INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES
Vol 16, Issue 3, (2026) E-ISSN: 2222-6990

A Bibliometric and Visualization Analysis of Industry 4.0 Technologies Adoption in the Traditional Garment Manufacturing Sector

Wenhua Chen[a,b], Muhammad Shabir Shaharudin[a], Yajing Lu[a,c], Luhuie[a], Guoqing Wang[a,d], Lianying Xiao[a,d], Peng Tian[a], Li Chen[a]
[a]School of Management, Universiti Sains Malaysia, Malaysia, [b]School of Management, Guangzhou College of Technology and Business, China, [c]Hua Xin College of Hebei Geo University, China, [d]School of Management, Guangzhou College of Technology and Business, China
Email: chenwenhua@student.usm.my, luyajing@student.usm.my, luhuie@student.usm.my, wangguoqing2023@student.usm.my, xiaolianying@student.usm.my, tianpeng@student.usm.my, chenli890606@student. usm. my
*Corresponding Author Email: shabir@usm.my

DOI Link: http://dx.doi.org/10.6007/IJARBSS/v16-i3/27975
Published Date: 15 March 2026

Abstract
Purpose: Industry 4.0 technologies, originating in Germany in 2011, have expanded rapidly across global manufacturing. However, high investment costs, rapid technological evolution, and a shortage of skilled professionals have constrained their adoption in many traditional sectors. The garment manufacturing industry, dominated by small and medium-sized enterprises and characterized by low automation, outdated equipment, and manual operations (Huynh, 2024), faces particular challenges. This study examines the current research status of Industry 4.0 technologies adoption in the traditional garment manufacturing sector and identifies future development directions. **Design/methodology/approach:** A systematic literature review combined with bibliometric analysis was employed. Relevant studies were retrieved from the Web of Science (WOS) database using defined keywords, and visualization was performed with VOSviewer 1.6.19 to map research hotspots and trends. **Findings:** The study provides a comprehensive overview of Industry 4.0 technologies adoption in garment manufacturing, highlighting current research focuses and emerging directions for future exploration. **Research limitations/implications:** Only five core Industry 4.0 technologies （Internet of Things, Cloud Computing, Big Data Analytics, Artificial Intelligence, and Smart Manufacturing） were analyzed. Future research could broaden this scope to capture a more holistic technological landscape. **Practical implications:** Industry 4.0 technologies adoption can transform

traditional garment production, enhance competitiveness, and support sustainable development. **Originality/value:** By integrating five foundational Industry 4.0 technologies into a unified analytical framework, this study establishes a theoretical foundation for future empirical research on digital transformation within traditional garment manufacturing.
Keywords: Industry 4.0 Technologies Adoption, Garment, Cloud Computing, Artificial Intelligence, Smart Manufacturing

Introduction

The garment industry is a key sector supporting the development of the global economy, with its supply chain spanning across the world. At the same time, economic globalization has accelerated the rapid expansion of the garment industry(Yiyan & Zakaria, 2024). According to a research report released by Mordor intelligence, a well-known market research and consulting firm, the size of the garment market is expected to be $1.36 trillion in 2024 and is expected to reach $1.78 trillion by 2029, with a compound annual growth rate of 4.63% during the forecast period (2024-2029). (mordor intelligence, 2023)

The traditional garment manufacturing sector is predominantly labour-intensive, with small and medium-sized enterprises accounting for over 70% of the industry. It is characterised by low worker educational attainment, outdated equipment, and a reliance on manual labour (Huynh, 2024). Findings from a survey of 100 Vietnamese garment enterprises indicate that the majority suffer from low technical capabilities, outdated management practices, obsolete machinery, and limited capacity for data analysis and collection(Huynh, 2024).

Industry 4.0 technologies adoption in the garment manufacturing sector has the potential to move the industry away from traditional production methods. The integration of these advanced Industry 4.0 technologies aims to achieve production flexibility and mass production while delivering higher-quality products and greater production efficiency. (Yiyan & Zakaria, 2024)

The concept of “Industry 4.0” originated in Germany, referring to the Fourth Industrial Revolution achieved by integrating next-generation information technology with manufacturing processes to realise intelligent, networked and flexible production workflows(What Is Industry 4.0, 2021). Industry 4.0 (also termed smart manufacturing) is fundamentally a paradigm that achieves real-time data sharing, intelligent analysis, and autonomous decision-making through the deep integration of physical operations with digital systems. An enterprise's Industry 4.0 technologies adoption level directly reflects its capacity to employ Fourth Industrial Revolution technologies in constructing intelligent, interconnected factories and value chains. The concept is typically defined as “a series of interconnected advanced technologies that synergistically enhance organizational effectiveness through complementary interactions”(Kulandaivel & Bandara, 2024). Within academic literature, this encompasses a suite of emerging tools, particularly Internet of Things (IoT), cloud computing, big data analytics, and artificial intelligence (AI), which collectively form the pillars of modern intelligent production systems(Zhou et al., 2024). Implementing Industry 4.0 entails embedding such technologies within traditional processes to establish a connected intelligent production ecosystem, thereby enhancing efficiency, productivity, and data-driven decision-making(Sahoo et al., 2024). Research indicates that adopting Industry 4.0 technologies significantly elevates operational efficiency and sustainability levels across manufacturing sectors including automotive, electronics, food, and textiles/garment (Kulandaivel & Bandara, 2024). Within the garment sector, the adoption of Industry 4.0 entails transforming historically labour-intensive, fragmented operations into intelligent, agile, data-driven workflows spanning design, production, and distribution. This broad adoption concept establishes the foundation for key technologies driving such digital transformation.

The key technologies of the Industry 4.0 era primarily encompass Internet of Things (IoT), cloud computing, big data analytics, artificial intelligence (AI), and smart manufacturing. The adoption of these technologies is profoundly transforming production methods and competitive landscapes within the manufacturing sector. For instance, in China, particularly among small and medium-sized garment manufacturers in Guangdong, the introduction of these technologies is regarded as a vital pathway for driving digital transformation and high-quality development(Zhao & Wang, 2024).

Methodology

Research Design

This study aims to systematically map the research status and evolutionary trajectory of Industry 4.0 technologies within the traditional garment manufacturing sector from 2020 to 2025. To this end, we employ a combined methodology of systematic literature review and bibliometric analysis. Originally developed for medical researchers, the systematic literature review represents a scientific methodology for investigating existing literature within a specific domain. Its primary advantage lies in developing a knowledge base through predefined protocols, followed by the systematic extraction of knowledge from existing studies. This approach significantly reduces researcher bias and imposes stricter scrutiny than traditional methods, which often involve purposeful selection and may fail to accurately reflect the true state of research (Pongboonchai-Empl et al., 2024).The subsequent research steps fully demonstrate the rigorous scrutiny inherent in systematic literature reviews.

Once the systematic collection and organisation of existing literature is complete, tools designed for analysing and visualising this data come into play. This paper primarily employs the traditional data analysis tool Excel and the bibliometric tool VOSviewer. Excel is a highly classical data analysis tool, excelling at statistical processing and graphical representation. VOSviewer is a highly popular bibliometric mapping tool, favoured by users primarily for its user-friendly interface and robust visualisation capabilities. Specialising in network visualisation, it effectively renders co-authorship, co-citation, and bibliographic coupling relationships. The diverse network visualisations it generates hold significant value across various fields. Its limitation lies in the absence of advanced statistical functions.(Kumar, 2025) 。 This study employs VOSviewer version 1.6.19. To compensate for its inherent limitations, the analysis is supplemented by Excel for auxiliary analysis and visualisation. The bibliometric analysis not only quantifies publication trends, institutional distribution, and keyword evolution, but also utilises VOSviewer for visual network analysis to reveal research themes, collaborative structures, and knowledge maps (Liu et al., 2025), Ultimately achieve the research objectives.

Research Procedure

As mentioned earlier, systematic literature reviews are subject to more rigorous scrutiny (Pongboonchai-Empl et al., 2024). A review of the literature reveals that Öztürk et al. state in their paper that bibliometric analysis primarily comprises four stages: research objectives, data collection, analysis and visualisation, and interpretation of findings and results (Öztürk et al., 2024). Ganti et al. also propose that conducting a bibliometric analysis primarily involves defining your research scope and objectives, locating and collecting data, data cleaning and processing, and data visualisation(Ganti et al., 2025). Therefore, drawing upon prior literature, the author has designed the research methodology for this paper to ensure the validity of the findings. The research procedure (Table 1) is as follows:

Table 1
The research procedure of this paper

Procedure	Description	Key actions
1	Defining the scope of research and keywords	Define the subject (Industry 4.0 technologies adaption in the garment manufacturing sector), timeframe (1 January 2020 to 11 November 2025), and keyword combinations (e.g.,'Industry 4.0 technologies' AND 'garment').
2	Select Retrieval Database	Execute search strategy in Web of Science Core Collection
3	Data Export and Preliminary Organisation	Export metadata (title, author, institution, country/region, year, journal, keywords, citation count, etc.) in RIS format; export statistical data.
4	Data cleansing and filtering	Upon thorough review, no instances of duplicate publications or retraction records were identified, resulting in the exclusion of 0 articles.
5	Bibliometric analysis	Using Excel to compile statistics on publication year, country/region distribution, keyword frequency, journal distribution, citation metrics, and other relevant data.
6	Visual analytics	Construct networks such as keyword co-occurrence and author co-citation using VOSviewer for visual analysis.
7	Interpretation and Discussion of Results	By integrating quantitative findings with visualised maps, we explore research hotspots and developmental trends, thereby proposing future research directions.

Data Source

This study selected the Web of Science database as its data source. As a globally renowned database, Web of Science primarily features English-language content and offers distinct advantages in citation tracking and interdisciplinary research. However, its drawbacks include subscription requirements, journal selection limitations, language restrictions (primarily English), and potential bias arising from the exclusion of non-journal publications such as books and conference proceedings (Ganti et al., 2025). To ensure the high quality of selected literature, the data retrieval scope was specifically confined to the Web of Science Core Collection, with only articles and review articles selected. This approach circumvented inherent limitations of the Web of Science platform, transforming its shortcomings into advantages for this study. The data retrieval period was set from 1 January 2020 to 11 November 2025, with the language restricted to English. Beyond these constraints, no additional filtering conditions were applied. To comprehensively cover both Industry 4.0 technologies and the broader garment sector, a rigorous retrieval strategy was adopted. A unified set of keyword combinations was established (Table 2), categorised into six distinct groups:

Table 2
The keyword Phrase of this paper

Serial Number	Keyword Phrase
1	“Industry 4.0 technologies AND garment “ OR “Industry 4.0 technologies AND garment” OR “Industry 4.0 technologies AND clothes”
2	“Internet of Things AND garment “OR “Internet of Things AND garment” OR "Internet of Things AND clothes"
3	"Cloud Computing AND garment" OR "Cloud Computing AND garment" OR "Cloud Computing AND clothes"
4	"Big Data Analytics AND garment" OR "Big Data Analytics AND garment" OR "Big Data Analytics AND clothes"
5	"artificial intelligence AND garment " OR "artificial intelligence AND garment" OR "artificial intelligence AND clothes"
6	"Smart Manufacturing AND garment " OR "Smart Manufacturing AND garment" OR "Smart Manufacturing AND clothes"

Following the aforementioned methodology, the final retrieval yielded 796 valid publications meeting the specified criteria, all sourced from the Web of Science Core Collection between 2020 and 2025. Upon thorough examination and verification, these 796 papers were confirmed to satisfy the requirements of this study, rendering the entire sample valid.

Findings

Overall Publication Status

Table 3
Number of publications published 2020-2025

Publication Years	Article Count	% of 796
2020	89	11.18%
2021	117	14.70%
2022	203	25.50%
2023	159	19.98%
2024	171	21.48%
2025	57	7.16%

According to data from the Web of Science Core Collection, between 2020 and 2025, a total of 796 research papers were published globally on Industry 4.0 technologies adoption within the garment sector. Annual publication volumes exhibited an initial rise followed by a decline, with 2022 recording 203 publications—accounting for 25.5% of the total and representing the five-year peak (Table 3, Figure 1). This publication trend indicates a waning research enthusiasm among international scholars regarding Industry 4.0 technology adoption within the specific context of the traditional garment sector. The prevailing characteristics of this industry—where over 70% of enterprises are small and medium-sized, labour-intensive, and employing relatively outdated production methods—remain pronounced (Huynh, 2024). Given that Industry 4.0 technologies remain neither widely adopted nor fully matured within traditional garment manufacturing, the reasons behind this retreat in scholarly interest warrant careful consideration.

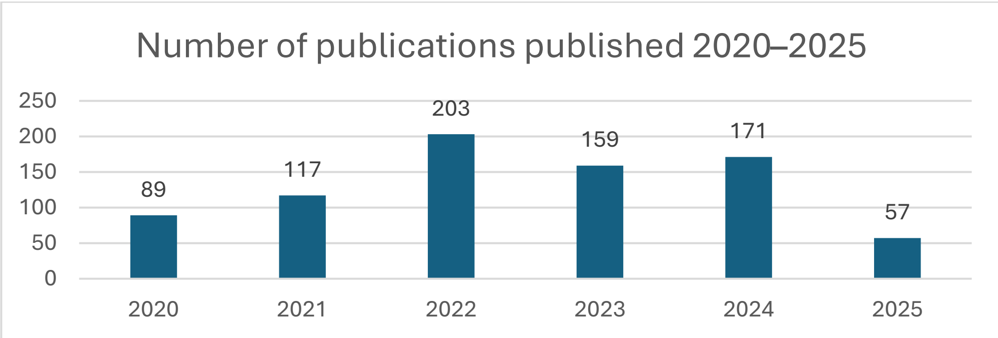

Figure 1. Trends in Industry 4.0 Technologies Adoption in the Garment Manufacturing Sector (2020-2025)

Countries of Publication

Table 4

Top 10 Countries by Publications 2020–2025

Serial Number	Countries/Regions	Article Count	% of 796
1	PEOPLES R CHINA	378	47.49%
2	USA	79	9.93%
3	SOUTH KOREA	71	8.92%
4	ENGLAND	54	6.78%
5	INDIA	52	6.53%
6	JAPAN	28	3.52%
6	SAUDI ARABIA	28	3.52%
7	ITALY	27	3.39%
8	BANGLADESH	24	3.02%
8	TAIWAN	24	3.02%

Among the top ten countries globally, China leads with 378 publications, accounting for 47.49% of the global total—nearly half (Table 4, Figure 2). China, as a major manufacturing powerhouse, possesses a vast scale of garment production with highly developed industrial and supply chains. Chinese garments are distributed across every corner of the globe. In terms of geographical distribution, among the top ten countries, seven are Asian nations alongside the United States, the United Kingdom, and Italy. This underscores Asia's pivotal role as a global hub for garment manufacturing.

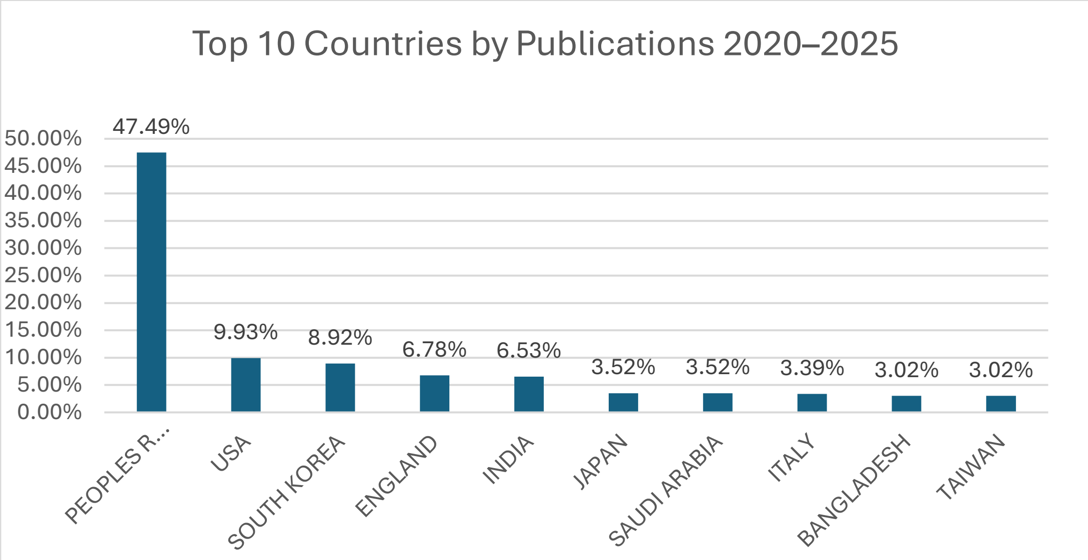

Figure 2. Top 10 Countries by Publications 2020–2025

Fields of Publication

Table 5

Top 10 fields by Publications 2020–2025

Web of Science Categories	Article Count	% of 796
Engineering Electrical Electronic	234	29.40%
Computer Science Information Systems	159	19.98%
Computer Science Artificial Intelligence	125	15.70%
Computer Science Software Engineering	119	14.95%
Telecommunications	111	13.95%
Materials Science Textiles	73	9.17%
Computer Science Theory Methods	65	8.17%
Materials Science Multidisciplinary	56	7.04%
Physics Applied	51	6.41%
Engineering Multidisciplinary	44	5.53%

From 2020 to 2025, the top ten fields for Industry 4.0 technology adoption in the garment manufacturing sector are primarily distributed across engineering electronics, computer science, telecommunications, materials science, applied physics, and interdisciplinary engineering. The top four fields—Engineering Electrical Electronic, Computer Science Information Systems, Computer Science Artificial Intelligence, and Computer Science Software Engineering—accounted for 29.40%, 19.98%, 15.70%, and 14.95% respectively (Table 5, Figure 3), indicating a prevailing focus on the research and development of the technologies themselves. Data indicates that fields such as economics and management did not feature in the top ten rankings. It is evident that their publication volumes lag significantly behind technical disciplines, suggesting insufficient scholarly emphasis on researching Industry 4.0 applications within the garment manufacturing sector. This deficiency is particularly pronounced in the absence of substantial, in-depth investigations from managerial, economic, and commercial perspectives. This hinders the rapid dissemination and widespread implementation of emerging technologies like Industry 4.0. It also explains why, despite over a decade of development, Industry 4.0 technologies adoption within traditional garment manufacturing remains both uncommon and immature.

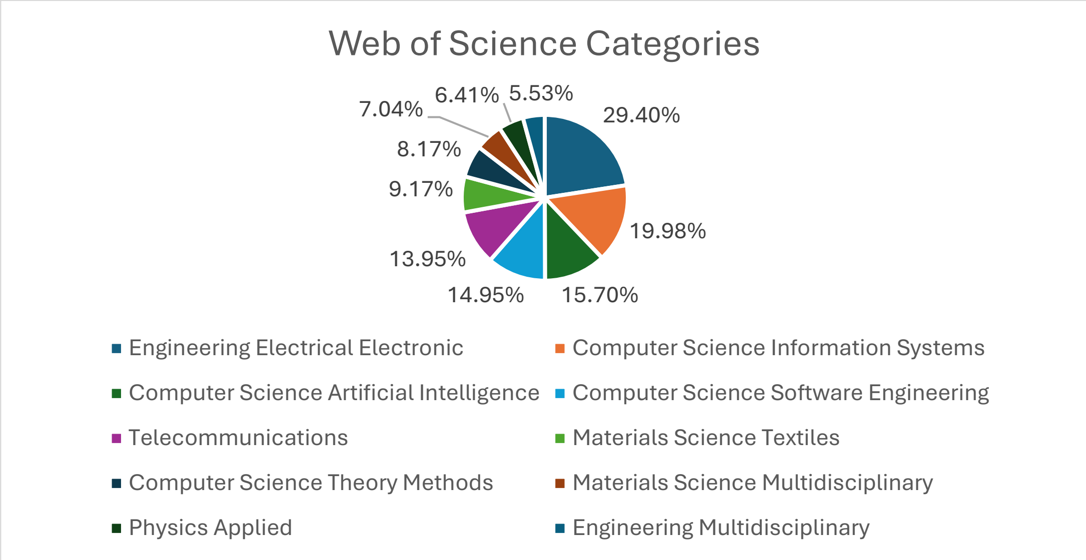

Figure 3. Top 10 fields by Publications 2020–2025

Journals of Publication

Table 6

Top 10 Journals by Publications 2020-2025

Serial Number	Publication Titles	Article Count	% of 796
1	IEEE ACCESS	38	4.77%
2	APPLIED SCIENCES BASEL	26	3.27%
2	IEEE TRANSACTIONS ON MULTIMEDIA	26	3.27%
2	SENSORS	26	3.27%
3	TEXTILE RESEARCH JOURNAL	21	2.64%
4	INTERNATIONAL JOURNAL OF CLOTHING SCIENCE AND TECHNOLOGY	19	2.39%
4	MULTIMEDIA TOOLS AND APPLICATIONS	19	2.39%
5	IEEE ROBOTICS AND AUTOMATION LETTERS	17	2.14%
5	IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE	17	2.14%
6	SUSTAINABILITY	13	1.63%

From the top ten publishing journals between 2020 and 2025, a broad publication scope and balanced distribution are evident. IEEE ACCESS, a highly renowned comprehensive SCI journal covering all IEEE technical domains, ranks first among publishing journals with a 4.77% share. APPLIED SCIENCES BASEL, which focuses on research in applied sciences such as engineering, materials, chemistry, and physics, holds considerable prestige within these fields; IEEE TRANSACTIONS ON MULTIMEDIA is a premier journal in multimedia technology; SENSORS concentrates on sensor science and technology; TEXTILE RESEARCH JOURNAL stands as a classic, long-established authority in textile science with a distinguished history. Other publications include those dedicated to garment science, technology, and management; those emphasising multimedia tool development and application; those specialising in robotics; top-tier journals in computer vision and artificial intelligence; and those focused on research into environmental, cultural, economic, and social sustainability, amongst others. These journals also provide a research foundation for subsequent studies on Industry 4.0 technologies adoption within the garment manufacturing sector. (Table 6, Figure 4)

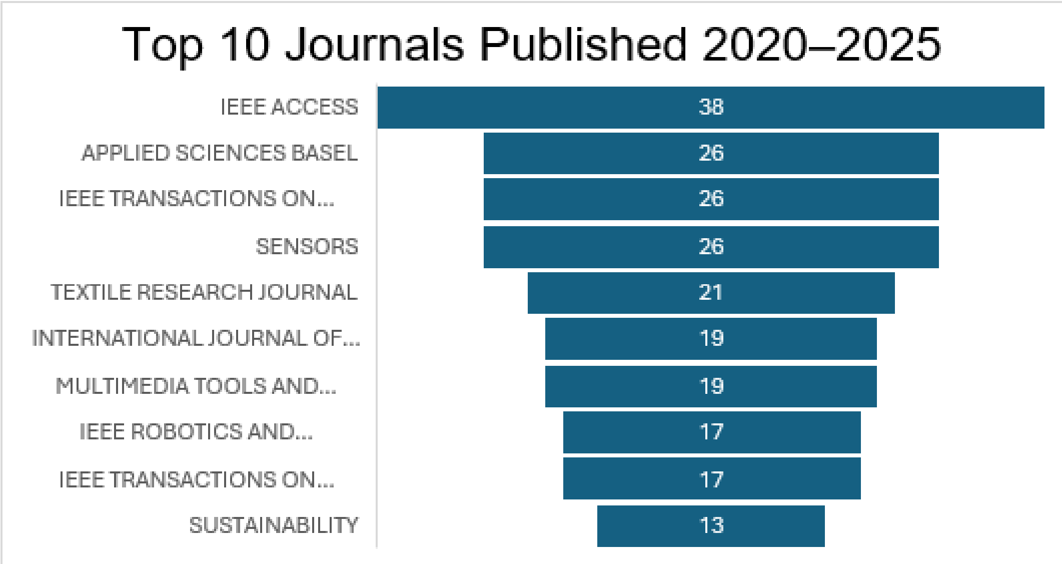

Figure 4. Top 10 Journals by Publications 2020-2025

Research Institutions of Publication

As Table 7 demonstrates, among the top ten research institutions globally, all but Seoul National University (SNU) from South Korea (ranked 10th) are based in China. Specifically, mainland China accounts for eight institutions (ranking within the top eight), while Hong Kong, China holds one position (ranked 9th) (Table 7). This indicates that research into Industry 4.0 technologies adoption within the garment manufacturing sector is predominantly conducted by Chinese research institutions. This aligns with the current state of development within China's garment manufacturing industry and its position within the global landscape.

Table 7
Top 10 Research Institutions by Publications 2020-2025

Serial Number	Affiliations	Article Count	% of 796
1	DONGHUA UNIVERSITY	32	4.02%
2	CHINESE ACADEMY OF SCIENCES	24	3.02%
3	ZHEJIANG UNIVERSITY	19	2.39%
4	HARBIN INSTITUTE OF TECHNOLOGY	16	2.01%
4	JIANGNAN UNIVERSITY	16	2.01%
5	TSINGHUA UNIVERSITY	14	1.76%
5	XI AN POLYTECHNIC UNIVERSITY	14	1.76%
6	HEFEI UNIVERSITY OF TECHNOLOGY	12	1.51%
6	HONG KONG POLYTECHNIC UNIVERSITY	12	1.51%
6	SEOUL NATIONAL UNIVERSITY SNU	12	1.51%

Authors and Co-authors of Publication

From 2020 to 2025, the research on Industry 4.0 technologies adoption in the garment manufacturing sector saw the highest number of published articles from Zhang HJ in China, with a total of 13 papers. The remaining authors in the top ten published between 6 and 9 articles each, with numbers closely matched (Table 8). The majority of authors hailed from China.

Table 8
Top 10 Authors by Publications 2020-2025

Serial Number	Authors	Article Count	% of 796
1	Zhang HJ	13	1.63%
2	Li Y	9	1.13%
2	Zhang Z	9	1.13%
3	Liu J	8	1.01%
4	Chen L	7	0.88%
4	Khan MA	7	0.88%
4	Kim S	7	0.88%
4	Zeng XY	7	0.88%
5	Kim J	6	0.75%
5	Liu LL	6	0.75%

Regarding co-authors, as illustrated in Figure 5, distinct collaborative research teams have emerged. For instance, Zhang HJ, Zhang Z, Liu LL and others have worked closely together, publishing a significant number of articles, with Zhang HJ frequently listed as the first author. Other research teams remain relatively dispersed and independent, with comparatively limited academic collaboration between groups. To advance research on promoting Industry 4.0 technologies adoption within the garment manufacturing sector, scholars are encouraged to strengthen cooperation and publish their research findings.

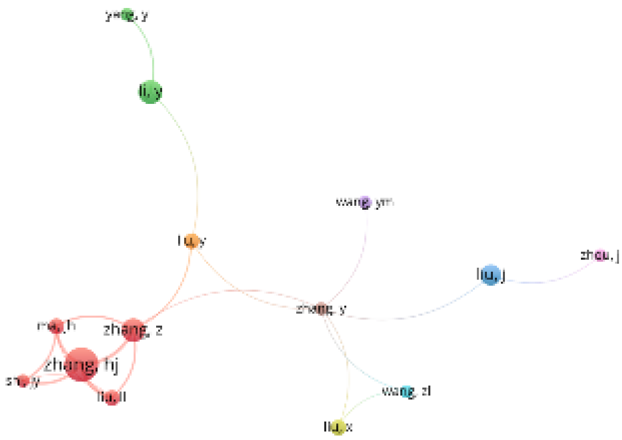

Figure 5. Authors and Co-authors Network visualization by Publications 2020-2025

Keywords of Publication

The co-occurrence map generated by VOSviewer (Figure 6) reveals two prominent knowledge clusters emerging within the research domain. The green cluster, centred around keywords such as ‘deep learning’, ‘clothing’, ‘feature extraction’, and ‘computer vision’, distinctly focuses on deep learning-driven visual computing research. This encompasses applications including image recognition, human pose estimation, virtual try-on, three-dimensional garment modelling, and image segmentation. The red cluster, centred around keywords such as ‘artificial intelligence’, ‘machine learning’, ‘performance’, “fashion”, and ‘sustainability’, reveals emerging trends in AI applications within garment industry management, sustainable design, and production performance evaluation. Overall, research hotspots predominantly reflect the specific applications of AI technologies within the textile and garment sector, with their technical trajectories highly dependent on the ongoing advancement of deep learning frameworks.

It should be noted that although this study explicitly defines Industry 4.0 technologies as Internet of Things (IoT), cloud computing, big data analytics, artificial intelligence (AI), and smart manufacturing in its theoretical section, foundational technologies such as IoT, cloud computing, and big data do not appear as high-frequency keywords in the co-occurrence visualization. This phenomenon is prevalent in bibliometric studies of Industry 4.0 literature. Foundational technologies typically manifest as system architectures, platforms, or technical contexts rather than as frequently co-occurring application keywords (Lee et al., 2015). Conversely, AI, particularly deep learning, has been extensively applied to tasks such as garment recognition and retrieval, garment keypoint annotation, and fabric defect detection. Demonstrating exceptional adaptability in production inspection and visual recognition scenarios within textile and garment smart manufacturing, it is consequently more readily presented as a core technological approach in empirical studies (Wu et al., 2025). Consequently, this study finds no contradiction between the delineation of Industry 4.0 technology categories and the visualization of literature keywords; rather, it reflects a natural stratification between theoretical and applied dimensions.

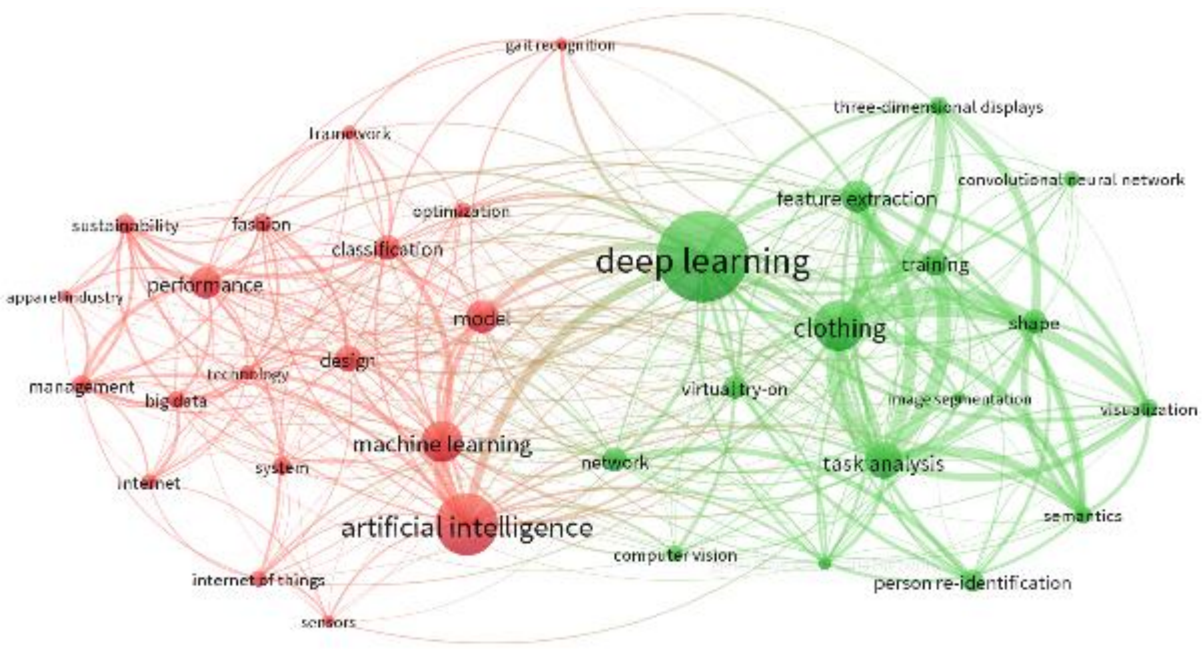

Figure 6. Keywords Network visualization by Publications 2020-2025

Citations by Publication
From the top ten most cited papers (Table 9), it is evident that research on Industry 4.0 technologies within garment manufacturing and related fields exhibits a pronounced trend towards diversification. Firstly, the most frequently cited study by Bai et al. (771 citations) evaluates Industry 4.0 technologies from a sustainability perspective, indicating that sustainable manufacturing and digital transformation have become core industry concerns.

Secondly, Paul et al. (207 citations) focus on supply chain recovery in the context of the pandemic, reflecting digital technology's pivotal role in supply chain resilience. Cubric's study (203 citations) highlights the drivers and barriers to AI adoption, demonstrating that artificial intelligence has become the dominant technology for industrial upgrading.

Within domains directly linked to garment manufacturing sector, 'Fashion Meets Computer Vision' (105 citations) demonstrates how computer vision is reshaping garment design, recognition, and production processes. Meanwhile, research by Yang et al. and Chao et al. (180 and 137 citations respectively) indicates mature applications of deep learning in human figure recognition, posture analysis, and motion capture, underpinning the development of intelligent garment applications such as virtual try-on and size prediction. Furthermore, the high citation counts of research on textile electronics and nano-powered fibres (e.g., Wang et al., Choudhry et al.) indicate that smart materials and wearable technologies are emerging as extension directions for Industry 4.0 within the garment sector.

Collectively, these highly cited publications reveal that AI (particularly deep learning), smart materials, sustainability, and supply chain resilience constitute the primary research focal points for Industry 4.0 within the garment manufacturing industry.

Table 9
Citations by Publications 2020-2025

Serial Number	***Title***	***Authors***	***Total Citations***	***Source Title***
1	Industry 4.0 technologies assessment: A sustainability perspective	(Bai et al., 2020)	771	INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS
2	Supply chain recovery challenges in the wake of COVID-19 pandemic	(Paul et al., 2021)	207	JOURNAL OF BUSINESS RESEARCH
3	Drivers, barriers and social considerations for AI adoption in business and management: A tertiary study	(Cubric, 2020)	203	TECHNOLOGY IN SOCIETY
4	Estimating the Impact of Humanizing Customer Service Chatbots	(Schanke et al., 2021)	185	INFORMATION SYSTEMS RESEARCH
5	Person Re-Identification by Contour Sketch Under Moderate Clothing Change	(Yang et al., 2021)	180	IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE

6	GaitSet: Cross-View Gait Recognition Through Utilizing Gait As a Deep Set	(Chao et al., 2021)	137	IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE
7	Large-scale fabrication of robust textile triboelectric nanogenerators	(Wang et al., 2020)	135	NANO ENERGY
8	Textronics-A Review of Textile-Based Wearable Electronics	(Choudhry et al., 2021)	129	ADVANCED ENGINEERING MATERIALS
9	Platform-based servitization and business model adaptation by established manufacturers	(Tian et al., 2022)	108	TECHNOVATION
10	Fashion Meets Computer Vision: A Survey	(Cheng et al., 2022)	105	ACM COMPUTING SURVEYS

Discussion, Implications and Limitations

Discussion

Building upon the bibliometric findings and the identified limitations, this study proposes a multi-dimensional theoretical framework to guide future empirical research on Industry 4.0 technologies adoption in the traditional garment manufacturing sector. This framework, illustrated in Figure 7, integrates the technological, organizational, and environmental contexts , while emphasizing the dynamic interplay between technology Adoption & stratification and systemic outcomes.

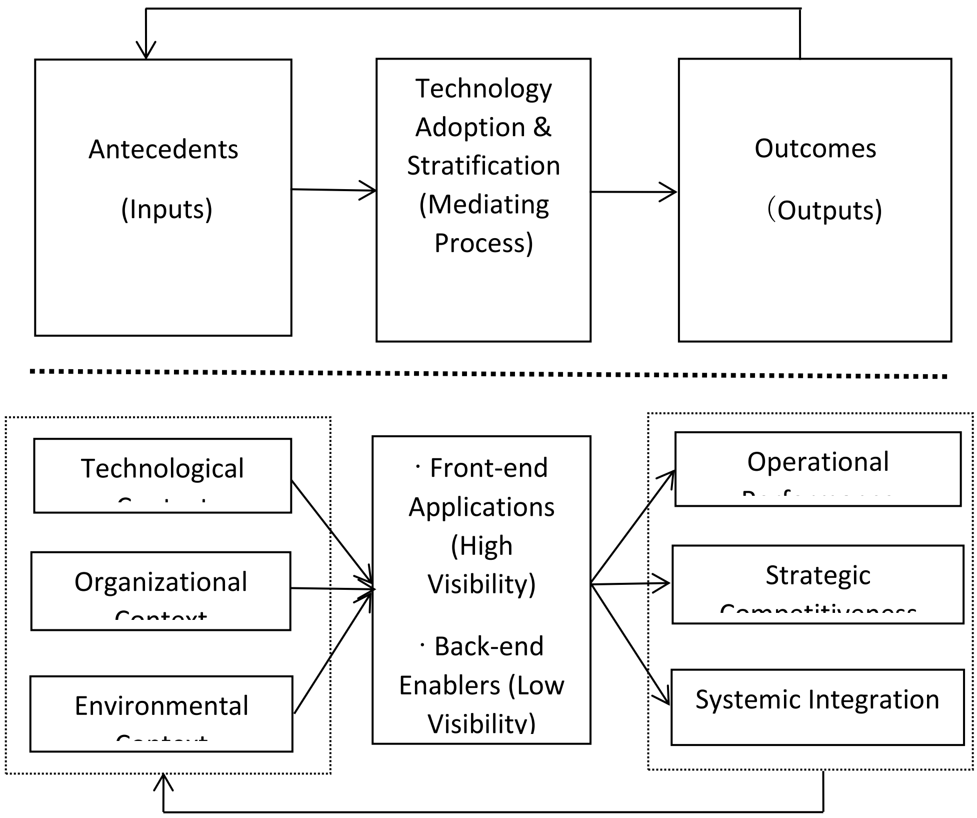

Figure 7. A Multi-level Theoretical Framework for Industry 4.0 Adoption in Garment Manufacturing

This framework is not built on a single theory but synthesizes several to explain the complex adoption phenomenon, as follows:
(1) Technology-Organization-Environment (TOE) Framework: Provides the foundational structure for the antecedent categories.
(2) Technology Acceptance Model (TAM) & Dynamic Capabilities Theory: Help explain how firms perceive and assimilate technologies (Adoption Process) and reconfigure their resources to achieve competitive advantage (Outcomes).
(3) Socio-Technical Systems Theory: Underpins the need to balance the "Technical Subsystem" (the technologies) with the "Social Subsystem" (skills, management, culture) for successful implementation.
The specific indicators of Figure 7 are described as follows:
(1) Antecedents (Inputs), These are the influencing factors at three levels.
Technological Context: Perceived benefits (efficiency, quality), complexity, cost, and compatibility of specific Industry 4.0 technologies(Davis, 1989).
Organizational Context: Firm size (SMEs vs. large), financial & technical resources, top management support, and employee digital skills(Huynh, 2024).
Environmental Context: Competitive pressure, supply chain partner readiness, government policy & incentives, and consumer demand for sustainability/customization (Zhao & Wang, 2024).
(2) Technology Adoption & Stratification (Mediating Process): This core process reflects the bibliometric finding of "technological stratification" (Lee et al., 2015). It differentiates between:

Front-end Applications (High Visibility): Technologies like AI (deep learning, computer vision) that directly impact performance and are readily researched (e.g., defect detection, virtual try-on)(Cheng et al., 2022; Wu et al., 2025).
Back-end Enablers (Low Visibility): Foundational technologies like IoT, Cloud Computing, and Big Data analytics that form the essential infrastructure for connectivity and data-driven decision-making but are less frequently the focus of application studies (Sahoo et al., 2024).
(3) Outcomes (Outputs): The resulting impacts of adoption, which feed back into the antecedents:
Operational Performance: Production efficiency, quality control, flexibility, and time-to-market.
Strategic Competitiveness: Supply chain (Paul et al., 2021), sustainability (ESG performance) (Bai et al., 2020), and capacity for mass customization.
Systemic Integration: The ultimate goal of achieving a fully integrated, intelligent ecosystem across the entire value chain (Zhou et al., 2024).
This framework serves as a roadmap, suggesting that future studies should not view adoption as a monolithic event but investigate:
(1) The Interdependence: How the adoption of back-end enablers (IoT sensors, cloud platforms) facilitates or constrains the effectiveness of front-end applications (AI vision systems).
(2) The Moderating Role of Context: How being an SME in a developing country, for instance, alters the relationship between antecedents and adoption decisions compared to a large enterprise in an industrialized nation (Kulandaivel & Bandara, 2024).
(3) The Causal Pathways: How specific technology combinations lead to specific outcomes, such as how AI-driven quality control (Front-end) supported by real-time production data (Back-end) enhances both operational performance and sustainability by reducing waste (Bai et al., 2020) (Wu et al., 2025).
By adopting this integrated framework, researchers can move beyond isolated case studies and technology-centric descriptions toward a more holistic and theoretically grounded understanding of digital transformation in this traditional sector.

Implications

Theoretical Implications

This study confirms that Industry 4.0 exhibits a ‘technological stratification’characteristic within the traditional garment manufacturing sector. Foundational technologies such as IoT, Cloud, and Big Data, serving as underlying enabling technologies, are not prominent in keyword co-occurrence analyses. Nevertheless, they form the structural foundation of intelligent manufacturing systems. Conversely, deep learning and visual computing, as technologies capable of directly generating measurable performance outcomes, tend to attract greater research attention. This reminds academia that when analysing the Industrial 4.0 technology ecosystem, it should avoid treating it as a ‘homogeneous technology package’ and instead understand its functional variations across different industries.

Current research exhibits a pronounced bias towards technological development, with insufficient attention paid to socio-technical systems such as organisational transformation, workforce retraining, and supply chain collaboration. The documents reveal that the majority of literature originates from engineering and computer science journals, with relatively fewer contributions from management and social science disciplines. This implies that future theoretical frameworks must incorporate perspectives from the Technology Acceptance Model, dynamic capabilities theory, and organisational change theory to explain why a disconnect exists between technological implementation and real-world application.

China exhibits high concentration in both research volume and institutional contributions (with Donghua University, Zhejiang University, and Jiangnan University among the leading institutions), indicating that industrial structure and national policy profoundly influence academic output. Consequently, future theoretical models should fully account for structural factors such as national innovation systems, industrial policies, and digitalisation strategies.

Practical Implications

Firstly, for enterprises, research indicates that visual intelligence represents the most mature implementation direction, encompassing applications such as defect detection, garment recognition, and virtual try-on. Consequently, garment companies with limited resources should prioritise entry through such applications rather than blindly pursuing end-to-end intelligent solutions.

Secondly, small and medium-sized garment enterprises commonly face challenges of inadequate technical capabilities, ageing equipment, and weak data collection capacity. This necessitates adopting a 'lightweight', "scalable", and 'modular' approach to digital transformation – such as leasing cloud-based manufacturing platforms and employing compatible sensor devices – rather than pursuing costly one-off upgrades.

Thirdly, highly cited literature indicates that supply chain resilience and sustainability are increasingly becoming key drivers for technology adoption. When advancing Industry 4.0 initiatives, enterprises should concurrently consider green manufacturing, carbon emissions management, and supply chain transparency, thereby aligning digital transformation with ESG objectives.

Limitations

Future research on Industry 4.0 technologies adoption within traditional garment manufacturing must gradually shift focus from the current emphasis on the technologies themselves towards examining their actual operational logic within enterprise and industrial ecosystems.

On the one hand, while existing research has yielded substantial outcomes in specific application areas such as deep learning and computer vision, there remains a lack of in-depth exploration into the practical deployment methods, data infrastructure foundations, and system integration challenges of underlying enabling technologies like IoT, cloud computing, and big data within garment enterprises. As the industry's digital foundations gradually mature, research should increasingly focus on how these technologies can be effectively integrated with core processes such as production workflows, quality control, and supply chain coordination. Simultaneously, the reality that SMEs form the backbone of the garment sector indicates a future need for more practical, contextualised research. This should explore low-cost, modular, and scalable digital transformation pathways to help enterprises better understand technological value, lower adoption barriers, and enhance implementation success rates.

Concurrently, future research must broaden its perspective from 'technology-driven' to 'system-driven,' placing greater emphasis on socio-technical factors such as human resources, management practices, institutional frameworks, and policy environments. Technology adoption is not a linear process; factors such as employee skills, organisational culture, supply chain power structures, and national industrial policies significantly influence firms' adoption motivations and implementation outcomes. Consequently, subsequent research should strengthen cross-national comparisons, interdisciplinary integration, and multi-level analysis to examine how diverse institutional environments and industrial ecosystems shape digital transformation pathways. Concurrently, as sustainability and supply chain resilience emerge as core industry imperatives, the role of Industry 4.0 in energy conservation, emissions reduction, resource optimisation, and supply chain transparency warrants deeper exploration. Only through systematic research spanning technological, organisational, industrial chain, and social responsibility dimensions can we comprehensively advance the industry's evolution towards intelligent and sustainable development.

Conclusion

This study systematically examines Industry 4.0 technologies adoption within the traditional garment manufacturing sector from 2020 to 2025. Employing methods including systematic literature reviews and bibliometric analysis, it constructs a comprehensive overview of the current research landscape and knowledge structure in this field. Overall, research exhibits high concentration in terms of quantity, geographical distribution, and thematic focus. However, significant room for development remains in technological depth, theoretical contributions, and integration with industrial practice.

Firstly, examining research scale and temporal trends reveals an academic publication trajectory over the past six years characterised by 'rapid growth—short-term peak—relative decline'. This indicates that while Industry 4.0 has undergone a period of intense discussion within garment manufacturing, overall research enthusiasm remains constrained by factors such as technological complexity and enterprise adoption challenges. Despite sustained growth in digitalization demands among traditional garment firms, the continuity and problem-oriented focus of academic research require strengthening.

Secondly, this study reveals a pronounced geographical concentration of research efforts, with China and East Asian nations contributing the vast majority of global literature output. This structure aligns closely with the actual layout of the global garment manufacturing supply chain, reflecting how industrial centres directly influence academic knowledge production. However, such high regional concentration implies that perspectives, institutional differences, and diverse practices from non-major producing nations remain underrepresented within the research landscape.

Thirdly, research exhibits pronounced technological bias in its thematic focus. Artificial intelligence, particularly deep learning and visual recognition technologies, represents the most scrutinised and rapidly advancing domain; conversely, exploration of foundational capabilities such as IoT, cloud computing, and big data remains relatively limited.

Moreover, highly cited literature spans a broad thematic spectrum, encompassing sustainability, supply chain resilience, smart materials, and intelligent recognition. This indicates that Industry 4.0 in the garment sector is not merely a technological issue but is intrinsically linked to supply chain structures, environmental responsibility, and future industry development models. The diversification of research hotspots reflects the systemic and cross-disciplinary nature of digital transformation, suggesting that future research should further strengthen interdisciplinary integration.

Overall, this study constructs a comprehensive knowledge map of Industry 4.0 technology adoption within the traditional garment manufacturing sector, revealing research structures, dominant forces, technological trends, and potential gaps. Findings indicate that while the sector possesses significant development potential, it currently remains dominated by technology-driven approaches, with insufficient theoretical depth and uneven implementation practices. To propel the industry towards genuine intelligent upgrading, future research must transition from isolated technological breakthroughs to systematic integration, shift from engineering-centric approaches to management and organizational frameworks, and evolve from piecemeal applications towards building comprehensive intelligent ecosystems across the entire production process.

Acknowledgement
I extend my heartfelt appreciation to the distinguished reviewers, editors, and experts associated with AAMC2025. Their gracious opportunity to showcase my scholarly perspectives at the esteemed conference is deeply appreciated.

References

Mordor Intelligence. (2023). Analysis of the apparel market size and share - Growth trends and forecasts (2024 - 2029). https://www.mordorintelligence.com/zh-CN/industry-reports/garment-market

IBM. (2021). *What is Industry 4.0?.* https://www.ibm.com/think/topics/industry-4-0

Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics, 229,* 107776. https://doi.org/10.1016/j.ijpe.2020.107776

Chao, H., Wang, K., He, Y., Zhang, J., & Feng, J. (2021). *GaitSet: Cross-view gait recognition through utilizing gait as a deep set* (arXiv:2102.03247). arXiv. https://doi.org/10.48550/arXiv.2102.03247

Cheng, W.-H., Song, S., Chen, C.-Y., Hidayati, S. C., & Liu, J. (2022). Fashion meets computer vision: A survey. *ACM Computing Surveys, 54*(4), 1–41. https://doi.org/10.1145/3447239

Choudhry, N. A., Arnold, L., Rasheed, A., Khan, I. A., & Wang, L. (2021). Textronics—A review of textile-based wearable electronics. *Advanced Engineering Materials, 23*(12), 2100469. https://doi.org/10.1002/adem.202100469

Cubric, M. (2020). Drivers, barriers and social considerations for AI adoption in business and management: A tertiary study. *Technology in Society, 62,* 101257. https://doi.org/10.1016/j.techsoc.2020.101257

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340. https://doi.org/10.2307/249008

Ganti, L., Persaud, N. A., & Stead, T. S. (2025). Bibliometric analysis methods for the medical literature. *Academic Medicine & Surgery.* https://doi.org/10.62186/001c.129134

Huynh, N.-T. (2024). Status and challenges of textile and garment enterprises in Vietnam and a framework toward industry 3.5. *International Journal of Logistics Research and Applications, 27*(2), 346–357. https://doi.org/10.1080/13675567.2022.2147490

Kulandaivel, S., & Bandara, A. (2024). Adopting industry 4.0 in developing economies: A roadmap for apparel industry. *2024 Moratuwa Engineering Research Conference (MERCon),* 199–204. https://doi.org/10.1109/MERCon63886.2024.10689205

Kumar, R. (2025). Bibliometric analysis: Comprehensive insights into tools, techniques, applications, and solutions for research excellence. *Spectrum of Engineering and Management Sciences, 3*(1), 45–62. https://doi.org/10.31181/sems31202535k

Lee, J., Bagheri, B., & Kao, H.-A. (2015). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. *Manufacturing Letters, 3,* 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001

Liu, Q., Ali, N. L., & Lee, H. Y. (2025). Applying VOSviewer in a bibliometric review on english language teacher education research: An analysis of narratives, networks and numbers. *Cogent Education, 12*(1), 2449728. https://doi.org/10.1080/2331186X.2025.2449728

Öztürk, O., Kocaman, R., & Kanbach, D. K. (2024). How to design bibliometric research: An overview and a framework proposal. *Review of Managerial Science, 18*(11), 3333–3361. https://doi.org/10.1007/s11846-024-00738-0

Paul, S. K., Chowdhury, P., Moktadir, M. A., & Lau, K. H. (2021). Supply chain recovery challenges in the wake of COVID-19 pandemic. *Journal of Business Research, 136,* 316–329. https://doi.org/10.1016/j.jbusres.2021.07.056

Pongboonchai-Empl, T., Antony, J., Garza-Reyes, J. A., Komkowski, T., & Tortorella, G. L. (2024). Integration of industry 4.0 technologies into lean six sigma DMAIC: A systematic review. *Production Planning & Control, 35*(12), 1403–1428. https://doi.org/10.1080/09537287.2023.2188496

Sahoo, S., Kumar, A., Kumar Mangla, S., & Tiwari, A. (2024). Industry 4.0 adoption and eco-product innovation capability—Understanding the role of supply chain integration. *Business Strategy and the Environment, 33*(8), 8798–8814. https://doi.org/10.1002/bse.3949

Schanke, S., Burtch, G., & Ray, G. (2021). Estimating the impact of “humanizing” customer service chatbots. *Information Systems Research, 32*(3), 736–751. https://doi.org/10.1287/isre.2021.1015

Tian, J., Coreynen, W., Matthyssens, P., & Shen, L. (2022). Platform-based servitization and business model adaptation by established manufacturers. *Technovation, 118,* 102222. https://doi.org/10.1016/j.technovation.2021.102222

Wang, W., Yu, A., Liu, X., Liu, Y., Zhang, Y., Zhu, Y., Lei, Y., Jia, M., Zhai, J., & Wang, Z. L. (2020). Large-scale fabrication of robust textile triboelectric nanogenerators. *Nano Energy, 71,* 104605. https://doi.org/10.1016/j.nanoen.2020.104605

Wu, Y., Li, D., Guo, P., & Liu, Y. (2025). Progress in fabric defect detection based on machine learning. *Journal of Shanghai Jiaotong University (Science).* Advance online publication. https://doi.org/10.1007/s12204-025-2804-x

Yang, Q., Wu, A., & Zheng, W.-S. (2021). Person re-identification by contour sketch under moderate clothing change. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 43*(6), 2029–2046. https://doi.org/10.1109/TPAMI.2019.2960509

Yiyan, W., & Zakaria, N. (2024). Technology integration to promote circular economy transformation of the garment industry: A systematic literature review. *Autex Research Journal, 24*(1). https://doi.org/10.1515/aut-2023-0006

Zhao, D., & Wang, M. (2024). Smart manufacturing promotes high-quality development of enterprises in China. *Sustainability, 16*(23), 10431. https://doi.org/10.3390/su162310431

Zhou, H., Zhou, B., Nie, Z., & Zheng, L. (2024). Identifying key success factors for industry 4.0 implementation: An empirical analysis using SEM and fsQCA. *Applied Sciences, 14*(12), 5244. https://doi.org/10.3390/app14125244