 doi:10.20944/preprints202207.0107.v1

Article

Advances in Digital Transformation: a Historical Review in Times of COVID

Pablo Reyes-Cornejo [1,] *, Yerco E. Uribe-Bahamonde [2,1], Joan Boada Grau [3] and Luis Araya Castillo [4,]

[1] Universidad Autónoma de Chile, Chile; pablo.reyes@uautonoma.cl 0000-0002-8153-3831
[2] Universidad de Talca; Chile; yuribe@utalca.cl ORCID: 0000-0002-1791-404X
[3] Universidad Rovira i Virgili; España; joan.boaga@urv.cat 0000-0002-1907-6887
[4] Universidad Andrés Bello; Chile; luis.araya@unab.cl 0000-0001-7574-3907
* Correspondence: pablo.reyes@uautonoma.cl

Abstract: The new SARS-CoV-2 coronavirus has brought with it an increase in the use of digital platforms and an exponential increase in the number of scientific papers worldwide. The purpose of this study is to show a global overview of the digital transformation from 1975 to the present (2021). The main collection of the Web of Science database was used to retrieve global scientific production on digital transformation. Bibliometric indicators of production, visibility, impact, and collaboration were analyzed to assess research progress on the topic. The results show that digital transformation is a construct of recent development, increasingly relevant and transdisciplinary, with a clear growth after the declaration of the global COVID-19 pandemic.

Keywords: Digital transformation; Bibliometric; Authors relationship; Web of Science

1. Introduction

The use of the term digital transformation (DT) has become frequent in recent years to refer to the challenge of innovation which companies take on by seeking better performance [1]. Organizations incorporate technology to achieve faster and better adaptation to a global and competitive context [2] which presents a strategic-level challenge [1;3] in an uncertain scenario. Organizations thus face the challenge to adapt or die, in what has been termed digital Darwinism [4; 5]. In this context, implementing the DT could mean earnings of 20 to 30% for manufacturing companies, and a cost reduction of 10 to 20%, leading to greater process efficiency [6].

To define the term, DT is a multidimensional phenomenon [5] which creates organizational change via technology [1] with profound repercussions, even in economic and social activities [7; 8]. Some authors state that this change affects society, politics and economic sciences, boosting innovation and promoting the development of products with greater added value [8; 9]. In this regard, DT increases products and services' availability [10], leading to changes in the relation between consumers and organizations via direct, immediate communication, which modifies the habits of people [11]. This subsequently leads to a demand for change in the way in which companies create value [12].

These changes can be implemented considering the large amount of low-cost data available which makes innovation more accessible [12]. It should be clarified that digital projects are not inherently transformative, and DT depends on both people and technology [13;14]. This logic accommodates the model of 5 dominions or DT forces [12] composed by dimensions for consumers, competitors, data, innovation and value. This model considers both technology and people, a condition which reinforces the importance of both aspects, since it is people who use technology [15] via their skills. From this perspective, skill development is considered a strategic management tool [16]. It is human skills

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which allow businesses to coordinate activities and make use of their assets, facilitating order fulfillment, new product development and service provision [17]. We will thus say that transformation is successful when it helps improve human behaviors [18]. This behavioral change is not easy if one considers that people are complex sets of emotions, sensations, thoughts, beliefs and behaviors [19].

The DT paradigm seeks to study how people perceive and react to the imminent transformation, revealing a central role for organizational culture [20] which presents a challenge for area managers, who must establish a strategy for the digital age [21]. In this type of culture, organizational structures are flexible, with strong internalization of information technologies [22]. Organizational agility also predominates, understood as the capacity of the organization to reassign resources effectively and efficiently to create and protect existing value [23].

Speaking about DT means talking about a complex process, where the first steps towards digitalization are characterized by high uncertainty demanding effort from the entire company, and where business strategy reformulation is key to success [24]. Authors disagree regarding whether the DT strategy should be linked with the business strategy, or an information technology (IT) strategy [1]. However, they agree that DT is about both people and technology [25: 26], in a change process which demands that people break with existing practices and replace the models currently in use [27]. Thus, for example, automation via technology eliminates repetitive or manual-type tasks, reinforcing the value of skills such as creativity, empathy, judgment, intuition, interpersonal sensitivity, problem solving and other specific human skills which machines lack [14].

The positive effects of DT have raised interest in developing digitalization [10]. This greater interest, in descriptive terms, has led to a rise in publications linked to the topic [28; 9]. For example, scientific productivity on WoS grew annually by an average of 7% between 2010-2021. However, in the final stretch of 2018-2022, citable documents pertaining to artificial intelligence (AI) have grown by about 40% on average. The same thing appears with research about Covid-19, a topic strongly related to DT (see Figure 1) by an average of 271.410%. The concomitant rises of the disease and confinement accelerated DT in various organizations, placing teleworking at the center of the community and thus, new digital communication systems [29; 14].

COVID 19

In late 2019, in the Chinese city of Wuhan, varied cases of pneumonia were reported [30]. Already by January 2020, dozens of people were diagnosed with COVID-19 infection [31] named -SARS-CoV-2- for being the seventh virus of the family to infect humans [32]. After some time, through the international air transport system, the COVID-19 disease spread in various parts of the world, causing the World Health Organization [33] to declare the phenomenon a pandemic on March 12, 2020. Following this, governments around the world closed their sea, air, and land borders, declared quarantines, and imposed total isolation and physical distancing of citizens, all measures which were previously very efficient in curbing and preventing the spread of diseases [34].

Physical distancing has been unavoidable. In this scenario, technology has aided in protecting this distancing without losing all social interaction [35]. In the work area, technologies have demanded the incorporation of agile focuses for project management, supporting increased collective intellectual capital [36]. A study done in service companies revealed that maintaining work performance during a crisis was strongly tied to leader-

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ship [37]. This leadership capacity is what allows for defining new strategies in all companies, regardless of size. Companies have to adjust their strategies to seek new opportunities and redefine sustainable business models in order to maintain competitiveness [38].

The pandemic has driven the incorporation of these changes at a structural level, with companies being forced to modify, update or directly close their operations [38]. Consequently, the COVID crisis has represented a period of instability and danger, but also a period of greater technology use [39]. Because of this, the DT has been accelerated in various organizations. One example of this is education, where virtual learning was available before the pandemic, but the pandemic strongly accelerated the position of virtuality as the only possible way to function during confinement [14]. In other cases, service companies installed teleworking, incorporating new digital communication systems which helped complement existing business models [29]. Regardless of the productive or service sector, there is a common conclusion: the COVID pandemic has necessarily accelerated the DT in organizations [14; 40].

Consequently, the main purpose of this publication is to allow researchers interested in the topic to know about the most relevant authors in this field, the most representative countries and institutions for study, the research networks in which they participate, the scientific journals producing the most knowledge, the collaboration centers and the possibilities for future study, providing not only a descriptive analysis of the information, but also a reflection on it. To this end, we have proposed a group of questions to guide analysis from a bibliometric perspective.

As DT is a relatively new topic, few studies of its productivity have been carried out in WoS. In 2021 a study focused on the construction industry, which has shown a significant development of DT in the last ten years [41]. Their results revealed that DT goes beyond technologies and affects different aspects of the industry. The authors identified the different aspects of DT in architecture, engineering, construction, and operations (AECO). Another study pointed to the synergy between technological development and business research as a driving force for increased interest in the subject. Researchers in [42] state that DT is about the field of digital technologies and their applications, arguing that DT is not an end, but a means to achieve digital economies, economic growth, a better quality of life, sustainable development, and sustainability. In addition to the above and in the same year, [43] looked at the disruptive effect of DT in companies, mainly targeting internal audits. Finally, in 2022 the article called "Emerging trends in digital transformation: a bibliometric analysis", showed the increase of publications on DT in the WoS "Social Science Citation Index" database and taking a sample bounded between the years 1997 to February 2020, which in extreme rigor, would be analysis between the years 1997 to 2019 complete [44].

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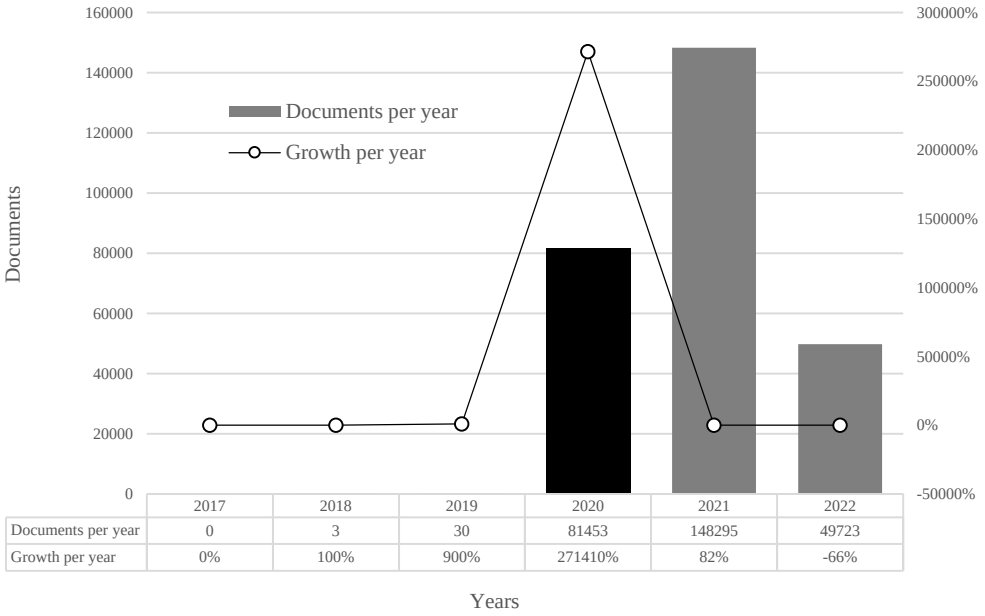

	2017	2018	2019	2020	2021	2022
Documents per year	0	3	30	81453	148295	49723
Growth per year	0%	100%	900%	271410%	82%	-66%

Figure 1. Number of papers belonging to the topic "Covid" citable published in web of science core collection along with the percentage growth between the years 2018-2022.

As we can see, the approaches to DT have been diverse, emphasizing industrial areas in some cases and service areas in others, with a focus on one discipline over another. However, the impact of the pandemic on scientific productivity in WoS has not been determined in bibliometric terms. Consequently, this article, using a descriptive bibliometric study, seeks to identify the documents that address DT and the impact of the pandemic on the development of the field, as well as helping to know the most relevant authors, the scientific journals where they publish their work, the institutions where they work and the research networks in which they participate. This can facilitate the insertion of new researchers to the field, in addition to helping new analyses on the subject, by being an updated element of the contribution to the management of global scientific DT research.

2. Methods

The analysis carried out in this article is classified as descriptive, transversal, and retrospective [45], developing a study for the total number of documents, in which a systematic categorization and description of indicators are generated for the evaluation and resolution of each of the questions posed, approaching information from the global to the singular.

Both the search and the inclusion and exclusion of documents were developed based on the PRISMA methodology [46] (See Figure 2). The present study included the analysis of 3143 documents published in WEB OF SCIENCE (Web of Science Core Collection) between 1975 and 2021. The collection of the documents was performed using the concept "Digital Transformation" which was entered into the WoS search system as:

TS= "Digital Transformation*"; Refined by: DOCUMENT TYPE: (Article; reviews) AND [excluding] YEARS OF PUBLICATION: (2022) Indexes: SCI-EXPANDED, SSCI, A&HCI, ESCI.

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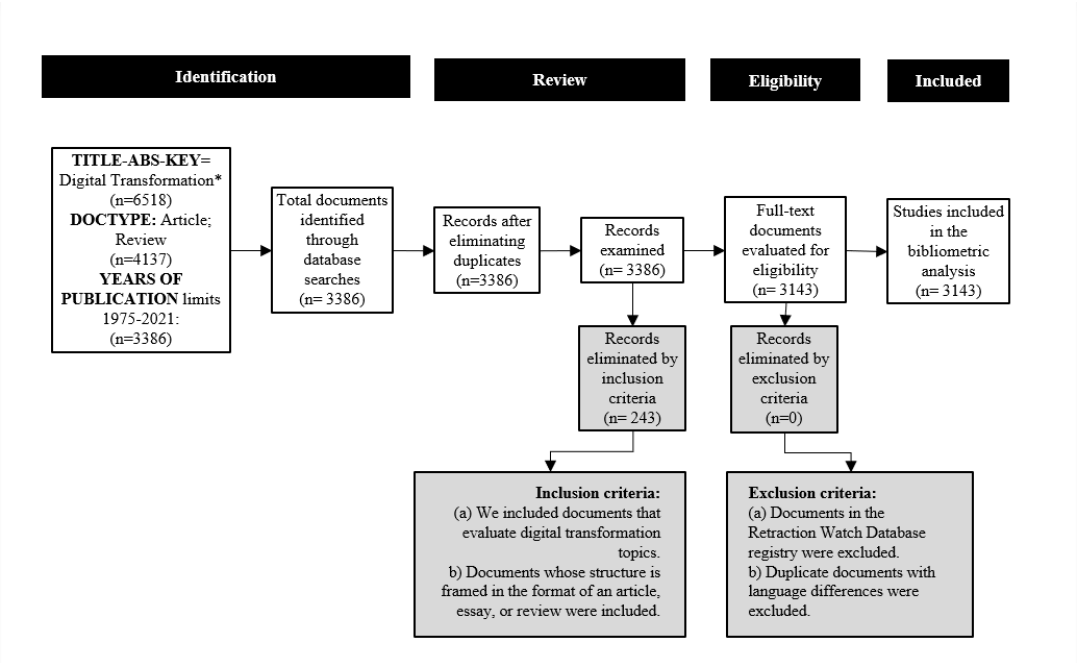

Figure 2. Flowchart showing the process of selection and filtering of documentation in WoS.

The database was standardized and corrected to eliminate document duplication, check data atomicity, and rule out completely missing or undeclared identifications [47]. The sample of scientific and relational production indicators, as well as tables and graphs, were elaborated and calculated in Microsoft Excel and then contrasted with R and biblioShiny bibliometrics package [48]. Finally, all graphics were standardized in Adobe Illustrator 2021. All the data obtained and processed are obtained from the databases where each of the documents is indexed.

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Table 1. General information data.

Category	Description	Results
Main information	Documents	3143
	Journals	1365
	Timespan	1986:2021
	Average citations per documents	7.68
Document contents	keywords (unprocessed)	9012
	keywords Plus	3111
Authors	Authors	9017
	Author Appearances	10640
	Authors of single-authored documents	499
	Authors of multi-authored documents	8518
Collaboration	Documents per Author	0.34
	Authors per Document	2.91
	Co-Authors per Documents	3.43
	Collaboration Index	3.32
	Single-authored documents	536

The study poses the following research questions:

1. What is the trend of publications related to DT? Method: Production count [47]. Relevance: the number and progress of publications and their citations are useful for the researcher to know the evolution of the field, supplying information that helps to interpret other analyses aimed at predicting future research topics.

2. What are the publications about DT with the greatest impact? Method: Citation analysis [48]. Citation numbers provide researchers with the most influential documents within a field, thus supplying argumentative and theoretical pillars on the subject.

3. Which countries/institutions have contributed to DT research? Method: Production count, Citation analysis, Collaboration indicators. Relevance: finding the countries, institutions, and research centers with the most contributions and citations, together with the degree of international collaboration, helps researchers to make strategic decisions for future international project proposals, both educational and research.

4. Which are the most relevant scientific journals related to DT? Method: Production count, Citation analysis [49]. Relevance: knowing the journals that concentrate the most information on the subject and receive the most citations help the researcher to organize knowledge and find the best evaluation groups for their research.

5. Who are the most important authors in DT research? Method: Production count, Citation analysis. Relevance: knowing the most relevant and cited authors in the subject helps researchers find the authors to follow and establish thematic axes according to their path.

6. What are the collaborative structures of leading authors on DT? Method: Co-authorship network. Relevance [50]: the diverse structures of collaboration by the most relevant authors make visible the groups of studies that help the construction of

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knowledge and thus broaden the spectrum of relevant authors for research collaboration.

7. What are the topics and how has their research focus evolved? Method: Joint word or co-word analysis, elaborated from research [51,52]. And Analysis of thematic evolution. Relevance: knowing both the conceptual structure and the evolution of knowledge of the topic provides researchers with the main research topics worked on, in addition to being able to find knowledge gaps which would provide future development opportunities.

3. Results

The following results consider three essential axes: document productivity, authors, affiliations, as well as their relational and thematic evolution. Therefore, bibliometric, citation, collaboration and relational indicators will be showed, as already expounded on in the research questions.

1.1 Papers in the Field under Study

Web of Science integrates with its search, documentation from the year 1986 to the date of consultation and a year above it. When consulted, it gave us 3,143 articles in a timeframe from 1986 to the year 2021. The first article about DT published in 1986 belongs to Hadi M. Yassine from Qatar University, with the title of General Analog-To-Digital Transformation, in the journal IEE Proceedings-G Circuits Devices and Systems. It is not until the year 2015 that the growth of documentation on the subject rises significantly to reach 1,495 documents published in 2021. Although early production is eventual and not consistent during the first 29 years, 2.6% of the literature on the subject was produced during that window of time, so that the bulk of it (97.4%) is concentrated in the last five years (see figure 3).

A substantial productivity rise appeared in early 2020, along with the occurrence of the COVID pandemic. During this period, publications rose from a total of 414 documents in 2019 to 856 in 2020, and then 1495 in 2021, which mean an increase of 107% in 2020 and 75% in 2021, respectively.

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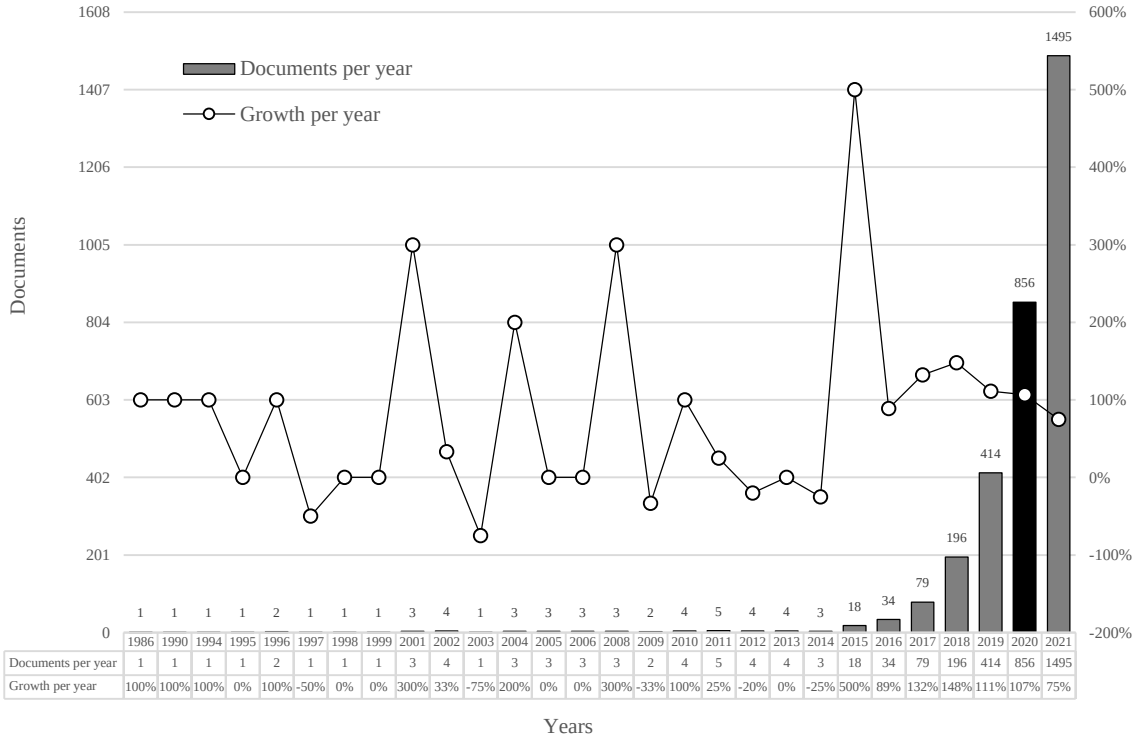

	1986	1990	1994	1995	1996	1997	1998	1999	2001	2002	2003	2004	2005	2006	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Documents per year	1	1	1	1	2	1	1	1	3	4	1	3	3	3	3	2	4	5	4	4	3	18	34	79	196	414	856	1495
Growth per year	100%	100%	100%	0%	100%	-50%	0%	0%	300%	33%	-75%	200%	0%	0%	300%	-33%	100%	25%	-20%	0%	-25%	500%	89%	132%	148%	111%	107%	75%

Figure 3. Distribution of scientific productivity and growth in scientific productivity per years, according to WoS, accountable papers between 1986 - 2020.

1.2 Citations in the Field under Study

The number of citations fully coincides with publication development (see figure 4). Since the growth in citations is contemporary (less than 5 years), the growth in citations has accelerated, to the point of not seeing the common decrease in the last year.

As for the distribution of citations obtained in Web of Science (see table 2), 1,027 documents do not present citations, which represents 32.67% of the sample, while 67.32% of the papers present at least one citation, distributed as follows: 2,023 papers present at least 50 citations (59.07%), 64 papers have between 50 and 100 citations (2.03%), 19 papers have between 101 and 200 citations (0.60%) and finally the 10 most cited papers of the sample with more than 200 citations each stand out with 0.31%.

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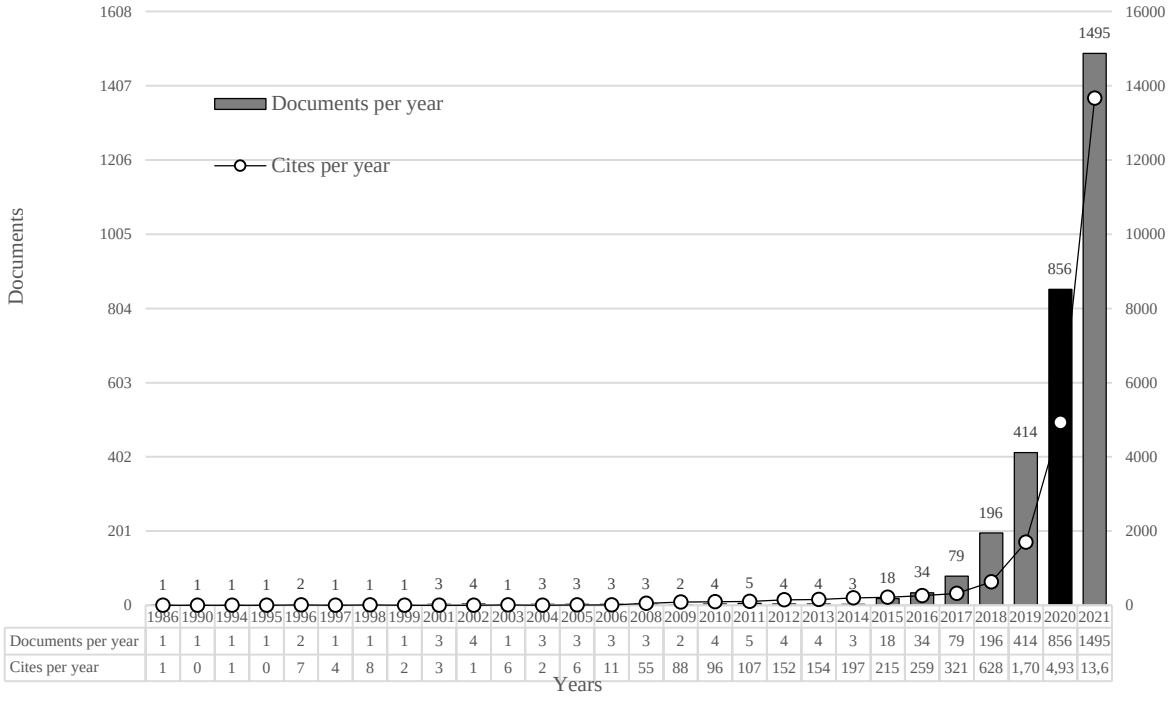

	1986	1990	1994	1995	1996	1997	1998	1999	2001	2002	2003	2004	2005	2006	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Documents per year	1	1	1	1	2	1	1	1	3	4	1	3	3	3	3	2	4	5	4	4	3	18	34	79	196	414	856	1495
Cites per year	1	0	1	0	7	4	8	2	3	1	6	2	6	11	55	88	96	107	152	154	197	215	259	321	628	1,70	4,93	13,6

Figure 4. Total number of citations and growth per year. According to WoS, accountable papers between 1986 - 2020.

Table 2. General citation structure.

Number of citations	Number of papers	% Of Papers
< 200	10	0.31%
>100 ≤200	19	0.60%
>50 ≤100	64	2.03%
≤50	2023	64.36%
Zero citation	1.027	32.67%
Totals	3,143	100.00%

Source: Compiled by the authors based on Web of Science data (2022).

The H-index (Hirsch impact index) of the selected documents is sixty-six; that is, sixty-six individual articles have at least sixty-six citations. The most cited articles include (see table 3): The authors, Candes, E. et al. in 2006 published the article called Fast discrete curvelet transforms in the journal Multiscale Modeling & Simulation, which has 1,462 as of the date of consultation. This article describes two digital implementations of a new mathematical transform, called second-generation curve, in two and three dimensions. It says that the first digital transformation is based on fast Fourier transforms, unequally spaced. The second digital transformation is based on specially selected Fourier samples. These implementations differ in the choice of spatial grids to translate the curves at each angle and scale. They are simpler, faster, and less redundant digital transforms. The second article is Frank, AG. et al. from 2019, with the article Industry 4.0 technologies: Implemen-

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tation patterns in manufacturing companies in the International Journal of Production Economics, which presents 497 citations. This publication aims to understand the adoption of Industry 4.0 technology patterns in manufacturing companies by proposing a conceptual framework for these technologies, which divided into front-end and base technologies. The findings show that Industry 4.0 is related to the systemic incorporation of front-end technologies, with a central role in smart manufacturing. The third article was written by Vial, G. in 2019, called Understanding digital transformation: A review and a research agenda, published in Journal of Strategic Information Systems, and has 436 citations. Finally, the fourth article, called Digital Transformation Strategies has 431 citations and was published in the scientific journal Business & Information Systems Engineering. This work developed by Matt, C. et al. et al. in 2015 has findings which demonstrate the multifunctional nature of DT strategies and the need for alignment with other functional and operational strategies. The alignment of IT strategies with other strategies remains a complex task. The interaction of digital transformation strategies with business development needs to be evaluated from a management perspective. Guidelines are needed to help companies to structure these processes, to achieve the establishment of shared objectives, the alignment of different strategies, and the cooperation between different actors in the company.

It is important to note the considerable number of citations presented by 6 articles published in 2019 and two in 2018.

Table 3. Most cited papers within scientific production/output.

Rank	Authors	Year	Title	DOI	Journal	Total Citations
1	Candes, E. et al.	2006	Fast discrete curvelet transforms	10.1137/05064182X	Multiscale Modeling & Simulation	1462
2	Frank, AG. et al.	2019	Industry 4.0 technologies: Implementation patterns in manufacturing companies	10.1016/j.ijpe.2019.01.004	International Journal of Production Economics	497
3	Vial, G.	2019	Understanding digital transformation: A review and a research agenda	10.1016/j.jsis.2019.01.003	Journal Of Strategic Information Systems	436
4	Matt, C. et al.	2015	Digital Transformation Strategies	10.1007/s12599-015-0401-5	Business & Information Systems Engineering	431
5	Agarwal, R. et al.	2010	The Digital Transformation of Healthcare: Current Status and the Road Ahead	10.1287/isre.1100.0327	Information Systems Research	366
6	Zhu, K. et al.	2006	Innovation diffusion in global contexts: determinants of post-adoption digital transformation of European companies	10.1057/palgrave.ejis.3000650	European Journal of Information Systems	296
7	Hess, T. et al.	2016	Options for Formulating a Digital Transformation Strategy	10.7892/BORIS.105447	Mis Quarterly Executive	284
8	Dimitrov, DV	2016	Medical Internet of Things and Big Data in Healthcare	10.4258/hir.2016.22.3.156	Geoforum	269
9	Nambisan, S. et al.	2019	The digital transformation of innovation and entrepreneurship: Progress, challenges, and key themes	10.1016/j.respol.2019.03.018	Research Policy	244
10	Warner, KSR. & Wager, M.	2019	Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal	10.1016/j.lrp.2018.12.001	Long Range Planning	206
11	Hinings, B. et al.	2018	Digital innovation and transformation: An institutional perspective	10.1016/j.infoandorg.2018.02.004	Information And Organization	200
12	Bogers, M. et al.	2018	Open Innovation: RESEARCH, PRACTICES, AND POLICIES	10.1177/0008125617745086	California Management Review	192
13	Horvath, D. & Szabo, RZ.	2019	Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?	10.1016/j.techfore.2019.05.021	Technological Forecasting and Social Change	191
14	Frank, AG. et al.	2019	Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective	10.1016/j.techfore.2019.01.014	Technological Forecasting and Social Change	186

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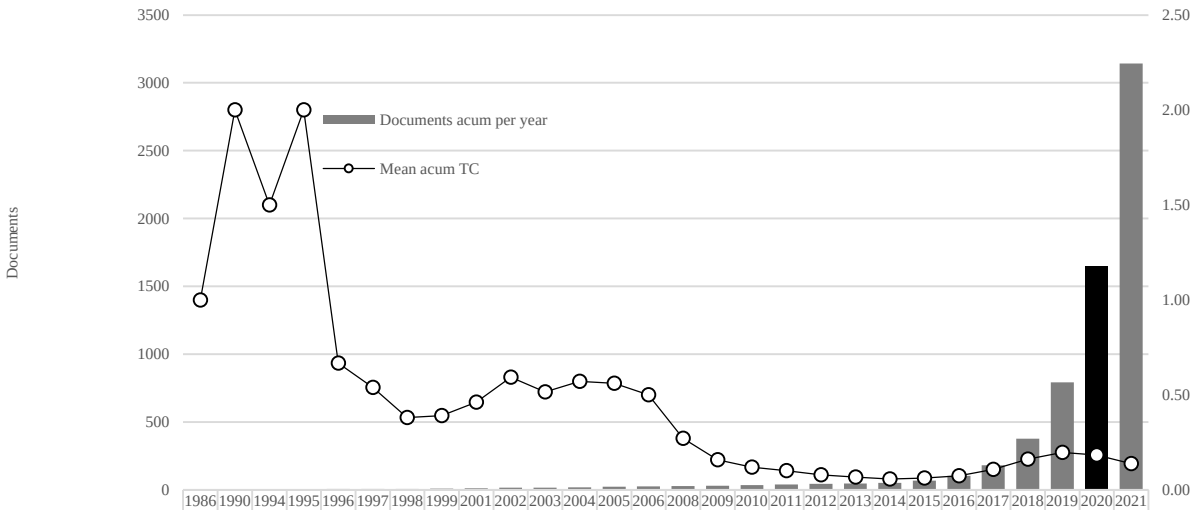
15	Verhoef, PC. et al.	2021	Digital transformation: A multidisciplinary reflection and research agenda	10.1016/j.jbusres.2019.09.022	Technological Forecasting and Social Change	183

Figure 5 shows the development of the topic from 1986 to 2021, showing the rise in publications and citations in this timeframe. There was a substantial rise in citations in 2006, which does not match with a greater publication volume. In particular, the article by Candes, Demanet, Donoho and Ying about "rapid discrete curve transformations" has 1434 citations, making it the most cited publication about digital transformation in the timeline. This article describes 2 digital implementations of a new mathematical transformation. This article was published in the journal Simulation of multiscale models, from the Society for Applied Industrial Mathematics. Its study field is similar to the first publication which mentions digital transformation in 1986. DT is used to indicate an alteration which improves prior implementations in curved mathematical models, simplifying conceptualization, increasing speed and reducing redundancy. Consequently, we can deduce that the definition of DT emerges from mathematics, as a phenomenon which causes a change that improves processes.

Figure 5 also helps identify that the median number of citations per year does not move in absolute synchronicity with the total number of documents. Thus, for example, the period between 2009 and 2014 has high citations, with figures above 2. Meanwhile, publications rose between 2016 and 2018, but did not lead to more citations. The downward citation trend reverses in 2019, and since that year, is aligned with the higher number of published documents.



	1986	1990	1994	1995	1996	1997	1998	1999	2001	2002	2003	2004	2005	2006	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Documents acum per year	1	2	3	4	6	7	8	9	12	16	17	20	23	26	29	31	35	40	44	48	51	69	103	182	378	792	1648	3143
Mean acum TC	1.00	2.00	1.50	2.00	0.67	0.54	0.38	0.39	0.46	0.59	0.52	0.57	0.56	0.50	0.27	0.16	0.12	0.10	0.08	0.07	0.06	0.06	0.07	0.11	0.16	0.20	0.18	0.14

Figure 5. Total number of citations and growth per year. According to WoS, accountable papers between 1986 - 2020

1.3 Countries

 doi:10.20944/preprints202207.0107.v1

After applying Bradford's law to the sample [53] (see table 4), the three most representative countries emerge. Scientific production is concentrated in 10 countries, representing 78.6% of total analyzed publications. Europe alone concentrates 52.84% of productivity.

Considering the criteria of the total number of documents produced, citations, H-index and the nationality of the leader on the publication, we can find three countries heading the list: Germany, the USA and England. Germany is the most productive country, with 13.36% of the total number of publications, 4,487 citations and an H-index of 31, i.e., at least 31 publications which were cited 31 times each. Additionally, when analyzing corresponding researchers' nationality as a criterion to determine publication leadership, we found that Germany led 77.78% of publications. The USA had 10.81% of all publications (335 articles), with 6,281 citations, an H-index of 34, and 58.51% of publication of leadership. Finally, England had 8.55% of publications (265 articles), 3,368 citations, an H-index of 32 and leadership on 49.06% of all publications.

Table 4. Productivity by country

Bradford	Rank	Country	N documents	%	Citations	H-Index	Corresponding	% Leader
Core	1	Germany	433	13.36%	4,487	31	322	77.78%
	2	United States	357	10.81%	6,281	34	196	58.51%
	3	Russia	329	9.85%	585	11	268	87.87%
Zone 1	4	Spain	292	9.23%	1,611	20	226	79.02%
	5	England	267	8.55%	3,368	32	130	49.06%
	6	Italy	259	8.17%	2,494	26	182	71.94%
	7	Peoples R. China	181	5.29%	1,321	17	110	67.07%
	8	Australia	130	4.29%	1,002	17	83	62.41%
	9	France	118	3.68%	1,818	21	61	53.51%
	10	Brazil	106	3.58%	1,227	15	82	77.78%

1.4 Institutions

Table 5 shows us the productivity index of the 10 most representative institutions. To identify productivity by institutions, our criteria were the number of documents produced, the number of citations and H-index. Consequently, the productivity leaders were the University of London, the Polytechnic University of Milan and the University of Turin.

The University of London had 44 documents with 319 citations and an H-index of 9. The Polytechnic University of Milan had 36 documents, 456 citations and an H-index of 10. Finally, the University of Turin had 22 documents, 252 citations and an H-index of 10.

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Table 5. Most productive institutions in WoS

Bradford	Rank	Institutions	N documents	%	Citations	H-Index
Core	1	League of European Research Universities LERU	92	3.20%	2042	20
	2	Ministry of Education Science of Ukraine	55	1.69%	122	6
	3	University of London	42	1.35%	378	10
	4	Russian Academy of Sciences	44	1.29%	78	5
	5	Polytechnic University of Milan	36	1.10%	566	11
	6	HSE University National Research University Higher School of Economics	33	1.01%	86	4
	7	University College London	27	0.83%	201	6
	8	University of Zagreb	26	0.80%	248	8
	9	University of Turin	23	0.70%	252	10
	10	Sapienza University Rome	22	0.67%	206	6

1.5 Journals

Out of all the journals considered in the sample, ten of them produced seventeen or more publications each, which concentrated a total of 13% of all articles regarding DT among them, equivalent to 402 publications. In terms of total productivity regarding DT, the top journal on the list is Sustainability, with 166 documents, 1,172 citations, an H-index of 18 and Q2, as shown in Table 6. This is an international journal, the property of MDPI Books, open access, interdisciplinary, includes peer reviewing and covers topics including the environment, culture, economics and sustainability. In the last five years its impact factor has been 3.473. Consequently, its publications are characterized by high scientific quality and high impact factor. It should be mentioned that Sustainability has seen annual growth above 100% in all of its publications. This growth volume indicates that this is the journal with the greatest number of articles about DT.

Second place is held by the journal Ieee Access, with 39 documents, 258 citations, an H-index of 9 and Q2. This is a multidisciplinary open-access journal which emphasizes application and is peer-reviewed at the Institute of Electric and Electronic Engineers. It continually presents studies carried out in relation with fields of interest to IEEE. Publication reviews are rapid, generally taking 4 to 6 weeks. There is no page limit. Its impact factor is 3.367.

The Journal of Business Research is in third place with 38 publications, 637 citations, an H-index of 12 and Q1. This journal discusses applications developed from research in business to the current business outlook. Its areas of interest include business decisions, processes and activities within current business operations. Its specific themes include incorporating empirical advances in consumer behavior, finances, organizational theory, marketing, risk, and more. It has published executives, researchers and students alike. Its readers are mainly in the UK, USA and China. Its impact factor is 7.55.

With the data appearing in Table 6, it is necessary to bear in mind that the Busines Process Management Journal is 0.8 away from being Q2. Meanwhile, Frontiers in Psychology is 0.5 away from being Q1, along with Sensors.

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Regarding productivity, it is important to differentiate that the greatest boom in publications about DT in Sustainability is related with the sustained growth of total articles which the journal has published. This is therefore growth in proportion to the total. For example, between 2011 and 2016 the journal published a total of 3,279 articles; between 2017 and 2019, a total of 14,492 articles; and in 2020 and 2021 alone a total of 24,568 articles.

Total publication growth in the journal Mis Quarterly Executive does not show such a sustained pattern over time. On the contrary, total publications in this journal show a downward trend, with 117 total publications between 2011 and 2016, 66 total publications between 2017 and 2019, and 47 articles between 2020 and 2021.

After reviewing which journal dedicated the most articles to DT, we can identify Mis Quarterly Executive, with over 10% of its articles mentioning the topic, followed by Business Process Management Journal, with over 5% of publications dedicated to DT, and in third place Sustainability, with 0.6% of publications from its total.

Table 6. Productivity by scientific journal, WoS

Bradford	Rank	Journal	N documents	%	Citations	H index	M index	Quartile 2020	JIF
	1	Sustainability	166	5.28%	1,172	18	3.6	Q2	54.93
	2	Technological Forecasting and Social Change	46	1.46%	820	13	2.6	Q1	85.95
	3	Journal of Business Research	38	1.21%	637	12	3	Q1	82.03
	4	Ieee Access	35	1.11%	258	9	1.5	Q2	59.94
Core	5	Applied Sciences Basel	30	0.95%	122	6	1.5	Q2	58.33
	6	Mis Quarterly Executive	19	0.60%	873	12	1	Q2	73.53
	7	Business Process Management Journal	17	0.54%	171	6	1.2	Q3	42.26
	8	Frontiers in Psychology	17	0.54%	77	4	1	Q2	69.64
	9	Journal of Medical Internet Research	17	0.54%	146	6	1.2	Q1	91.12
	10	Sensors	17	0.54%	110	7	1.4	Q2	70.15

Table 6b. Sample participation in proportion to total documents published in the 10 most relevant journals, 2011-2021.

Rank	Journal	Documents in the total number of documents in the journal ratio			N thematic documents		
		2011 - 2016	2017 - 2019	2020 - 2021	2011 - 2016	2017 - 2019	2020 - 2021
1	Sustainability	0	0.131%	0.598%	0	19	147
2	Ieee Access	0	0.021%	0.112%	0	5	34
3	Journal of Business Research	0	0.228%	1.948%	0	3	35
4	Technological Forecasting and Social Change	0	1.078%	2.179%	0	12	26
5	Applied Sciences Basel	0	0.031%	0.133%	0	3	28
6	Journal of Medical Internet Research	0	0.265%	1.008%	0	4	26
7	Mis Quarterly Executive	5.128%	12.121%	10.638%	6	8	5

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8	Business Process Management Journal	0	2.823%	5.464%	0	7	10
9	Frontiers in Psychology	0	0.026%	0.148%	0	2	15
10	Sensors	0	0.023%	0.190%	0	3	14

Mis Quarterly Executive presents over 10% of its content and Business Process Management Journal has more than 5% of its articles oriented towards the topic of DT.

To indicate the growth of the investigation, we have broken down the total of publications in the sample into three time blocks. The first is 2011-2016, the second is 2017-2019, and the third is 2020-2021. This grouping is intended to identify publication growth over time, recognizing the effect of the pandemic.

Our analysis draws us to the cross-sectional leadership of Mis Quarterly Executive, with 5.128% of publications about DT during the first time block, 12.121% of publications in the second block, and 10.638% of all DT-related publications in the third time block. In this regard, there is a drop in publications after the beginning of the pandemic, diverging from the expected behavior considering the other journals' behavior.

This greater productivity after the beginning of the pandemic becomes clear upon analyzing all publications about DT in the Business Process Management Journal, which began to publish during the second time block, with 2.823% of all publications focusing on DT. This journal increased its DT-related production by over 90% in the third time block, with 5.464% of the total studies, during a time period marked by the pandemic. These increases in DT publication growth after the beginning of the pandemic occur in all of the participating journals from the sample.

1.6 The most productive authors

At least 9,017 individual authors have studied digital transformation. Given that it is a relatively new theme, there is no evidence of a major concentration of scientific production by author. The author with the largest number of publiations has 15 articles. Ten authors concentrate 2.54% of all scientific production in this regard.

In terms of publications, the top of the list is occupied by Sullivan, with 15 articles, 70 WoS citations and a 5 H-index. From authorship order, we can see that Sullivan has been a thesis advisor on 10 occasions and led 5 publications. Claire Sullivan is an associate professor and runs the digital health research network at the University of Queensland, in the Health Services and Research Centre.

The second most productive author is Sheikh, with 11 articles, 146 WoS publications, and a 5 H-index. As a bit of relevant background, based on authorship order, Sheikh has not lead any publications or been a thesis advisor; his publication volume indicates co-authorship appearances. Aziz Sheikh is a research and development professor in primary care at the Usher Institute in the University of Edinburgh, UK.

The third place, with 9 publications, 60 WoS citations and a 4 H-index, is held by Staib. Authorship order appearances indicate that he has not led any publications, although he has been a thesis advisor twice. Andrew Staib is an emergency room doctor and clinical informatician, as well as the joint director of Emergency Medicine at the Princess Alexandra South Metro Hospital, Australia.

The fourth place, with 8 publications, is held by Hess. He has the highest number of WoS citations at 885, and a 6 H-index. Hess has led one publication and been a thesis advisor 5 times. Thomas Hess is the director of the School of Administration and Institute for Digital Administration at the University of Munich, Germany.

One publication from Hess has 1,793 citations overall, incorporating various databases. This greater citation coincides with a year which saw a strong increase in the number of publications about DT, 2015. Given the greater interest in studying the construct, Hess has been widely cited by subsequent authors. This has centered on the publication "Digital transformation strategies", which proposes an approach for coordinating, prioritizing and implementing digital transformations in a company.

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One interesting background element for analysis is that Ghobakhloo has 7 publications, a 4 H-index led 5 publications and advised for 2 theses. Appearance order review is key to distinguish leading publication authors from co-authors.

Table 7. Productivity by author

Bradford	Rank	Author	N documents	%	WoS Citations	Local Cited	H index	Corresponding	First author	Last author
Core	1	Sullivan C	15	0.48%	70	16	5	5	3	10
	2	Sheikh A	11	0.36%	146	13	5	0	0	0
	3	Staib A	9	0.29%	60	16	4	0	1	2
	4	Hess T	8	0.26%	885	108	6	1	1	5
	5	Barata J	7	0.23%	65	<6	3	3	3	5
	6	Burton-jones A	7	0.23%	55	16	3	2	0	0
	7	Ghobakhloo M	7	0.23%	271	15	4	5	5	2
	8	Savastano M	7	0.23%	75	<6	4	3	3	2
	9	Steiber A	7	0.23%	13	16	2	4	5	3
	10	Anto JM	6	0.19%	135	8	5	0	0	0

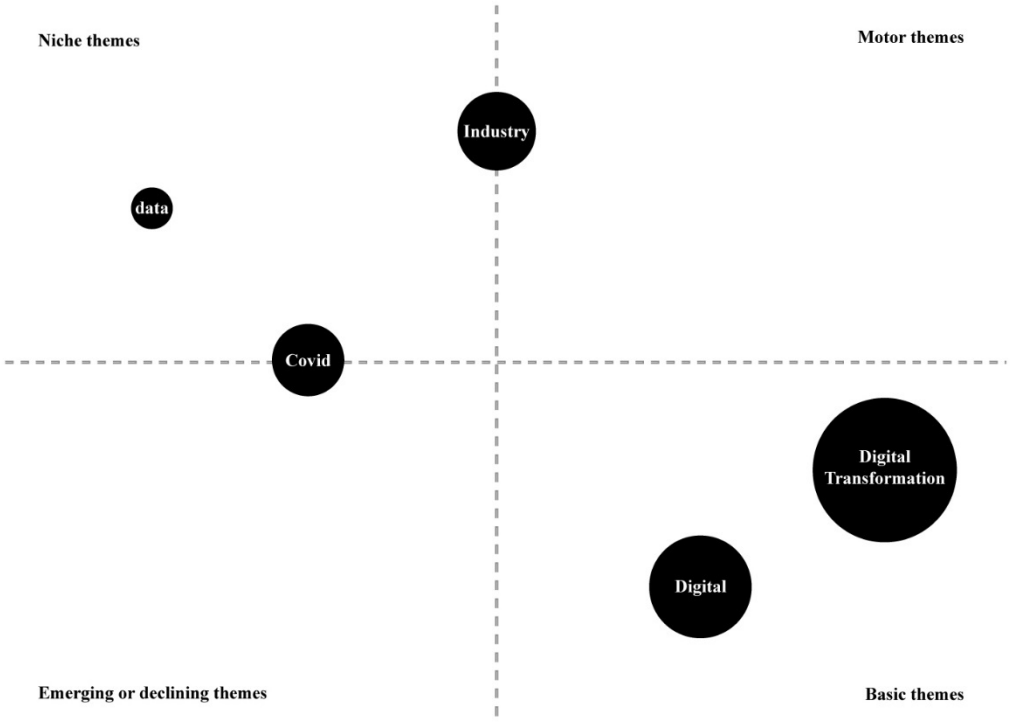

Figure 5. Strategic diagram of author keywords, according to WoS citable papers.

 doi:10.20944/preprints202207.0107.v1

After observing the conceptual subdomains (see figure 5), through the cross between mapping and performance analysis, based on the keyword concurrence proposed by Covo et al. (2011), these present 5 cores: data, Covid, Industry, Digital, Digital Transformation. When analyzed, they are grouped as follows:

A. Motor themes (TM): These present high density and strong centrality. They are relevant to the structure and development of the area: Industry (134), manufacturing (46), industry (32), digital twin (28), smart (25), systems (23), industries (21), fourth industrial revolution (18), industrial internet of things (18), smart manufacturing (18), skills (15) and technological innovation (15).

B. Highly developed and isolated topics (TADA): These present no background and lack general importance within the area; however, they are highly specialized and concentrated: Digital (268), Transformation (176), artificial intelligence (112), big data (100), internet of things (56), machine learning (46), blockchain (43), cloud computing (41), IOT (27), cybersecurity (24), automation (24), e-commerce (21), platforms (18), and augmented reality (17).

C. Emerging or Declining Themes (EDT): These present low centrality and density. These themes are generally in decline or indicate new trends: Covid-19 (125), higher education (64), education (55), ITC (37), social media (34), pandemic (30), learning (27), case study (26), digital skills (25), collaboration (21), digital health (22), digital literacy (20) and e-learning (19).

D. Basic and cross-cutting themes (TBT): these show high relevance in the research area, but do not yet show a good level of development. The topics presented are general and cross-cutting: Digital transformation (1026), digitalization (279), innovation (126), industry 4.0 (100), digital economy (86), digitization (75), technology (74), management (71), digital technologies (69), sustainability (65), digitalization (56), digital technology (45), business model (39), strategy (39) and digital innovation (35).

1.8 Authors and collaboration networks

Based on figure 6 we can identify three clearly differentiated collaboration groups. In Group 1, we can see a median cooperation relationship between CR, DGM, MA and TD, with CR being the one who can bring together the other authors. Similarly, we see a median collaborative relationship between BS, HK and FA, with BS attracting other authors. Group 2 shows a strong collaboration between NP, BD and PD. NP attracts two research subgroups. Finally, in group 3 we see a strong relation between PV and SD. In turn, there is a median collaboration between PV, KA, WJ and SD. In this group, PV generates collaboration networks with other research groups. The role of authors capable of connecting research groups is essential, particularly for new authors. This appears in the group formed by LM, DMA, CC and LG, who are linked to NP via PD. The same occurs with SJ, DM and PS, who are linked to PA via MG.

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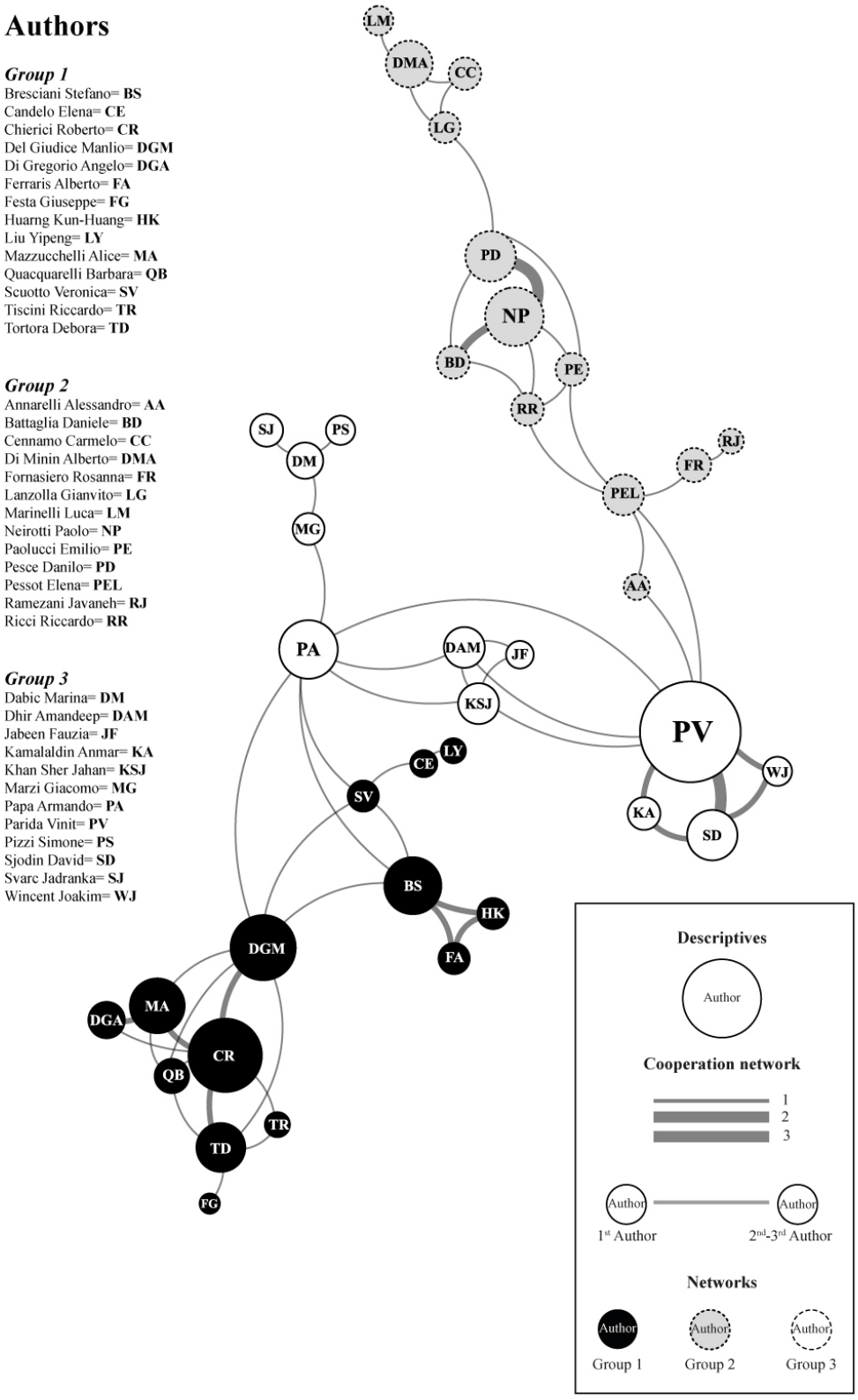

Figure 6. Collaboration groups among authors

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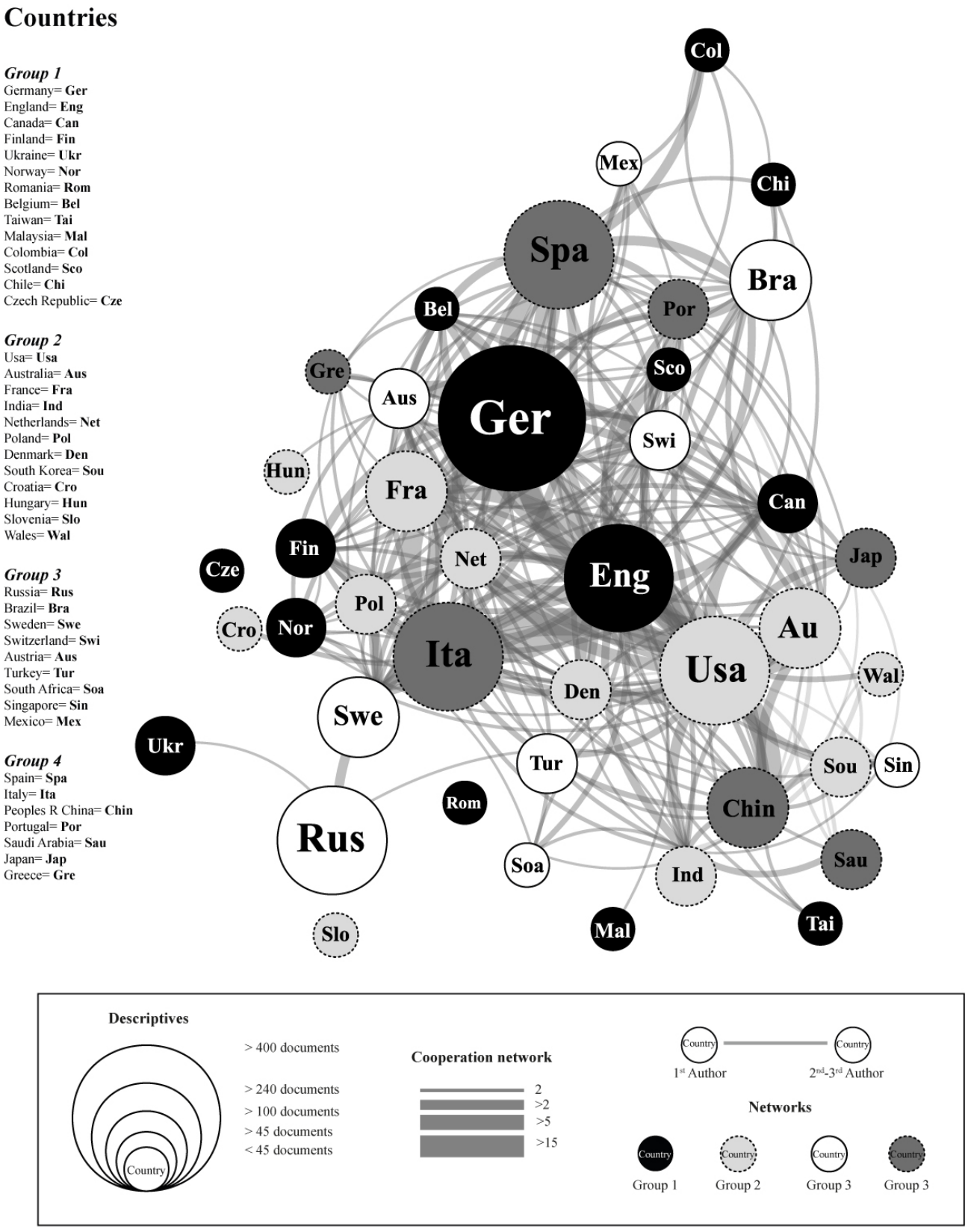

Figure 7. Collaboration networks among countries

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Figure 7 shows the leadership of Germany, with a total of 414 documents, a significant capacity to attract others (degree: 52), a high capacity for relations with other countries (closeness; 0.81) and a potential for connection (betweenness) of 0.07. Next in leadership is England, with 265 total documents, a capacity to attract others of 56, closeness of 0.85 and betweenness of 0.07. In third place we have Spain, with 286 total documents, a capacity for relations with other countries of 46, closeness of 0.86 and betweenness of 0.07.

There is evidence for a clear collaborative nucleus linked to geographical proximity. This, for instance, lets us appreciate the relation between European countries, among countries in Eastern Europe, with North America and Oceania, for Latin America and Asia. The exception to this collaborative logic is Japan, which has more collaboration with Australia, the USA and Canada.

Table 7. Analysis of Social Networks applied to the sample, separated by groups and countries (see figure X), Centrality of Degree, Centrality of Intermediation and Centrality of Closeness.

Cluster	Label	N documents	Degree	Closeness	Betweenness
1	GERMANY	433	52	0.81	0.07
1	ENGLAND	267	56	0.85	0.07
1	CANADA	74	36	0.68	0.01
1	FINLAND	69	39	0.7	0.02
1	UKRAINE	69	8	0.52	0
1	NORWAY	54	28	0.62	0.01
1	ROMANIA	43	22	0.59	0.01
1	BELGIUM	38	33	0.66	0
1	TAIWAN	37	17	0.56	0.01
1	MALAYSIA	35	15	0.53	0
1	COLOMBIA	33	16	0.55	0.01
1	SCOTLAND	26	31	0.65	0
1	CHILE	22	12	0.53	0
1	CZECH REPUBLIC	22	14	0.55	0
2	USA	357	52	0.81	0.05
2	AUSTRALIA	130	46	0.76	0.03
2	FRANCE	118	37	0.69	0.01
2	INDIA	96	42	0.72	0.03
2	NETHERLANDS	78	44	0.74	0.03
2	POLAND	75	40	0.71	0.05
2	DENMARK	57	32	0.65	0
2	SOUTH KOREA	53	23	0.6	0.01
2	CROATIA	40	15	0.55	0
2	HUNGARY	36	16	0.56	0
2	SLOVENIA	25	15	0.56	0
2	WALES	23	17	0.56	0
3	RUSSIA	329	31	0.65	0.03
3	BRAZIL	106	33	0.66	0

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3	SWEDEN	98	36	0.67	0.01
3	SWITZERLAND	83	35	0.67	0.01
3	AUSTRIA	71	40	0.71	0.02
3	TURKEY	59	30	0.64	0.01
3	SOUTH AFRICA	37	24	0.61	0
3	SINGAPORE	33	30	0.64	0.01
3	MEXICO	27	24	0.6	0
4	SPAIN	292	46	0.76	0.07
4	ITALY	259	46	0.76	0.04
4	PEOPLES R CHINA	181	45	0.75	0.03
4	PORTUGAL	80	38	0.69	0.01
4	SAUDI ARABIA	61	25	0.59	0.01
4	JAPAN	45	31	0.65	0.02
4	GREECE	33	28	0.62	0.01

Degree (Centrality of Degree): England, Germany, USA, Australia, Italy and Spain are the countries with the highest number of documents which in turn work with various authors and generate a nexus capable of expanding reach and density of coauthors' network.

Betweenness (Centrality of intermediation): Central node represented by bridge authors: Germany (), Spain (), England (), Poland () and USA (). Connection nexuses between groups X and X for groups X and X.

Closeness (Centrality of Closeness): England (), Germany (), USA (), Spain (), Italy (), Australia (), Peoples R China (), Netherlands () and India (), are the authors with the best capacity to connect with other actors in the Network.

4. Discussion

The scientific literature on TD presents a sustained increase, coinciding with the greater need to use technology in work and social spaces. Thus, for example, the occurrence of the COVID-19 pandemic and subsequent confinement forced organizations to digitize both processes and practices, in order to maintain operations in a context of social isolation, accelerating DT and consequently increasing research interest in understanding the phenomenon.

In terms of relationships, it is not surprising that the most productive collaborative nuclei correspond to highly industrialized countries with greater availability of resources and technology from Europe, North America, or Asia — The Group of Eight (G8) or The Group of Twenty (G20)—. In this sense, it would be interesting to contrast the development gap in TD between developed economies versus other emerging ones, for instance, taking into account the ecosystem that surrounds each one. On the other hand, the focus on R&D is likely to be greater in developed economies, where applied research can already be glimpsed, as opposed to emerging economies, where research appears relegated to the educational sphere or theoretical exploration. This difference would account for the lower availability of resources for the application and implementation of DT in emerging economies.

The initial development of the topic allows us to conclude that, given the initial maturity level of the research, the analysis type will have to be replicated within 5 years to evaluate productivity behavior over time. This is an incipient study area, which reveals the need to reach agreements about the dimensions which are part of the construct. There

are frequent qualitative-type studies that seek to determine the process wherein DT is carried out in specific productive companies. These studies aim to identify the drivers behind DT and the benefits in general terms for organizational administration and competitiveness. Due to this, there is no notable theoretical integration of scientific disciplines interested in studying the same phenomenon.

One interesting gap to highlight is the lack of a psychometric instrument to quantify the level of development of an organization undergoing DT, focusing on clearly established dimensions, which constitutes a study opportunity for subsequent research.

Having an instrument would allow standardized comparisons to be made, contributing to the development of advanced models in DT.

It should be noted that out of the 15 most cited publications, none of them addresses DT from a behavioral science perspective. The disciplines dedicated to studying the transformation have mostly been mathematics, administration sciences, and information sciences. Even though this is a phenomenon with a cognitive-behavioral impact, psychology-linked studies are scarce.

This point is particularly relevant, given that the understanding of DT without the human component is inconclusive, which would leave out individual constructs such as motivations, cognitions, and attitudes, as well as collective constructs such as organizational culture, climate, and organizational change, among others. All these elements have proven to be decisive when defining success in the implementation of a DT strategy since it is the people who create, develop and use the technology.

The first limitation of the study is related to an intrinsic trait of bibliometric studies, related to the results' sensitivity to the type of database used. This limitation supposes that an important amount of publications are not part of the analysis, due to their limited impact. The second limitation is due to the lack of agreement about the dimensions of the construct. While the general definition of DT has some points in common from the discipline wherein it is studied, this does not happen when defining the dimensions which are part of the construct, which presents the need to create multidisciplinary research teams incorporating administration sciences, information sciences and behavioral sciences.

As part of the research challenges, it will be necessary to review the explanatory potential of the COVID pandemic in the increase in publications, beyond the publication increases which are evident in descriptive terms.

5. Conclusions

This article presents a bibliometric analysis about digital transformation. There is no explanation of the causality of scientific production with other variables, but there is an ample base of knowledge to study academic literature about DT. Consequently, the main purpose has been to allow researchers interested in the subject to approach it, facilitating access to authors, their collaborative networks and publication media. There is also an expression in descriptive terms of the effect of the pandemic on the rise in publications linked to DT.

The first conclusion is the rise in publications about digital transformation. This rise broke the historical productivity trend in 2006, and has maintained sustained growth since that date, which has risen strongly together with the pandemic in 2020, a period during which productivity reached 1,098 publications. The beginning of the pandemic

 doi:10.20944/preprints202207.0107.v1

allowed us to deduce greater interest in the study of DT due to the implementation of new technologies in a teleworking context. This is a hypothesis which could be proven in a future study in this regard. DT is a contingent topic with direct organizational application. Thus, it can be foreseen that more research about DT will continue to appear in the future, given the increasingly central role of technology in development of human processes. It has also raised interest in the economic, productivity and efficiency benefits it presents to organizations.

The most cited article is Candes, E. et al. in 2006, a year which saw a progressive rise in publications about DT. The author is incorporated into the basis of other researchers' studies. This article was based on mathematics, similar to the first article of 1986. After analyzing the content of both publications, we can see that the use of the definition "digital transformation" arises from mathematics to describe a disruption which generates an improvement in internal processes, facilitating organizations' response capacity to environmental challenges. The following place for citations is held by the study applied to industries by Frank, AG. et al. in 2019, followed by the theoretical study by Matt, C. et al. in 2015.

Productivity by country shows the leadership of Germany, and the capacity of this country to attract other European countries, forming a well-defined collaborative nucleus. Consequently, the most productive institutions are the University of London, the Polytechnic University of Milan, and the University of Turn, all of which have an H-index of 9 or greater, over 200 citations and over 20 associated documents.

Geographical proximity is related with the various collaborative centers. There is evidence for collaborative nuclei in Europe, Eastern Europe, Asia, North America, and Latin America.

Regarding the authors, three groups have been established, according to their degree of connection and collaboration. From this grouping, we can identify that each group has a principal author, capable of establishing cooperative relations with other authors and other research subgroups. Thus, for example, the first research group shows Chierici Roberto in this role; the second group has Neirotti Paolo as the most connected author; and group three has Parida Vinit.

The keywords in the studies' development have been organized into quadrants. In the 1) motor themes quadrant, with high density and strong centrality there are application areas of DT, such as industries and manufacturers. There are also some DT drivers, such as the Internet of Things (IoT), skills and technological innovation. Quadrant 2) high development and isolated themes is centered on concepts such as technology, digital, AI, big data, IoT, and others. Quadrant 3) is about emerging or declining topics, with low centrality and density, and includes topics such as higher education, pandemic, learning, case studies, digital skills, collaboration, digital health, and others. Finally, quadrant 4) has basic and cross-sectional topics with high relevance and good development that show general and broad keywords, such as digital transformation, innovation, technology, business models, and others.

Analyzing the development of the subjects by journal has allowed us to differentiate total productivity of the percentage of publications dedicated exclusively to DT. With this separation, we can recognize that Mis Quarterly Executive is the journal with the largest amount of articles dedicated to DT. The journal with the most total publications about DT is Sustainability. This journal has seen sustained total publication growth over time. This increase has reached 749%, from the beginning of its publications, reaching a cumulative total of 24,568 publications in the period 2020-2021. Due to this, there is also

evidence of a greater number of publications about DT, for a total of 166 from the beginning of publications until 2021. The greater global publication rate of this journal could be related to its open-access, swift-publishing nature.

Upon analyzing productivity by author, given that it is a subject of recent investigative interest, article concentration is still modest. The largest number of publications associated with one author is 15. It is important to distinguish between lead authors, coauthors and authors working as thesis advisors. From this perspective, Sullivan stands out by leading 5 publications, with an H-index of 5, i.e., at least 5 articles cited 5 times, as well as being a thesis advisor who participated in 10 theses. Hess also stands out, with 855 total citations, a 6 H-index, leadership on one publication and 5 thesis advisory roles.

6. Patents

Author Contributions: Author contributions: Conceptualization: P.R.C.; method: Y.E.U-B. and P.R.C., writing: P.R.C., Y.E.U.-B. and editing: P.R.C., Y.E.U.-B., J.B.G., and L.A.C. All authors have read and accepted the published version of the manuscript.

Data Availability Statement: The exploratory sample was collected on January 1, 2022 and was finally rectified on April 16, 2022. The entry records were made using the University of Granada's licenses. Individual values may vary according to the institutional agreement signed.

Acknowledgments: This work was supported by the Doctoral Program in Law and Business Administration, University of Lleida, Spain, and the Programa de Investigación Asociativa (PIA) en Ciencias Cognitivas, Research Center on Cognitive Sciences (CICC), Faculty of Psychology, Universidad de Talca, Chile.

Conflicts of Interest: This paper presents no conflicts of interest.

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