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The Triple Intersection: Digital Transformation, Industry 4.0, and Sustainability-An SLR Perspective

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ABSTRACT

This study explores the connection between Industry 4.0, digital transformation, and sustainability through a comprehensive examination of the literature. Using the "Theories, Contexts, Characteristics, and Methods (TCCM) framework" and the "Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol", fifty-two research articles were elicited using predefined keywords and inclusion/exclusion criteria from the Scopus content. This research specifically pioneers the study of The Triple Intersection: Digital Transformation, Industry 4.0, and Sustainability-An SLR Perspective through a systematic review of 52 academic articles. The objectives of the review are to 1) analyse current research on digital transformation to find knowledge gaps and potential research topics. 2) understand the current trend of Industry 4.0, 3) evaluate their efficacy and pinpoint areas for development, study the theoretical frameworks and research methods used in the fields of "sustainability", "Industry 4.0", and "Digital Transformation", 4) fill in the identified gaps, create a thorough research plan for the future. The review clarifies important developments in our understanding of the "Resource-based view theory" and the "Dynamic capabilities theory perspective", which serve as the foundation for this study. Also, this review paper identifies persistent gaps in areas such as the change in technology changes, Sustainable practices adopted by the firms, and methodological approaches.

Keywords: *Digital transformation, Sustainability, Sustainable development, Industry4.0, Digitalization, Digital technologies, Environmental sustainability*

INTRODUCTION

The fusion of digitalization and upgradation can be known as digital transformation. It offers a way to quickly connect with people around the world, save time, and enjoy life. Customers receive value from it, and it creates a boom for industries connecting with every area, state, nation, and continent. It provides technological advancements, waste management, resource management, process optimization, and a thriving sustainable economy. Innovations in "artificial intelligence," "the Internet of Things," "robotics," "augmented reality," "virtual reality," "big data," and other fields that enable industries to expand beyond their present boundaries gave rise to the idea of Industry 4.0. The Industrial Revolution named Indusrty4.0 which is a fourth revolution in numbers, describes how industries are currently trending toward automation and data exchange. Systems. "The Internet of Things", "AI", "Big data", Cloud Computing", are all integrated and moving toward the automation process and customer-friendly procedure. Research on the Triple Intersection among Digital Transformation, Industry 4.0, and Sustainability includes a large pool of disciplines, including, economics, psychology, marketing, and manufacturing, indicating its broad relevance and the diverse factors contributing to its manifestation. The table below presents a "systematic literature review (SLR)" of seminal articles of the period 2018 to 2024, highlighting key findings, theoretical advancements, and the methods used in the papers related to digital transformation, industry 4.0, and sustainability. The fact that these papers have appeared in several prestigious journals, including "Research Technology Management," "International. Journal of Production Research," "Journal of Cleaner Production," "International. Journal of Production Economics," and "Business Strategy. and the Environment," highlights the topic's wide approachability. Additionally, a systematic literature review (SLR) of prestigious journals that have been published since the 1970s is shown in the table. Most journals have been connected to Scopus for a considerable amount of time. Their citation score and impact factor are extremely bizarre. The below table highlights the

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importance of every journal and its associated seminal articles. The significance of each journal and the foundational papers that are linked with it are shown in the table below. The majority of the research articles are from the "Journal of Cleaner Production," "Business Strategy and the Environment", and "Technological Forecasting and Social Change". They made a significant combined contribution to this study. Before COVID, research conducted between 2018 and 2020 yielded fewer publications and paid less attention to sustainability. Although they significantly contribute to the conceptual foundations of digital transformation, businesses face significant obstacles as a result of this change (Li et al., 2018).

There was a radical shift in the industries during the COVID era (2020-202). The manufacturing, marketing, purchasing, and selling processes underwent a revolution. The primary focus of this revolutionary era is now Industry 4.0, which includes digitalization, automation, energy conservation, and sustainability—a topic that is still up for debate. "Industry4.0, innovation, and Sustainable Development: A Systematic Review and a Roadmap to Sustainable Innovation", as well as "The Effects of Business Analytics Capability on Circular Economy Implementation, Resource Orchestration Capability, and Firm Performance", are the main titles that have good citations of that period. After COVID era, the demand for digitalization and sustainability has been increased tremendously due to the absence of the infrastructure and regulations in Energy Intensive Industries faced by industries in the COVID era. (Malarvizhi Kaniappan Chinnathai, Bugra Alkan, 2024). Research has examined the COVID-19 pandemic's effects on Behavior and Psychological well-being, bringing with it new insights and challenges to the industries.

Table 1: List of studied that are incorporated into the Systematic Literature Review

Inception Year of the journal	Journal	Impact Factor	Year of publication	Article name	Citation	Authors(s)
1988	Research Technology Management	2.2	2018	Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in ManufacturingMoving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies.	306	Sjödin D.R.; Parida V.; Leksell M.; Petrovic A.
2013	International Journal of Production Research	9.2	2019	Blockchain technology and its relationships to sustainable supply chain management	1969	Saberi S.; Kouhizadeh M.; Sarkis J.; Shen L.
1993	Journal of Cleaner Production	9.7	2019	Sustainability strategy as a moderator in the relationship between digital business strategy and financial performance	130	Ukko J.; Nasiri M.; Saunila M.; Rantala T.
1991	International Journal of Production Economics	12	2020	A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs- A	222	Kamble S.S.; Gunasekaran A.; Ghadge A.; Raut R.

				review and empirical investigation		
1993	Journal of Cleaner Production	9.7	2020	Sharing for a circular economy? an analysis of digital sharing platforms' principles and business models	70	Schwanholz J.; Leipold S.
1992	Business Strategy and the Environment	12.5	2021	Industry 4.0, innovation, and sustainable development: A systematic review and a roadmap to sustainable innovation	148	Ghobakhloo M.; Iranmanesh M.; Grybauskas A.; Vilkas M.; Petraitė M.
1991	International Journal of Production Economics	12	2021	The effects of business analytics capability on circular economy implementation, resource orchestration capability, and firm performance	158	Kristoffersen E.; Mikalef P.; Blomsma F.; Li J.
1993	Journal of Cleaner Production	9.7	2021	Industry 4.0 and opportunities for energy sustainability	114	Ghobakhloo M.; Fathi M.
1970	Technological Forecasting and Social Change	12	2021	Internationalization, digitalization, and sustainability: Are SMEs ready? A survey on synergies and substituting effects among growth paths	220	Denicolai S.; Zucchella A.; Magnani G.
1971	Industrial Marketing Management	10.3	2021	CO2 reduction through digital transformation in long-haul transportation: Institutional entrepreneurship to unlock product-service system innovation	17	Haftor D.M.; Climent R.C.
1984	Journal of Product Innovation Management	10.5	2021	The Gordian Knot of Practicing Digital Transformation: Coping with Emergent Paradoxes in Ambidextrous Organizing Structures*	72	Smith P.; Beretta M.
1992	Business Strategy and the Environment	12.5	2022	The impact of sustainable development strategy on sustainable supply chain firm performance in the digital transformation era	43	Nayal K.; Raut R.D.; Yadav V.S.; Priyadarshinee P.; Narkhede B.E.

1992	Business Strategy and the Environment	12.5	2022	A framework of digital technologies for the circular economy: Digital functions and mechanisms	50	Liu Q.; Trevisan A.H.; Yang M.; Mascarenhas J.
1995	International Journal of Operations and Production Management	9.9	2022	Socially responsible operations in the Industry 4.0 era: post-COVID-19 technology adoption and perspectives on future research	40	Asokan D.R.; Huq F.A.; Smith C.M.; Stevenson M.
1973	Journal of Business Research	11.5	2022	Sustainability through digital transformation: A systematic literature review for research guidance	71	Guandalini I.
1980	Journal of Business Strategy	3.4	2022	Competitive empathy: sharing values and strategies with rivals	3	Ghezzi A.
1993	Journal of Cleaner Production	9.7	2022	A new approach to identifying high-tech manufacturing SMEs with sustainable technological development: Empirical evidence	12	Pylaeva I.S.; Podshivalova M.V.; Alola A.A.; Podshivalov D.V.; Demin A.A.
1993	Journal of Cleaner Production	9.7	2022	Industry 4.0 applications for sustainable manufacturing: A systematic literature review and a roadmap to sustainable development	126	Ching N.T.; Ghobakhloo M.; Iranmanesh M.; Maroufkhani P.; Asadi S.
1993	Journal of Cleaner Production	9.7	2022	Time to clean up food production? Digital technologies, nature-driven agility, and the role of managers and customers	5	Frau M.; Moi L.; Cabiddu F.; Keszey T.
1993	Journal of Cleaner Production	9.7	2022	Sustainability related impacts of digitalisation on cooperation in global value chains: An exploratory study comparing companies in China, Brazil and Germany	9	Niehoff S.; Matthess M.; Zwar C.; Kunkel S.; Guan T.; Chen L.; Xue B.; de Oliveira Pereira Grudzien D.I.; Pinheiro de Lima E.; Beier G.
2006	Journal of Hospitality and Tourism Management	8.3	2022	Paradoxes and actualities of off-the-beaten-track tourists	8	Seeler S.; Lück M.; Schänzel H.

1990	Production Planning and Control	8.3	2022	The impact of Industry 4.0 on the reconciliation of dynamic capabilities: evidence from the European manufacturing industries	104	Felsberger A.; Qaiser F.H.; Choudhary A.; Reiner G.
1996	Supply Chain Management	8.6	2022	Analyzing the mediating role of organizational ambidexterity and digital business transformation on industry 4.0 capabilities and sustainable supply chain performance	83	Belhadi A.; Kamble S.; Gunasekaran A.; Mani V.
1996	Supply Chain Management	8.6	2022	Smart green supply chain management: a configurational approach to enhance green performance through digital transformation	54	Lerman L.V.; Benitez G.B.; Müller J.M.; de Sousa P.R.; Frank A.G.
1970	Technological Forecasting and Social Change	12	2022	An analysis of the sustainability goals of digital technology start-ups in Berlin	15	Lammers T.; Rashid L.; Kratzer J.; Voinov A.
1970	Technological Forecasting and Social Change	12	2022	Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises	243	Chauhan C.; Parida V.; Dhir A.
1992	Business Strategy and the Environment	12.5	2023	What digital-enabled dynamic capabilities support the circular economy? A multiple case study approach	4	Neri A.; Negri M.; Cagno E.; Kumar V.; Garza-Reyes J.A.
1994	Engineering, Construction and Architectural Management	5.7	2023	A multivariate regression analysis of barriers to digital technologies adoption in the construction industry	3	Chen X.; Chang-Richards A.Y.; Yiu T.W.; Ling F.Y.Y.; Pelosi A.; Yang N.
1980	Industrial Management and Data Systems	4.2	2023	Industrialisation, ecologicalisation and digitalisation (IED): building a theoretical framework for sustainable development	5	Shi Y.; Hu J.; Shang D.T.; Liu Z.; Zhang W.
1984	Journal of Advanced Transportation	2.24	2023	Machine Learning for Promoting	7	Mansoursamaei M.; Moradi M.; González-Ramírez R.G.; Lalla-Ruiz E.

				Environmental Sustainability in Ports		
1986	Journal of Business and Industrial Marketing	3.319	2023	Digital transformation in a cross-laminated timber business network	4	Hamalainen M.; Salmi A.
1993	Journal of Cleaner Production	9.7	2023	Enabling productivity goals through construction 4.0 skills: Theories, debates, definitions	4	Siriwardhana S.; Moehler R.C.
1993	Journal of Cleaner Production	9.7	2023	A digital life-cycle management framework for sustainable smart manufacturing in energy intensive industries	8	Kaniappan Chinnathai M.; Alkan B.
1993	Journal of Cleaner Production	9.7	2023	Laminating STRATH block chain technology-SWOT architectures to endure business strategy between digital transformation, firms and supply chains capabilities for sustainability	8	Sahu A.K.; Sahu N.K.; Sahu A.K.
1970	Technological Forecasting and Social Change	12	2023	Artificial intelligence enabling circular business model innovation in digital servitization: Conceptualizing dynamic capabilities, AI capacities, business models and effects	21	Sjödin D.; Parida V.; Kohtamäki M.
1970	Technological Forecasting and Social Change	12	2023	Overcoming barriers to manufacturing digitalization: Policies across EU countries	4	Senna P.P.; Bonnin Roca J.; Barros A.C.
1970	Technological Forecasting and Social Change	12	2023	Blockchain technologies for sustainability in the agrifood sector: A literature review of academic research and business perspectives	34	Dal Mas F.; Massaro M.; Ndou V.; Raguseo E.
1981	Technovation	12.5	2023	Resilience in healthcare systems: Cyber security and digital transformation	43	Garcia-Perez A.; Cegarra-Navarro J.G.; Sallos M.P.; Martinez-Caro E.; Chinnaswamy A.
1990	Information Systems Research	4.9	2023	Information Systems Research for Smart Sustainable Mobility: A	7	Ketter W.; Schroer K.; Valogianni K.

				Framework and Call for Action		
1986	Journal of Information Technology	5.8	2023	Digitalization and network capability as enablers of business model innovation and sustainability performance: The moderating effect of environmental dynamism	3	Li Y.; Cui L.; Wu L.; Lowry P.B.; Kumar A.; Tan K.H.
1992	Business Strategy and the Environment	12.5	2024	Sustainable and resilient cold chains: Enhancing adaptability, consistency, and digital transformation for success in a turbulent market	0	Vandana; Sangwa N.R.; Ertz M.; Shashi
1992	Business Strategy and the Environment	12.5	2024	Smart, sustainable, and resilient food supply chains in disruptive events context	0	Sezer M.D.; Kazancoglu Y.; Mangla S.K.; Lafçı Ç.
1973	IEEE Transactions on Engineering Management	4.6	2024	Can Corporate Digital Innovation Speed Up Climate Change Mitigation? Evidence From China	1	Dong J.; Tian J.; Lin H.; Suo X.; Wu H.; Zeng R.
1973	IEEE Transactions on Engineering Management	4.6	2024	Shaping the Future of Cold Chain 4.0 Through the Lenses of Digital Transition and Sustainability	8	Shashi; Ertz M.; Centobelli P.; Cerchione R.
1973	IEEE Transactions on Engineering Management	4.6	2024	Determining the Critical Failure Factors for Industry 4.0: An Exploratory Sequential Mixed Method Study	8	Sony M.; Antony J.; Tortorella G.; McDermott O.; Gutierrez L.
1993	Journal of Cleaner Production	9.7	2024	Unveiling green digital transformational leadership: Nexus between green digital culture, green digital mindset, and green digital transformation	1	Alabdali M.A.; Yaqub M.Z.; Agarwal R.; Alofaysan H.; Mohapatra A.K.
1993	Journal of Cleaner Production	9.7	2024	The evolution of digitalization capabilities during strategic renewal: A case study based on the ecological restoration enterprise practice	0	Hou E.; Zhang T.; Yin X.; Chen J.; Ding Y.

1993	Journal of Cleaner Production	9.7	2024	Socioenvironmental assessment and application process for IOT: A comprehensive approach	0	Cavalieri A.; Reis J.; Amorim M.
1993	Journal of Cleaner Production	9.7	2024	Enhancing domestic food supply in the UAE: A framework for technology-driven urban farming systems	0	Sharma R.; Wahbeh S.; Sundarakani B.; Manikas I.; Pachayappan M.
2003	Journal of Purchasing and Supply Management	6.1	2024	Artificial intelligence and machine learning in purchasing and supply management: A mixed-methods review of the state-of-the-art in literature and practice	2	Spreitzenbarth J.M.; Bode C.; Stuckenschmidt H.
1988	Research Technology Management	2.2	2024	Dimensions of Digital Transformation for Digital Supply Chains—Evidence from an Automotive OEM Group: This article highlights five dimensions of digital transformation that impact digital supply chains and presents a multidimensional framework to help guide companies' development of or involvement in digital supply chains.	0	Valdivia C.A.S.; Mamédio D.F.; Loures E.D.F.R.; Tortato U.
1970	Technological Forecasting and Social Change	12	2024	Evaluating the emergence of contactless digital payment technology for transportation	0	Mogaji E.; Nguyen N.P.

Source: Created by the author (s), as on 10/07/2024

In more recent years (2024), the focus shifted towards the influence of digital environments and indusrty4.0 on sustainability.

The aim of this paper based on "systematic literature review" is to discuss that body of knowledge that is currently available on "Industry 4.0" and "digital transformation" and "sustainability", and identify important trends along with the existing knowledge gaps to lay the foundation for further research projects. This paper targets to impart a more comprehensive understanding of Industry 4.0 and provide guidance for addressing its negative effects on society and the environment by analyzing the development of the field's research over the last two decades. Specifically, the objectives of this study are to:

1. Analyse current research on digital transformation to find knowledge gaps and potential research topics.
2. Understand the current trend of Industry 4.0

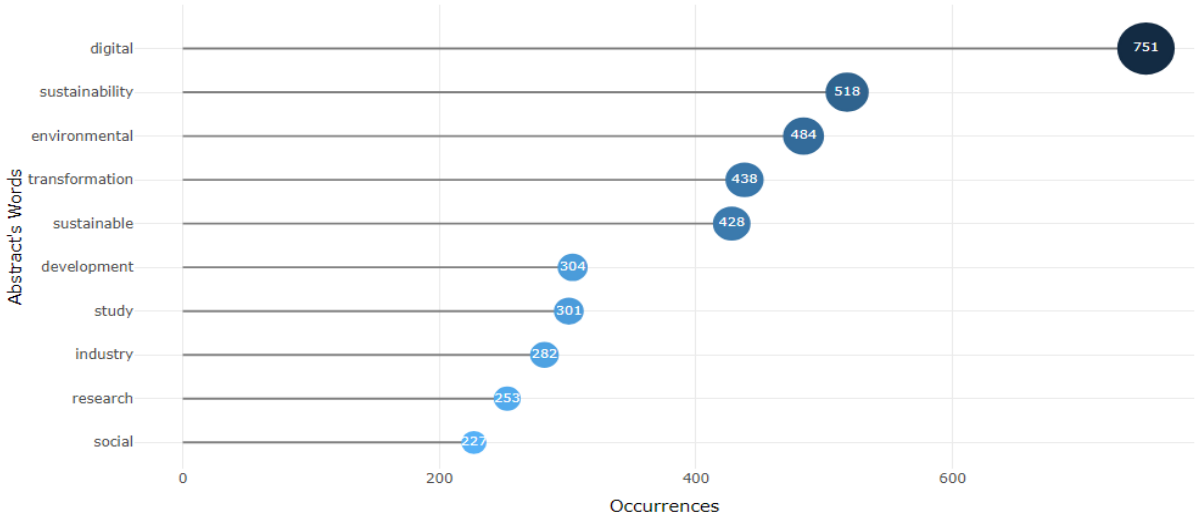
3. evaluate their efficacy and pinpoint areas for development, study the theoretical frameworks and research methods used in the fields of "sustainability", "Industry 4.0", and "Digital Transformation".
4. Fill in the identified gaps, create a thorough research plan for the future

This study consists of various phases. Beginning with the "scientific procedures and rationales for systematic literature reviews (SPAR-4-SLR) method", this study explain the step-by-step process used to review the findings on "Digital transformation", "Industry 4.0", and "Sustainability". After that, the researchers follow "the theories, contexts, characteristics, and methods (TCCM) framework" (Paul & Rosado-Serrano, 2019) to present the results and discussion of the "systematic literature review". Based on the TCCM framework, this study also suggets future research directions also. The managerial and societal ramifications of the study are finally examined by the researchers.

Fig 1: Word cloud: Top 50 words used in the papers

Source: (Made by authors using Biblioshiny)

Fig 2: Most Occurrence words from Abstract



(Source: Made by author using biblioshiny)

2. LITERATURE REVIEW METHODOLOGY

Compared to other methods of literature reviews, the SLR approach is highly regarded for its thoroughness, quality, and clarity (Paul et al., 2021; Paul & Criado, 2020). A double-verification system and the development of a research protocol that integrates feedback from several subject matter experts enable it to lessen bias in the selection and analysis stages (Paul et al., 2021). This approach is especially suitable for providing a thorough and integrated summary of the content on "Digital Transformation and sustainability". The primary goal of the research is to identify the limitations and knowledge gaps in this significant area of study.

Table 2 Summary of findings in the top 10 cited articles

Article Name	Findings
Blockchain technology and its relationships to sustainable supply chain management	• Blockchain tech benefits supply chain sustainability, faces adoption barriers. • Blockchain reduces intermediaries, enhances transparency, and security in supply chains
Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises	• IoT and AI key in CE transition, focusing on barriers. • PSS crucial for digitalization-enabled CE, highlighting business model innovation. • Framework developed for digitalization-enabled CE, linking research streams for insights
Internationalization, digitalization, and sustainability: Are SMEs ready? A survey on synergies and substituting effects among growth paths	• AI readiness boosts SMEs' international performance. • Digitalization and sustainability compete when SMEs internationalize. • Sustainability enhances digitalization but competes with AI in internationalization
Industry 4.0 applications for sustainable manufacturing: A systematic literature review and a roadmap to sustainable development	• Identified 15 sustainability functions of Industry 4.0 for sustainable manufacturing • Developed a roadmap for leveraging Industry 4.0 for sustainable development • Applied ISM to establish interrelationships among sustainability functions • Explored how Industry 4.0 technologies impact sustainability outputs in manufacturing
A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs- A review and empirical investigation	• Identified performance measures for Industry 4.0 enabled smart manufacturing systems. • Developed Smart Manufacturing Performance Measurement System (SMPMS) framework for SMMEs

The effects of business analytics capability on circular economy implementation, resource orchestration capability, and firm performance	• BAC positively impacts CE implementation and firm performance through mediation. • CE-specific BAC enhances CE implementation, IT ROC, and organizational performance. • Empirical support for BAC's effect on CE implementation, ROC, and performance.
The impact of Industry 4.0 on the reconciliation of dynamic capabilities: evidence from the European manufacturing industries	• Industry 4.0 impacts dynamic capabilities, sustainability, and market requirements. • Digital transformation enhances competitiveness and sustainability in European manufacturing industries. • Digitalization positively affects production processes, supply chain, and sustainability performance
Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing Moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies.	• Smart factories revolutionize manufacturing with digitalization, agile processes, and modular technologies. • Preliminary benefits include increased productivity and lower operational costs. • Challenges in smart factory implementation include understanding technology and developing vision. • Financial investments and explicit strategies ensure successful smart factory implementation.
Industry 4.0, innovation, and sustainable development: A systematic review and a roadmap to sustainable innovation	• Industry 4.0 enables sustainable innovation through 11 functions. • The study developed a strategic roadmap for sustainable innovation leveraging Industry 4.0. • Identified complex precedence relationships among sustainable innovation functions of Industry 4.0
Analyzing the mediating role of organizational ambidexterity and digital business transformation on industry 4.0 capabilities and sustainable supply chain performance	• DBT mediates I4.0 capabilities and sustainable performance through circular principle. • OA substitutes CBMs to develop sustainable business models and ensure sustainability. • The study provides empirical support for the effect of I4.0 capabilities. • Offers granular perspective on I4.0 capabilities, DBT, OA, CBMs, and sustainability.

Source: Created by the author (s)

Table 3 Top three theoretical backgrounds with research questions.

Theoretical background	No. article	Related article	Journal	Research questions
Digital Transformation	19	Neri A.; Negri M.; Cagno E.; Kumar V.; Garza-Reyes J.A. (2023)	Business Strategy and the Environment	• How do digital technologies support circular economy practices? • What dynamic capabilities are enabled by different digital technologies? • How do digital technologies foster circular transition in industrial firms?
		Chen X.; Chang-Richards A.Y.; Yiu T.W.; Ling F.Y.Y.; Pelosi A.; Yang N. (2023)	Engineering, Construction and Architectural Management	• What are the critical barriers to adopting different DTs in construction? • How do organizational characteristics impact barriers to DT adoption?
		Dong J.; Tian J.; Lin H.; Suo X.; Wu H.; Zeng R. (2024)	IEEE Transactions on Engineering Management	• Impact of corporate DI on carbon emission intensity in China. • Role of corporate governance in driving firms' carbon reduction targets. • Influence of DI elements on integrating renewable energy and reducing CE.
		Shi Y.; Hu J.; Shang D.T.; Liu Z.; Zhang W. (2023)	Industrial Management and Data Systems	• What are the relationships among different modules in IED framework? • How can online databases serve circular economy and industrial symbiosis? • How can AI and digital tech optimize raw material use?
		Kristoffersen E.; Mikalef P.; Blomsma F.; Li J. (2021)	International Journal of Production Economics	• Effect of business analytics on resource orchestration and circular economy implementation. • Impact of resource orchestration and circular economy on firm performance.
		Hamalainen M.; Salmi A. (2023)	Journal of Business Research	• Investigate CLT construction network and digital

				transformation in business interactions. • Explore the adoption of Construction 4.0 solutions in CLT construction
		Guandalini I. (2022)	Journal of Business Research	• How can digital transformation enhance sustainability goals? • What are the thematic connections between digital transformation and sustainability? • What are the research gaps in the digital sustainability field
		Alabdali M.A.; Yaqub M.Z.; Agarwal R.; Alofaysan H.; Mohapatra A.K. (2024)	Journal of Cleaner Production	• Investigates Green Digital Transformational Leadership, Mindset, and Organizational Culture interplay. • Explores the impact of Green Digital Transformational Leadership on ecological awareness. • Examines the role of Organizational Green Digital Culture in leadership effectiveness
		Kaniappan Chinnathai M.; Alkan B.(2023)	Journal of Cleaner Production	• What strategies improve process understanding in Energy Intensive Industries? • How can digital transformation support sustainability in EIIs?
		Pylaeva I.S.; Podshivalova M.V.; Alola A.A.; Podshivalov D.V.; Demin A.A. (2022)	Journal of Cleaner Production	• What indicators assess sustainable technological development in high-tech SMEs? • How does the proposed approach identify promising high-tech SMEs for Industry 4.0?
		Spreitzenbarth J.M.; Bode C.; Stuckenschmidt H. (2024)	Journal of Purchasing and Supply Management	• Research questions focus on AI, ML in purchasing and supply management. • Address gaps in literature, expert assessments, and operational areas. • Explore dynamic capabilities for successful organization transformation
		Valdivia C.A.S.; Mamédio D.F.; Loures E.D.F.R.; Tortato U. (2024)	Research Technology Management	• What are the dimensions of digital transformation in supply chains?

				• How do smart digital networks enhance digital supply chain performance?
		Sjödin D.R.; Parida V.; Leksell M.; Petrovic A. (2018)	Research Technology Management	• How to implement smart factories effectively for process innovation? • What are the benefits of smart factory implementation in manufacturing?
		Senna P.P.; Bonnin Roca J.; Barros A.C. (2023)	Technological Forecasting and Social Change	• Comparison of EU countries' strategies for digital technology adoption in manufacturing. • Identification of barriers and initiatives in national digital strategies
		Lammers T.; Rashid L.; Kratzer J.; Voinov A. (2022)	Technological Forecasting and Social Change	• Do digital start-ups prioritize economic goals over sustainability? • How does demographic diversity influence sustainability prioritization in start-ups?
		Denicolai S.; Zucchella A.; Magnani G. (2021)	Technological Forecasting and Social Change	• Relationship between AI readiness and international performance in SMEs. • Impact of sustainability readiness on digitalization and internationalization in SMEs
		Garcia-Perez A.; Cegarra-Navarro J.G.; Sallos M.P.; Martinez-Caro E.; Chinnaswamy A. (2023)	Technovation	• What constructs drive healthcare digital resilience? • How does uncertainty impact security in healthcare digital transformation? Are knowledge and awareness correlated with cyber security in healthcare
		Ketter W.; Schroer K.; Valogianni K.(2023)	Information Systems Research	• What design attributes increase human trust in AI applications? • How can smart mobility business models balance efficiency and sustainability? • What coordination approaches exist for smart mobility environments? • How should mobility demand response interventions be designed for user behavior? • What are the complexities for supply-side actors in smart mobility environments

		Li Y.; Cui L.; Wu L.; Lowry P.B.; Kumar A.; Tan K.H. (2023)	Journal of Information Technology	• How digitalization and network capability influence business model innovation? • Does environmental dynamism moderate the effects of digitalization and network capability
		Smith P.; Beretta M. (2021)	Journal of Product Innovation Management	• How do firms manage digital transformation efforts on a daily basis? • What are the implications of a hybrid organizing model for digital transformation? • How do organizational members cope with paradoxes in digital transformation?
Sustainability	13	Vandana; Sangwa N.R.; Ertz M.; Shashi (2024)	Business Strategy and the Environment	• How do disruptions affect cold chains? Relationship between sustainability and resilience in CC management. Decision tools for sustainable CC management. Sustainable and resilient CC performance areas and metrics. Impact of data-driven digital transformation on CC evolution. Strategies for developing sustainable and resilient CCs.
		Mansoursamaei M.; Moradi M.; González-Ramírez R.G.; Lalla-Ruiz E. (2023)	Journal of Advanced Transportation	• Impact of selected articles, most cited works, and authors discussed. • Environmental problems in port operations identified and discussed.
		Guandalini I. (2022)	Journal of Business Research	• How can digital transformation enhance sustainability goals? • What are the thematic connections between digital transformation and sustainability? • What are the research gaps in the digital sustainability field
		Kaniappan Chinnathai M.; Alkan B. (2023)	Journal of Cleaner Production	• What strategies improve process understanding in Energy Intensive Industries? • How can digital transformation support sustainability in EIIs?

		Sharma R.; Wahbeh S.; Sundarakani B.; Manikas I.; Pachayappan M. (2024)	Journal of Cleaner Production	• Investigate technology-based urban farming approaches in the UAE. Explore logistics strategies and crop production practices for resource efficiency
		Frau M.; Moi L.; Cabiddu F.; Keszey T. (2022)	Journal of Cleaner Production	• Explores digital tech impact on food production sustainability. • Investigates nature-driven agility and environmental sustainability in agri-food industry. • Examines the role of managers and customers in cleaner food production.
		Schwanholz J.; Leipold S. (2020)	Journal of Cleaner Production	• Research question one: Analyzing business models of digital sharing platforms. • Examining circular economy principles and political goals.
		Ukko J.; Nasiri M.; Saunila M.; Rantala T. (2019)	Journal of Cleaner Production	• Investigate sustainability strategy impact on digital business and financial performance. • Examine managerial and operational capabilities in digital business strategy. • Analyze the relationship between sustainability strategy, digital business, and financial performance.
		Sjödin D.; Parida V.; Kohtamäki M. (2023)	Technological Forecasting and Social Change	• What AI capacities drive circular business model innovation? • How can AI empower circularity in industrial digital servitization
		Senna P.P.; Bonnin Roca J.; Barros A.C. (2023)	Technological Forecasting and Social Change	• Comparison of EU countries' strategies for digital technology adoption in manufacturing. • Identification of barriers and initiatives in national digital strategies
		Lammers T.; Rashid L.; Kratzer J.; Voinov A. (2022)	Technological Forecasting and Social Change	• Do digital start-ups prioritize economic goals over sustainability? • How does demographic diversity influence sustainability prioritization in start-ups?

		Denicolai S.; Zucchella A.; Magnani G.	Technological Forecasting and Social Change	• Relationship between AI readiness and international performance in SMEs. • Impact of sustainability readiness on digitalization and internationalization in SMEs
		Ketter W.; Schroer K.; Valogianni K. (2023)	Information Systems Research	• What design attributes increase human trust in AI applications? • How can smart mobility business models balance efficiency and sustainability? • What coordination approaches exist for smart mobility environments? • How should mobility demand responseinterventions be designed for user behavior? • What are the complexities for supply-side actors in smart mobility environments
Industry4.0	6	Sony M.; Antony J.; Tortorella G.; McDermott O.; Gutierrez L. (2024)	IEEE Transactions on Engineering Management	• What are the CFFs of I4.0 implementation? • How do CFFs vary by business nature and size?
		Asokan D.R.; Huq F.A.; Smith C.M.; Stevenson M. (2022)	International Journal of Operations and Production Management	• How can Industry 4.0 tech improve supply chain transparency efficiency? • What competitive advantages are gained by adopting Industry 4.0 technology? • How can SMEs be incentivized to implement Industry 4.0 technology? • Opportunities for Industry 4.0 in improving local sourcing and economic growth? • To what extent can Industry 4.0 tech be used to restore supply chains?
		Pylaeva I.S.; Podshivalova M.V.; Alola A.A.; Podshivalov D.V.; Demin A.A. (2022)	Journal of Cleaner Production	• What indicators assess sustainable technological development in high-tech SMEs? • How does the proposed approach identify promising high-tech SMEs for Industry 4.0?

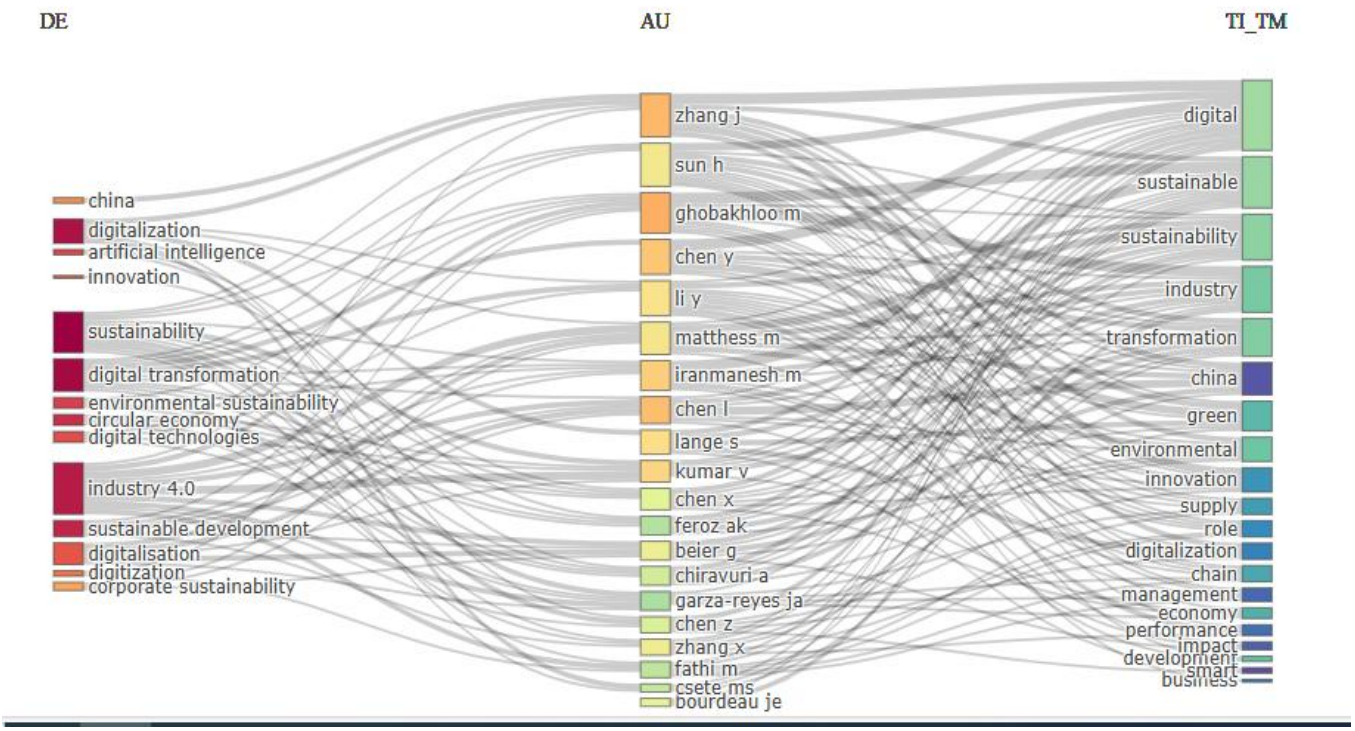
		Ghobakhloo M.; Fathi M. (2021)	Journal of Cleaner Production	• How Industry 4.0 contributes to energy sustainability functions? • What are the energy sustainability functions of Industry 4.0?
		Felsberger A.; Qaiser F.H.; Choudhary A.; Reiner G. (2022)	Production Planning and Control	• Investigate impact of Industry 4.0 on sustainability in manufacturing industries. • Explore reconciliation of dynamic capabilities due to Industry 4.0 implementation. • Examine implications of Industry 4.0 on economic, environmental, and social aspects. • Evaluate the role of dynamic capabilities in achieving sustainable competitive advantage
		Belhadi A.; Kamble S.; Gunasekaran A.; Mani V. (2022)	Supply Chain Management	• What accelerates interaction between I4.0 capabilities and sustainable performance? • How do DBT, OA, and CBMs affect the relationship in supply chains? • What are the limitations and future research scope identified in the study

Source: Created by author(s)

This Systematic Literature Review (SLR) is field-specific and employs a framework-driven content analysis approach to get a comprehensive summary of literature in that particular field as well as a structured research agenda for future studies. As a result, it fits the definition of a domain-based SLR (Paul & Criado, 2020; Paul et al., 2021). Additionally, SLR outlines future research directions and guides how to accomplish these goals, which helps to identify possible areas for further investigation. This study adopts the TCCM framework in view point to achieve the above-mentioned research goals.

Using a rigorous methodology, this SLR applies the "SPAR-4-SLR" convention. The methods for choosing search terms, databases, inclusion criteria, data extraction strategies, and analytical techniques are all covered in detail in this protocol. The SLR quality becomes coherent, rigorous, transparent, and state-of-the-art when this innovative protocol is followed (Paul et al., 2021, Jain et al., 2023). SLR process is broken down into three main stages and six smaller stages using the "SPAR-4-SLR" structure. Putting together, planning, and evaluating are the three main phases. Each primary stage consists of two sub-part: - identification and acquisition, organization and purification, and evaluation and reporting. This procedure ensures a thorough, meticulous, and transparent review.

Fig 3: Three field plot



Three field Plot: Made by authors using bilioshiny

Figure3 depicts the three-field plot diagram. This plot is based on the Keywords, authors' name and then tittles of the papers. This plot depicts how keywords are connected with author and their associated topics. The number of papers related to each element is indicated by the size of each rectangle in each list. This depicts the three-way connections of the keywords, authors and titles.

2.1 **Assembling**

2.1.1 | Identification

Under the "SPAR-4-SLR" paradigm, establishing the source type, source published, source quality, and domain of the research is the part of the identification stage. This study, which is a domain-based review, is concerned with "Digital transformation", "Industry4.0" and "sustainability". The main goals of this study are to determine future paths for this field of study, comprehend the existing state of research on Industry 4.0 features, and examine how digital transformation has affected society over the past few decades. This subject covers a lot of ground and has a sensible scope. The following are the research questions that pertain to this study:RQ1: What level of research is being done on digital transformation today, especially in the field of industry?

- RQ2: What level of research has been done on sustainability and digital transformation??
- RQ3: What is the predominant research focuses and methodologies used in these studies?
- RQ4: Why is it important for industry leaders, educators, and policymakers to understand these concepts?

English-language scholarly works published in peer-reviewed journals were chosen for this review. These papers had undergone a thorough peer review procedure, guaranteeing their caliber and value to the scholarly conversation. To ensure a high level of scrutiny, books, chapters, dissertations, and non-academic sources were not included in this review. Because of their extensive coverage and rigorous

academic standards, the articles that were included were those that were indexed in reliable databases such as ABDC List and Scopus list.

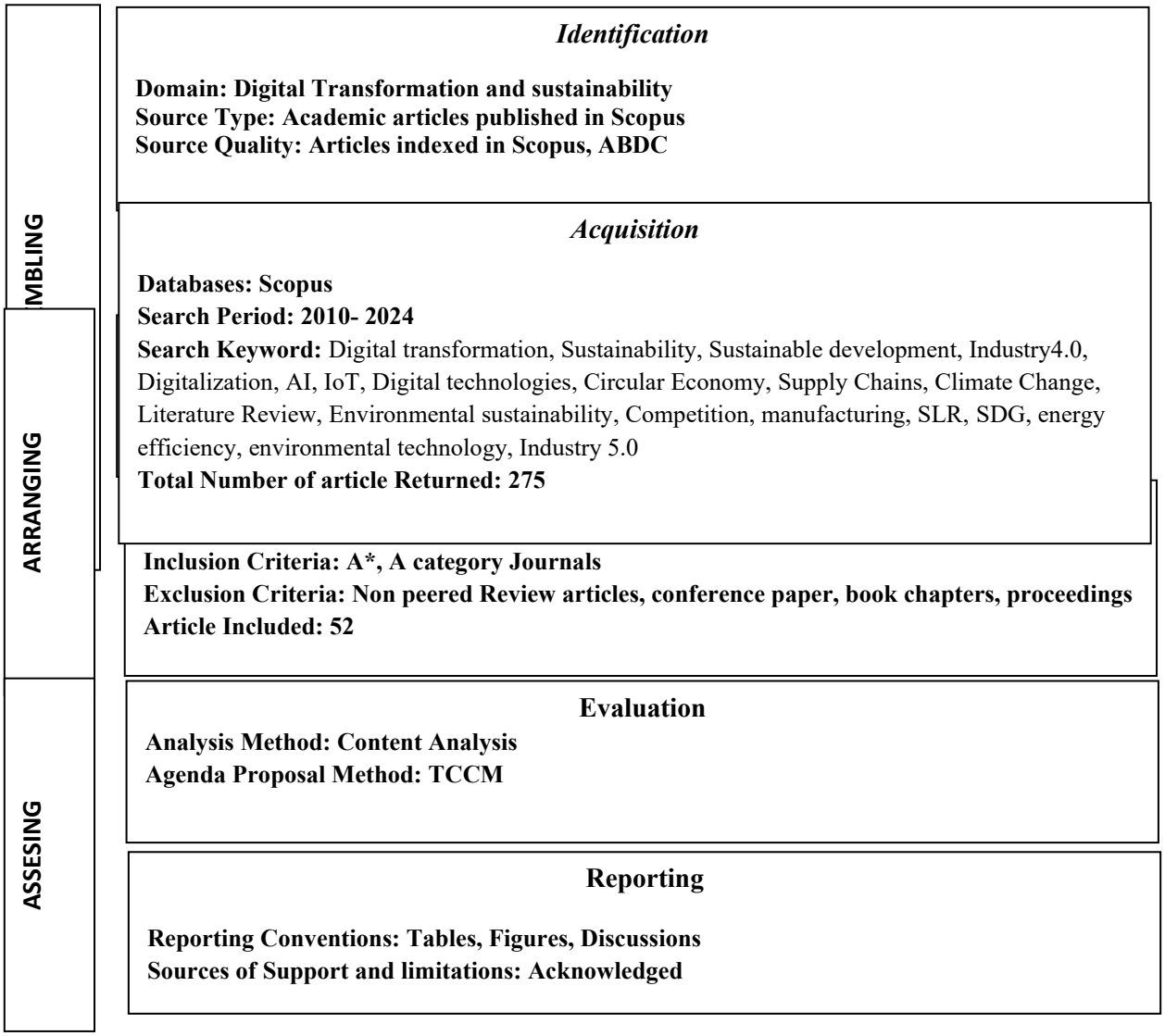
2.1.2 | Acquisition

Using predetermined search criteria, the acquisition sub-stage involves gathering pertinent literature from designated databases. The primary database for this review was chosen to be Scopus because of its extensive coverage of academic research with the highest level of authenticity. The search was conducted between 2010 and 2024 to include both pandemic time and current trends in Industry 4.0 and Digital Transformation.

After refinement, the researchers developed a list of keywords. The search was performed using the following keywords: "Digital Transformation," "Sustainability", and "Industry4.0," which were combined into Boolean search strings and with further refinement after adding more keywords like “Digitalization”, “AI”, “IoT”, “Digital technologies”, “Circular Economy”, “Supply Chains”, “Climate Change," the results yielded 275 articles in total.

The framework that has been followed in this paper is as follows:

Figure 1: SPAR-4-SLR framework



Source: Created by author(s)

2.2 Arranging

2.2.1 | Organization

In this sub- stage, the selected articles are systematically organized to facilitate detailed analysis. The organizing process for this review involved coding the articles based on specific attributes: author, article name, year of publication, journal name, and citation. This coding system ensures that each article can be easily identified and referenced throughout the review process.

The organizing framework employed is the TCCM (Theory-Context-Conceptual-Methods) framework. It allows for a structured analysis of the literature by categorizing the studies based on their theoretical foundations, the context in which the research was conducted, the key concepts explored, and the methodologies used.

2.2.2 | Purification

Then the author categorizes each paper with their ABDC ranking from the authenticate ABDC (Australian Business Deans Council) List. This criterion ensures that the articles included have undergone rigorous peer review and contribute significantly to the academic discourse. Out of 275 articles, 79 come in A category, 6 in A* category, 27 in B category, 45 in C category and rest 117 articles belongs to category Q1, Q2, Q3 and Q4. Here A category and A* category papers have been considered for discussion.

To ensure the review's quality, the exclusion criteria were also precisely outlined. Conference papers, book chapters, non-peer-reviewed and articles of proceedings were excluded from the study. This decision was made to ensure that the analysis is based on high-quality, peer-reviewed research that has been scrutinized and validated by experts in the field.

After inclusion and exclusion total 52 articles have been considered for review. This stringent selection procedure guarantees the review's reliability and thoroughness, offering insightful analysis and a structured research agenda for upcoming studies.

2.3 Assessing

2.3.1 | Evaluation

The chosen articles go through a thorough analysis of the SPAR-4-SLR framework's evaluation sub-stage to glean important insights and patterns. Content analysis offers a thorough overview of the research domain by assisting in the understanding of the underlying trends and relationships found in the literature.

To propose a well-structured research agenda, the TCCM (Theory-Context-Conceptual-Methods) framework is used. This framework aids in categorizing the findings from the literature based on theoretical foundations, research contexts, key concepts explored, and the methodologies employed. By organizing the study in this way, the review can highlight the benefits, drawbacks, gaps, and possible directions for further research in the fields of “Industry 4.0”, “sustainability”, and “digital transformation”.

2.3.2 | Reporting

The reporting sub-stage has its focus on providing an organized and understandable presentation of the review's findings. Tables, figures, and discussions in reporting standards are useful tools for effectively communicating the content analysis results and the proposed research plan. Key information is summarized using tables and figures, including the distribution of studies across themes, the frequency of different research techniques, and the conceptual frameworks that were employed. Conversations offer a story-based overview of the results, combining the quantitative information from tables and figures with the qualitative understanding gained from the content analysis.

The selected papers were downloaded from various sources and even asked the authors directly for their publication. Most of the paper has been retrieved from Emerald Publishing House and directly from the authors. A list of downloaded papers with their appropriate names has been made in a separate folder.

An essential part of reporting is acknowledging the sources of assistance and any limitations. The contribution of databases (Scopus and ABDC-indexed journals) towards the improvement of the research questions and methodology are acknowledged in this review.

3.1 | Theories (T)

A theory is a collection of related concepts, constructions, and propositions that, via defining relationships between variables, offer a methodical understanding of phenomena and help explain or forecast them. (p. 93), (Kerlinger and Lee)

To follow, the authors created a separate Excel sheet for each paper's theory and methodology. Every theory and technique had been carefully gleaned from the publications. In light of the aforementioned segregation, a separate table was created that shows the number of articles that use the same theory. It was discovered that the theory of dynamic capabilities theory perspective was used in the greatest number of articles.

Table 4 Theories used in the study

Theory	Number of Articles	Reference
Dynamic capabilities theory perspective	11	Helfat et al., 2007, Collis, 1994; Winter, 2003, Sirmon et al. (2007)
Resource-based view theory	7	Penrose (2009), (Barney, 1991), Barney
Contingency theory	3	Fred Edward Fiedler (1964)
Resource dependence theory	2	Pfeffer and Salancik (1978)
Transaction Cost Economics theory	2	Barringer & Harrison, 2000; Williamson, 1975
Grounded theory	1	(Glaser & Strauss, 1967)
Transformational leadership theory	1	Bass and Avolio (1993)
Abductive logic	1	Timmermans and Tavory
Business network model	1	Håkansson and Snehota, 1995
Descriptive analysis and content analysis	1	Yang and Tate (2012)
Digital transformation theory	1	Wessel et al.
FuDE-VIR approach	1	Atul Kumar Sahu
Fuzzy Set Qualitative Comparative Analysis	1	Greckhamer et al., Pappas Woodside
Information processing theory	1	Flynn, Huo, and Zhao (2010)
Normalization process theory	1	May and Finch (2009
Organisational size impact theory	1	Ramilo and Embi
Paradox lens theory	1	Smith and Lewis (2011)
Post-positivism paradigm	1	Henderson (2011)
Product life-cycle management capability (PLMC)	1	(Gmelin & Seuring, 2014)
Qualitative content analysis	1	Miles et al. (2014)

Real options theory	1	Myers (1977), McDonald and Siegel (1986), Myers and Majd (1990) as well as Dixit and Pindyck (1994)
Servitization theory	1	David R. Sjodin
Stimuli-Organism-Response model	1	Mehrabian and Russell (1974)
TCE	1	Podsakoff Organ (1986)
The stakeholder theory	1	(Awan et al., 2021; Bag, Dhamija, et al., 2020)
TOE	1	Dyllick Hockerts (2002)
Two cycle coding method	1	Saldana (2015)
Uncertainty and Interdependence theory	1	A. Garcia-Perez et al

Source: Prepared by author

The main theories on which most of the papers are based.

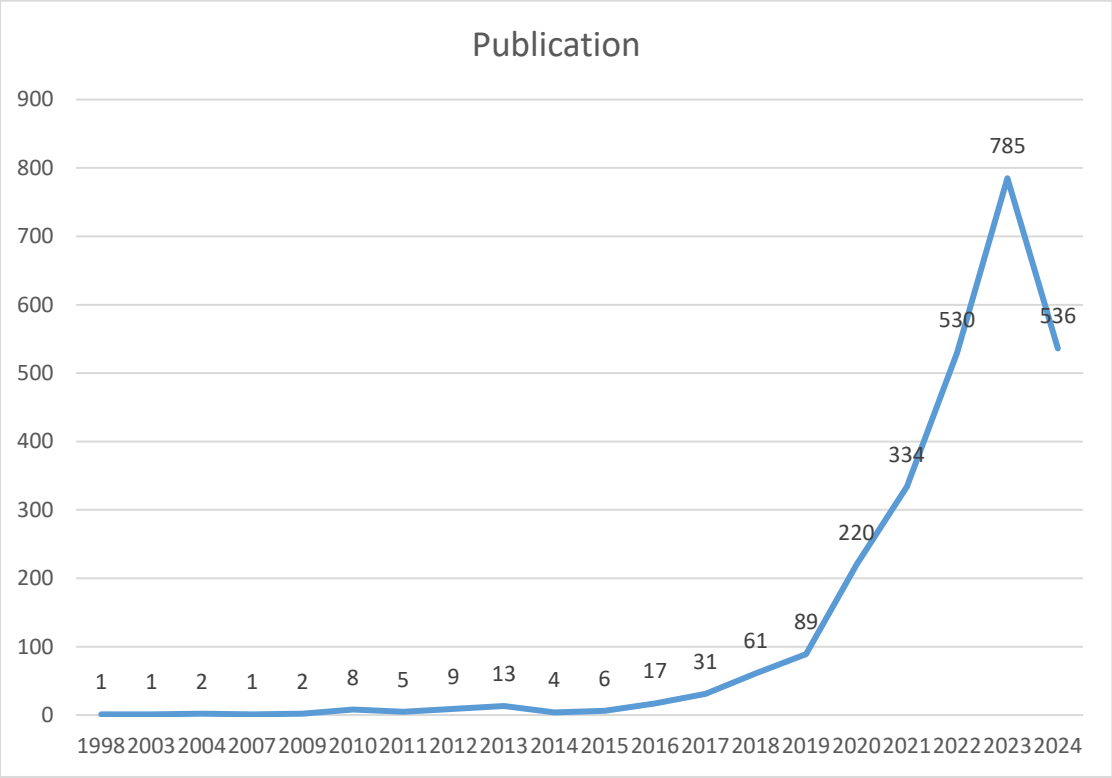
Dynamic capabilities theory perspective:
According to "the dynamic capabilities theory," companies need to have specific talents that enable them to develop, integrate, and alter their resource base in order to thrive and adapt to changes in their environment (Teece, 2007; Beske, 2012; Helfat et al., 2007). Dynamic Capabilities (DCs) have caught the interest of academics studying organizational strategy, particularly concerning the growth of resources and capacities.

Resource Based View
A framework for strategic management known as the "resource-based view" (RBV) looks at a company's competitive advantage by analyzing its internal resources and capabilities. The key concept of Resource based view are internal resources ad capabilities, VRIO framework, competitive advantage by leveraging resources.The theories used like Dynamic capabilities theory (DCT) explained digital transformation in dynamic environments in the study of Li Y. et al.The Theories applied in smart mobility research explained societal challenges and solutions in the study by Ketter W. et al. In the study of Haftor D.M. et al. multi-theoretical approach explained mechanisms for reducing CO2 emissions. The theory Uncertainty-Interdependence theory included digital transformation, cyber security, and healthcare system used by Garcia-Perez A et al. in their studies. DCV and PBV theories explained dynamic capabilities and organizational transformation practices mentioned in the article of Belhadi A. et al. In their study Sjodin D. et al. explained that smart factory implementation guided by digitalization process and automated technologies. The study of Ukko J. et al. put more focus on sustainability and explained that Sustainability strategy is the integration of the ideas of sustainable development into business operations; digital business strategy is the relationship between managerial and operational capabilities; and operational capability is inhibited but promoted by sustainability strategy. The central theme of Guandalini I's research was the relationship between digitization and sustainability. The theory of stimulus-response emerged from the preliminary ideas of conditioning, which was a behavioral process in which reinforcement causes a response to become more frequent or predictable in a particular setting. In the study of Alabdali M.A et al. (1999) conceptualized business network change processes was discussed. Fitzgerald et al. (2014) highlighted digital technology value for organizations. Study by Kamble S.S. explained the performance measures for smart manufacturing systems and identified sustainable dimensions influencing smart manufacturing systems also focused on improving diagnostic and prognostic performance in smart manufacturing. Multivariate regression analysis was used in Chen X. et al.'s study to link organizational features to adoption hurdles for digital transformations. Existing studies investigated barriers facing in follow digital transformation in construction industry. Applying these theories, it has been observed that managing relationships and operations through digital transformation improves green performance.

3.2 | Contexts (C)

The research team in this systematic literature review (SLR) looked at a range of contexts, but they classified the contexts using three paradigms: (1) Industry 4.0; (2) Sustainability; and (3) Digital Transformation. Research on technology change, expansion, efficiency, innovativeness, environmental impact, and human capital interaction are divided among the studies featured in this SLR. However, it's crucial to remember that these publications' other contextual references also highlight the dearth of worldwide research. Much of the literature explored was conducted using data collected within Germany. A focus on sustainability through digitalization is the final new development in the modern research that this study has highlighted.

Fig:2 Trend of Publications on Digital transformation and Sustainability



Source:
https://www.scopus.com/term/analyzer.uri?sort=plf&src=s&sid=09c58042a90a5f3fc15e349f2690bf76&sot=a&sdt=a&sl=60&s=TITLE-ABS-KEY%28digital+AND+transformation+AND+sustainability%29&origin=resultslist&count=10&analyzeResults=Analyze+results

Table 5: Countries and number of publications

Countries	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
Austria			1			2	1	1				5
Belgium	1				1							2

Brazil				1	1	3	7	5	2			19
Bulgaria						1						1
China	1			4	87	4	2					98
Finland					1	1	2	1				5
Germany				1	79	73	2	1				156
India				5	7	3	2				1	18
Italy					3	1	4	2	1			11
Iran				5	6	7	1					19
Lithuania				3	4	5						12
Netherlands					78							78
New Zealand							1	2				3
Nigeria								1		1		2
Norway								29				29
Poland								12				12
Russia							1	1				2
Saudi Arabia											5	5
Singapore										1		1
Sweden					21							21
U.K					1		3	12				16
U.S.A					6	2	7	1				17
UAE										1	1	2
Vietnam									1			1

Source: Compiled by author (s) based on the selected papers

3.3 Characteristics

"Digital transformation" is characterised by digital technologies, technological change, expansion and transferability aspect. Various studies highlights these concepts like Neri A.; Negri M.; Cagno E.; Kumar V.; Garza-Reyes J.A. (2023), Chen X.; Chang-Richards A.Y.; Yiu T.W.; Ling F.Y.Y.; Pelosi A.; Yang N. (2023), Dong J.; Tian J.; Lin H.; Suo X.; Wu H.; Zeng R. (2024), Shi Y.; Hu J.; Shang D.T.; Liu Z.; Zhang W. (2023), Kristoffersen E.; Mikalef P.; Blomsma F.; Li J. (2021), Hamalainen M.; Salmi A. (2023), Guandalini I. (2022), Alabdali M.A.; Yaqub M.Z.; Agarwal R.; Alofaysan H.; Mohapatra A.K. (2024),

Kaniappan Chinnathai M.; Alkan B.(2023), Pylaeva I.S.; Podshivalova M.V.; Alola A.A.; Podshivalov D.V.; Demin A.A. (2022), Pylaeva I.S.; Podshivalova M.V.; Alola A.A.; Podshivalov D.V.; Demin A.A. (2022), Spreitzenbarth J.M.; Bode C.; Stuckenschmidt H. (2024), Valdivia C.A.S.; Mamédio D.F.; Loures E.D.F.R.; Tortato U. (2024), Sjödin D.R.; Parida V.; Leksell M.; Petrovic A. (2018), Senna P.P.; Bonnin Roca J.; Barros A.C. (2023), Lammers T.; Rashid L.; Kratzer J.; Voinov A. (2022), Denicolai S.; Zucchella A.; Magnani G. (2021), Garcia-Perez A.; Cegarra-Navarro J.G.; Sallos M.P.; Martinez-Caro E.; Chinnaswamy A. (2023), Ketter W.; Schroer K.; Valogianni K.(2023), Li Y.; Cui L.; Wu L.; Lowry P.B.; Kumar A.; Tan K.H. (2023), Smith P.; Beretta M. (2021).The concept of Sustainability is characterized by Efficient, Innovativeness, Environmental impact. These charateristics has been supported by the articels of the autheors Vandana; Sangwa N.R.; Ertz M.; Shashi (2024), Mansoursamaei M.; Moradi M.; González-Ramírez R.G.; Lalla-Ruiz E. (2023), Guandalini I. (2022), Kaniappan Chinnathai M.; Alkan B. (2023), Sharma R.; Wahbeh S.; Sundarakani B.; Manikas I.; Pachayappan M. (2024), Frau M.; Moi L.; Cabiddu F.; Keszey T. (2022), Schwanholz J.; Leipold S. (2020), Ukko J.; Nasiri M.; Saunila M.; Rantala T. (2019), Sjödin D.; Parida V.; Kohtamäki M. (2023), Senna P.P.; Bonnin Roca J.; Barros A.C. (2023), Lammers T.; Rashid L.; Kratzer J.; Voinov A. (2022), Denicolai S.; Zucchella A.; Magnani G(2021), Ketter W.; Schroer K.; Valogianni K. (2023).The articles on Indusrty 4.0 depicts the Smart Automation and human- machine interlinkage characteristics of the concept of Industry 4.0 and supported by the authors Sony M.; Antony J.; Tortorella G.; McDermott O.; Gutierrez L. (2024), Asokan D.R.; Huq F.A.; Smith C.M.; Stevenson M. (2022), Pylaeva I.S.; Podshivalova M.V.; Alola A.A.; Podshivalov D.V.; Demin A.A. (2022), Ghobakhloo M.; Fathi M. (2021), Felsberger A.; Qaiser F.H.; Choudhary A.; Reiner G. (2022), Belhadi A.; Kamble S.; Gunasekaran A.; Mani V. (2022).

3.4 Methods

Several studies have adopted a variety of rigorous methodologies for assessing the interaction of "Digital transformation" and "Industry 4. 0" an "sustainability". Study by Smith P.; Beretta M. (2021), Haftor D.M.; Climent R.C. (2021) applied long-term single-case analysis of a company to gain insights about digital transformation, PLS-SEM is used by Li Y.; Cui L.; Wu L.; Lowry P.B.; Kumar A.; Tan K.H. (2023), Garcia-Perez A.; Cegarra-Navarro J.G.; Sallos M.P.; Martinez-Caro E.; Chinnaswamy A. (2023), Belhadi A.; Kamble S.; Gunasekaran A.; Mani V. (2022), Alabdali M.A.; Yaqub M.Z.; Agarwal R.; Alofaysan H.; Mohapatra A.K.(2024), Kristoffersen E.; Mikalef P.; Blomsma F.; Li J. (2023), Regression analysis has also been used by Denicolai S.; Zucchella A.; Magnani G.(2021), Pylaeva I.S.; Podshivalova M.V.; Alola A.A.; Podshivalov D.V.; Demin A.A. (2022). The approach of EFA and CFA is apllied by Guo Q.; Geng C.; Yao N.in their article published on 2023, questionnaires has also been a contributing player by Sony M.; Antony J.; Tortorella G.; McDermott O.; Gutierrez L.(2024)

Qualitative approach like thematic approach has been applied by some of the authors Sjödin D.R.; Parida V.; Leksell M.; Petrovic A. (2018), In-depth case study with observation, interviews, and document analysis has been performed in the artcle Valdivia C.A.S.; Mamédio D.F.; Loures E.D.F.R.; Tortato U. (2024). Empirical methods like econometrics and qualitative case studies are also been emphasized by Ketter W.; Schroer K.; Valogianni K. (2023), Content analysis has also been used by Dal Mas F.; Massaro M.; Ndou V.; Raguseo E.(2023), Senna P.P.; Bonnin Roca J.; Barros A.C. (2023), Felsberger A.; Qaiser F.H.; Choudhary A.; Reiner G. (2022), Ghobakhloo M.; Fathi M. (2021), Frau M.; Moi L.; Cabiddu F.; Keszey T. (2022), Guandalini I. (2022)Mixed methods has been also applied by Schwanholz J.; Leipold S. (2020), Sony M.; Antony J.; Tortorella G.; McDermott O.; Gutierrez L. (2024), Chen X.; Chang-Richards A.Y.; Yiu T.W.; Ling F.Y.Y.; Pelosi A.; Yang N. (2023)

Figure 3: Illustration of findings using the theories, contexts, characteristics, and methods (TCCM) framework.

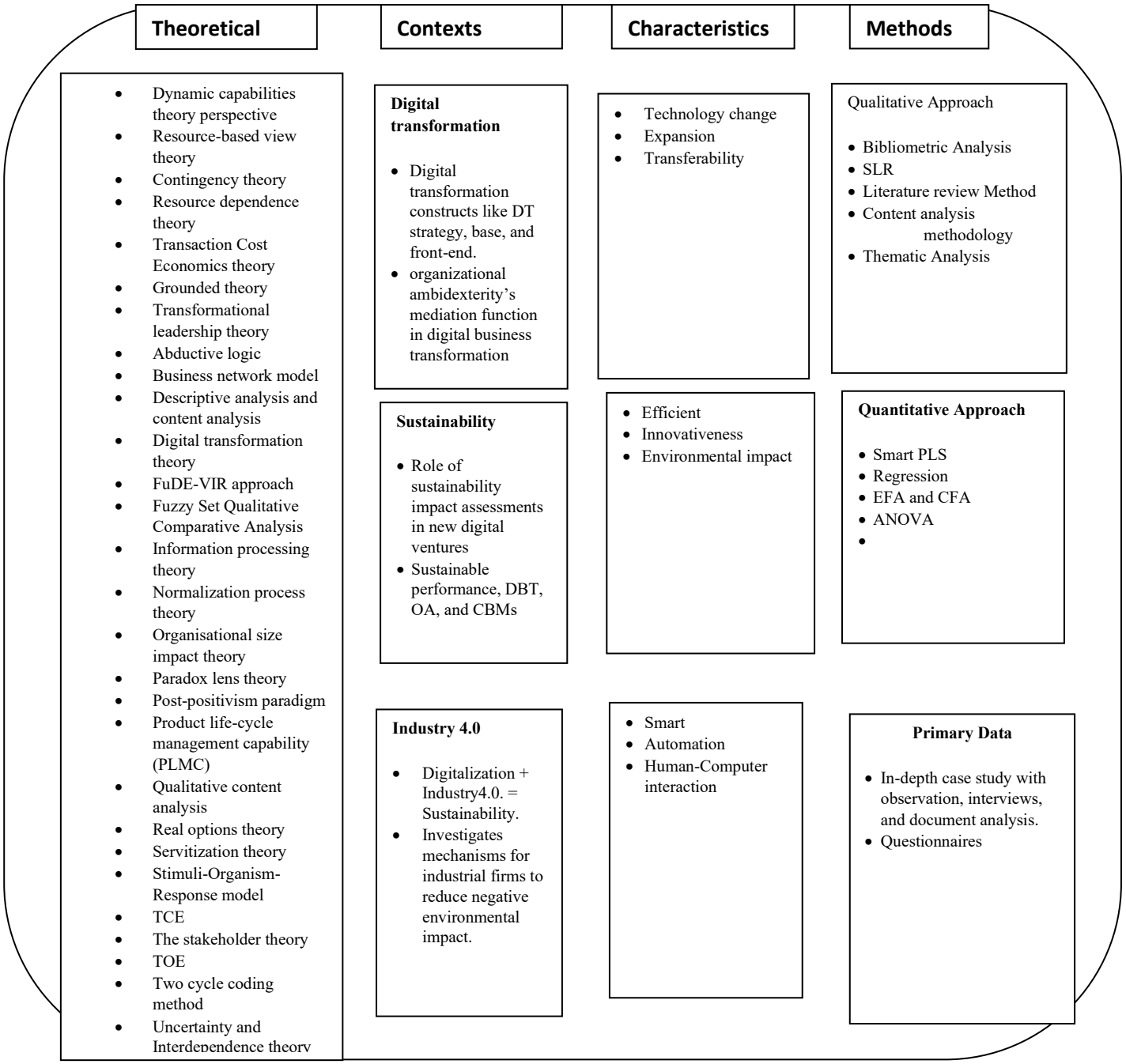


Figure 3: Illustration of findings using the theories, contexts, characteristics, and methods (TCCM) framework. Source: Created by author(s).

Figure 4: Conceptual Framework

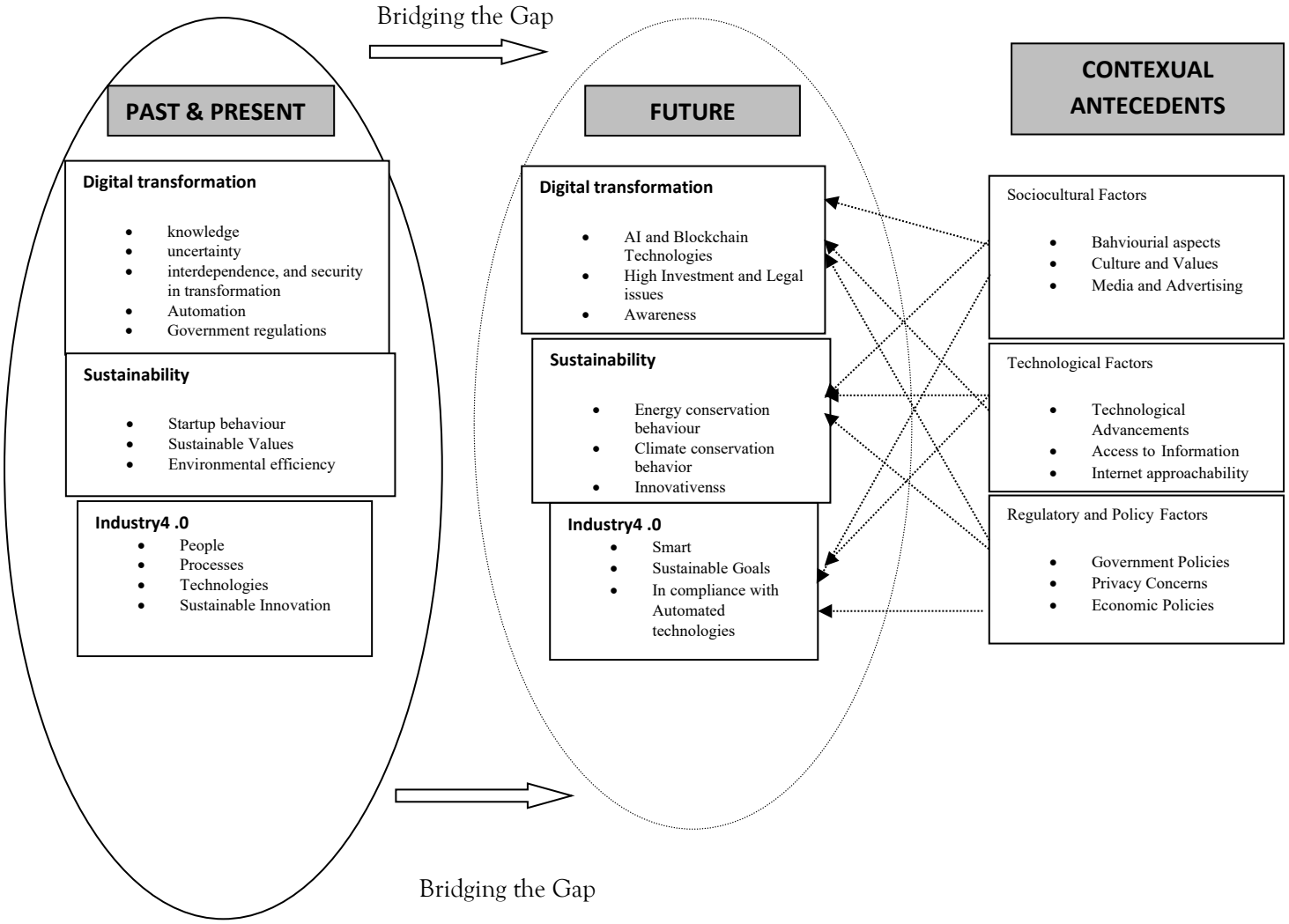


FIGURE 4: Conceptual Frameworks. Source: Created by author(s).

4 | DIRECTION FOR FUTURE RESEARCH

The researchers propose a forward-looking agenda organized within the Technology, Consumer, Context, and Market (TCCM) framework, as detailed in table 6. Furthermore, a conceptual framework outlining the historical development and present state of research on adaptive apparel is shown in Figure 4. It outlines future research directions, emphasizing potential antecedents that align with compulsive buying behavior. This framework not only synthesizes existing knowledge but also guides future investigations aimed at understanding the complex dynamics of digital transformation.

TABLE 6 Summary of future research scopes Future research questions and directions

Theories	• How to find the digital transformation's impact on economic and environmental performance? • How to create a design effective incentive strategies for smart mobility demand response? • How to investigate the intertwined future scenarios of digitalization and sustainability in SMEs? • How to analyze the impact of political changes on digitalization policy implementation? • How should digital technologies be examined in relation to green supply operations? • What are the best ways to look into how digitization affects the rise in manufacturing productivity? • How to make a quantitative assessment of digital transformation maturity in the automotive industry? • How to analyze the impact of political changes on digitalization policy implementation?
Contexts	• How may the impact of the digital revolution be studied in relation to economic and environmental outcomes? • How to balance efficiency, sustainability, and customer satisfaction in mobility business models? • How can the contribution of digital technology to lessening environmental effects be examined? • How might the reciprocal relationship between digital change and uncertainty be examined? • How to investigate the effect of sustainability of SMEs' digital transformation in a moderating way? • How to study the challenges firms face in adopting CE business models? • How to explore smart factory impact on traditional manufacturing processes? How can the impact of Industry 4.0 on the development of novel, sustainable goods be quantified?
Characteristics	• How to investigate data gathering for AI technologies to build trust? • How to examine the hidden effects of Industry 4.0 and the digital revolution on sustainability? • How to explore the practical applicability of theoretical frameworks in digital sharing platforms? • How to examine Industry 4.0 technology affect sustainability results? • How to explore environmental sustainability with block-chain for supply chain effectiveness? • How to explore technology adoption by SMEs for social responsibility? • How to explore legislative frameworks and support programs needed for Industry 4.0?

Methods	• How can the impact of Industry 4.0 technology be quantified in terms of sustainability outcomes? • How to study Longitudinal studies on CLT business network evolution over time? • How to identify new themes or modules for the open framework? • How to bridge gap between theory and practice? • How to assess energy and material efficiency through holistic sustainability evaluations? • Ho w to apply TAM, institutional theory, and innovation diffusion theory for technology acceptance? • How to conduct longitudinal research on reasons for shifting sustainability goals in start-ups?

DISCUSSION:

The findings emphasize how important it is to comprehend "Industry 4.0" and "digital transformation" completely in context of sustainability. The shift in research focus over the years toward digitalization is a reflection of the changing consumer consciousness as well as the influence of outside variables like economic downturns and pandemics like COVID 19 etc.The identified gaps in theory indicate that the concept of digitalization and Industry 4.0 may prove beneficial for future research. In particular, combining theories from economics and environmental science may lead to deeper insights. The necessity of broadening research contexts to encompass digital environments and sustainability is underscored by empirical gaps. To attain sustainability, new dynamics, and complexity are introduced by the rise in the use of online platforms. The results demand more robust and varied research designs in terms of methodology. Qualitative approaches are still important for obtaining a thorough understanding even though quantitative methods have dominated the field. Mixed-method research that blends quantitative and qualitative information may offer a more thorough understanding of the digitization concept.In order to build a more comprehensive grasp of the concepts of "digital transformation" and "Industry4.0," it will be necessary to address the identified conceptual, context-specific and operational gaps. This will ultimately lead to more effective ways of achieving sustainability. The findings of this comprehensive evaluation of the literature highlight the value of an interdisciplinary approach and provide a solid foundation for further investigation.

5 | IMPLICATION

The research's conclusions have important management and social ramifications that could have a big impact on society's well-being and corporate practices. By exploring broader demographic pools, developing accurate assessment methods, and leveraging advanced technologies, this study provides a thorough comprehension of "digital transformation", "Industry 4.0" and "sustainability". For managers and governments looking to promote sustainable and ethical approaches, these findings are essential. The implications outlined in this paper highlight the necessity for targeted interventions and strategic adjustments in both corporate and public sectors.

- Technology Integration: Understanding the relationship between "sustainability" and "Industry 4.0/Digital Transformation" can help promote the integration of big data, AI, IoT, and other technologies in a way that promotes sustainable practices.
- Cost Reduction: By enhancing productivity, cutting waste, and optimizing resource usage, the adoption of digital and sustainable practices can lower operating expenses.
- Diminution of Carbon Footprint: The sustainable practices of Industry 4.0 can aid in lowering carbon footprint and greenhouse gas emissions.
- Generate Employment: The creation of new jobs and the transformation of current roles can be facilitated by new technologies and sustainable practices, which call for the acquisition of new knowledge and training.
- Global Implications: Integrating Industry 4.0 and digital transformation with sustainability can help meet some of the Sustainable Development Goals set forth by the UN.

Furthermore, the systematic literature review found that “digital transformation” and “smart manufacturing” had a significant role in influencing sustainability. The emergence of online commerce has brought about new dynamics that require further investigation to fully understand the concept of digital transformation. There are promising opportunities to enhance the theoretical frameworks in the above research by incorporating theories from fields such as economics and environmental science. This multidisciplinary approach should lead to a deeper knowledge of the underlying mechanisms and triggers behind sustainability and digital transformation. Crucially, the review presents a well-defined research agenda to fill in existing knowledge gaps and improve comprehension. Subsequent research endeavors ought to delve into digital domains, manufacturing domains and societal domains. These kinds of efforts not only improve theoretical understanding but also provide information for focused policies and interventions aimed at reducing the negative impacts of digitalization on people, businesses and society.
To sum up, the extensive review of the literature on "sustainability," "Industry 4.0," and "digital transformation" sheds light on the condition of the area now and points out important directions for further study and care. This study assists in concentrating future research efforts on unexplored or understudied areas by highlighting knowledge and literature gaps. The detrimental effects of emerging technologies on individuals, companies, and society can be readily identified by scholars by addressing shortcomings in methodological rigor and theoretical integration.

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