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Mapping the Intellectual Landscape of Digital Transformation in Manufacturing: A Bibliometric Analysis

Sheng Jiang [1,*]

[1] The University of Manchester, Manchester, Greater Manchester, United Kingdom
* Correspondence: Sheng Jiang, The University of Manchester, Manchester, Greater Manchester, United Kingdom

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Abstract: Driven by advanced manufacturing technologies (AMTs) and the evolving frameworks of Industry 4.0 and Industry 5.0, the manufacturing sector is experiencing a swift digital transformation. Despite significant growth in related research, a comprehensive synthesis of its intellectual landscape is still lacking. To address this gap, the present study applies a large–scale bibliometric approach, analysing 4,949 peer–reviewed articles from the Web of Science Core Collection with the aid of CiteSpace, HistCite, and VOSviewer, aiming to delineate research trends, thematic groupings, and collaboration patterns. The results show a sharp increase in publications after 2017, with growing attention to cyber–physical systems, digital supply networks, servitisation, and sustainability. Co–citation and keyword analyses reveal a shift from technology–focused studies toward integrated, human–centric, and value–oriented digital strategies. The analysis further highlights fragmented collaboration patterns and underexplored thematic linkages, indicating opportunities for interdisciplinary and international research. Overall, this study provides a structured, data–driven overview of the field and offers insights to support both future research and managerial decision–making in manufacturing digital transformation.

Keywords: digital transformation; advanced manufacturing technologies; manufacturing sector; bibliometric analysis; Industry 4.0; Industry 5.0

1. Introduction

1.1. Research Background

The manufacturing sector is experiencing significant change propelled by the advent of Industry 4.0 and the ongoing development of Industry 5.0. Industry 4.0 brings together digital innovations including the Internet of Things (IoT), cyber–physical systems, and artificial intelligence (AI) to improve operational efficiency, adaptability, and data–informed decision–making within production systems. Extending this technological base, Industry 5.0 focuses on human–centered manufacturing, highlighting collaboration between humans and robots, as well as priorities such as sustainability, system resilience, and customized value delivery [1,2].

Advanced manufacturing technologies (AMTs), including AI, machine learning, robotics, and additive manufacturing, have fundamentally reshaped production systems by strengthening automation, analytics capabilities, and mass customisation [2,3]. These technologies support more intelligent and sustainable manufacturing environments while enabling closer integration between digital systems and human expertise [4].

Despite the rapid expansion of research on digital transformation (DT) in manufacturing, the intellectual structure of this field remains fragmented. Existing studies typically focus on specific technologies, applications, or industrial contexts, making it difficult to identify overarching research trajectories, dominant themes, and influential contributions. Although prior work–particularly in journals such as the *International Journal of Production Research*–has examined DT and AMTs across sectors including automotive manufacturing, pharmaceuticals, and smart equipment design, a comprehensive and longitudinal mapping of the field is still lacking [5–8].

To address this gap, this study applies bibliometric analysis to systematically map the intellectual landscape of DT and AMTs in manufacturing. By tracing thematic evolution, research clusters, and collaboration patterns, the study aims to provide a structured, data–driven synthesis that supports future empirical research and applied work in production and operations management.

Figure 1 illustrates the historical evolution of manufacturing from mechanisation to advanced manufacturing technologies, highlighting the progression from Industry 1.0 to Industry 5.0 and the increasing role of digital transformation in shaping production paradigms.

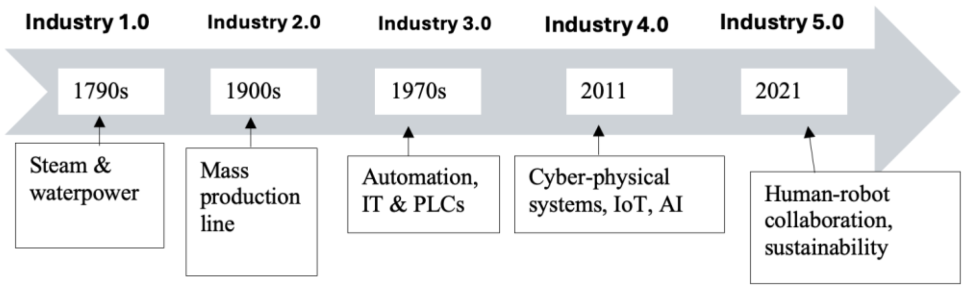


Figure 1. Digital Transformation in Manufacturing.

1.2. Research Questions and Objectives

Aim:

This study aims to examine how advanced manufacturing technologies (AMTs) and digital transformation (DT) have been conceptualised and investigated in the academic literature through a large–scale bibliometric analysis.

Objectives:

1) To identify key research trends, thematic structures, and influential studies related to DT and AMTs.
2) To analyse publication patterns, co–authorship networks, keyword clusters, and citation bursts using CiteSpace, HistCite, and VOSviewer.
3) To derive managerial implications from the identified trends in order to support decision–making related to digital strategy, innovation, and operational performance in manufacturing.

1.3. Research Methodology and Steps

This study adopts a macro–level bibliometric approach to analyse the evolution of DT and AMTs research. Data are drawn from the Web of Science Core Collection (WoSCC), ensuring high–quality, peer–reviewed sources with comprehensive bibliographic metadata. CiteSpace and HistCite are used to examine research trajectories, co–citation structures, and thematic clusters, while VOSviewer supports keyword co–occurrence analysis and visualisation of research intensity. Particular emphasis is placed on temporal dynamics, citation bursts, and network evolution.

1.4. Research Innovation and Contribution

This research contributes to the production research literature by offering a large–scale, data–driven overview of the intellectual development of DT and AMTs over the past two decades. By revealing key research streams, emerging themes, and collaboration patterns, the study identifies underexplored areas and provides a foundation for future empirical investigation. The findings also inform the development of decision–support perspectives for managing digital transformation in manufacturing contexts.

1.5. Structure of the Paper

The structure of this paper is outlined as follows. Section 2 details the procedures for data acquisition and the bibliometric techniques applied. In Section 3, the outcomes of the bibliometric study are reported, covering publication patterns, thematic developments, and collaboration structures. Section 4 explores the practical and scholarly implications derived from the analysis. Finally, Section 5 provides concluding remarks and suggests avenues for future investigation.

2. Data Collection and Bibliometric Methods

This study adopts a macro–level bibliometric research design to analyse the intellectual landscape of digital transformation (DT) and advanced manufacturing technologies (AMTs). The methodology combines systematic literature retrieval with quantitative bibliometric techniques to ensure rigour, transparency, and replicability.

2.1. Literature Screening and Data Collection

The Web of Science Core Collection (WoSCC) was selected as the primary data source due to its comprehensive coverage of high–quality, peer–reviewed journals across disciplines and its suitability for bibliometric analysis. To capture literature at the intersection of DT and AMTs, a broad search strategy was employed using topic–based queries that included variations of advanced manufacturing– and digital transformation–related terms:

(((((((((TS = (advanced manufacture)) OR TS = (advanced production)) OR TS = (advanced manufactural)) OR TS = (advanced fabrication)) OR TS = (advanced manufacturing)) OR TS = (advanced manufacturing technology))) OR TS = ("Industry 4.0")) OR (TS = "Industry 5.0")) AND ((((TS = (digital transformation)) OR TS = (digital transition)) OR TS = (digitalization transformation)) OR TS = (digital changes))

The literature screening process is illustrated in Figure 2. An initial search identified 5,368 records. After excluding publications outside the 2000–2025 period (n = 247), non–article materials such as book chapters and editorials (n = 42), and non–English publications (n = 130), a final dataset of 4,949 records was obtained. No duplicate records were identified.

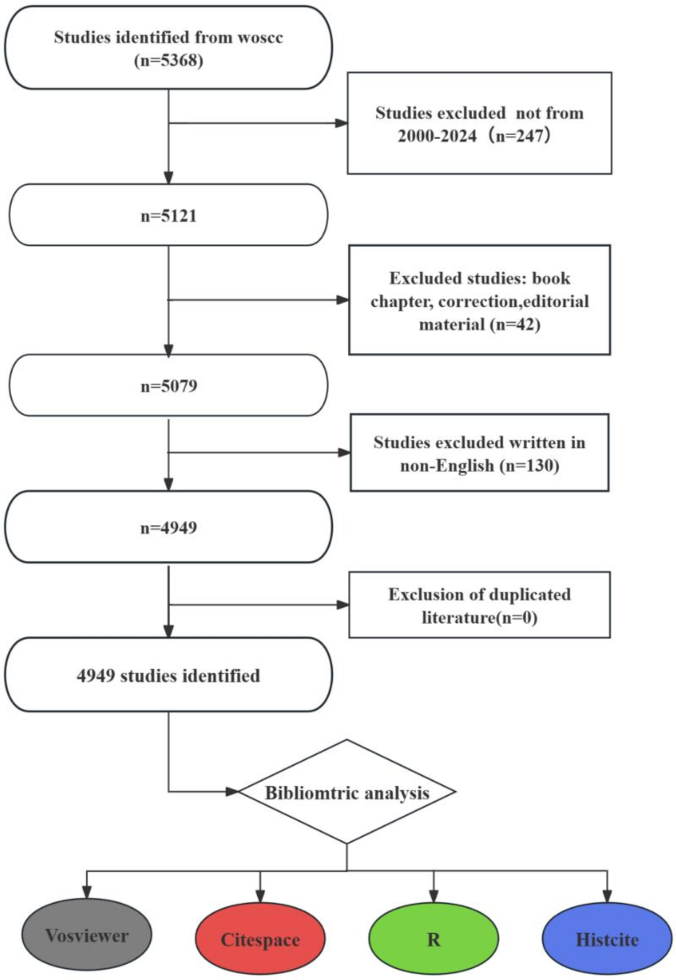


Figure 2. Coarse Screen for bibliometric analysis.

All records were downloaded in plain text format ("Full Record and Cited References"), including bibliographic metadata such as publication year, authors, affiliations, countries, journals, document types, and cited references. The final dataset comprised 2,923 journal articles, 1,477 conference papers, and 549 review articles, authored by 15,193 researchers from 4,715 institutions and published across 2,487 journals within 185 subject categories (Table 1). This dataset forms the empirical basis for subsequent bibliometric analyses.

Table 1. Query result.

Categories	Publication	Articles	Proceeding paper	Review	Authors	Institutions	Journals	Subject categories
Amount	4949	2923	1477	549	15193	4715	2487	185

2.2. Bibliometric Analysis

Multiple bibliometric tools were employed to capture complementary analytical perspectives.

1) CiteSpace (version 6.2.R4) was used to analyse co–citation networks, collaboration patterns, keyword clustering, and citation bursts. The dataset was analysed over the period 2000–2025 using one–year time slices. Keyword clustering was conducted across four temporal intervals (2000–2006, 2007–2012,

2013–2018, and 2019–2025), while reference clustering and burst detection were applied to identify emerging research fronts and influential publications.

2) HistCite Pro 2.1 was applied to identify seminal publications and visualise citation trajectories. Local Citation Score (LCS) and Global Citation Score (GCS) were used to rank influential studies, with citation networks generated for the top 30 publications based on LCS.
3) Alluvial diagrams were generated to visualise the longitudinal evolution of research themes. Keyword co–occurrence networks produced in CiteSpace were exported and processed using the Alluvial Generator to track the emergence, persistence, and convergence of thematic modules over time.
4) VOSviewer was employed for keyword co–occurrence analysis and visualisation of research density and collaboration networks. Keyword clusters and density maps were generated to identify dominant research topics and emerging intersections, with node size indicating keyword frequency and colour gradients representing temporal trends.
5) Descriptive statistical analysis and selected visualisations were additionally supported using R (version 4.2.2) and Microsoft Excel to summarise publication distributions by country and document type.

3. Bibliometric Analysis Results

This section presents the results of the bibliometric analysis conducted using CiteSpace, VOSviewer, and HistCite, focusing on publication trends, co–citation structures, and influential contributions within the literature on digital transformation and advanced manufacturing technologies.

3.1. Publication Trends and Patterns

3.1.1. Annual Publication Growth

A total of 4,949 publications related to digital transformation in advanced manufacturing were identified, including 2,923 journal articles, 1,477 conference papers, and 549 review articles. These publications were authored by 15,193 researchers from 4,715 institutions and published across 2,487 journals within 185 subject categories (Table 1).

As illustrated in Figure 3, research activity remained relatively limited between 2000 and 2017, with fewer than ten publications per year in the early 2000s. From 2018 onwards, publication output increased sharply, accelerating after 2021 and peaking at 1,014 publications in 2024. This trend reflects the growing academic attention to Industry 4.0 and, more recently, Industry 5.0 paradigms.

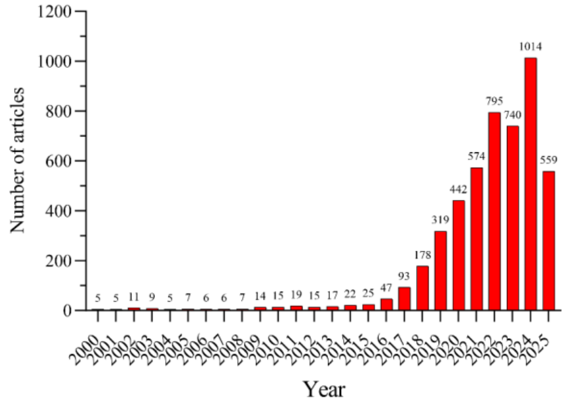


Figure 3. Annual distribution of publications on digital transformation in advanced manufacturing (2000–2025).

Figure 4 shows the top publishing journals in the field. Sustainability leads with 246 publications, followed by Applied Sciences–Basel (96) and Technological Forecasting and Social Change (70), indicating that research on digital transformation in manufacturing is concentrated in interdisciplinary and technology–oriented journals.

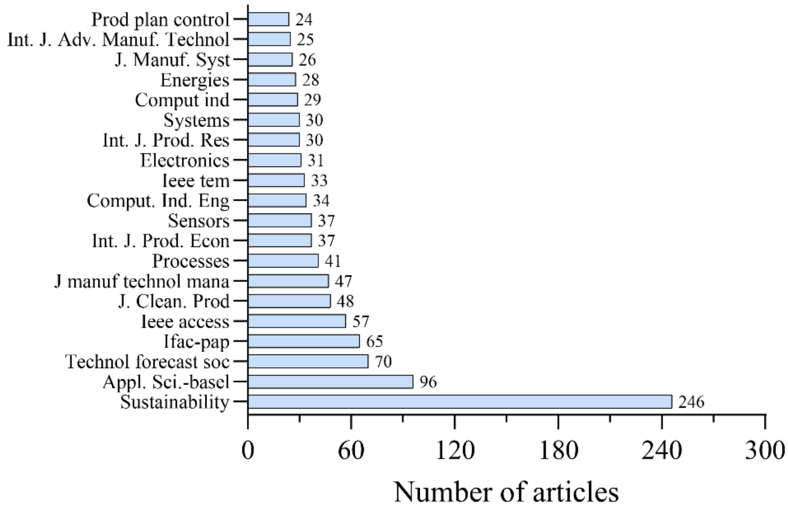


Figure 4. Top 20 journals by the number of publications on digital transformation in advanced manufacturing (2000–2025).

3.1.2. The Vein of Research on Digital Transformation in Advanced Manufacturing

The co–citation network (Figure 5) comprises 2,287 nodes and 7,135 links, revealing a highly interconnected knowledge structure. The temporal distribution of nodes indicates a clear evolution of the field. Early foundational studies (2000–2010) form dense core clusters, while the period from 2011 to 2018 reflects diversification and theoretical expansion. Since 2019, the network has developed into larger, more cohesive clusters, signalling thematic consolidation around topics such as Industry 4.0 frameworks, digital servitisation, and smart manufacturing [9].

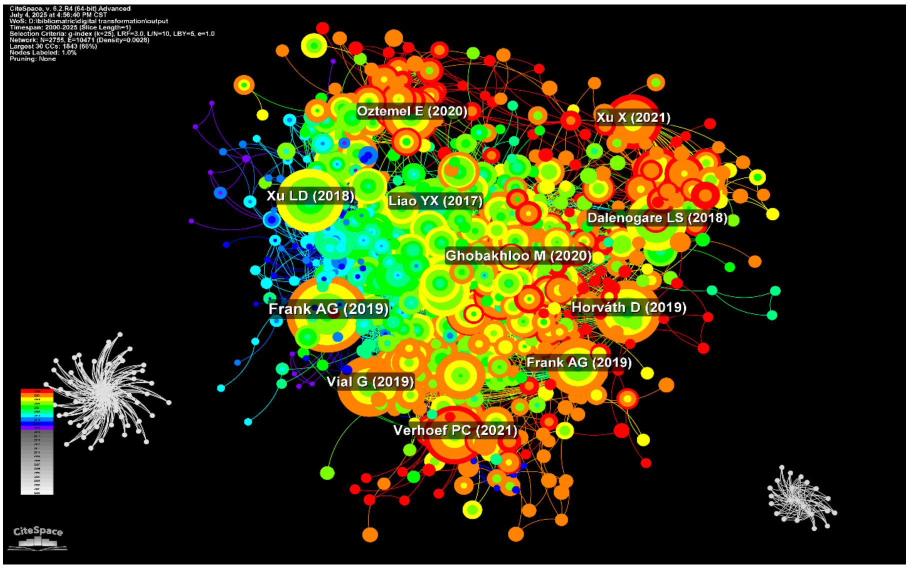


Figure 5. Co–citation network of core literature on digital transformation in advanced manufacturing (2003–2025). The colour gradient from outer (blue) to inner (red) indicates the temporal progression of citations.

Several highly cited authors occupy central positions within the network, including Frank AG, Xu LD, Liao YX, Vial G, Verhoef PC, Ghobakhloo M, Oztemel E, Horváth D, Xu X, and Dalenogare LS, highlighting their influence in shaping the intellectual trajectory of the field.

Table 2 summarises the most influential publications based on Local Citation Score (LCS) and Global Citation Score (GCS). The three most cited works are "Industry 4.0 Technologies: Implementation Patterns in Manufacturing Companies" (LCS = 313; GCS = 1544), "Servitization and Industry 4.0 Convergence in the Digital Transformation of Product Firms" (LCS = 190; GCS = 702), and "The Future of Manufacturing Industry: A Strategic Roadmap Toward Industry 4.0" (LCS = 159; GCS = 623). These studies represent key intellectual anchors linking technological, organisational, and strategic perspectives on digital transformation.

Table 2. Most Cited Publications on Digital Transformation in Advanced Manufacturing (2000–**2025).**

NO.	Article information	Journal	LCS	GCS
760	Industry 4.0 technologies: Implementation patterns in manufacturing companies	INT J PROD ECON	313	1544
762	Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective	TECHNOL FORECAST SOC	190	702
427	The future of manufacturing industry: a strategic roadmap toward Industry 4.0	J MANUF TECHNOL MANA	159	623
425	The industrial management of SMEs in the era of Industry 4.0	INT J PROD RES	143	766
1690	Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium–sized manufacturers	PROD PLAN CONTROL	139	685
751	The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics	INT J PROD RES	138	1090
813	Digital servitization business models in ecosystems: A theory of the firm	J BUS RES	90	892
459	Smart Factory Implementation and Process Innovation A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing	RES TECHNOL MANAGE	81	289
497	China's manufacturing locus in 2025: With a comparison of Made–in–China 2025" and "Industry 4.0""	TECHNOL FORECAST SOC	76	1010
195	Tangible Industry 4.0: a scenario–based approach to learning for the future of production	PROC CIRP	75	531
1052	Organizational learning paths based upon industry 4.0 adoption: An empirical study with Brazilian manufacturers	INT J PROD ECON	68	275
1064	Corporate survival in Industry 4.0 era: the enabling role of lean–digitized manufacturing	J MANUF TECHNOL MANA	68	656
487	Industry 4.0 as policy–driven discourse to institutionalize innovation systems in manufacturing	TECHNOL FORECAST SOC	63	316
291	A review of the meanings and the implications of the Industry 4.0 concept	PROCEDIA MANUF	63	243

1173	Lessons learned from Industry 4.0 implementation in the German manufacturing industry	J MANUF TECHNOL MANA	62	286
1163	Digital servitization in manufacturing: A systematic literature review and research agenda	IND MARKET MANAG	59	236
1055	Industry 4.0: Opportunities and Challenges for Operations Management	M&SOM–MANUF SERV OP	54	417
1126	The impact of Industry 4.0 implementation on supply chains	J MANUF TECHNOL MANA	54	204
331	Business model innovation through Industry 4.0: A review	PROCEDIA MANUF	51	385
323	Adopting a platform approach in servitization: Leveraging the value of digitalization	INT J PROD ECON	51	341
307	Development of an Assessment Model for Industry 4.0: Industry 4.0–MM	COMM COM INF SC	49	244
1161	Internet of things technologies, digital servitization and business model innovation in BtoB manufacturing firms	IND MARKET MANAG	49	269
1174	An Industry 4.0 maturity model proposal	J MANUF TECHNOL MANA	47	349
1627	Industry 4.0 and supply chain sustainability: framework and future research directions	BENCHMARKING	46	177
507	Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises	PROC CIRP	46	301
1095	Determinants of information and digital technology implementation for smart manufacturing	INT J PROD RES	46	151
397	Procurement 4.0: factors influencing the digitisation of procurement and supply chains	BUS PROCESS MANAG J	45	238
1069	Moving towards digitalization: a multiple case study in manufacturing	PROD PLAN CONTROL	44	139
494	The industrial internet of things (IIoT): An analysis framework	COMPUT IND	44	180
1770	Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs	J MANUF TECHNOL MANA	42	230

By integrating CiteSpace and HistCite analyses, this study identifies the structural topology of the research field, highlights seminal contributions, and reveals how core research themes have evolved over time.

3.1.3. Scientific Cooperation

The collaboration networks shown in Figures indicate a high level of scientific cooperation in research on digital transformation and advanced manufacturing at country, institutional, and author levels.

At the country level, the collaboration network includes 86 nations connected by 636 co–authorship links. China, the United States, the United Kingdom, Germany, and Italy emerge as the most productive contributors, with strong cross–border collaboration reflecting the global nature of research in this field (Figure 6).

Figure 6. Country collaboration network on digital transformation in advanced manufacturing. Node size indicates publication volume; link thickness indicates the strength of international co–authorship.

At the institutional level, 491 institutions are connected through 480 collaboration links (Figure 7). Prominent hubs include the Chinese Academy of Sciences, Centre National de la Recherche Scientifique (CNRS), Polytechnic University of Milan, Fraunhofer Gesellschaft, and RWTH Aachen University, indicating their central role in knowledge production and international research partnerships.

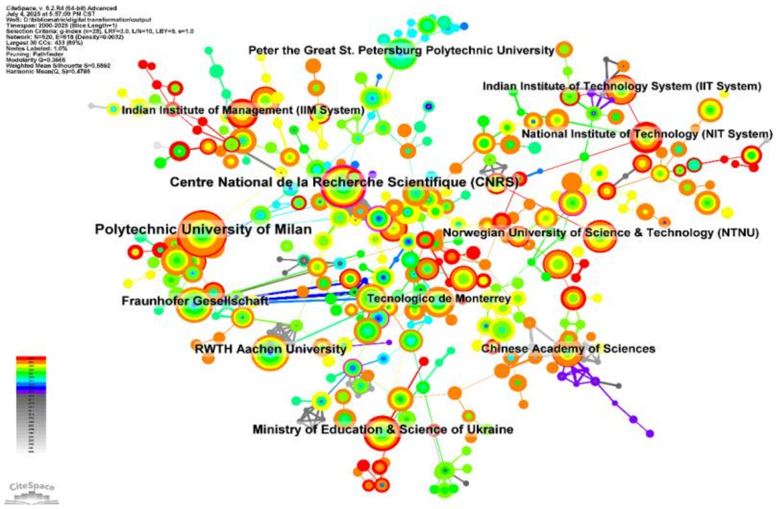


Figure 7. Institutional collaboration network on digital transformation in advanced manufacturing. Node size indicates publication volume; edge density reflects institutional co–authorship strength.

At the author level, several cohesive collaboration clusters are observed (Figure 8). Notable groups include researchers led by Acerbi, Terzi, and De Carolis, as well as Scavarda, Garza–Reyes, and Tortorella, whose interconnections suggest collaboration spanning strategic and operational perspectives. Another prominent cluster includes Romero, Rakic, and Marjanovic, focusing on industrial digitalisation. Together, these clusters reflect the emergence of structured research communities that shape the intellectual development of the field.

Figure 8. Author collaboration network in digital transformation and advanced manufacturing. Node size reflects publication volume; links indicate co–authorship relationships.

3.2. Variation of the Most Active Topics

3.2.1. Subject Category Burst

Between 2000 and 2025, 158 out of 171 subject categories exhibited citation bursts, indicating periods of intensified scholarly attention (Figure 9). Early bursts were dominated by technically oriented disciplines, including Imaging Science & Photographic Technology, Engineering (Aerospace), and Physical Geography, reflecting the technological foundations of early digital transformation research.

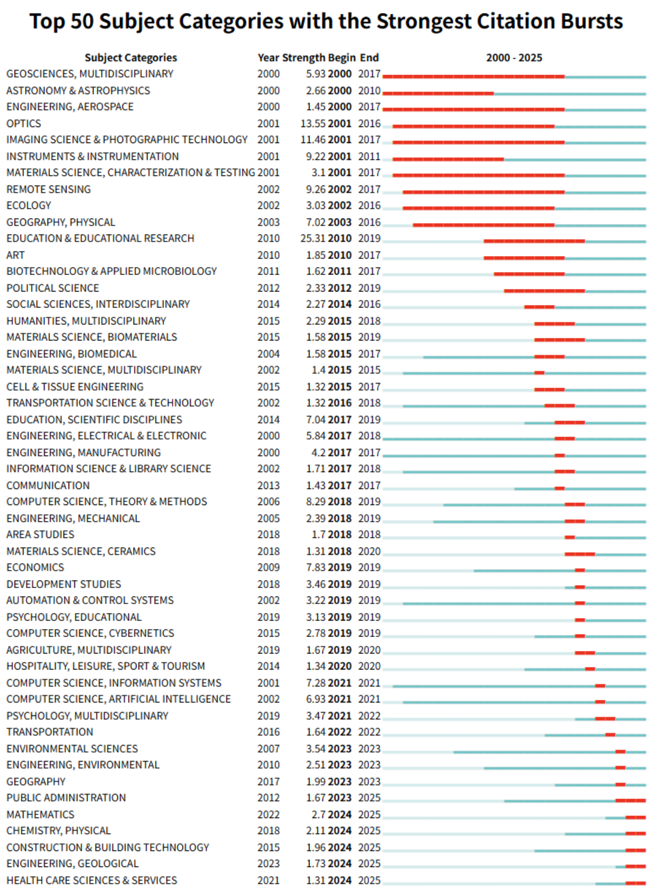


Figure 9. Top 50 subject categories with the strongest citation bursts in the field of digital transformation and advanced manufacturing (2000–2025).

The strongest burst occurred in Education & Educational Research (strength = 25.31; 2010–2019), highlighting growing interest in learning, skills development, and knowledge transfer during technological transformation. More recent bursts emerging from 2023 onward are concentrated in Environmental Sciences, Geography, Public Administration, and Mathematics, signalling a shift toward sustainability, governance, and complex systems modelling. Overall, this diversification of subject categories reflects the increasing maturity and societal integration of digital transformation research, particularly under Industry 4.0 and Industry 5.0 frameworks.

3.2.2. Reference Burst

Keyword burst analysis provides finer–grained insights into thematic evolution. Between 2000 and 2025, 522 keywords experienced citation bursts, revealing shifting research priorities (Figure 10). The keyword *"industry 4.0"* exhibited the strongest burst (strength = 103.67; 2016–2019), underscoring its central role in shaping early research agendas. This period also saw strong bursts for *"smart manufacturing"* and *"smart factory"*, reflecting an emphasis on digital integration and intelligent production systems.

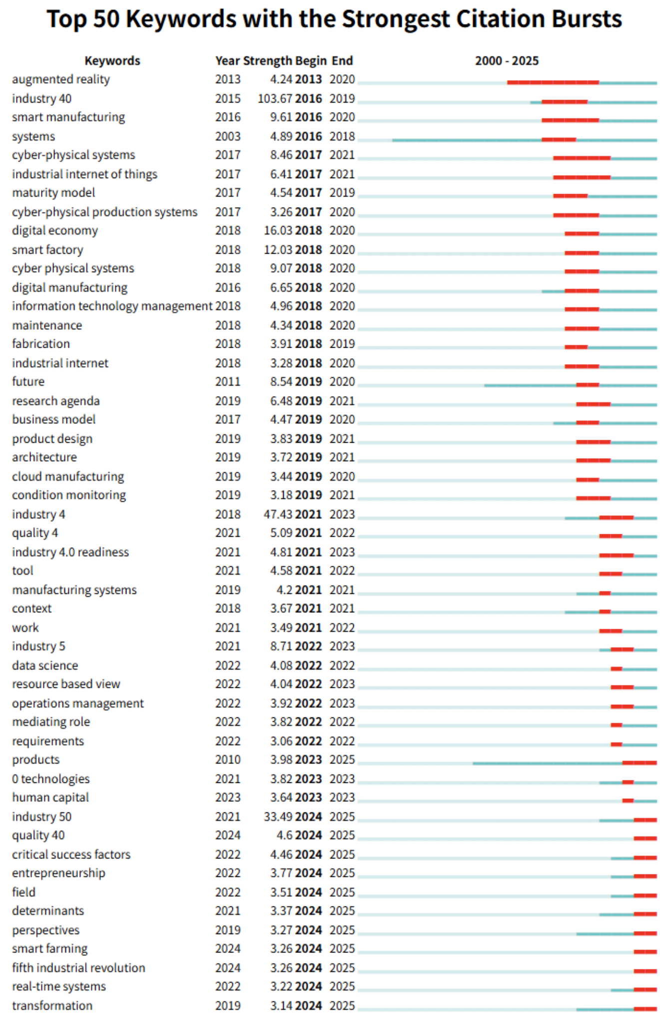


Figure 10. Top 50 Keywords with the Strongest Citation Bursts (2000–2025).

More recent bursts (2024–2025) highlight emerging post–Industry 4.0 themes, including *"industry 5.0"*, *"fifth industrial revolution"*, *"critical success factors"*, *"real–time systems"*, and *"resource–based view"*. These keywords point to a conceptual shift from technology–centric studies toward human–centric, strategic, and sustainability–oriented perspectives. The increasing prominence of terms such as *"determinants"*, *"requirements"*, and *"perspectives"* further suggests growing interest in theoretical, organisational, and policy frameworks guiding digital transformation. Table 3 summarizes the key references with significant citation bursts across different periods, illustrating how influential studies have shaped the evolution of this research field over time.

Table 3. References Exhibiting Citation Bursts over Various Time Periods.

References	Year	Strength	Begin	End	2004 – 2024
Porter ME, 2014, HARVARD BUS REV, V92, P64	2014	16.89	2016	2019	
Hermann M, 2016, P ANN HICSS, V0, PP3928, DOI 10.1109/HICSS.2016.488, DOI	2016	37.39	2017	2021	
Lee Jay, 2015, MANUFACTURING LETTERS, V3, P18, DOI 10.1016/j.mfglet.2014.12.001, DOI	2015	36.3	2017	2020	
Schumacher A, 2016, PROC CIRP, V52, P161, DOI 10.1016/j.procir.2016.07.040, DOI	2016	34.91	2017	2021	
Lasi H, 2014, BUS INFORM SYST ENG+, V6, P239, DOI 10.1007/s12599–014–0334–4, DOI	2014	27.01	2017	2019	
Oesterreich TD, 2016, COMPUT IND, V83, P121, DOI 10.1016/j.compind.2016.09.006, DOI	2016	23.78	2017	2021	
Qin J, 2016, PROC CIRP, V52, P173, DOI 10.1016/j.procir.2016.08.005, DOI	2016	22.95	2017	2021	
Roblek V, 2016, SAGE OPEN, V6, P0, DOI 10.1177/2158244016653987, DOI	2016	21.31	2017	2021	
Monostori L, 2016, CIRP ANN–MANUF TECHN, V65, P621, DOI 10.1016/j.cirp.2016.06.005, DOI	2016	18.84	2017	2021	
Brettel M, 2014, INTERNATIONAL JOURNAL OF SCIENCE, V0, P0	2014	15.06	2017	2019	
Lee J, 2014, PROC CIRP, V16, P3, DOI 10.1016/j.procir.2014.02.001, DOI	2014	12.54	2017	2019	
Stock T, 2016, PROC CIRP, V40, P536, DOI 10.1016/j.procir.2016.01.129, DOI	2016	29.76	2018	2021	
Liao YX, 2017, INT J PROD RES, V55, P3609, DOI 10.1080/00207543.2017.1308576, DOI	2017	28.57	2018	2022	

Zhong RY, 2017, ENGINEERING–PRC, V3, P616, DOI 10.1016/J.ENG.2017.05.015, DOI	2017	21.49	2018	2022
Hofmann E, 2017, COMPUT IND, V89, P23, DOI 10.1016/j.compind.2017.04.002, DOI	2017	21.45	2018	2021
Lu Y, 2017, J IND INF INTEGR, V6, P1, DOI 10.1016/j.jii.2017.04.005, DOI	2017	18.65	2018	2021
Kang HS, 2016, INT J PR ENG MAN–GT, V3, P111, DOI 10.1007/s40684–016–0015–5, DOI	2016	15.05	2018	2021
Hecklau F, 2016, PROC CIRP, V54, P1, DOI 10.1016/j.procir.2016.05.102, DOI	2016	15.05	2018	2021
Erol S, 2016, PROC CIRP, V54, P13, DOI 10.1016/j.procir.2016.03.162, DOI	2016	14.63	2018	2021
Wang SY, 2016, INT J DISTRIB SENS N, V0, P0, DOI 10.1155/2016/3159805, DOI	2016	13.37	2018	2021
Rosen R, 2015, IFAC PAPERSONLINE, V48, P567, DOI 10.1016/j.ifacol.2015.06.141, DOI	2015	12.98	2018	2020
Posada J, 2015, IEEE COMPUT GRAPH, V35, P26, DOI 10.1109/MCG.2015.45, DOI	2015	11.36	2018	2020
Wang SY, 2016, COMPUT NETW, V101, P158, DOI 10.1016/j.comnet.2015.12.017, DOI	2016	15.72	2019	2021
Schwab K, 2017, THE FOURTH INDUSTRIAL REVOLUTION, V0, P0	2017	13.85	2019	2022
Kiel D, 2017, INT J INNOV MANAG, V21, P0, DOI 10.1142/S1363919617400151, DOI	2017	13.38	2019	2022
Xu LD, 2018, INT J PROD RES, V56, P2941, DOI 10.1080/00207543.2018.1444806, DOI	2018	14.36	2020	2023
Frey CB, 2017, TECHNOL FORECAST SOC, V114, P254, DOI 10.1016/j.techfore.2016.08.019, DOI	2017	14.28	2020	2021
Ghobakhloo M, 2018, J MANUF TECHNOL MANA, V29, P910, DOI 10.1108/JMTM–02–2018–0057, DOI	2018	11.49	2020	2021
Dalenogare LS, 2018, INT J PROD ECON, V204, P383, DOI 10.1016/j.ijpe.2018.08.019, DOI	2018	12.38	2022	2023

Vial G, 2019, J STRATEGIC INF SYST, V28, P118, DOI 10.1016/j.jsis.2019.01.003, DOI	2019	16.42	2023	2025	

In addition, 81 references entered citation burst phases from 2024 onward, indicating a new wave of highly influential research (Table 4). Among the top 20 recent bursts, both review articles and empirical studies are represented, reflecting a dual emphasis on theoretical consolidation and practical application.

Table 4. The references with citation bursts from beginning to 2024.

Begin	End	Strength	Year	Type	Title
2024	2025	25.65	2021	Article	Industry 4.0 and Industry 5.0–Inception, conception and perception
2024	2025	18.95	2022	Review	Industry 5.0: Prospect and retrospect
2024	2025	18.31	2021	Review	Digital transformation: A multidisciplinary reflection and research agenda
2024	2025	16.98	2022	Article	Industry 5.0: A survey on enabling technologies and potential applications
2023	2025	16.42	2019	Review	Understanding digital transformation: A review and a research agenda
2024	2025	13.42	2023	Article	The Industry 5.0 framework: viability–based integration of the resilience, sustainability, and human–centricity perspectives
2024	2025	12.4	2022	Review	Future of industry 5.0 in society: human–centric solutions, challenges and prospective research areas
2023	2025	11.18	2021	Review	The PRISMA 2020 statement: an updated guideline for reporting systematic reviews
2024	2025	11.17	2021	Review	A Systematic Review of the Literature on Digital Transformation: Insights and Implications for Strategy and Organizational Change
2024	2025	11.15	2021	Review	Digital twins–based smart manufacturing system design in Industry 4.0: A review
2023	2025	10.85	2022	Article	Industry 5.0 and Society 5.0–Comparison, complementation and co–evolution
2024	2025	10.1	2021	Review	Industry 4.0 Technologies for Manufacturing Sustainability: A Systematic Review and Future Research Directions
2023	2025	10.01	2022	Article	Outlook on human–centric manufacturing towards Industry 5.0
2023	2025	9.89	2021	Review	Review of digital twin about concepts, technologies, and industrial applications
2023	2025	9.73	2022	Article	Identifying industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values
2024	2025	9.69	2021	Article	Developing a unified definition of digital transformation
2024	2025	9.66	2022	Article	Can digital transformation promote enterprise performance? – From the perspective of public policy and innovation

2024	2025	9.22	2022	Article	Disruptive Technologies and Operations Management in the Industry 4.0 Era and Beyond
2023	2025	8.9	2021	Article	Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs
2024	2025	8.78	2022	Article	Industry 5.0: improving humanization and sustainability of Industry 4.0

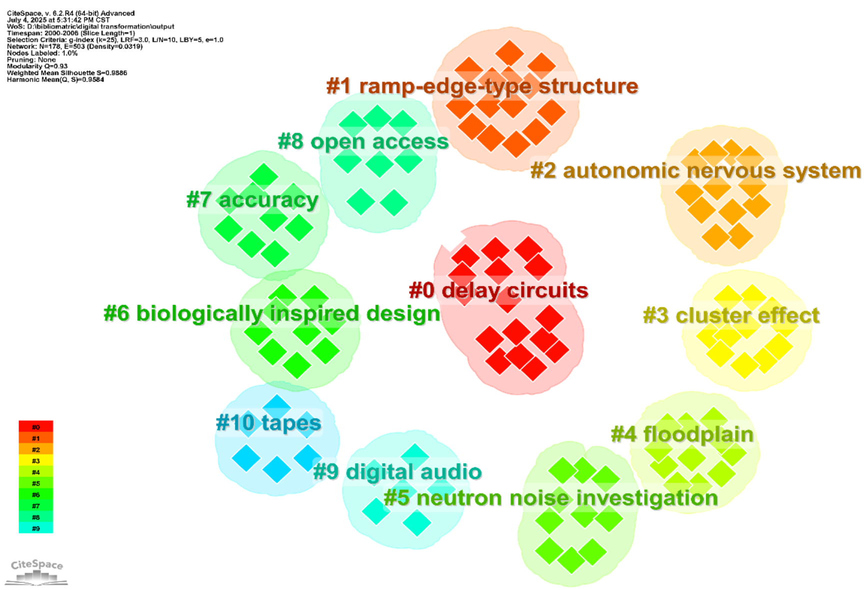
The strongest burst is associated with *"Industry 4.0 and Industry 5.0 – Inception, conception and perception"* (2021), which exhibited a burst strength of 25.65 during 2024–2025. Several high–impact reviews and articles follow, collectively signalling a thematic transition from the technology–centric orientation of Industry 4.0 toward the human–centric, resilient, and sustainability–driven vision of Industry 5.0. Prominent themes include digital twins, unified conceptualisations of digital transformation, and strategic pathways for SMEs and sustainable development.

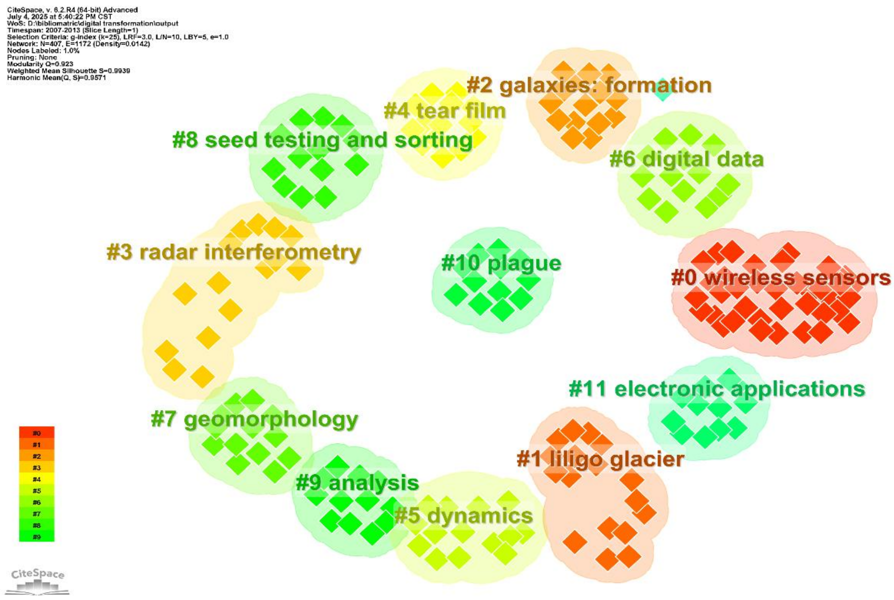
Recent burst publications also demonstrate increasing integration of digital innovation with social, ethical, and organisational dimensions, as well as growing attention to performance outcomes, policy implications, and operational decision–making. Overall, the concentration of high–burst references during 2024–2025 indicates that Industry 5.0–oriented research is rapidly shaping emerging scholarly agendas and future strategic frameworks.

3.3. Collaboration Networks Analysis

3.3.1. Country–Level Collaboration Patterns

Keyword co–occurrence clustering was used to examine the temporal evolution of research themes in digital transformation and advanced manufacturing over a 25–year period. The analysis was divided into four consecutive time windows, with keyword cluster snapshots presented in Figure 11.




#2 galaxies: formation
#4 tear film
#8 seed testing and sorting
#6 digital data
#3 radar interferometry
#10 plague
#0 wireless sensors
#11 electronic applications
#7 geomorphology
#1 liligo glacier
#9 analysis
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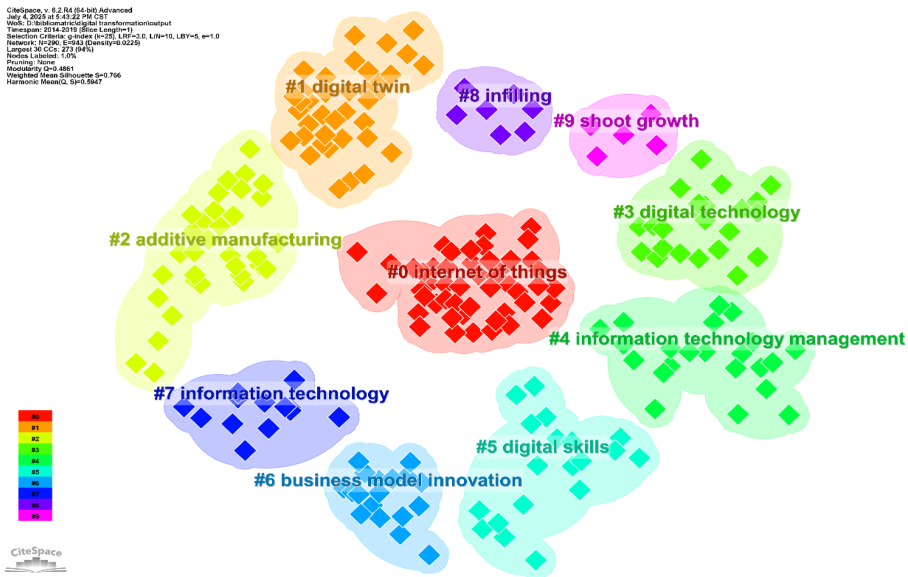

#1 digital twin
#8 infilling
#9 shoot growth
#3 digital technology
#2 additive manufacturing
#0 internet of things
#4 information technology management
#7 information technology
#5 digital skills
#6 business model innovation
CiteSpace

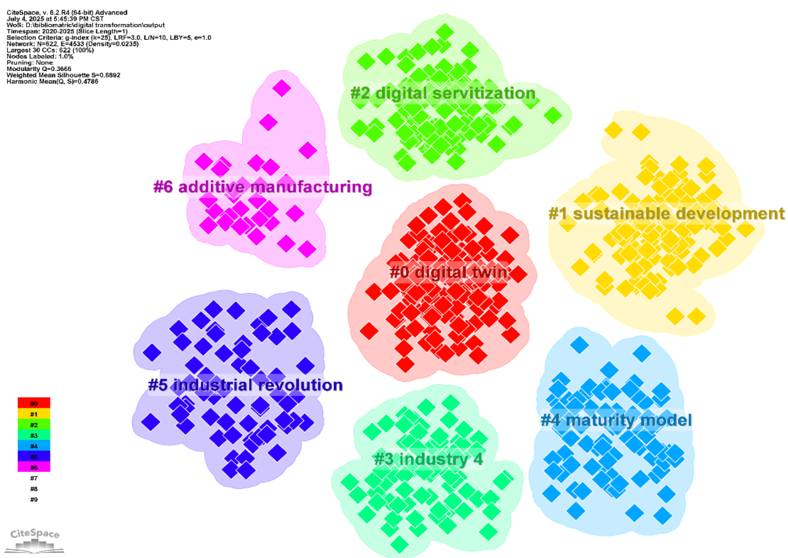

#2 digital servitization
#6 additive manufacturing
#1 sustainable development
#0 digital twin
#5 industrial revolution
#4 maturity model
#3 industry 4
CiteSpace

Figure 11. Keyword cluster maps in digital transformation and advanced manufacturing across four time periods: (a) 2000–2006, (b) 2007–2012, (c) 2013–2018, (d) 2019–2025.

During the early period (2000–2006), research clusters were primarily associated with fundamental system and circuit–level topics, such as delay circuits and control–related structures, showing limited relevance to manufacturing digitalisation. In the subsequent period (2007–2012), clusters remained largely domain–specific, although topics such as wireless sensors began to provide early technological foundations for later industrial applications.

A clear shift occurred during 2013–2018, when manufacturing–oriented digital concepts gained prominence. Dominant clusters included the Internet of Things, digital twins, and additive manufacturing, marking a turning point toward smart and data–driven production systems.

The most substantial thematic consolidation emerged in the period 2019–2025, characterised by seven major clusters centred on digital twins, sustainable development, digital servitisation, Industry 4.0, maturity models, industrial revolutions, and additive manufacturing. Compared with earlier phases, research themes in this period are more focused and application–driven, reflecting the maturation of digital transformation research.

Collectively, these clusters highlight a transition from technology–enabling foundations toward integrated industrial applications, with increasing emphasis on sustainability, service–oriented innovation, implementation readiness, and human–centric manufacturing under Industry 4.0 and Industry 5.0 paradigms.

3.3.2. The Keyword Alluvial Flow Visualisation

The alluvial flow visualisation (Figure 12) illustrates the longitudinal evolution of keyword clusters in digital transformation and advanced manufacturing. Over time, thematic streams merge, split, and reconfigure, reflecting shifting research priorities across the 25–year observation period.

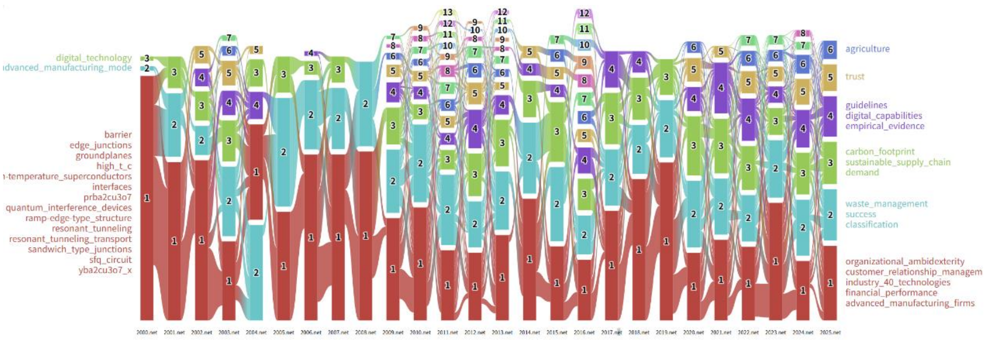
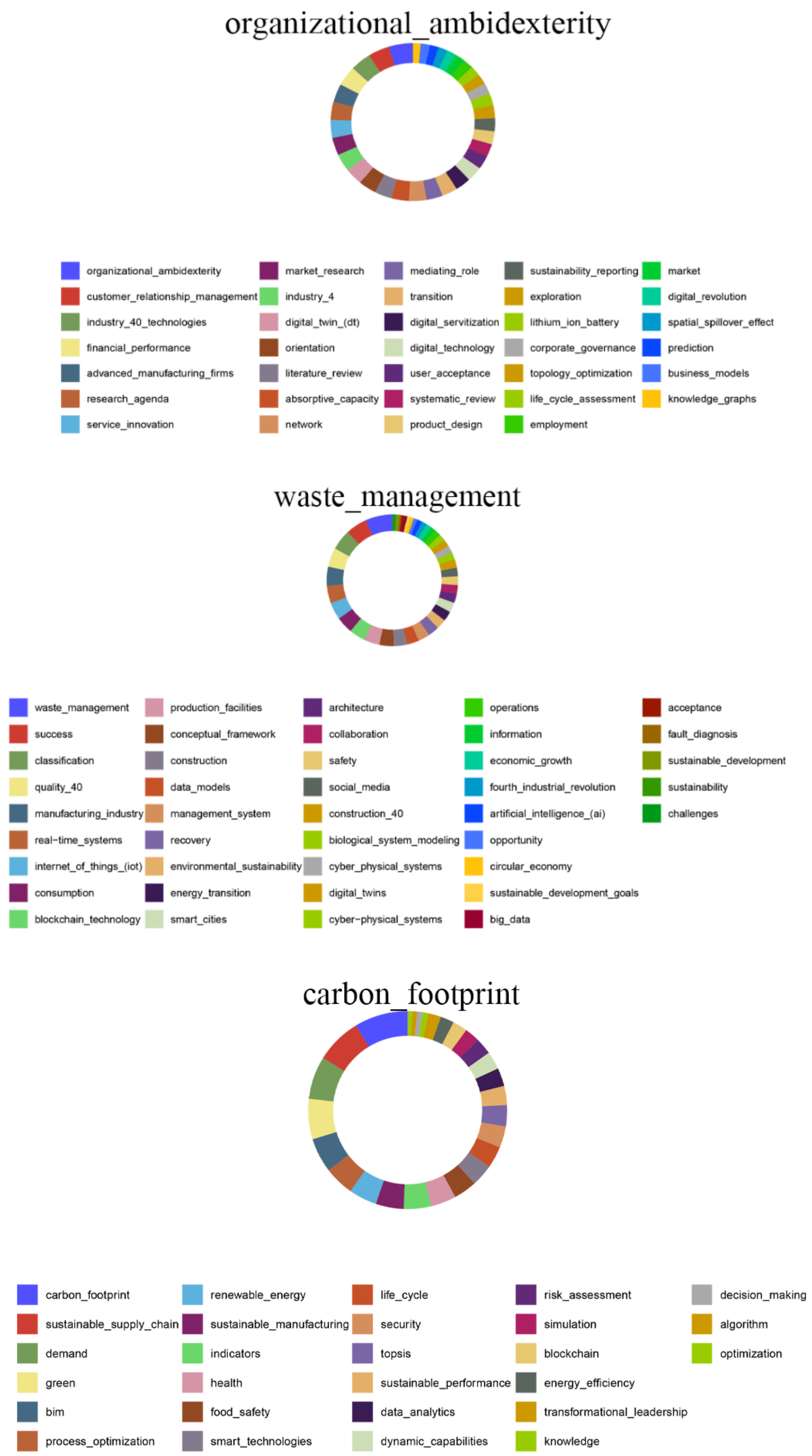


Figure 12. Alluvial flow map of keyword clusters in digital transformation and advanced manufacturing (2000–2025). The x–axis represents the time, and the y–axis represents evolving keyword modules.

Overall, the analysis reveals a clear transition from early technical and physics–oriented themes (e.g., circuit design and quantum–related topics) toward interdisciplinary, management– and sustainability–focused research. Three dominant patterns emerge. First, persistent keyword flows–such as those related to digital technology and advanced manufacturing modes–remain influential across multiple time slices, indicating sustained scholarly interest. Second, emerging themes including digital capabilities, Industry 4.0 technologies, sustainable supply chains, and organisational ambidexterity gain prominence after 2015 and continue to expand through 2025. Third, earlier science–oriented streams gradually fade, signalling a declining disciplinary relevance over time.

Figure 13 highlights the most influential modules by flow volume, showing increasing dominance of management– and performance–oriented themes in recent years. In particular, the leading module in 2025 centres on organisational ambidexterity and integrates concepts such as digital twins, Industry 4.0 technologies, absorptive capacity, and financial performance.



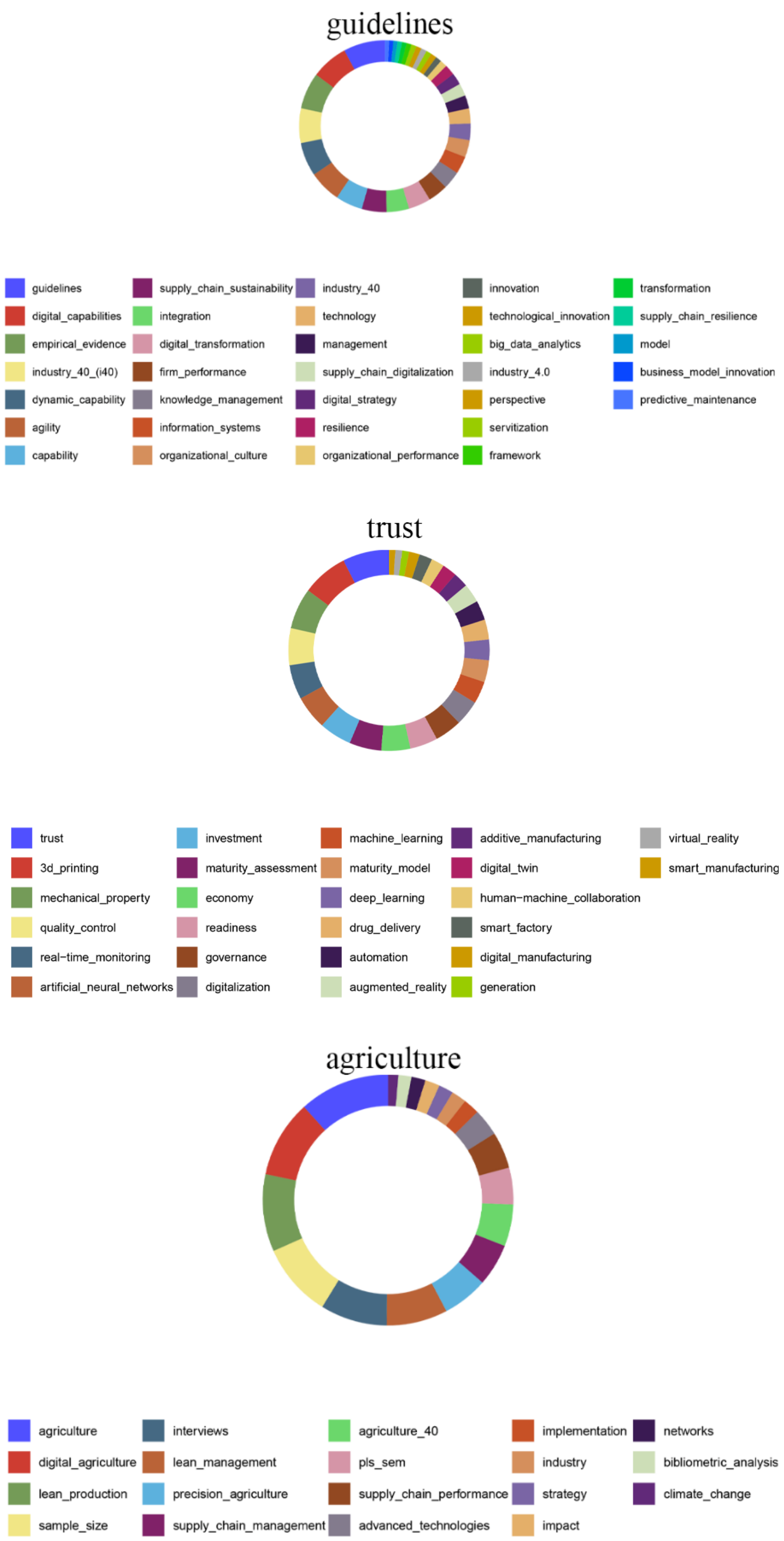


Figure 13. Modules (A) (B) (C) (D) (E) (F).

Other prominent modules reflect sustainability and environmental performance, digital strategy and implementation guidelines, trust and governance in intelligent systems, and sector–specific applications such as digital agriculture (Figure 14).

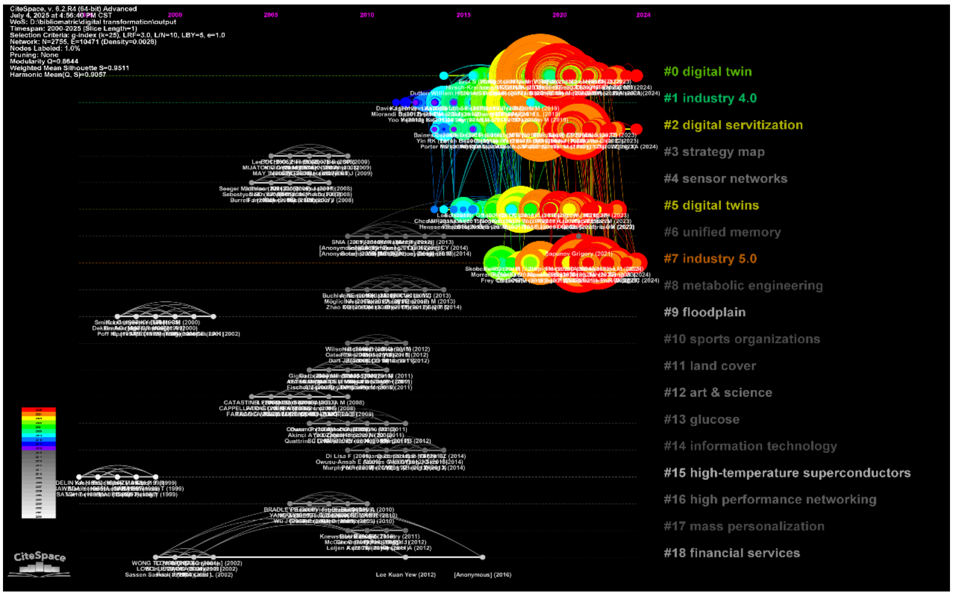


Figure 14. Timeline visualisation of co–cited reference clusters in digital transformation and advanced manufacturing (2000–2024).

Together, these findings indicate that current and future research on digital transformation in advanced manufacturing is increasingly oriented toward balancing technological innovation with organisational capability, sustainability performance, and system trust–key pillars of Industry 5.0–driven transformation.

3.3.3. The Timeline Visualisation of References

The timeline visualisation of co–cited references (Figure 15) illustrates the temporal evolution of research themes in digital transformation and advanced manufacturing from 2000 to 2025. A total of 19 reference clusters were identified, enabling the distinction between emerging, persistent, and declining research streams.

Figure 15. The emerging literature from #0, #1, #2, #5, #7.

Several clusters remain active and continue to attract recent citations, including those centred on digital twins, Industry 4.0, digital servitisation, and Industry 5.0. The sustained activity within these clusters indicates ongoing scholarly interest and highlights their relevance for future research. In contrast, clusters associated with topics such as floodplain studies, sports organisations, biomedical indicators, and high–performance networking exhibit little recent citation activity, suggesting a thematic departure from the core digital transformation literature.

The timeline further reveals a set of highly influential publications that anchor key clusters and shape the intellectual foundations of the field. Prominent examples include Frank AG (2019) on Industry 4.0 implementation patterns, Xu LD (2018) on Industry 4.0 research synthesis, Vial G (2019) on digital transformation frameworks, Fuller A (2020) on data–driven smart manufacturing, and Xu X (2021) on digital twin concepts and applications. These studies serve as conceptual reference points linking technological, organisational, and strategic perspectives.

Citation trajectory analysis indicates differentiated patterns of influence over time (see Figure 16). Early foundational works, such as Xu LD (2018), show rapid initial impact followed by stabilisation, whereas more recent contributions–particularly Vial G (2019) and Xu X (2021)–exhibit delayed but accelerating citation growth, aligning with current research frontiers in digital strategy and digital twin applications. Overall, the timeline analysis highlights how core references evolve in influence, providing insight into both established foundations and emerging momentum within the field.

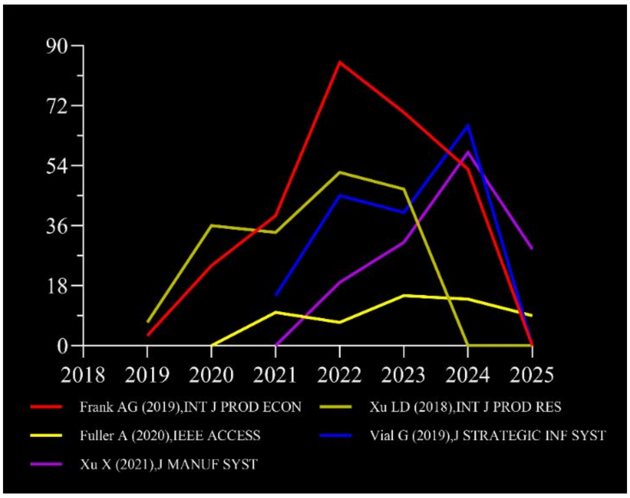


Figure 16. Citation trends (2018–2025) of four high–impact studies in digital transformation and smart manufacturing.

3.4. Keyword Co–occurrence Network and Keyword Density Map

The keyword co–occurrence network and density map (Figure 17 and Figure 18) provide an overview of the dominant research themes in digital transformation (DT) and advanced manufacturing technologies (AMTs). Core keywords such as *Industry 4.0*, *digital twin*, *artificial intelligence*, *Internet of Things*, *big data*, and *additive manufacturing* occupy central positions in the network, underscoring their foundational role in enabling flexible, data–driven, and intelligent manufacturing systems.

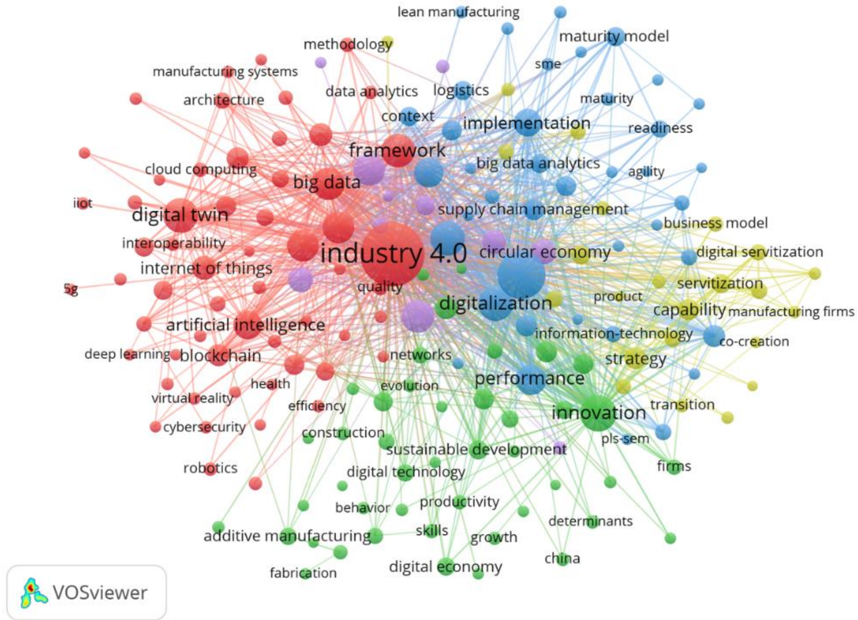


Figure 17. Keyword co–occurrence network in DT and AMTs research (VOSviewer, 2000–2025)

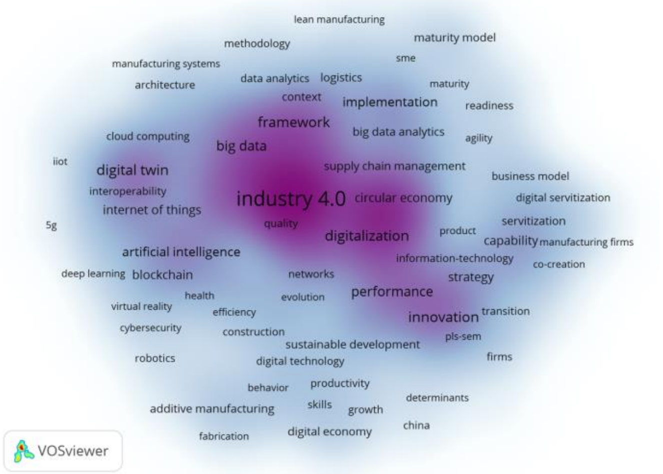


Figure 18. Keyword density map showing research intensity in DT and AMTs (VOSviewer).

Clusters associated with *implementation*, *readiness*, *maturity models*, and *supply chain management* highlight the organisational and strategic dimensions of DT adoption, emphasising the alignment between technological innovation, operational capability, and system integration. These themes reflect a shift from purely technological concerns toward implementation–oriented and value–driven perspectives.

Although *Industry 5.0* has emerged as an important concept in recent citation burst and clustering analyses, it does not yet appear as a dominant keyword in the co–occurrence network or density map. This suggests that Industry 5.0 research is still in a formative stage, with many studies addressing its principles indirectly through related themes such as sustainability, human–centric manufacturing, digital servitisation, and resilience rather than explicitly using the term as a keyword.

The keyword density map further confirms that *Industry 4.0*, *digitalisation*, *performance*, *innovation*, and *sustainable development* remain high–intensity research areas. Emerging topics such as *digital servitisation*, *business models*, and *co–creation* indicate a growing shift from product–centric manufacturing toward service–oriented and platform–based value creation. Additionally, the increasing prominence of *circular economy*, *supply chain resilience*, and *sustainable development* reflects rising concern for environmental and social responsibility in DT research.

Overall, the convergence of technological, organisational, and sustainability–related themes suggests that future research and practice will increasingly focus on integrated digital strategies that support intelligent operations, organisational capability development, and long–term resilience in manufacturing systems.

3.5. Summary of Bibliometric Findings

This chapter synthesises the evolution of research on digital transformation (DT) and advanced manufacturing technologies (AMTs) from 2000 to 2025 based on large–scale bibliometric analysis. The results reveal a clear shift from foundational technological themes–such as Industry 4.0, cyber–physical systems, and digital twins–toward more applied and integrative topics, including digital servitisation, value creation, and sustainable development.

Although Industry 5.0 has gained increasing visibility in recent discourse, its limited presence in dominant co–occurrence keywords suggests that it remains at an early stage of consolidation, with core ideas dispersed across related themes such as sustainability, resilience, and human–centric manufacturing. Timeline and alluvial analyses further indicate a transition from technology–centred research toward strategic, implementation–oriented perspectives, with growing emphasis on organisational capabilities, maturity models, and digital readiness.

Co–citation analysis identifies several landmark studies–most notably Frank et al., Vial, Fuller, and Xu (2021)–that continue to anchor the intellectual structure of the field by linking digital technologies to strategy and value creation [1,10–12]. Geographical and institutional mapping highlights strong global engagement, led by China, Germany, and the United States, while also revealing persistent gaps in sector–specific analysis and practical implementation guidance.

From a managerial perspective, the findings suggest that effective DT requires coordinated investment in enabling technologies, stronger cross–functional integration, the development of service–oriented digital business models, and alignment with organisational capabilities–particularly for SMEs. In line with the emerging Industry 5.0 paradigm, sustainability and human–centric considerations are becoming central to long–term digital transformation strategies.

4. Conclusion

This paper presents an extensive bibliometric analysis of digital transformation (DT) research within the manufacturing sector, drawing on 4,949 publications indexed in the Web of Science Core Collection between 2000 and 2025. The study uncovers central thematic clusters, significant scholarly contributions, and dynamic research trends that define the development of this multidisciplinary domain.

The findings reveal a marked acceleration of scholarly activity after 2017, with research converging around smart manufacturing, cyber–physical systems, and advanced manufacturing technologies within Industry 4.0 and emerging Industry 5.0 paradigms. Co–citation and keyword analyses highlight a growing shift toward servitisation, sustainability, and digitally enabled supply networks. Geographical and institutional mapping further shows strong research leadership from Europe and China, alongside relatively fragmented international collaboration, indicating opportunities for deeper cross–border engagement.

By synthesising large–scale bibliometric evidence, this study contributes to both theory and practice. It clarifies how DT has been conceptualised and structured within manufacturing research, while offering insights relevant to managerial decision–making and strategic digital adoption. Future research could combine bibliometric approaches with empirical investigations to examine sector–specific implementation challenges, organisational capabilities, and long–term performance outcomes across diverse manufacturing contexts.

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