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Demystifying Artificial Intelligence based Digital Twins in Manufacturing- A Bibliometric Analysis of Trends and Techniques

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Demystifying Artificial Intelligence based Digital Twins in Manufacturing- A Bibliometric Analysis of Trends and Techniques

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Abstract: Nowadays, data is considered as a new life force for operations of physical systems in various domains such as manufacturing, healthcare, transportations, etc. However, the hugely generated data, which mirrors the working essence of the product life cycle, is still underutilised. Digital Twin (DT), a collective representation of active and passive captured data, is a virtual counterpart of the physical resources that could help prevent effective preventive maintenance in any applied domain. Currently, lots of research is going on about the applicability of digital twin in smart IOT based manufacturing industry 4.0 environment. Still, it lacks a formal study, which can provide a bird's eye view about the research efforts and directions. In this paper, the authors represent a bibliometric survey of the digital twin concept based on the Scopus database to present a global view about scholars' contributions in the manufacturing area. The study was conducted by retrieving 844 Scopus research papers published from 2015-2020 and analysed to find out critical insights such as publication volume, co-authorship networks, citation analysis, and demographic research distribution. The study revealed that significant contribution is made via concept propositions in conferences and some papers published in the journal. However, there is a scope of lots of research work in the direction of actual and secure digital twin implementation.

Keywords: Digital Twin, Machinery, Predictive Maintenance, Artificial Intelligence, Internet of Things

Introduction:

The concept of the Digital twin was introduced at the University of Michigan during a presentation given by Grieves in 2003[1]. However, after 2010, when the initiation of work on IoT, sensor fusion, and cloud computing surfaced, the research around implementable digital twin also started gaining momentum. Digital Twin aims to create a highly faithful virtual model of a physical system or process to simulate system behaviour, condition monitoring, detection of abnormal pattern, a reflection of system performance, and future trend prediction [2]. It provides a pathway for mapping the relation between virtual and real-world resources, which can help to find known unknowns as well as also help to discover unknowns. [3]. It is an amalgamation of modelling techniques, simulation software, and live operational data, which makes it suitable for designing the physical resource and being a constant virtual companion throughout the product lifecycle and data-powered predictive analytics. Digital twin is finding its applications in various fields where a multi-processing asset has a role to play. This asset can be machinery, or a human organ, or a cyber-physical process. Depending upon that, the definition and implementation logic of digital twin changes accordingly. The various current application areas and perception of the digital twin in these domains are shown in Table 1.

Table 1: Application domains of digital twin

Sr No	Application Domain	DT application base	DT Input Source	Processing Parameters	DT components	Use cases	Common Challenges
1	Healthcare [4][5][6]	The human body, specific human organ, healthcare monitoring machines	Wearables, sensors, RFID tags	Pulse rate, sugar levels, speech, Movement assessment, oxygen levels	health parameters, patient metadata and data flow models	Precision medicines, Well-being management, Disease prediction	Data security and privacy guarantee Outcome reliability Infrastructure cost Scalable data fusion The massive amount of data generation and management Prediction accuracy Real-time simulation and process transparency System failure management and mitigation strategies
2	Industry 4.0 [7][8][9][10]	Industry Machinery, Assembly lines	Smart Sensors, actuators, cameras	Vibrations, sound, temperature, Rotating frequencies	Machine working parameters, external environment factors	Predictive maintenance, Fault diagnosis, Lifecycle management	
3	Aviation, aeronautics, astronautics [11][12]	Aeroplanes, air travel routes	Smart Sensors, actuators, cameras	Vibrations, sound, temperature, Air pressure,	Aerospace vehicle parameters, external environment factors	Flight model simulation, Fatigue life and aerothermal model prediction, Aerospace vehicle maintenance	
4	Energy Sector [14][15][16]	Electricity grids, transportation, Greenhouse production	Smart Sensors, actuators, RFID Tags	Temperature, flow rate	Nodes virtual data and energy flow mapping models	Predictive maintenance, Fault diagnosis, Lifecycle management, Usage analysis	
5	Social Media [17]	Individual internet surfing pattern	Web surfing logs	Visited platforms, comments, likes, uploaded info, shared posts following pages, tweets, etc	Individual digital identity parameters of person and data flow among the modules	Sentiment analysis, Trend analysis, Fraud detection, Marketing strategy enhancement	
6	Precision Agriculture [18][19]	Plants	Smart Sensors, actuators, cameras	Soil moisture level, light intensity, humidity, temperature	Environment parameters and plant images	Well-being management, Disease prediction	
7	Meteorology [20][21][22]	Geographical regions, i.e. terrain, buildings etc.	Smart Sensors, actuators, cameras, satellites	Temperature, humidity, proximity, radiation, pressure, particle	Environment parameters and images	Weather prediction, ageing infrastructure, geospatial	

						asset management	
8	Education [23][24]	Educational Content and delivery system	Generated e-content, recorded videos, animations	e-content, recorded videos, animations	Combination of eLearning platform, contents, and teaching pedagogy	Effective delivery of knowledge via an online platform, skill enhancement	

Out of the above mention application areas, our study is focused on research activity in the manufacturing domain. With the help of various services, Digital twin holds good command on manufacturing planning and production control processes through two-way connectivity between virtual and physical model, which helps to achieve smart manufacturing [25]. According to market research in 2017, it was forecasted that the market of Digital Twin would be captured around $15.66 billion investment in various fields by 2023 with an annual growth rate of around 37.87% [26].

Now a days manufacturing process moves from conventional knowledge-based to data-driven manufacturing. In the manufacturing aspect, to bridge the gap between design and manufacturing, virtual models of manufactured products are essential, which helps to mirror the real and virtual world [27]. Due to DT technology, it is easy to do quick virtual verification. One can perform rapid changes against flaws in the system by improving design and optimising the process simultaneously [28]. Digital twin provides complete healthcare management of a product throughout its product life cycle by providing a digital footprint of the products by considering its geometry, structure, behaviour, and function properties [29]. Now digital twin use for broader concepts that use virtual representation in the manufacturing aspect such as products, working conditions, geometries of products, etc. [29]. Digital twins are considered intelligent agents with prognostics, data processing, and communication [26]. Figure 1 shows an overview of the digital twin setup for manufacturing industries proposed by Wang et al. [30]. The setup's main modules include a physical system, sensor networks, virtual model, AI-based analytics module, data visualisation tools, continuous machine monitoring procedure, decision support system, and a feedback loop for automated improvements. Combining these technologies makes sure that a digital avatar of the physical machine is always available to the shop floor engineering team, which will help throughout the management of the manufacturing life cycle. We can design and implement the digital twin concept at the unit, system, and systems-level in industries.

To implement each submodule, multiple technology options are available. Many miscellaneous implementation setups are currently under the trail to check the overall efficiency and find the ideal combination of techniques. As shown in Figure 2, the on-ground implementation of the industry digital twin is divided into layers connected via the bidirectional data flow. Each layer exhibits a specific task and is executed via a specific set of either software or protocols or data stores. In manufacturing, digital twin extends the capacity to replicate, simulate, and minimise the operation and production system, which helps with a proper visualisation of every process from manufacturing a part until its assembly.

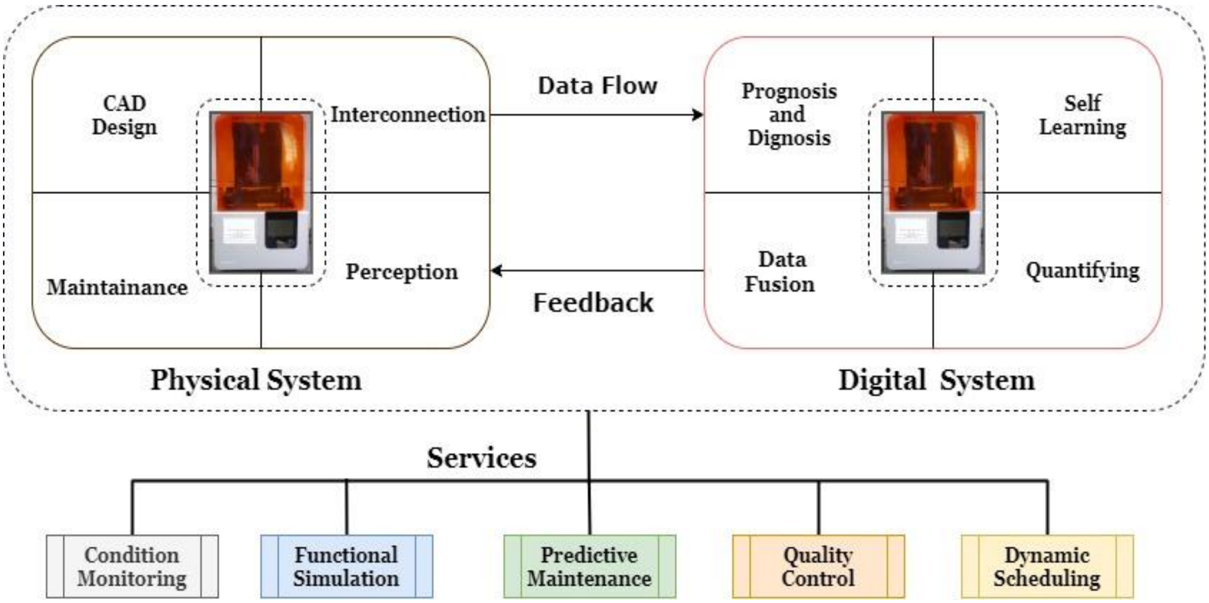

Figure 1: Digital Twin architecture for industry 4.0 smart machinery setup.

The digital twin will allow manufacturers to minimise costs, boost customer service, and find new ways to generate revenue. Manufacturers can add value for any machinery's full lifecycle processes, i.e., from design to maintenance. Now presently in the Industry 4.0 context, sensors' connectivity to the machinery, machine to machine communication, Real-time monitoring, Advanced analytics, Predictive Maintenance, etc. are being studied. In short, we can say Digital twin is the combination of the different techniques which enables users to understand, predict, and optimise the performance. Predictive maintenance (PdM) is one of the significant areas that other industries and researchers are focusing on. It can be applied to many types of machinery that help reduce unplanned downtimes.

The amalgamation of Artificial Intelligence and Digital Twin can unlock multiple opportunities for the manufacturing sector. One of the capabilities of Digital Twin is to generate simulated data. A simulated environment has to go through infinite loops of scenarios. The generated simulated data can then be used to effectively train a naïve AI model on the different aspects of the manufacturing processes. In this way, the AI model can learn to identify potential real-world conditions which otherwise be very difficult to locate. This is also known as reinforcement learning. The second capability of the digital twin is to identify, plan and test new features, which can be used to augment data operations in a machine learning process. The machine learning results can be further tweaked to find optimal solutions.

An example can be a Digital twin can be explored for a generation of test solutions such as pedestrian detection in autonomous driving. Finally, a digital twin can assist in data augmentation for imbalanced datasets. For example, Infield cases where data collection is tedious due to difficulty in sensor placement, a digital twin can be used for generation of training data that can simulate the behaviour of machinery and produce data with a high degree of accuracy.

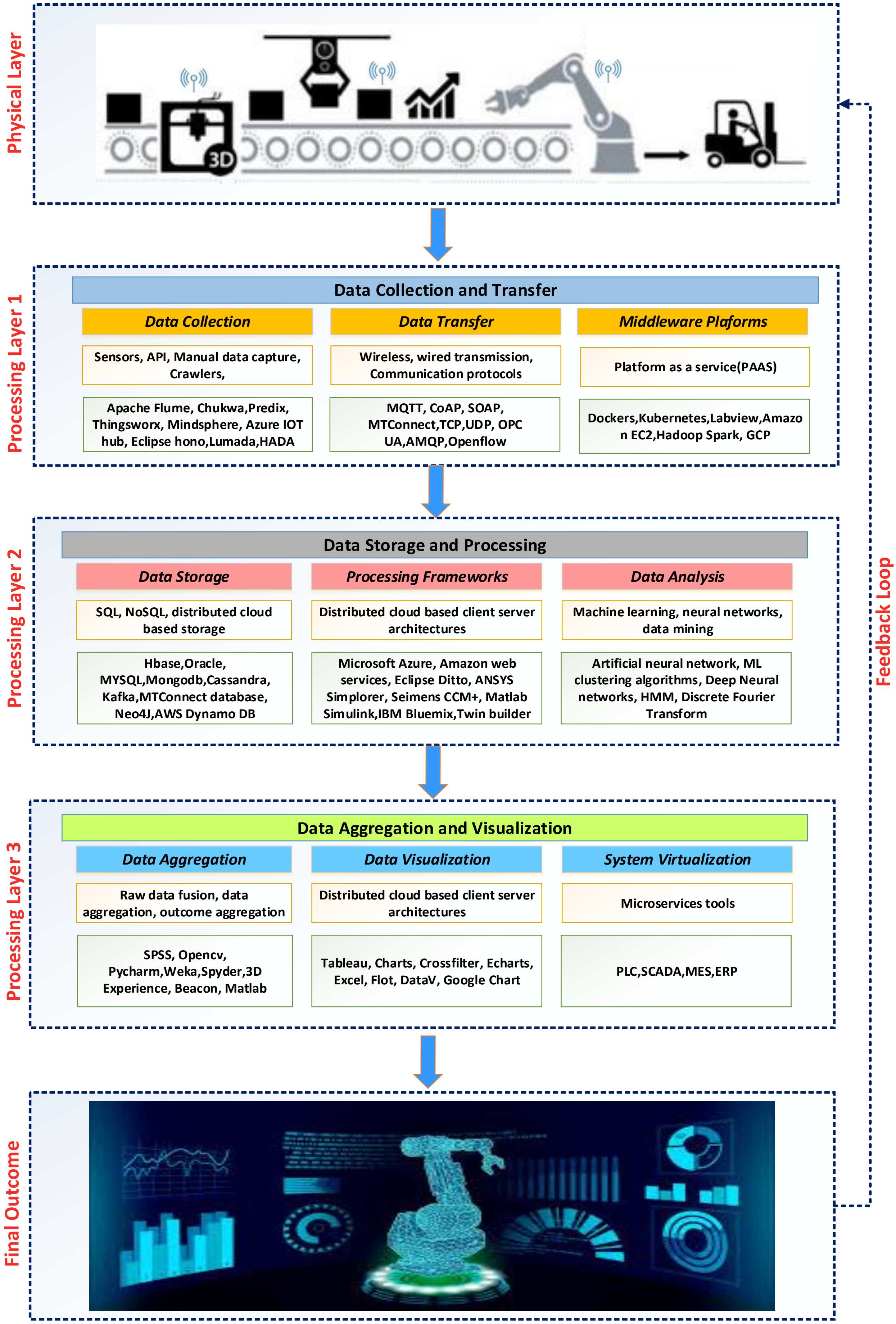

Figure 2: The implementation stack and technology options of the digital twin in manufacturing

2. Bibliometric Analysis of digital twin using Artificial Intelligence techniques.

The term "Bibliometrics" can be split up as 'Biblio' which means books and 'metrics' implies measurement. The bibliometric technique is generally used to quantitatively analyse research data based on articles, journals, citations, geographical locations, and other parameters. This type of analysis also helps the authors in finding the gaps in the literature. [31].

The objectives of this bibliometric survey are as follows:

- To examine the research trend in the area of the digital twin.
- To distinguish the development in the area of digital twin based on geographical locations of the world
- Identify the developments in publication across affiliations of universities and research institutions and their contributors
- To study the citation, the citation count of the publications
- To identify the type of language used in the publications.

While researching a specific area, it is necessary to have in-depth knowledge of advancing research in that field and the number of authors contributing to such research. As technology advances, large quantities of information are available, various methods such as bibliometric, webometrics, scientometrics, and H-index are used to classify different trends. To achieve these objectives, a bibliometric analysis was done to study used data collected from Scopus to define a collection of bibliometric enactment indicators such as quantitative indicators indicating efficiency, and qualitative indicators include citations and Hirsch index (h -index).

2.1 Analysis of Keywords:

Table 2: List of Primary and Secondary keywords

Primary keyword	"Digital Twin"
Secondary keyword using (AND)	"Machinery"
Secondary keywords using (OR)	"Industry 4.0" "Predictive Maintenance" "Remaining Useful Life" "Anomaly Detection" "Machine Learning" "Deep Learning" "Artificial Intelligence" "Smart Manufacturing"

Table 2 shows the primary and secondary sets of keywords that were used in the query, which was used to search the documents in Scopus. The final question was as given:

"Digital Twin" AND "Machinery" OR "Industry 4.0" OR "Predictive Maintenance" OR "Remaining Useful Life" OR "Anomaly Detection" OR "Machine Learning" OR "Deep Learning" OR "Artificial Intelligence" OR "Smart Manufacturing"

2.2 Initial search results:

The basis for this research paper is the Scopus database. It gives all 824 publications by using the keywords as mentioned above. Here we focus primarily on the English language, which provides 788 publications. Table 3. summarises trends in the language used in manuscripts of Digital Twin.

Table 3: Digital Twin languages trends

Publication Language	Publications
English	800
Chinees	26
German	11
Russia	4
French	1
Italian	1
Portuguese	1

Source: http://www.scopus.com (assessed on 29th August 2020)

For this survey, all types of published publications consist of journal papers, essays, book chapters, conference proceedings, etc.

Table 4: Type of Publications in Digital Twin

Types of Publication	Number of Publications	Percentage
Conference Paper	443	52.49
Article	294	34.83
Conference review	35	4.15
Book Chapter	34	4.03
Review	30	3.55
Book	2	0.24
Editorial	2	0.24
Business article	1	0.12
Erratum	1	0.12
letter	1	0.12
Note	1	0.12

Source: http://www.scopus.com (assessed on 29th August 2020)

The search result was analysed based on the type of publication used in publishing documents. Table 4. shows different types of publications in the digital twin area. 52.49 % of the researchers have publicised their work in conference paper followed by Articles, which contributes 34.83%, followed by conference review articles contribute 4.15%. It is observed that publication in the book chapter, review article, Book, editorial, etc. are the least contribution.

2.3 Exploratory data highlights

Documents related to Digital Twin were collected from 2005 to 2021 for 17 years. Table 5 exhibits trends in the number of publishing counts per year in the Digital Twin research area. By analysing this data, it is simple to estimate that the research area contributed more in the years 2018 and 2020. However, very few researches were carried out in the span of the year 2005 to 2017.

Table 5: Yearly publishing trends in Digital Twin

YEAR	Publication Count
2021	7
2020	280
2019	397
2018	112
2017	40
2016	5
2015	2
2005	1

Figure 3. is the graphical representation of Table 4. The graph represents an influential year in which research papers are published in 2019, with the largest number of publications of 397 documents in total.

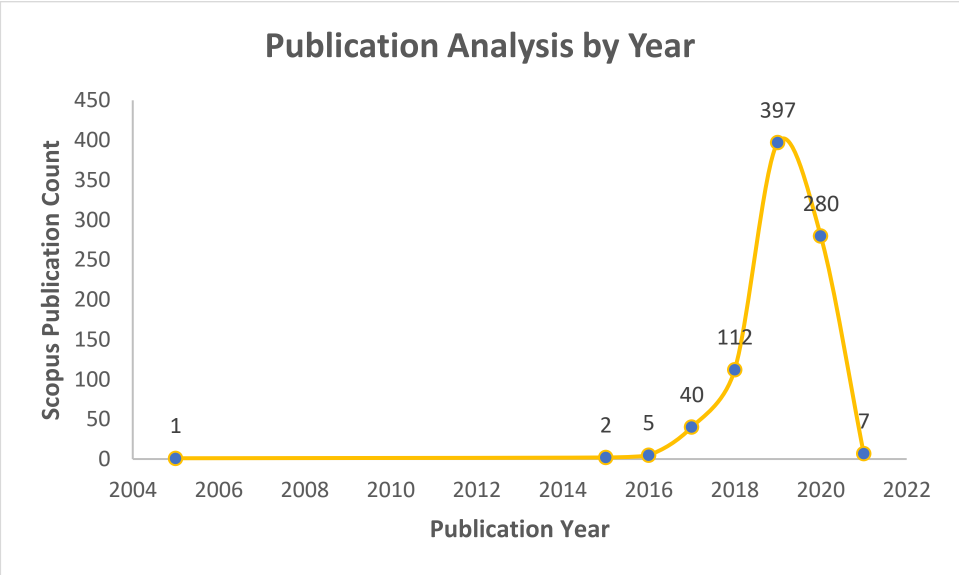

Figure 3: Yearly publishing trend in Digital twin

Source: https://www.scopus.com/ **(assessed on 29th August 2020)**

2.4 Analysis by geographic location:

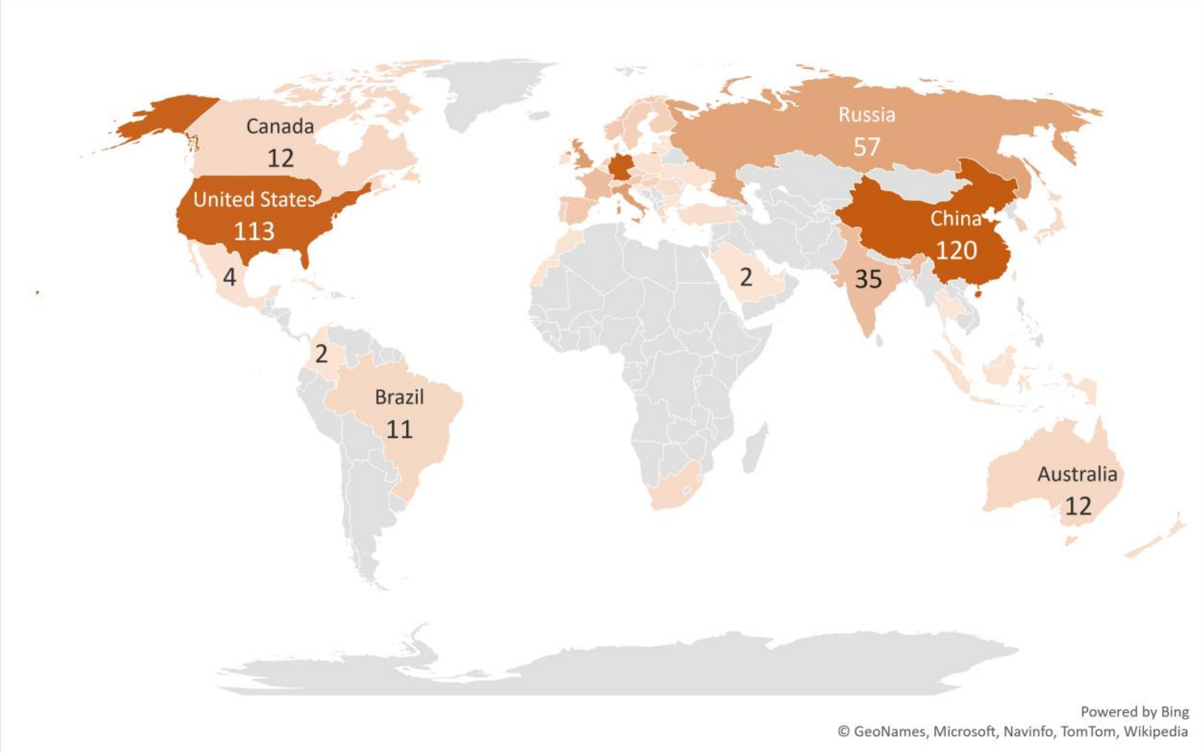

Figure 4: Geographic locations of research related to Digital Twin

Source: https://www.scopus.com/ **(assessed on 29th August 2020)**

Figure 4 is drawn using excel showing geographical regional location clusters of published papers. This map shows countries with their research counts. The maximum research in digital twins was observed in has taken place in China (120), followed by Germany (116) and the united states (113). The other countries following the maximum publication include the United Kingdom, Italy, Russia, India, France, Austria, Norway, Spain, etc

2.5 Subject area analysis

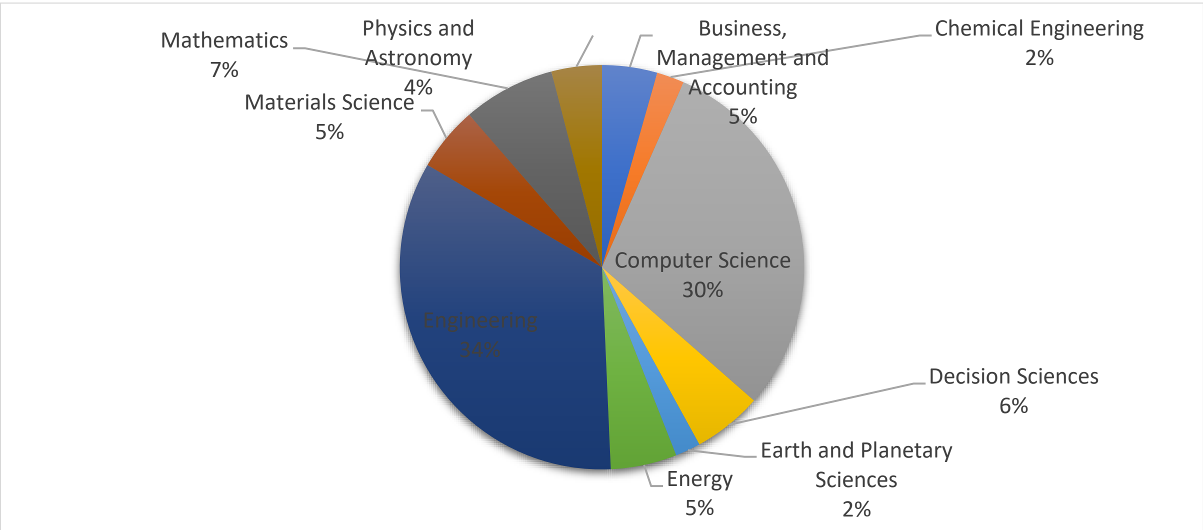

Figure 5: Top ten most popular subject areas.
Source: https://www.scopus.com/ **(assessed on 29th August 2020)**

Figure 5 shows the subject area-wise classification for the Digital twin research area. It is clear from the figure that maximum research has been carried out in Engineering and followed by computer science. The research carried out in other subject areas is negligible, ranging from 7 to 2% approximately.

3.0 Network Analysis

Using graphical formats, the network analysis is used to represent the relationship among various computable attributes. There are several resources available to do the same. However, VOSviewer, Gephi, and NodeXL are used in this research paper to render the network analysis graphs.

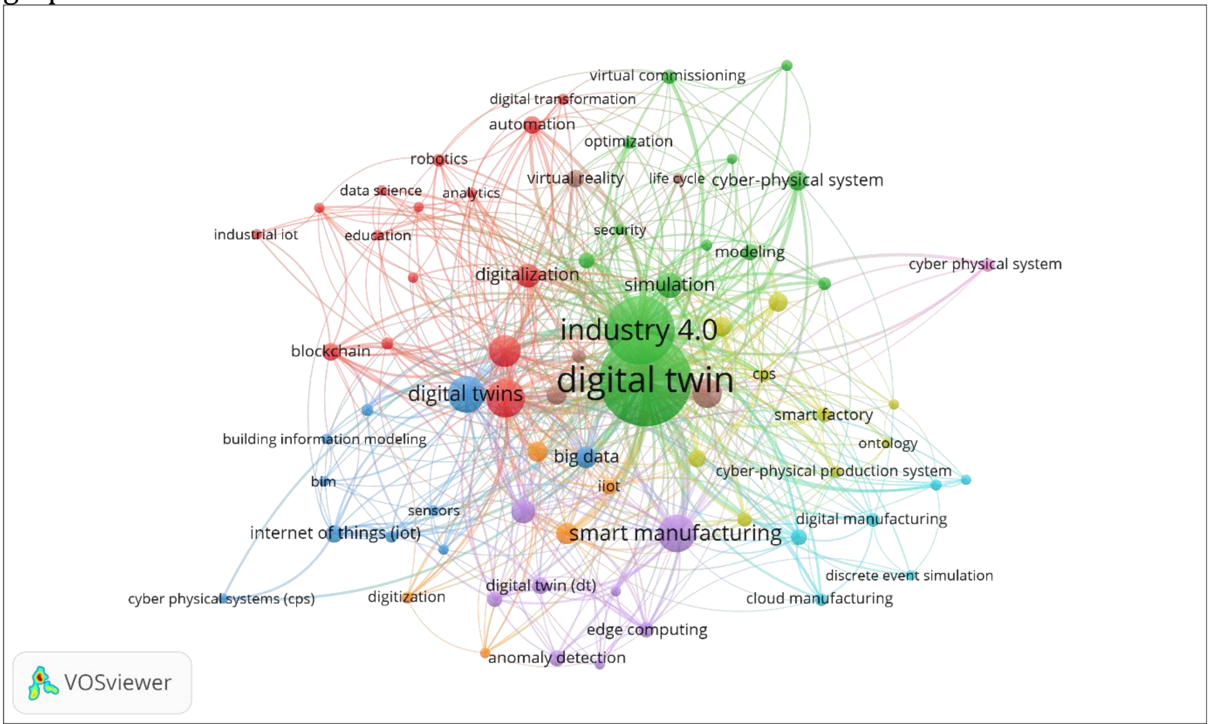

Figure 6: Network visualisation diagram based on keywords and source title.
(Source: https://www.vosviewer.com)

Figure 6 is the chart of network analysis focused on the combination of keywords with Scopus source names. Circles in the map reflect keywords used in extracted document source names. The wider the circle higher the level of keyword incidence. The Links connecting the circles signify the distance between two keywords. If the relation size is smaller, the correlation between the keywords would be more extensive. The same colour represents the cluster formed by keywords. The figure has nine different colours representing nine other clusters. The threshold value for the minimum number of keyword occurrences is limited to 5. 68 keywords met the threshold value. The relevance score is calculated for 68 terms. So, 68 keywords were selected to draw the relation between keywords and source titles.

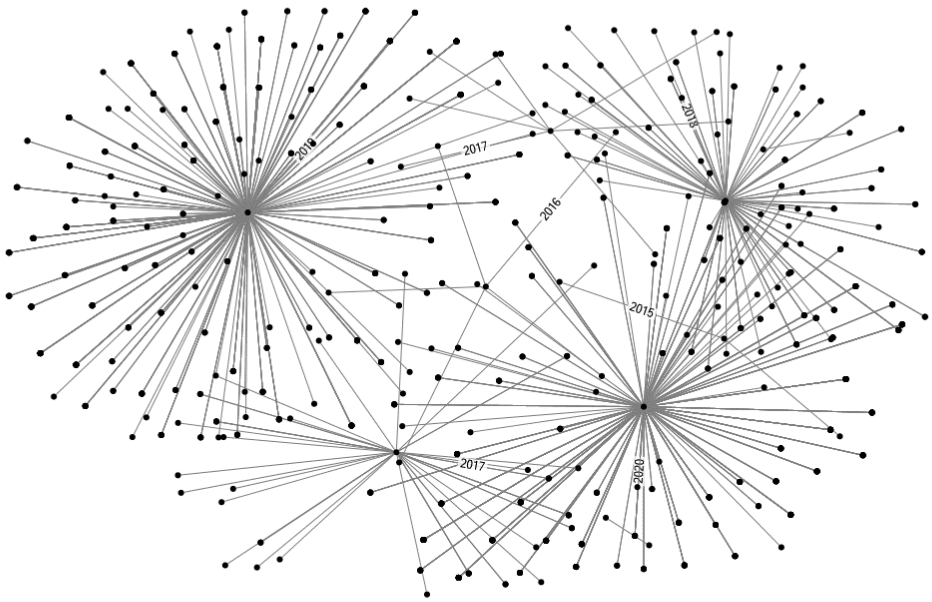

Figure 7. Network analysis diagram depicting a cluster of publication year and its title. (Source: https://nodexl.com/)

Figure 7 depicts a cluster of publishing titles and their respective publishing year. This diagram is drawn using open source tool NodeXL, which is usually used for network analysis. Here nodes are various entities, such as the title of the publication and the year of publication. The relations between these entities are called edges. The Fruchterman-Reingold style is used to map data about the year of publication and title of the publications. The cluster size indicates that most of the publications in Digital twin are publicised in the year 2019, followed by 2020.

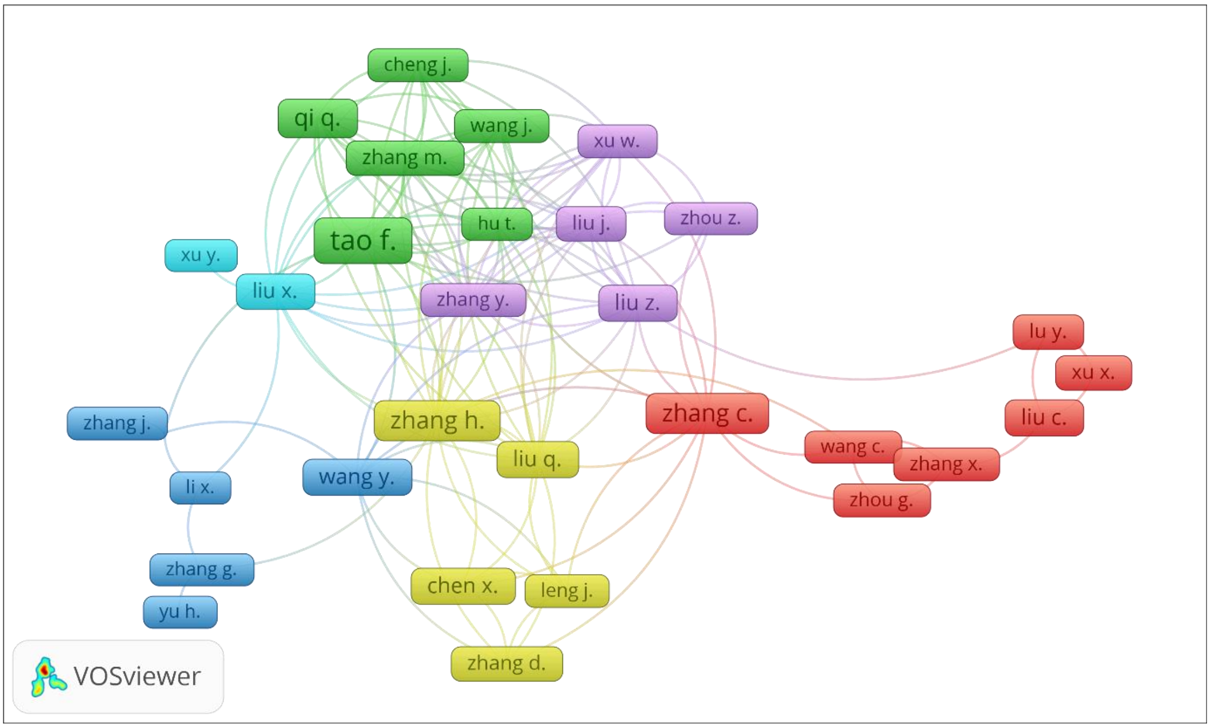

Figure 8: Network analysis diagram of co-authors and authors based on co-appearance among the same papers (Source: https://www.vosviewer.com)

Figure 8 represents a cluster of co-authors and authors co-appearing among the same papers. The collaborative work is shown among the authors. The link describes the collaborative work of authors on the documents published. The author's threshold value having a minimum number of documents was set manually to 3, which resulted in 115 authors. The total strength of the co-authorship links with other authors is calculated and displayed in Figure 6.

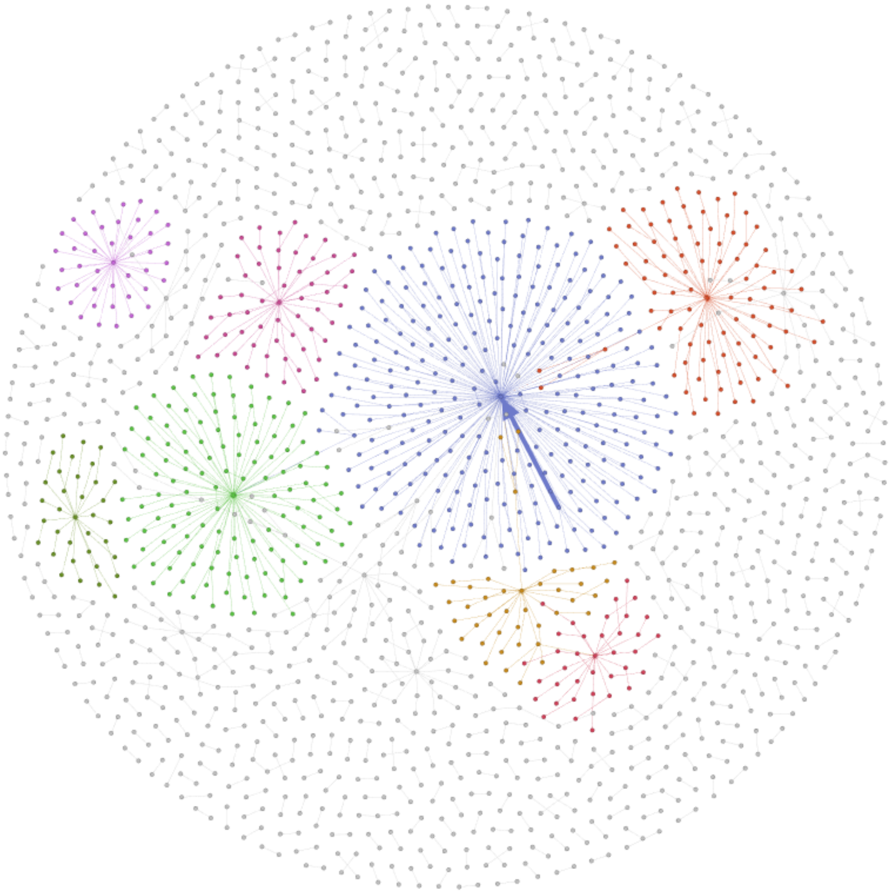

Figure 9 Network map of publication title and the citations received by publications
(Source: https://gephi.org/)

Figure 9 describes the network map of the publication title and the citations received by publications published. Gephi, open software is used to draw this diagram. The Fruchterman-Reingold layout is used to plot diagrams. The layout shows 478 nodes as the publication title is a collaborative work of the authors and 425 edges. The edges were set to in degree property, which means that the arrows coming towards a specific node has cited that paper. The dark colour dot represents the publication title that received the highest number of citations.

3.2 Statistical analysis based on Affiliations

The topmost ten universities and organisational affiliations contributing to the field of Digital Twin are represented in Figure 10. Beihang University shows maximum contribution towards the research in Digital Twin, followed by Politecnico di Milano university.

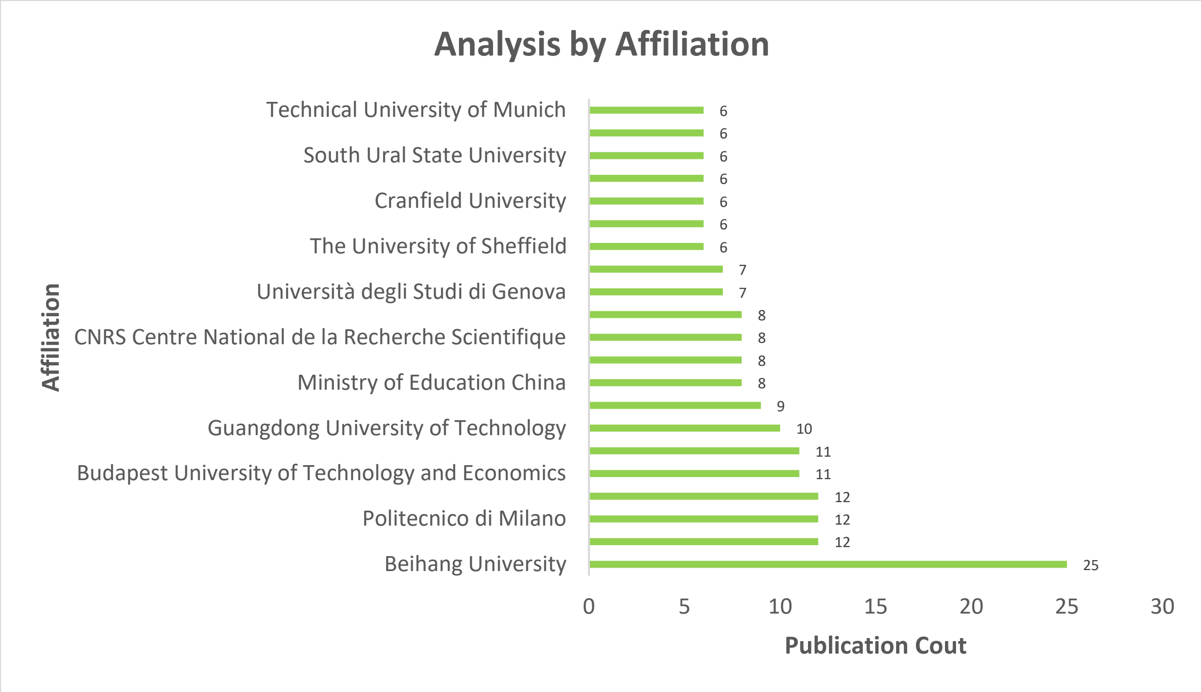

Figure 10: Analysis by Affiliation.
Source: https://www.scopus.com/ **(assessed on 29th August 2020)**

3.3 Statistical analysis based on Source Types

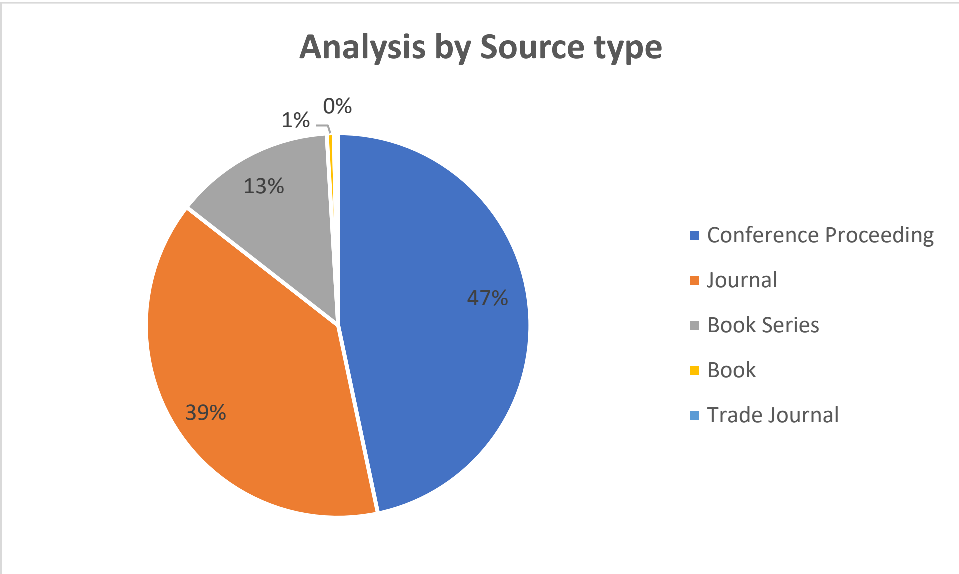

Figure 11: Analysis based on Source type.
Source: https://www.scopus.com/ **(assessed on 29th August 2020)**

Figure 11 shows the source types of scholarly articles, which means where the original research work is published. From the Scopus extracted literature of Digital Twin, it can be clearly stated that 47% of the publications are conference proceedings followed by 39% of publications in Journals. It has been observed that review publications for the Digital Twin are a little more than implementation publication. Therefore, this becomes one of the motivations to write this bibliometric review on Digital Twin. Figure 12 shows the analysis based on authors who have published in this field and their publication count.

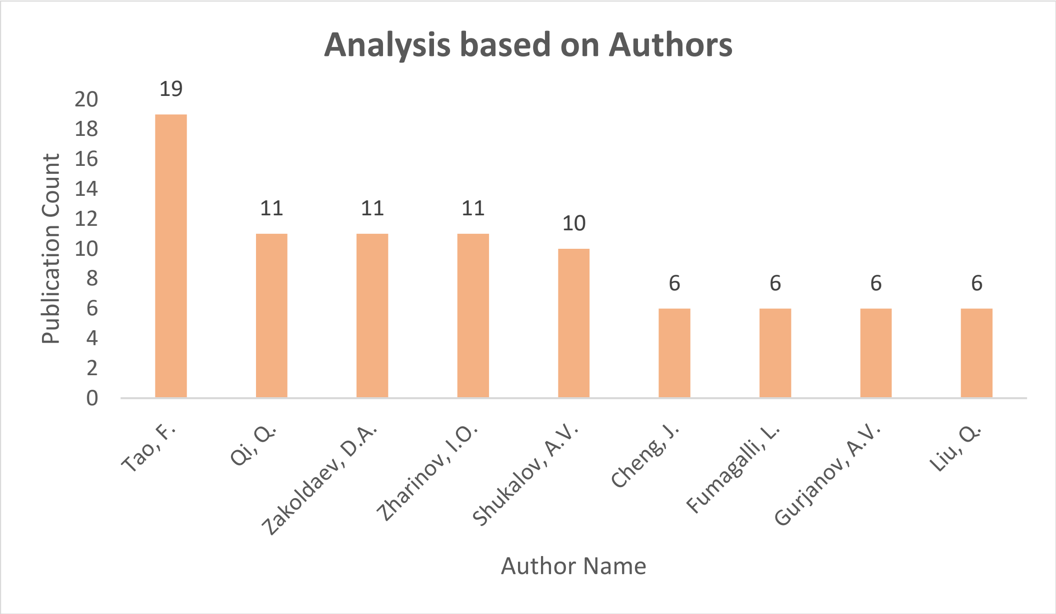

Figure 12: Statistical analysis based on the author.
Source: https://www.scopus.com/ **(assessed on 29th August 2020)**

3.4 Analysis based on publication citations

Table 6 displays citations extracted from publications received in the Digital Twin field on an annual basis. To date, the total citation count of 8 publications is 4089. Very few documents are cited from the years 2015 to 2016. The maximum citation was found in the year 2019 and 2020.

Table 6: Analysis based on citations for publications in Digital Twin

Year	**<2015**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
No. of Citations	9	12	222	1305	1174	1367	2124	4089

The top ten publication titles extracted from the Scopus database that received the maximum number of citations to date are represented in Table 7. It can be inferred that the research work with the title 'The Digital Twin: Realising the Cyber-Physical Production System for Industry 4.0' has the highest citations in this field of the digital twin.

Table 7: An analysis of top ten publication based on citations in Digital twin

Sl No	**Publication Title**	**Citations received by the Publications yearly**							
		<2015	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
1	The Digital Twin: Realising the Cyber-Physical Production System for Industry 4.0				5	39	81	75	200
2	Digital Twin Shopfloor: A New Shop-Floor					31	88	78	197

	Paradigm Towards Smart Manufacturing								
3	A Review of the Roles of Digital Twin in CPS-based Production Systems					27	86	80	193
4	Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison					25	83	81	189
5	Digital Twin Data Modelling with Automation ML and a Communication Methodology for Data Exchange				4	14	53	43	114
6	The Digital Twin: Demonstrating the Potential of Real-Time Data Acquisition in Production Systems				1	20	46	39	106
7	Digital twin workshop: a new paradigm for a future workshop				5	18	49	26	98
8	Digital twin-based smart production management and control framework for the complex product assembly shop-floor					5	42	50	97
9	Digital Twin in Industry: State-of-the-Art						27	67	94
10	A Digital Twin-Based Approach for Designing and Multi-Objective Optimisation of Hollow Glass Production Line					8	37	37	82

3.9 Statistical analysis based on source titles

Statistics based on the top ten source titles from retrieved literature are represented in Figure 13 for publications in Digital Twin; it is observed that the maximum numbers of publications are done in source title IFAC-Papers OnLine followed by other journals such as Procedia CIRP, IEEE Access, Procedia Manufacturing, etc.

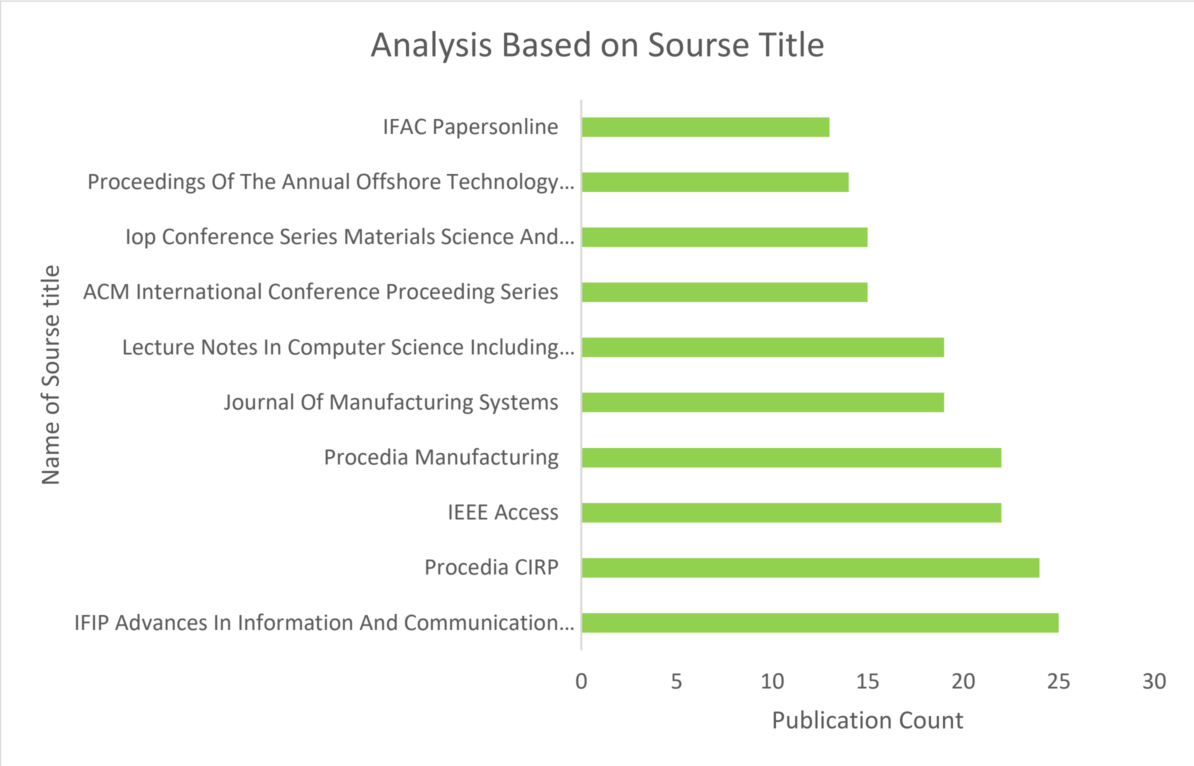

Figure. 13 Analysis based on Source title.
Source: https://www.scopus.com/ **(assessed on 29th August 2020)**

3.10 Analysis based on Funding Sponsors

Statistical analysis based on Funding sponsors in the Digital Twin research area is shown in Figure 14. The top 10 funding sponsors are considered and can be based on the statistics; it can be inferred that the National Natural Science Foundation of China is the highest funding foundation followed by the Horizon 2020 Framework Programme.

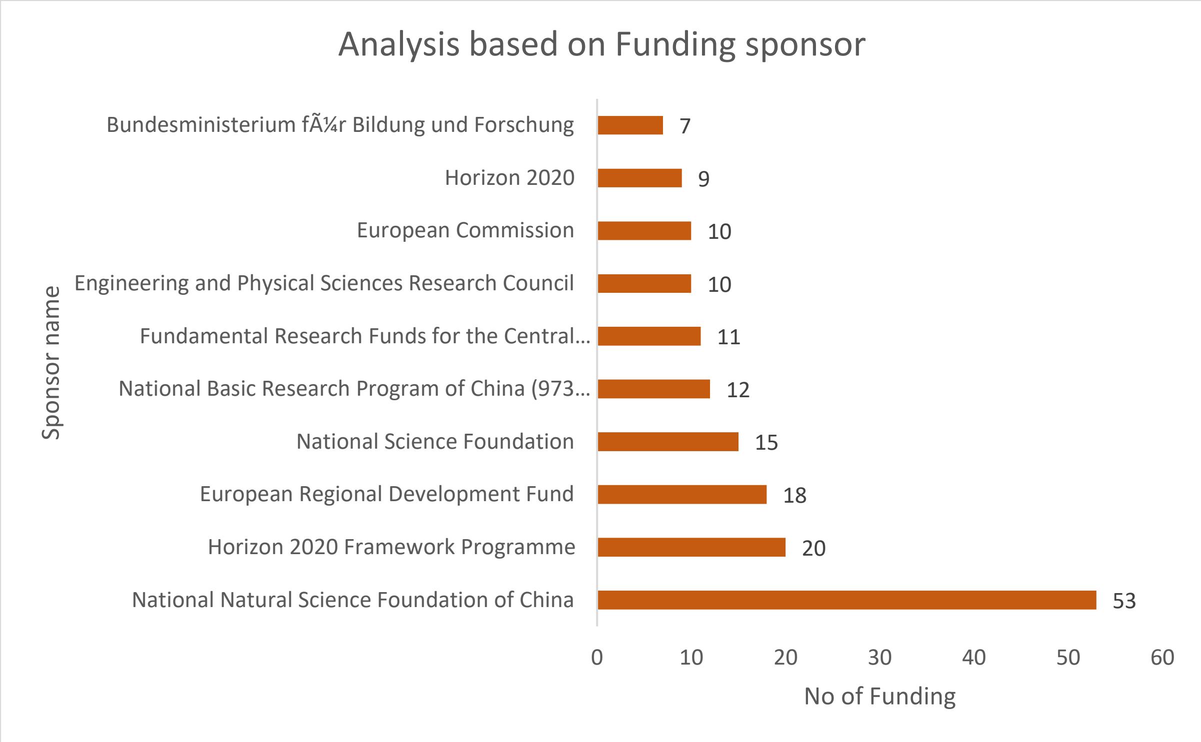

Figure 14: Analysis based on funding sponsor
Source: https://www.scopus.com/ **(assessed on 29th August 2020)**

4. Inferences and limitation of the present study:

A study in the field of Digital Twin stretches its borders worldwide and is expanding tremendously. This review carried out in paper will illustrate the importance and contribution of authors, country, funding agency, etc. in the digital twin area.

Reports accompanied by conference papers are primarily the types of publications in the corresponding area. These are the powerful brainstorming channels on the research concept and refine the research questions based on the scholars' input. The majority of the researchers use the English language to publish the papers. Based on the extracted literature, it is observed that out of 846 papers, only thirty are review papers.

For the present review, publications that are only accessible in the Scopus database are considered. Technical records may be accessible from other research sources such as Web of Science, Google Scholar, which are not used for the current study. The authors had chosen the keywords used to query the Scopus database. The combination of keywords used for the study may be rearranged, modified, and updated according to the researcher's viewpoint.

5. Conclusion

The bibliometric analysis enables researchers to gain a more in-depth insight into the topic's potential and identify the gaps. This helped the authors identify the various factors that could be considered during research in Digital Twin. The study was mainly based on the Scopus database, which helped understand the prospective journals, Publication, Citation, and authors, etc. The keyword analysis mainly helps in deciding further research. The digital twin has a lot of scope in many fields such as health care, aviation, precision agriculture, education, energy sector, etc. This paper mainly focuses on implementing digital twin in manufacturing due to its broad scope in this field. The study's findings reveal that research-oriented towards those subject areas benefit the industry and humanity by reducing its cost.

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