keywords identification, a searching rule development, databases identification, selection of adoption criteria, papers retrieval, quantitative and qualitative analyses and discussion.

The following databases were chosen to be searched: Web of Science, Scopus and Science Direct. The searching process was based on title, abstract and keywords review. The search was performed with the use of keywords such as "digital twin" and "sustainable development". Other words related to these keywords were also used and they are: "Digital Twins", "Production", "Sustainability", "Sustained Development", "Sustainable-Development" and "Sustainable Growth". It was also important to search the papers connected with manufacturing processes. Therefore, such keywords as "manufacturing" and "production" were used. Moreover, the search was focused on real-time monitoring, data, decision-making etc. Thus, the keyword "real-time" was applied in the searching process.

The following searching rule was applied: *("Digital Twin" OR "Digital Twins") AND (Manufacturing OR Production) AND "Real-time" AND ("Sustainable Development" OR "Sustainability" OR "Sustained Development" OR "Sustainable-Development" OR "Sustained Growth").*

Literature search was limited to journal and conference papers, as well as book chapters written in English. After elimination of duplicates 20 paper left for further analysis. For 17 papers full texts were available. For the 20 papers quantitate analysis was performed. In the quantitative analysis such criteria as the number of publications published in different

years and publication type were used to illustrate the published works. Qualitative analysis was connected with keywords analysis. Deeper qualitative analysis was performed on full texts of the papers.

Results analysis

A list of the retrieved papers is presented in Table 1. 3 papers are registered in Web of Science. 4 papers are registered in Scopus and 16 papers are registered in Science Direct. 1 from 20 papers is a conference paper coming from International Conference on Intelligent Systems.

Other conference papers are published, among others, in Procedia Manufacturing (4 papers) and Procedia CIRP (3 papers). 3 publications are book chapters coming from the following books: Advances in Computers (2 papers) and Digital Twin Driven Smart Design (1 paper). Other articles are published, for example in such journals as Sustainability, Interna-

Table 1
Searching results

Paper ID	Authors	Title	Journal Publication	Paper type	Full text	Database
01	He & Bai (2020)	Digital twin-based sustainable intelligent manufacturing: a review	Advances in Manufacturing	Article	Yes	WoS
02	Wang et al. (2019)	Event-Driven Online Machine State Decision for Energy-Efficient Manufacturing System Based on Digital Twin Using Max-Plus Algebra	Sustainability	Article	Yes	WoS Scopus
03	Barni et al. (2018)	Exploiting the Digital Twin in the Assessment and Optimization of Sustainability Performances	International Conference on Intelligent Systems	Conference paper	Yes	WoS Scopus
04	Min et al. (2019)	Machine Learning based Digital Twin Framework for Production Optimization in Petrochemical Industry	International Journal of Information Management	Article	Yes	Science Direct
05	Constantinescu et al. (2020)	A holistic methodology for development of Real-Time Digital Twins	Procedia CIRP	Conference paper	Yes	Science Direct
06	Hungud & Arunachalam (2020)	Digital twin: Empowering edge devices to be intelligent	Advances in Computers	Book chapter	No	Science Direct Scopus
07	Czwick & Anderl (2020)	Cyber-physical twins - definition, conception and benefit	Procedia CIRP	Research Article	Yes	Science Direct
08	Evangeline (2020)	Digital twin technology for "smart manufacturing"	Advances in Computers	Book chapter	No	Science Direct
09	Schützer et al. (2019)	Contribution to the development of a Digital Twin based on product lifecycle to support the manufacturing process	Procedia CIRP	Conference paper	Yes	Science Direct
10	Gkournelos et al. (2019)	Model based reconfiguration of flexible production systems	Procedia CIRP	Conference paper	Yes	Science Direct
11	Liu et al. (2020)	Digital twin driven process design evaluation	Digital Twin Driven Smart Design	Book chapter	No	Science Direct
12	Bazaz et al. (2019)	5-Dimensional Definition for a Manufacturing Digital Twin	Procedia Manufacturing	Conference paper	Yes	Science Direct
13	Ferrario et al. (2019)	A Multipurpose Small-Scale Smart Factory For Educational And Research Activities	Procedia Manufacturing	Conference paper	Yes	Science Direct
14	Uhlemann et al. (2017)	The Digital Twin: Demonstrating the Potential of Real Time Data Acquisition in Production Systems	Procedia Manufacturing	Conference paper	Yes	Science Direct

Table 1 [cont.]

Paper ID	Authors	Title	Journal Publication	Paper type	Full text	Database
15	Cattaneo & MacChi (2019)	A Digital Twin Proof of Concept to Support Machine Prognostics with Low Availability of Run-To-Failure Data	IFAC-PapersOnLine	Conference paper	Yes	Science Direct
16	Söderberg et al. (2017)	Toward a Digital Twin for real-time geometry assurance in individualized production	CIRP Annals	Article	Yes	Science Direct
17	Kousi et al. (2019)	Digital twin for adaptation of robots' behavior in flexible robotic assembly lines	Procedia Manufacturing	Conference paper	Yes	Science Direct
18	Zhang et al. (2020)	Digital twin-based opti-state control method for a synchronized production operation system	Robotics and Computer-Integrated Manufacturing	Article	Yes	Science Direct
19	Zabala et al. (2020)	Virtual testbed for model predictive control development in district cooling systems	Renewable and Sustainable Energy Reviews	Article	Yes	Science Direct
20	Taylor et al. (2018)	Defining Production and Financial Data Streams Required for a Factory Digital Twin to Optimise the Deployment of Labour	Communications in Computer and Information Science	Conference paper	Yes	Scopus

tional Journal of Information Management, Robotics and Computer-Integrated Manufacturing or Renewable and Sustainable Energy Reviews.

Figure 1 presents how the interests about the analysed topic has been increasing in time. Only in last four years publications related to SD and DT were publishing in context of manufacturing and the real-time context. The interest has grown rapidly in 2019, when 8 papers appeared.

In the next step author keywords were analysed. 101 keywords were identified in all analysed papers and grouped to identify the discussed topics. In the Table 2 the identified topics together with the related keywords are presented. It is also indicated how many times the keywords appeared in total during the searching process. The frequency of the appearance of keywords shows which topics are more often and which are less often discussed in publications.

Such issues as production planning, simulations, control process, process optimization, robots, maintenance, IoT, real-time computing, edge computing, machine learning, cloud analytics, decision support, quality assurance and others were discussed. In two papers economic issues were mentioned in keywords (Business aspects, Financial metrics).

In three papers sustainability were mentioned in keywords (Sustainability assessment, Sustainable manufacturing, Sustainable value networks). One paper refers directly to energy saving (Energy efficient operation).

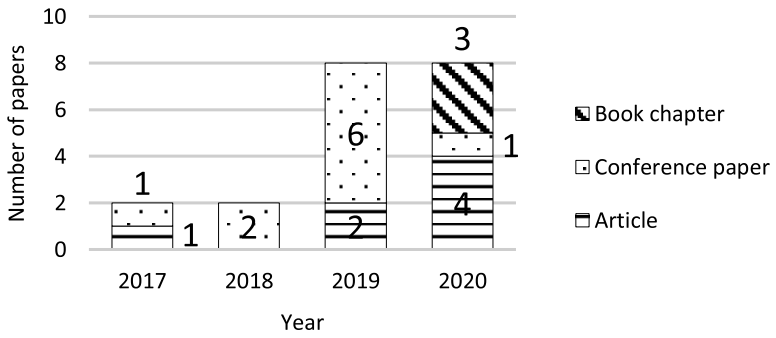

Fig. 1. Number of papers in years by type

Table 2
Topics and keywords; Nk – Number of keywords

Topic	Keywords	Nk
Digital twin	Digital twin/digital twins/factory digital twin/Cyber-physical twins/digital twin data	18
Cyber Physical System (CPS)	Cyber-Physical System/Smart Factories/Smart Manufacturing/Intelligent manufacturing/Advanced manufacturing/Digitalization	8
Planning process	Production Planning/Scheduling/reconfigurable process plan/reconfiguration/ Labour resource planning/Production demand	7
Industry 4.0	Industrie 4.0/Industry 4.0/Tools for Industry 4.0	5
Simulations	Discrete Event Simulation/Simulation/Random coefficient statistical method/ Stochastic event/Modelling	5
Control process	Resilient Control/Synchronized Control/control/Inventory Control	4
Optimization	Process optimization/production control optimization/Process evaluation/Optimal State	4
Robots	Mobile dual arm workers/mobile robot/Human robot collaboration/Perception	4
Maintenance	Condition-Based Maintenance/Remaining Useful Life prediction/Uncertainties/Fault diagnosis	4
Internet of Thing (IoT)	Industrial Internet of Thing/IoT/internet of things	3
Sustainability	Sustainability assessment/Sustainable manufacturing/Sustainable value networks	3
Real-time data	Real-time 3D scanning/real-time data/Data Ownership	3
Designing	Designing/Engineering Design Methods/Development Process	3
Edge/fog computing	Edge/fog computing	2
Artificial intelligence	Machine learning	2
Economic aspects	Business aspects/Financial metrics	2
Life Cycle Assessment (LCA)	End to end process/Life Cycle Assessment	2
Services	Services/Microservices architecture	2
Assembly	Assembly	1
Clouds	Cloud analytics	1
Decision process	Decision support	1
Ecological aspects	Energy efficient operation	1
Quality	Quality assurance	1
Other	District cooling, Testbed, VOSviewer, Research hotspots, MPC, Modelica, China Manufacturing 2025, Engineering Education, MATLAB-Simulink, Max-plus Algebra, Petrochemical industry, Manufacturing/Manufacturing Process/manufacturing system (MS), C2PC Architecture	15

Problems analysed in the context of SD

Taking into account SD aspects (economic, ecological and social aspects) keywords analysis was insufficient to see how the papers address SD aspects. Therefore, in the next step, the available full texts were read and issues connected with SD and discussed in certain papers were identified. The results of the analysis are presented in Table 3. The lines present the problems discussed in specific works, at the same time pointing to the connection with certain aspects of SD.

The paper 01 presents a review of issues connected with digital twin-based sustainable intelligent manufacturing systems. The paper identifies three aspects of sustainable intelligent manufacturing: system, equipment and service. The authors consider the life cycle perspective, namely: design, production, logistics and sales. The proposed framework of

Table 3
Connections of the analysed papers and problems discussed, with SD aspects

Sustainable Development			Paper ID
Ecological aspects	Economical aspects	Social aspects	
Product environmental footprint	Virtual prototyping	Human-machine collaboration	01
Energy efficient MS	Energy efficient MS	–	02
Environmental impact assessment	–	–	03
Forecasting raw material demand, forecasting the energy consumption, optimizing the consumption of water and electricity	Economic benefits of petrochemical production through production control	Predicting human behaviour and risk forecasting for safety of people	04
Real-time monitoring of energy, forecasting the energy consumption	Increase of productivity, decrease defects number	Humans as universal sensors	05
Natural resources efficiency, decrease of waste, energy consumption and emission	Increasing the economic efficiency, increase of product lifecycle, time reduction of new implementation	Customer satisfaction	07
–	Efficient productivity, higher efficiency, accuracy and economic gains	–	09
–	Flexible production systems to improve efficiency	Human operators-mobile dual arm robotic workers collaborations	10
Waste reduction, Environmental data utilization (temperature, humidity, air quality)	Efficiency improvements, Lean Manufacturing, reduce inventory	Social networking, Human-machine interface, Human control elimination	12
–	–	I4.0 impact on employees, human skills development	13
–	Resource efficiency	Knowledge transfer	14
–	Productivity increase, Machine failures preventing	–	15
–	Assembly process optimization	–	16
–	Flexible production systems	Mobile dual arm robotic workers, Humans collaboration with mobile multi-arm robots, Human behaviour	17
–	A synchronized production operation system	–	18
Energy savings	Economic benefits through energy savings	–	19
–	Financial metrics	–	20

sustainable intelligent manufacturing includes: sustainable intelligent design with virtual prototyping, comprehensive sustainability with sustainable technology that could reduce emissions in the life cycle of products, sustainable intelligent manufacturing with virtual and augmented reality, sustainable intelligent manufacturing for product environmental footprint, human-machine collaboration to enable a human to be more effective, sustainable intelligent manufacturing equipment, system and service. The following enabling technologies for sustainable intelligent manufacturing are indicated by the authors: DT, big data, artificial intelligence, IoT (He & Bai, 2020).

The paper 02 presents a digital twin of an energy efficient manufacturing system. The authors performed simulation experiment for an automotive production

line taking into account input parameters such as MTBF, MTTR, cycle time and power rate as well as buffer parameters to assess, among others: total system energy cost, energy cost per part and energy cost saving per part. The possible savings have positive influence on ecological and economical aspects of SD (Wang et al., 2019).

In the paper 03 the authors propose a sustainability framework to support optimization of industrial value network (supply chain, manufacturing, use, reuse, end-of-life). In the framework the following aspects are taken into consideration: data acquisition (real-time and simulated data, internal and external data), analysis only of important data, environmental impact assessment with the use of LCA (Life Cycle Assessment) methodology, decision-making process connected with determining better materials, manufacturing processes and supply path. The proposed model was preliminary validated in woodworking sector (Barni et al., 2018).

The paper 04 is focused on petrochemical industry. The authors propose a framework for a digital twin to be applied in petrochemical industry. IoT, data mining and machine learning technologies are applied. The authors presents implications for practice of the proposed solution. Economic, ecological and social aspects are clearly specified (Min et al., 2019).

The paper 05 presents a methodology and a motivation scenario for further validation in an innovative set-up of an automated measurement cell. Research team used a holistic methodology for development of Real-Time Digital Twins concepts, where state-of-the-art technologies, such as autonomous AGV (Automated Guided Vehicle), mobile 3D laser scanning and automated processes are integrated (Constantinescu et al., 2020). In the paper all sustainability aspects are mentioned.

The paper 07 presents the benefits of using cyber-physical twins to monitor a product life cycle and condition of its components which should not be exchanged too early for the new ones if their technical condition is still acceptable. Thanks to the use of I4.0 elements, including cyber-physical twins, it is possible to significantly improve the economic efficiency of resources and shorten the time of developing and implementing new components. The article places big emphasis on the rational use of natural resources, decrease of waste and energy consumption. In addition, the benefits of cyber-physical twins are discussed (Czwick & Anderl, 2020).

The paper 09 presents concepts of a research project to the development of a Digital Twin based on product lifecycle to support a manufacturing process. The research team analysed existing research projects in the field. DTs as a part of I4.0 provides a number of benefits in the current industrial scenario, but so far has been mainly used for customer products or services. To explore the gaps in the literature and extend these benefits to full processes, the presented project aims to investigate the DT life cycle and apply its principles to the development of a manufacturing process DT (Schützer et al., 2019).

The paper 10 is focused on an assembly line. Considering the fluctuating market that constantly requests new and customized products, flexibility has become a key to sustainability of manufacturing companies. In the paper authors present a novel execution control framework combined with digital twins. The set of digital services has been deployed and tested in a case study from the automotive industry employing mobile dual arm robotic workers and human operators (Gkournelos et al., 2019).

The paper 12 proposes a comprehensive model of a DT approach for a manufacturing environment and related production processes. The research in the paper is based on a literature review of articles about the DT concept and its application in manufacturing carried out over the period 2016-2018. The research problems included in the paper focused on the building and implementation of DT in production (methods of data acquisition) and the impact of DT on reducing resource consumption. The result of the work was the creation of a DT procedure based on a sample CNC machine covering all aspects of the machine's machining capabilities (Bazaz et al., 2019). The ecological aspects discussed in the paper mostly concern used environmental data. While, social aspects are connected with data acquisition, utilization and transfer in the system.

The paper 13 describes the implementation of a smart-factory in an academic location. Skills development thorough a learning by doing approach, and providing a research platform will expand the collaboration of practitioners and academia in developing and testing new technologies. In this paper the SUPSI Mini-factory and its main building blocks supported by I4.0 elements such as DTs have been presented. The mini-factory is an experimental facility that allows research and education to find a common playfield where mutually beneficial experiences can be integrated (Ferrario et al., 2019). The paper does not deal with environmental or economical aspects.

The paper 14 introduces a learning factory based concept to demonstrate the potentials and advantages of real-time data acquisition and subsequent simulation based data processing. The article presents the profit of DT of a manufacturing system application compared to the common value stream mapping ap-

proach to increase transparency and reveal the possibilities of optimization activities in production systems. The concept addresses SME's need to derive short-term production control as well as data-driven optimization in near real-time. The main goal of the learning factory is to make participants aware of the advantages of the DT in I4.0 applications (Uhlemann et al., 2017).

The paper 15 present study using a Digital Twin Proof of Concept for monitoring and forecasting equipment failure. Lack of data related to the condition of machines and the unpredictability of failures reduce the availability of machines and, as a result, decrease productivity. The use of tools known in I4.0, such as DT, IoT, Big Data, Cloud computing and Artificial Intelligence allows to predict the most critical failures. The paper develops a maintenance DT solution for a drilling machine that lacks of historical data, describing the entire process from data acquisition to Remaining Useful Life prediction (Cattaneo & MacChi, 2019).

The paper 16 proposes a DT for geometry assurance to be used in design phase to design a robust product and in manufacturing phase to monitor and optimize a process sequence. The DT contains geometry representation of the assembly with kinematic relations and material properties, enables finite element analysis and Monte Carlo simulation, as well as, has a link to inspection database (Söderberg et al., 2017).

In the paper 17 the authors examine the application of digital modelling techniques using DT in hybrid production systems to enable reconfiguration of the system through a common environment. Driven by this need, the DT system presented in the work, provides the infrastructure for integrating all the hardware components involved in the assembly process and synthesizing all the data coming from the shop floor under a unified common environment. Presented system has been implemented and tested in a case study from the automotive sector for an assembly line (Kousi et al., 2019).

The paper 18 proposes a digital twin-based optistate control method to be applied in a synchronized production operation system. The method supports decision-making process in the system by delivering real-time data. The data are used in optimization process under the framework of digital twin (Zhang et al., 2020). The paper focuses on production system performance.

The paper 19 presents a definition of detailed models based on real data of chillers installed in a district cooling plant, along with the design of a model predictive control (MPC) to control the production plant. In this regard, the paper presents the progress and results of the implementation of a virtual testbed based on a DT of a district cooling production plant. The power consumed by the chillers was significantly reduced with the MPC, resulting in an average saving of 50% in the power consumption compared to the baseline operation (Zabala et al., 2020).

The paper 20 is focused on simulation of a production system to assess production strategies influence on production and financial metrics. Among others, cost of materials, selling prices, wages and salaries, depreciation, demand rate, cash flow are analysed (Taylor et al., 2018).

Figure 2 summarizes the frequency with which the identified topics appear. The problems discussed in the available full texts of the papers are summarized in Table 4.

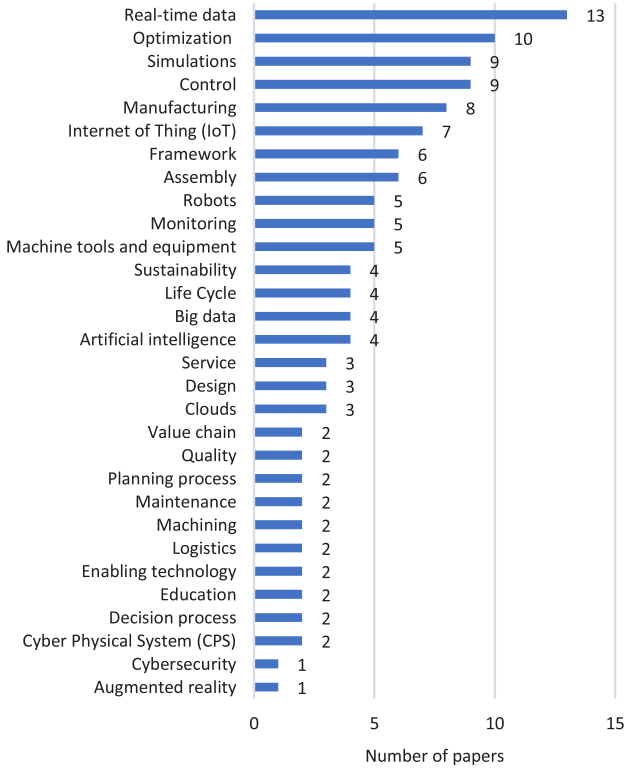

Fig. 2. Topics discussed in the papers

From the Figure 2 it can be seen that the topics mostly discussed in the paper are real-time data, optimization, simulations and control. Probably it is because with the use of the real-time data the process can be in the real-time optimized as well as controlled, and possible future problems can be simulated. This will prevent problems and improve the quality of manufacturing processes. In the same time will have a positive influence on the SD.

Table 4
Connections of the analysed papers and problems discussed, with SD aspects

Problems	Paper ID	Number of papers
Artificial intelligence	01, 04, 09, 12	4
Assembly	01, 10, 14, 16, 17, 20	6
Augmented reality	13	1
Big data	02, 04, 13, 15	4
Clouds	12, 13, 15	3
Control	01, 04, 09, 10, 13, 15, 17, 18, 19	9
Cyber Physical System (CPS)	12, 15	2
Cybersecurity	13	1
Decision process	15, 18	2
Design	01, 13, 19	3
Education	13, 14	2
Enabling technology	01, 05	2
Framework	01, 02, 03, 04, 10, 18	6
Internet of Thing (IoT)	01, 03, 04, 12, 13, 15, 18	7
Life Cycle	01, 03, 07, 09	4
Logistics	01, 05	2
Machine tools and equipment	01, 05, 12, 13, 15	5
Machining	01, 12	2
Maintenance	01, 15,	2
Manufacturing	01, 03, 04, 05, 09, 10, 12, 14	8
Monitoring	01, 05, 07, 09, 15	5
Optimization	01, 03, 04, 05, 09, 12, 14, 16, 18, 20	10
Planning process	17, 20	2
Quality	05, 07	2
Real-time data	01, 02, 03, 04, 05, 07, 09, 12, 14, 15, 16, 17, 18	13
Robots	01, 05, 10, 13, 17	5
Service	01, 02, 04	3
Simulations	01, 02, 03, 04, 07, 09, 13, 16, 20	9
Sustainability	01, 02, 03, 07	4
Value chain	01, 03	2

Discussion

Analysing the first research question (RQ1) asking how much SD and DT are discussed in the literature in context of manufacturing organizations and the real-time context, it can be said that very few papers have been published. Totally, 20 articles were retrieved and they were published in last 4 years (2017–2020). Although, in last 2 years the interest with the topics significantly increased.

It should be emphasized that this study only focused on production organizations and therefore other areas were rejected. A small number of papers referring to the context of production organizations and the real-time gives a picture of great opportunities for future research in these areas.

The second research question (RQ2) concerned the topics mostly discussed in conjunction with SD and DT in context of manufacturing organizations and the real-time context. From Fig. 2 can be seen that the mostly discussed is real-time data, as DTs are fed with the real-time data. Then the data can be used in real-time optimization. DTs allow to perform simulations and predict future states. Furthermore, DTs facilitate process control. The least visible topics concern augmented reality and cybersecurity. Also, for example, design process is marginally discussed although, it is very important form sustainability point of view (Dostatni et al., 2015).

From SD perspective, as it is presented in Table 3, it can be seen that the most discussed are economical aspects. 15 papers refer to economical benefits connected with DTs. 9 papers concern social aspects and 8 papers are connected with ecological aspects. Only 5 papers discuss all SD aspects. The topics discussed under ecological aspects concern: energy saving, water consumption, emissions, waste reduction, environmental data utilization, environmental impact, what can be influenced by DTs application. Social aspects are mostly connected with human-machine collaboration, safety problems, knowledge acquisition and transfer. For example, issues connected with employees motivation and their openness for continuous improvement are neglected (Stadnicka & Sakano, 2017). Two of the analysed papers concern educational process in which DTs can be used. Knowledge connected with DTs is recognized as a part of knowledge in mechanical engineering area (Hamrol et al., 2019).

It is surprising that there are no articles showing the use of DT in the area of flexible manufacturing systems related to value stream flow. The ability to model the value stream flow in real time in the DT environment would reduce wastes. The decision-making

process would be much more efficient without affecting real production. As we can see, this area has a great potential for using DT in the future in the context of SD.

Conclusions and future work

The presented systematic literature review shows that the topic being under the research is still not widely discussed. Although, DTs can bring many different advantages for SD, the advantages were not discussed in detail in literature. Especially, social and ecological aspects need to be studied further.

Not only benefits but also problems can arise. In future work the authors will try to identify what kind of problems and advantages connected with certain SD aspects and caused by DTs implementation can be identified.

This work is focused on manufacturing processes and companies. The aim of this study was to show how production organizations are prepared to use DT in production areas in terms of SD. The conclusions are clear that there are many areas where the potential of DT has not yet been noticed. An example is the aforementioned value stream flow in an application for flexible manufacturing systems. The lack of the described research in this area also gives a signal to conduct them on their own.

It is expected that in the future there will be papers covering this research area. The future work can include different areas of applications, different industries and analyse different size companies.

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