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Digital Transformation in the Engineering Research Area: Scientific Performance and Strategic Themes

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Abstract. In recent years, digital transformation has gained increasing interest from researchers and practitioners, putting efforts towards developing a better understanding, resulting in emerging independent research areas. Consequently, the research under the digital transformation, even though becoming a hotspot, remains very fragmented. This study has tried to provide a quick overview of the scientific output in this field, recognizing prolific authors, most productive countries and most relevant and influential journals in the DT field by using bibliometric analysis on 946 publications published during the timespan 2001:2022, retrieved from Thompson Reuters Web of Science. Also, this study presented the thematic analysis and provided insights to researchers and scholars in the field of DT regarding the current research landscape and prospects. The resulting knowledge will help scholars and researchers detect research opportunities and gaps for future works and contribute to continuing research in this area.

Keywords: Digital Transformation, Engineering Research, Bibliometric Analysis, Bibliometrix.

1 Introduction

Digital technologies are disrupting the way we connect and create value for users, by transforming business models and how businesses introduce innovations and sustain their competitive advantages, enabling manifold benefits [1]–[4]. Digitization and digital transformation (DT) have been occurring in organizations since the 1950s [5]. However, it has been 342 years since Gottfried Wilhelm Leibniz developed the binary system in 1679 and 75 years since ENIAC (ENIAC-Electronic Numerical Integrator and Calculator), the first computer to start its use was built in 1946 at the University of Pennsylvania. From then, and especially in recent years, the concept of digital transformation has gained increasing interest from both researchers and practitioners, putting efforts towards developing a better understanding, resulting in emerging independent research areas [6].

Many authors have used bibliometric analysis to identify aspects of science that receive the most contributions from authors, journals, countries, and the collaborative and co-occurrence networks among them [7]–[12]. To contribute to a better understanding of DT performance in the scientific literature, including its intellectual and social structure, several studies performed a bibliometric analysis of the DT literature [6], [13]–

[16]. Unlike the previously mentioned studies, by using a bibliometric analysis we wanted to focus on an in-depth analysis of DT in the engineering research area.

The primary purpose of this study was to investigate DT scientific performance and strategic themes landscape in the engineering research area. The resulting knowledge will help scholars and researchers detect research opportunities and gaps for future works and contribute to continuing research in this area [17], [18].

2 Research Methodology and Dataset

The search and data collection was conducted on the 1st of February 2022 in the online bibliographic database Clarivate Analytics Web of Science (WoS) Core Collection. We used the search string: “Digital transformation” in the Topic field (including title, abstract and keywords) for the period 2001 till 2022 (inclusive). 2001 was taken as the starting year, as no publication matching the search criteria had been identified before that year. From the retrieved database under the category Document types, we excluded: editorial materials, corrections, additions, book reviews, retracted publications, biographical items and reprints. Furthermore, the search was restricted to the Engineering research area and English language articles. We exported the Full record with cited references (all article information available, including the authors' name, abstract, keywords, editors, references etc.) in plaintext format; A total of 946 documents and 2,958 keywords were included for analysis.

Query link: <https://www.webofscience.com/wos/woscc/summary/f5aed942-add3-43f8-8da3-f7702c9f84b5-3371e9b5/relevance/1>

Finally, we used the "bibliometrix" R-package software for quantitative research in bibliometrics and scientometrics developed by Aria and Cuccurullo and written in the R language [19]. Specifically, we used a web interface Biblioshiny aimed at users without coding skills.

3 Performance Analysis

Before moving forward with the analysis, the following section provides the descriptive characteristics of DT literature. The final dataset consisted of 946 publications published during the timespan 2001:2022. There were 506 articles (including early access) comprising 53.5 % of total production, followed by 440 proceedings papers. These publications were produced by 3034 authors (93 authors of single-authored documents and 2941 authors of multi-authored documents) with 3341 author appearances and 0.312 documents per author. In addition, there were 97 single-authored and 849 multi-authored articles with 3.53 co-authors per document and a collaboration index of 3.46 (calculated as Total Authors of Multi-Authored Articles/Total Multi-Authored Articles).

Publications Scientific Production Over Time. Fig. 1 graphically represents the dynamic of the scientific production over time. It is possible to observe in Fig. 1 the appearance of the first publication in 2001. Until 2015 publications related to DT were circumstantial, and the number of publications published per year stagnated. There was limited production at the start, but literature production grew exponentially from 2017

until today. Total citations per year increased exponentially from 2017, with the maximum number of citations reached in 2021 (3,313). In total, 6,309 citations, 5,863 without self-citations with 6.67 citations average per item and the h-index 36. The h-index value is based on a list of publications ranked in descending order by the times cited count. It looks like publications and citations are decreasing after 2021, but it must be noted that Fig. 1 doesn't present all data for 2022 but only until April.

The Performance Analysis of Countries. Research contribution to the collection of 946 publications originated from 81 countries. Table 2 shows two sets of data, summarizing the top 10 contributing countries with the highest scientific production frequency in the publications collection (left side) and the total citations (TC) of publications (right side). The most productive country by far is the Germany (n=249), followed by China (n = 141), the USA (n=138), the Russia (n=130), the Italy (n=127), UK (n=103), Spain (n=94), Brazil (n=77), Portugal (n=60) and India (n=56). Ten most productive countries have more than 57.8% of all countries' frequency in publications collection, while Germany solely has more than 12.25%. Germany comes in first place in TC as well.

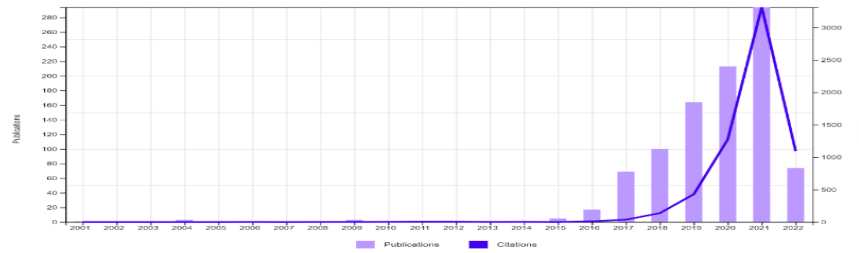


Fig. 1. Citations and publications over time.

Table 1. Most productive/cited countries.

Country	Frequency	Country	TC
Germany	249	Germany	953
China	141	Brazil	743
USA	138	UK	526
Russia	130	Italy	380
Italy	127	China	310
UK	103	Spain	307
Spain	94	USA	293
Brazil	77	Iran	272
Portugal	60	Austria	200
India	56	Canada	180

The Performance Analysis of Journals. Table 2 ranks the journals based on number of publications per source (No. A) with their source impact indicators (h-index and TC). These are the core sources for publishing DT related research in engineering research area. The most relevant source is the IEEE Access, followed by the Applied Sciences-Basel and Sensors.

Table 2. Most productive journals

Sources	No. A	H-index
IEEE Access	37	8
Applied Sciences-Basel	35	7
Sensors	23	8
IEEE Transactions on Engineering Management	18	3
Journal of Manufacturing Technology Management	17	6
Electronics	14	3
Production Planning & Control	13	8
Advanced Engineering Informatics	12	5
International Journal of Production Economics	11	7
Automation in Construction	9	4

The Performance Analysis of Authors. Table 3 shows the top 10 most cited and productive authors, based on the number of published articles (No. A) and TC. It is possible to observe that Leitao, P. is the most productive author, followed by Romero, D. and Stjepandic, J. However, Ayala, N.F., Dalenogare, L.S. and Frank are the most cited. A.G. Their contribution is concentrated in one joint article, ‘Industry 4.0 technologies: Implementation patterns in manufacturing companies’ [20] which is also the most cited publication in the database. In this article, the authors aimed to analyze the adoption patterns of Industry 4.0 technologies in manufacturing firms. These authors are followed by Ghobakhloo, M., whose main contribution is concentrated in two articles: ‘Industry 4.0, digitization, and opportunities for sustainability [22] which contributes to the sustainability literature by systematically identifying the sustainability functions of Industry 4.0, and ‘Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing ‘ [23] demonstrating how small manufacturing firms can leverage their Information Technology (IT) resources to develop the lean-digitized manufacturing system that offers sustained competitiveness in the Industry 4.0 era.

Table 3. Most cited/productive authors.

Most cited authors	No. A	TC	Most productive authors	No. A
Ayala, NF	1	505	Leitao, P	10
Dalenogare, LS	1	505	Romero, D	8
Frank, AG	1	505	Stjepandic, J	8
Ghobakhloo, M	4	298	Pfouga, A	7
Mangla, SK	2	133	Deschamps, F	6
Li, J	5	125	Li, J	5
Kassem, M	1	119	Moller, DPF	5
Greenwood, M	1	115	Wuest, T	5
Macchi, M	4	112	Barata, J	4
Fathi, M	2	110	Barbosa, J	4

Also, the author that appears on both sides is Li, J. It must be highlighted here that Barata, J and Barbosa, J, with four publications, are on this list because the order of the authors is listed alphabetically. Apart from them, several other authors have published four publications, which are not listed in the table among the most productive authors but are among the most cited authors. The most productive authors Leitao, P. (No., A=10), has 59 citations, Romero, D. (No. A=8) has 43 citations and Stjepandic, J. (No. A=8) has 65 citations.

4 Mapping Strategic Themes

A thematic map is constructed based on a full-time span from 2001 to 2022 by employing co-word analysis. We have used the top 400 keywords, and the minimum cluster frequency was set to 5 per thousand documents. First, co-word analysis allowed us to discover the clusters of closely tied keywords (and their interconnections) [21]. Then, these clusters were considered as themes and analyzed according to their relevance and level of development [22]. According to the semantic strength of their density (y-axis) and centrality (x-axis), themes were classified and mapped in a two-dimensional space or thematic map. The centrality measures the importance of the selected theme by the degree of collaboration among different topics (external associations), and density measures the development of the chosen theme by the cohesiveness among the keywords (internal associations). Thus, in the high-density and high-centrality quadrant (Q1), we would find the primary research themes that attract the most scientific output and citations related to this topic: the “motor themes.” Conversely, we see emerging themes or those fading out in the low-density, low-centrality quadrant (Q3). The upper left-hand quadrant, representing high density and low centrality, refers to those highly developed themes internally but isolated—unconnected to other networks (Q2). Finally, in the lower right-hand quadrant (Q4) (low density and high centrality), we find those essential or core themes that cut across various areas of knowledge [11], [21], [23]. The number of representative labels in each theme is set to 3. The most central keyword (with the highest value) is used to label each thematic network.

Notable, from the Fig. 2 clusters such as “manufacturing” and “sustainability” are central and intensively discussed in relation to DT in engineering research area. We could call them a mainstream theme. It could be noted that “manufacturing” is sandwiched between Q1 and Q4, is well developed and capable of structuring the research field and it remains the leading theme in the field due to its centrality. The theme “sustainability” lies in the border of the Q1 and Q2 on and may thence be described as having a modest external connection. This theme is central to the research area but requires more focus. Clusters in Q2 such as “sustainable development” and “change management” with their sub-topics have developed internal bonds, may be considered as specialized but still under-represented with marginal contribution the development of the field. These findings suggested that themes need to be more connected to DT.

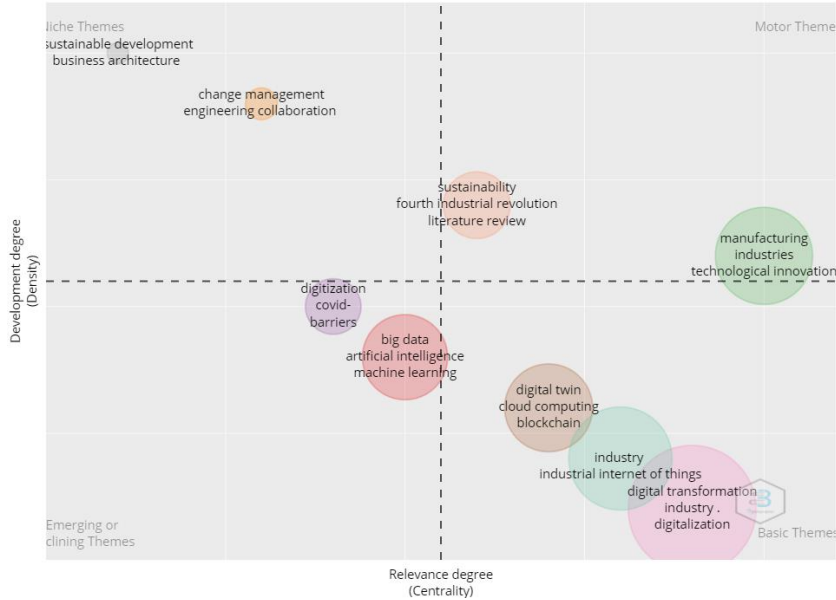


Fig. 2. Thematic Map.

Researchers in this field can expand these concepts and explore their potential interconnections with other topics in the field. When we look at the “big data” cluster in Q3 with its sub-topics it appears that it is emerging and transverses to Q4. These themes converge on “digital twin” cluster in Q4 and are very important for the further development and maturing of the manufacturing and DT research field [24], [25]. On the contrary, it could be assumed that “digitalization” cluster with sub-topics related to the Covid-19 and the pandemic are declining themes since more than two years have passed since the beginning of the pandemic and the intensity of research is declining. Clusters “digital transformation”, “Industry 4.0”, “digital twin” in Q4 are the basics, general, and transversal themes with high external associations, and are very important for DT field’s development in engineering research. They may correspond to the mainstream themes in the future.

5 Conclusion

This study has tried to provide a quick overview of the scientific output in this field, recognizing prolific authors, most productive countries and most relevant and influential journals in the DT field by using bibliometric analysis. This study revealed that the first publication on DT in the engineering research area was published in 2001, but until 2015 publications were circumstantial and stagnated. Literature production grew exponentially from 2017 until today. Foremost among the publishing journals revealed by the study is the “IEEE Access.” This result provides an important guide to scholars

regarding the suitable publishing outlet for their research papers. Also, this study presented the thematic analysis and provided insights to researchers and scholars in the field of DT regarding the current research landscape and prospects. New and emerging technologies connected with the “big data” cluster theme are significant for the further development and maturing of the research field. The study's weakness is the sample data collection. The analysis was limited to articles and proceeding papers in English, collected only from WoS. Collecting bibliographic data from multiple databases with expanded keywords would improve the study significantly. Future studies should include intellectual, conceptual and social structure and more in-depth co-word, co-citations and collaboration networks. Also, studies should be performed to explore the DT thematic evolution structure in the engineering area over time and investigate each thematic cluster in more depth to identify perspectives of the research field.

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