

Preliminary literature review and 100 annotated bibliographies on strategic operations transformation in manufacturing: How circular economy and Industry 5.0 integration shape managerial decision-making, process redesign and sustainable performance

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Abstract

This article begins by demonstrating the goals, content, and format of a critical literature review for doctoral research on the topic of strategic operations transformation in manufacturing: How Circular Economy and Industry 5.0 Integration Shape Managerial Decision-Making, Process Redesign, and Sustainable Performance. It also underlines how the research topic might be built around these key characteristics. This paper conducted a critical review of over 100 pieces of literature connected to the research issue. It also summarises the article's key points and important information.

The article concludes with a preliminary literature review on the above-mentioned study topic. This preliminary literature review concentrated on the core vocabulary of the research topic. It also emphasises the incorporation of the circular economy and Industry 5.0 into strategic manufacturing operations management. This portion of the report identifies substantial gaps in the literature and proposes key research issues for future study.

The Purpose of a Critical Literature Review in Doctoral Research

A critical literature review forms the foundation for doctoral research, not simply listing past studies but building an analytical framework (Yakymyshyn, Falovych, and Krauje, 2025). To grasp the full scope of a subject area, it maps key theories, methods, and results tied to the central issue (Sasso, Filho, and Ganga, 2024). When exploring how circular economy ideas merge with Industry 5.0 tools in strategic operations, the review shows where these concepts align, diverge, or create tension in industrial settings (Tavares et al., 2025). Rather than standing apart, this research connects to ongoing conversations by highlighting unaddressed questions and explaining its necessity (Siratan et al., 2025). More than placement, though, it combines scattered insights into unified stories, exposing consistencies, conflicts, and shifts across current scholarship (Setyadi, Pawirosumarto and Damaris, 2025).

Content of the Critical Literature Review in Doctoral Research

One way to build a strong literature review is to centre it on core ideas, models, and themes closely tied to the study's main question (Sajadieh and Noh, 2025). When examining how operations management shifts due to the merging of the circular economy with Industry 5.0, the analysis weaves together multiple linked areas. Foundational texts come into play early; they set firm meanings and theories about the circular economy, going beyond just reusing materials to dig into long-term strategies such as keeping resources in use, cutting waste, and designing for renewal (Korhonen, Honkasalo and Seppälä, 2018). Another piece steps forward when Industry 5.0 appears not merely as an upgrade from Industry 4.0 but as a mindset combining technological advances with care for people, environmental balance, and strength during disruption (Ali, Nguyen and Oh, 2025). Examples matter, so it helps to see what car makers, gadget builders, drug producers, and others actually do with these approaches (Van and Chin, 2025). Stress staying sharp by questioning rather than just accepting claims. Sticking points come up, too; things like company habits, tools available, rules set by governments, or shared mindsets can slow change down or speed it forward – J. and Munro (2023) explore those levers. Newer tools like live system mirrors, smart algorithms, secure ledgers, or next-gen machines start making circular loops realistic under modern industrial thinking – Singh et al. (2025) show how these fit in.

Format of Critical Literature Review of Doctoral Research

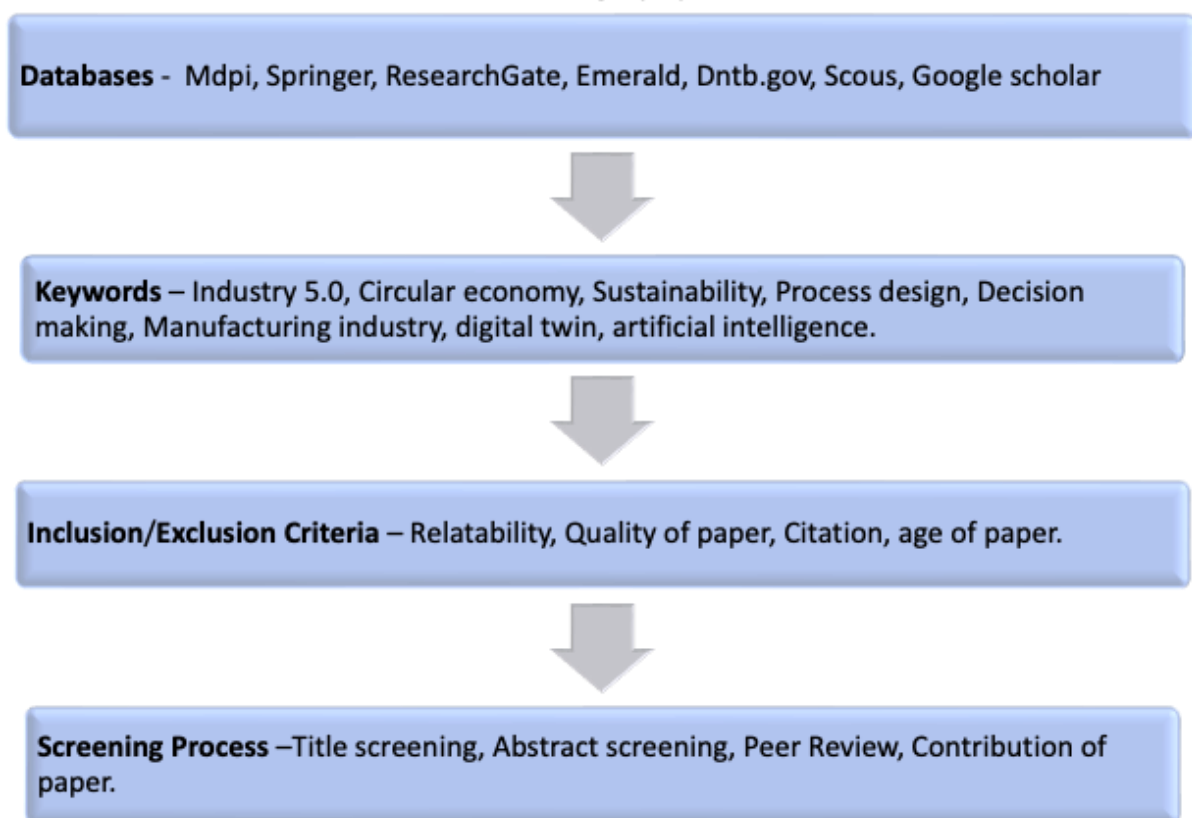
A strong literature review fits wide coverage into a clear shape, often between 5,000 and 10,000 words in high-level PhD studies, built using layered sections that lead the reader step-by-step through key themes (Solomon et al., 2024). Instead of listing sources by date or writer, top reviews group ideas around central topics, showing how theories connect and grow (Shahin et al., 2026). Starting wide helps ground the subject, providing background on the broader discipline before easing into finer points and where they overlap (Holly et al., 2023). From general to precise, the movement pulls readers from big debates down to focused analysis without losing sight of the whole picture.

A close examination of the structure means peeling back the layers. First, big-picture thinking sets the stage – circular economy ideas rise up where old straight-line systems fail, while Industry 5.0 enters as a shift blending care for people and the planet into efficient work (Trzcielinska and Trzcielinski, 2025). Zooming in a little, middle-ground insights gather threads from past writings, showing how theory meets real-world moves inside managing operations (Galindo and Herrera, 2025). Closer still, small-scale findings dive into actual projects, real cases, and tools built to make hybrid methods function on the ground (Sharma, A. and Prakash, A., 2025). After each layer settled, a short wrap-up linked what was found to the heart of the original question.

Comprehensive Review of 100 Relevant Sources

Methodological Rigour: PRISMA Style

Prisma Flow Diagram for 100 annotated Bibliography



This section of the article showcases 100 annotated bibliographies of articles about the research topic. The primary focus of the 100 articles is also covered in this section, along with how they relate to the subject of research.

SL No	Citation	Authors	Year	Key Focus	Utility and Key Points
1	(Adenike et al., 2024)	Adenike, Y., Adebayo, Y. A., Ikevuje, A. H., et al.	2024	Circular economy techniques in the oil and gas industry: A corporate concept of sustainable resource management.	Investigates the incorporation of CE into oil and gas operations, with a focus on sustainable resource management. studies waste reduction, resource recovery, and closed-loop systems. Identifies both competitive advantages (cost savings, risk reduction, compliance, reputation) and implementation problems.
2	(Akundi et al., 2022)	Akundi, A., Euresti, D., Luna, S., et al.	2022	Current research trends in the State of Industry 5.0 are analysed and identified.	A text mining study of 196 published publications identified I5.0 research themes and trends. AI, big data, supply chain, IoT, digital transformation, and machine learning are cited as critical enablers. It highlights five key areas, including supply chain examination and corporate innovation.
3	(Ali, Singh and Chauhan, 2025)	Ali, F., Singh, N., Chauhan, S. S.	2025	The Smart Industrial Revolution: Combining Virtual Reality (VR), the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data	A comprehensive study of Industry 5.0 technology integration, with a focus on IoT, big data, cloud, AR/VR, and RFID. Investigates I5.0 applications in small, medium, and large enterprises. Smart tools are used to demonstrate the benefits of technology to both companies and consumers.

4	(Amalyadi and Hossain, 2026)	Amalyadi, R.; Hossain, I.	2026	I5.0-CE focuses on strategic alignment, measurable sustainability outcomes, environmental and economic performance, and risk management.	Critically analysed that strategic alignment of I5.0 and CE results in measurable long-term consequences, such as lower emissions/energy use and improved economic performance through increased efficiency. It shows that a complete strategy that combines technology improvements with risk management is critical to managerial decision-making. Provides more empirical support for the CE-I5.0 integration-performance relationship.
5	(Antikainen, Uusitalo and Kivikytö-Reponen, 2018)	Antikainen, Uusitalo, Kivikytö-Reponen	2018	Demonstrates how digitisation facilitates the move to a circular economy.	Explains how data exchange and digital tools promote circular operations redesign.
6	(Assad, 2026)	Assad, N.	2026	I5.0 combines sustainability throughout the industrial value chain, with CE serving as its base, as well as human creativity and ethical monitoring in strategic decisions.	Presents CE practices as a critical foundation for the Industry 5.0 framework and a key driver of long-term industrial transition away from linear paradigms. Human engagement remains critical in strategic decision-making and product innovation, notwithstanding technology developments. Incorporates the human-centricity dimension into managerial decision-making in the CE-I5.0 transformation.

7	Mügge et al. (2024)	Mügge, J., Seegrün, A., Hoyer, T.K., Riedelsheimer, T. and Lindow, K.,	2024	CE measurements and LCA integration; digital twin visualisation; customised and human-centric manufacturing; and net-zero production	Explains how merging CE measurements with LCA gives a guiding framework for manufacturing decisions that can be visualised in a digital twin environment. I5.0-CE integration is envisioned as the path to personalised production, human-centric manufacturing, and net-zero carbon emissions. Highlights prospects for process redesign to provide longer-life, repairable products with minimal emissions. Part 3 on sustainable process redesign has a strong evidence base.
8	(Awan and Sroufe, 2022)	Awan, U., Sroufe, R.	2022	Designing circular business models for sustainability in the circular economy: insights and dynamics.	An interview-based inductive study identifies essential variables for designing CEBMs that incorporate sustainability. Creates a conceptual model outlining strategic enablers (management, monitoring) and tactical goals. Addresses micro-firm capabilities that impact CEBM implementation.
9	(Brändewall and Borden, 2025)	Brändewall, D. and Borden, E.	2025	A Smart Factory Strategic Framework: Advanced Manufacturing Transformation	Presents a strategy for a major consumer electronics manufacturer to develop a smart manufacturing architecture. Utilises digital twin, additive manufacturing, robots, automation, and sophisticated materials. Identifies ecosystem partners and ensures

					governance compliance.
10	(Bag et al., 2021)	Bag et al.	2021	Compares Industry 4.0 with the circular economy.	Effective for detecting overlaps, gaps, and future research possibilities in operations strategy.
11	(Bhatt and S, 2022)	Bhatt, K., Kumar, M. S.	2022	The Road to a Digital Society: MSMEs' Digital Transition from Industry 4.0 to Industry 5.0	Discusses I4.0 technologies (cloud, 5G/6G, AI, AR, and cyber-physical systems) for MSMEs' digital transformation. Emphasises the Industry 5.0 paradigm change toward human-machine collaboration. Addresses the prospects of technological development supporting the I4.0-to-I5.0 transition.
12	(Sun, 2025)	Sun, L.,	2025	An Illustration of Industrial Internet-Driven Digital Transformation in Manufacturing: Foxconn's BEACON Platform	An analysis of Foxconn's BEACON platform, which integrates mobile internet, cloud, IoT, big data, and smart manufacturing technologies. Displays advancements in automation, intelligence, and networking. Concentrates on talent development and culture. Infrastructure, teamwork, and policy creation are all recommended.

13	(Carayannis and Morawska-Jancelewicz, 2022)	Carayannis, Morawska-Jancelewicz	2022	Expands Industry 5.0 beyond manufacturing to include societal development.	Useful for larger contextual framing and connecting industry change to knowledge governance and future-focused strategy.
14	(Centobelli et al., 2022)	Centobelli et al.	2022	Develops a sustainability framework for Industry 5.0 supply chains.	Effectively integrates supply chain redesign, decarbonisation, and sustainable performance.
15	(Chen et al., 2025)	Chen, B., Zhang, Z., Wang, M., et al.	2025	Distributed MOM and Smart Factory Operating Systems for Industry 5.0	A four-level distributed architecture is proposed to promote human-centric manufacturing. Autonomous decision-making is enabled by cloud-edge-end collaboration, multi-agent systems, and federated learning. Addresses I5.0 standards for flexible, small-batch manufacturing
16	(Choi, Wallace and Wang, 2018)	Choi, Wallace, Wang	2018	Big data analytics in operational choices.	Effective for connecting data-driven decision-making to performance enhancement and sustainability.
17	(Chu et al., 2024)	Chu, C., Bernstein, W. Z., Zhang, Y., et al.	2024	Extended Reality in Design and Manufacturing: A Special Issue	A comprehensive review of XR (VR, AR, and MR) applications in design and manufacturing. Showcases XR's role in I5.0 realisation as a human-centric technology. Examines a variety of applications, including augmented reality programming, human-computer interaction, cybersecurity, and collaborative manufacturing.

18	(De Giovanni, 2021)	De Giovanni	2021	Integrates digital tools with circular economy implementation.	Useful for showing how IoT, blockchain, and digital platforms aid traceability and reverse logistics.
19	(Dhirani et al., 2023)	Dhirani, L. L., Mukhtiar, N., Chowdhry, B. S., et al.	2023	A Review of Privacy Issues and Ethical Dilemmas in Emerging Technologies	Explores the ethical and privacy implications of I5.0 technology. Addresses ambiguous regulatory standards and discrepancies in regional policies that cause compliance issues. Methods for dealing with legal and regulatory difficulties in technology implementation are proposed.
20	(Djebbouri et al., 2025)	Djebbouri, K., Atofaysan, H., Hassan, F. A., et al.	2025	Industry 5.0 Digital DNA: A Genetic Code for Human-Centred Smart Manufacturing	Presents a bio-inspired digital DNA architecture for simulating Industry 5.0 change. Organisational skills (adaptability, technology, governance, and cultural genes) are encoded for human-centric results. Identifies three archetypes of metamorphosis. It provides a diagnostic tool for assessing I5.0 readiness.
21	(Dyllick and Muff, 2016)	Dyllick, Muff	2016	Identifies different levels of corporate sustainability.	Useful for scrutinising shallow sustainability promises and determining true transformation.
22	(Ellen MacArthur Foundation, 2013)	Ellen MacArthur Foundation	2013	Seminal circular economy framework.	The primary source on circular economy definitions, commercial rationales, and closed-loop logic.

23	(Fraga-Lamas, Lopes and Fernández-Caramés, 2021)	Fraga-Lamas, P., Lopes, S. I., Fernández-Caramés, T.	2021	An Industry 5.0 Application of Green IoT and Edge AI as Crucial Technological Facilitators for a Sustainable Digital Transition Towards a Smart Circular Economy	Examines the G-IoT paradigm, weighing edge AI benefits against energy consumption issues. Presents the I5.0 smart workshop use case, highlighting operator safety. Assesses the influence of carbon footprint. Provides instructions for developing Edge-AI G-IoT systems.
24	Rahaman, M.T. and Pranta, A.D., 2025	Rahaman, M.T. and Pranta, A.D.,	2025	Innovative Entrepreneurship in the Footwear Industry: Applying Circular Economy Principles to Startup Projects Using Recycled Materials	Examines CE innovation in footwear businesses utilising recycled materials (polyester waste, coconut fibres, coffee grounds, and mycelium leather). Discusses management techniques (Lean Startup, Design Thinking, and Impact Modelling) and institutional systems that promote circular footwear innovation.
25	SISTI, A., 2024	SISTI, A.,	2024	Reshoring and circular economy.	Provides a strategic geographic dimension to operational redesign and supply chain decisions.
26	(Gaffley and Pelser, 2025)	Gaffley, G. R., Pelser, T. G.	2025	Creating a digital transformation strategy for manufacturing leadership: Take into account technological advancements to promote Industry 5.0 in smart manufacturing.	To develop a DTx strategy model for the I4.0-to-I5.0 transition, 2500 South African manufacturing leaders participated in a mixed-methods research study. identifies critical success traits, such as human-machine intelligence and resilience, collaboration, sensor technologies, AI integration, and connectivity.

27	(Galindo and de Jesús Gil-Herrera, 2025)	Galindo, D.F. y De Jesús Gil Herrera, R.	2025	Lean–I5.0–CE integration roadmap; updated implementation methodology; sustainable and resilient manufacturing	Updates and improves a methodological roadmap for implementing Lean Manufacturing, I5.0, and CE principles together. Relevant for the process redesign theme and for Part 3 on how operational configurations are structured in CE–I5.0 transformation. Provides a practical implementation dimension often absent from conceptual literature.
28	(Geissdoerfer et al., 2017)	Geissdoerfer et al.	2017	Critically compares the circular economy and sustainability.	Essential for a serious examination of whether a circular economy always produces sustainable outcomes.
29	(Ghobakhloo et al., 2023)	Ghobakhloo, M., Iranmanesh, M., Tseng, M., et al.	2023	Industry 5.0 is defined as a thorough analysis of technology, concepts, components, and values.	Content-centred review synthesis I5.0 architectural elements, constituents, and smart features. The importance of stakeholder involvement and governance is emphasised. Addresses societal challenges that I4.0 does not sufficiently address. Managers and policymakers might benefit from this detailed insight.

30	(Ghobakhloo et al., 2026)	Ghobakhloo, M.; Fathi, M.; Okwir, S.; Al-Emran, M.; Ivanov, D.	2026	I5.0 human-centric mindset, CE environmental sustainability, responsible technology usage, and the Adaptive Social Manufacturing (ASM) framework.	It introduces the ASM framework, which aligns with I5.0's human-centred philosophy and incorporates CE principles to improve environmental sustainability and responsible technology use. Critical for understanding the organisational competence and governance dimensions required for CE-I5.0 integration. Supports the gap in governance and human-centric manufacturing change.
31	(Gomaa, 2025)	Gomaa, A.	2025	Lean Six Sigma and Industry 4.0 are combined in LSS 4.0, a conceptual framework for smart manufacturing excellence.	Explains how Lean Six Sigma and I4.0 technologies (AI, IoT, digital twins, and big data) are combined in the LSS 4.0 framework. Digital twin simulation, IoT-driven monitoring, and AI-powered analytics are suggested as ways to rethink DMAIC. demonstrates the advancement of human-centred automation in I5.0.
32	(Govindan and Hasanagic, 2018)	Govindan, Hasanagic	2018	Reviews CE drivers, barriers, and practices.	Useful for managerial decision-making and detecting inertia as a significant implementation impediment.
33	(Grosse et al., 2023)	Grosse, E. H., Sgarbossa, F., Berlin, C., et al.	2023	Creating and overseeing human-centred logistics and manufacturing systems as we transition from Industry 4.0 to Industry 5.0	Editorial launching a special issue on the transition from I4.0 to I5.0, with an emphasis on the human-centric pillar. Proposes a systematic strategy that incorporates empirical, multi-method investigations while taking into account

					operator diversity and ethical concerns. Determines future research directions.
34	(Guo et al., 2025)	Guo et al.	2025	Sustainability performance through I5.0 and CE.	Useful for connecting stakeholder theory to long-term performance and investment decisions.
35	(Hansen, Christiansen and Lassen, 2024)	Hansen, A., Christiansen, L., Lassen, A. H.	2024	Industry 4.0 requires more than just technology; concentrate on SMEs and obstacles to digital transformation.	A study of 30 manufacturing SMEs examined the hurdles to digital transformation. emphasises worker capabilities as critical to transformation success. proposes a scaffolding strategy to support competency development during the stages of digitisation. Addresses fundamental concept comprehension and strategic management.
36	(Hossain, Haque and Amalyadi, 2026)	Hossain, I.; Haque, A.M.; Amalyadi, R.	2026	I5.0 for sustainable production and low-carbon economies; CE principles (closed-loop, remanufacturing, and resource efficiency); and AI-driven, data-driven decisions.	Explains how I5.0 facilitates the transition of low-carbon economies by introducing circularity into production. Closed-loop supply chains and remanufacturing are examples of CE concepts that represent movements away from linear production. AI-driven analytics, digital twins, and sophisticated data analytics provide for data-driven decisions, process optimisation, and transparency in strategic operations.

					Key to Part 3 decision-making and process redesign synthesis.
37	(Hsu et al., 2024)	Hsu et al.	2024	An Industry 5.0 and circular economy transition strategy.	Highly applicable to managerial decision-making, business model reinvention, and strategic operations.
38	(Kannan et al., 2024)	Kannan, D., Amiri, A. S., Shaayesteh, M. T., et al.	2024	A strategic prioritisation approach for identifying obstacles to the adoption of Industry 5.0 and a blockchain-based circular economy in industrial sectors.	Finds barriers to the integration of I5.0 and blockchain-based CE in the manufacturing of electric car batteries. It uses the non-linear gauge system technique with fuzzy weighted effect. The biggest obstacle is thought to be inexperienced technology providers.
39	(Akhai and Abbass, 2026)	Akhai, S. and Abbass, M.	2026	Integrating AI and Robotics for Carbon-Neutral Smart Factories: A Path to Net-Zero Manufacturing	Investigates AI-enhanced robotics (collaborative robots, predictive maintenance, computer vision) toward net-zero emissions. Edge computing, digital twins, and virtual simulation reinforcement learning are all discussed. Supports the Paris Agreement's implementation through intelligent factories.

40	(Khan et al., 2025)	Khan, S.A.R.; Sheikh, A.A.; Kolade, O.; Kamble, S. (eds.)	2025	CE expansion via smart technological innovation (IR 4.0-5.0), hyperagility and resilience capacity, agile strategy, and sustainable performance.	Investigates the extension of CE through smart technology innovation, such as IR 4.0 and 5.0. Investigates the effects of integration, hyperagility, and resilience capability on agile strategy and long-term performance. Reduces environmental impacts across the whole product lifetime, including process redesign and waste management. Useful for connecting agility and resilience capabilities to long-term operations performance.
41	(Kirchherr, Reike and Hekkert, 2017)	Kirchherr, Reike, Hekkert	2017	Reviews 114 circular economy definitions.	Valuable for uncovering definitional inconsistencies and theoretical ambiguities in CE research.
42	(Korhonen, Honkasalo and Seppälä, 2018)	Korhonen, Honkasalo, Seppälä	2018	Critique the circular economy's systemic and thermodynamic boundaries.	Very excellent for doctoral-level analysis of circular economy assumptions and practical limitations.
43	(Kudapa and Kamruzzaman, 2025)	Kudapa, S. P., Kamruzzaman, M.	2025	H-DEABSF: Using cyber-physical methods, model predictive control and digital twin-driven process control are implemented and verified in real time in smart factories.	Presents MPC and DT as part of a hybrid discrete-event and agent-based simulation architecture for intelligent manufacturing process control. It increases throughput by 22.8%, reduces latency by 39%, and improves forecast accuracy by 96.2%. Validates the scalable architecture for intelligent optimisation.

44	(Leng et al., 2022)	Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D. and Wang, L.,	2022	Reviews the Industry 5.0 literature and identifies its main pillars.	An effective synthesis source for manufacturing resilience, sustainability, and human-robot cooperation.
45	(Leong, 2025)	Leong, W. Y.	2025	Engineering Curriculum for Technical and Vocational Education and Training Based on Internet of Things Integration and Digital Twins for the Smart Industry	Creates a TVET programme that combines DT and IoT for smart manufacturing competencies. Emphasises modular, competency-based learning combined with live-data experimentation. Fills in the skills gaps in Industry 5.0 settings, such as predictive maintenance and real-time monitoring.
46	(Mahdikhani and Karbasi, 2025)	Mahdikhani, M., Karbasi, A.	2025	Supply chain integration of TQM and circular economy concepts: industry perspectives	Machine learning is used to analyse supply chain news from 2000 to 2024 and identify the evolution of TQM-CE integration. TQM demonstrates continuous improvement, customer satisfaction, and communication, while CE demonstrates reduction, reuse, and repair. Offers a complete knowledge framework.
47	(Majiwala and Kant, 2025)	Majiwala, H.; Kant, R.	2025	A hybrid MCDM technique for circularity solutions under I5.0, with practical suggestions for executives and policymakers.	Presents a hybrid MCDM framework for categorising and ranking circularity solutions under I5.0. Makes practical recommendations for CEOs and legislators. Useful for the managerial decision-making and sustainable performance parts; fills a gap in predefined

					decision frameworks for CE-I5.0 integration.
48	(Manetti et al., 2025)	Manetti, S.; Ni, M.; Supino, S.; Troisi, O.	2025	CE-I5.0 transition as a deep value chain reconfiguration; critique of techno-solutionism; and the need for systemic transformation to ensure sustainability.	Argue that the CE-I5.0 transition necessitates a fundamental reorganisation of value chains, moving beyond techno-solutionist methods. The primary goal is to improve sustainability through transformational rather than incremental change. Critically necessary for Part 3's methodological tensions section and supporting doctoral-level critique of over-reliance on technology as a sustainable solution.
49	Rawat et al., 2025	Rawat, R., Nagal, K. and Sharma, R.	2025	Digital Twins as Facilitators of Resilient and Sustainable Industries 5.0: An Overview of Infrastructure	A thorough examination of DT applications in Industry 5.0 (supply chain, smart manufacturing, and urban planning). Sixty academic publications are synthesised. Proposes a conceptual framework to accelerate DT adoption in I5.0. Addresses the practical difficulties of data integration costs and cybersecurity.

50	(Marconnet et al., 2024)	Marconnet, B., Gaha, R., Assuad, C., et al.	2024	Using Industry 4.0/5.0 technologies to choose sustainability metrics for smart product design: a methodological framework analysis and recommendation	Examines I4.0 technologies (VR, AR, DT, and robotics) for evaluating sustainability indicators. Introduces a system integration framework for manufacturing and smart product design. Provides a decision-making framework for maximising environmental, social, and economic impacts.
51	(Roumeliotis et al., 2024)	Roumeliotis, C., Dasygenis, M., Lazaridis, V. and Dossis, M.	2024	Revolutionising the Mining and Metals Industries: A Digital Transformation Framework for Efficiency and Sustainability	proposes a DT framework for the mining and metals industries that addresses safety, cost, efficiency, and sustainability. Blockchain, cloud computing, artificial intelligence, IoT, and digital twins are all examined. Includes case studies for ArcelorMittal and Rio Tinto. Addresses historical integration, expertise, and cybersecurity concerns.
52	(Mourtzis, Angelopoulos and Panopoulos, 2022)	Mourtzis, D., Angelopoulos, J., Panopoulos, N.	2022	A Review of the Literature on the Possibilities and Difficulties of Making the Shift from Industry 4.0 to Society 5.0	An analysis of the literature on the transition from I4.0 to Society 5.0. highlights a change in design that is durable, human-centred, and sustainable. The key values of I5.0 are discussed, including societal impact and human well-being. Provides a framework for industry and society interaction.

53	(Müller, Kiel and Voigt, 2018)	Müller, Kiel, Voigt	2018	Identifies the organisational and sustainability drivers and impediments to Industry 4.0.	It is helpful as a managerial foundation for comprehending adoption decisions, even though it comes before Industry 5.0.
54	(Nahavandi, 2019)	Nahavandi, S.	2019	Industry 5.0: A Human-Centred Approach	Introduces the I5.0 concept, which focuses on human-machine collaboration through advancements in brain-machine interface. Addresses the need to increase production while keeping the workforce. Describes major characteristics and issues for manufacturers. Compares the economic benefit of employment creation vs. job displacement.
55	(Nandi et al., 2021)	Nandi et al.	2021	Supply chain redesign under disruption.	Strong in terms of resilience, digital circularity, and strategic redesign under uncertainty.
56	(Narula et al., 2023)	Narula, S.; Tamvada, J.P.; Kumar, A.; Puppala, H.; Gupta, N.	2023	I5.0 influences CE features in production, expert-based surveys, the AHP approach, and empirical ranking of CE dimensions.	Using expert-based surveys and AHP methodologies, the study investigates the impact of I5.0 on CE issues in manufacturing. Provides an empirical ranking of how I5.0 factors influence various CE practices. Relevant for managerial decision-making and determining which I5.0 skills have the most impact on CE adoption in manufacturing scenarios.

57	(Nascimento et al., 2018)	Nascimento, D. L. de M., Alencastro, V., Quelhas, O. L. G., et al.	2018	Examining Industry 4.0 technologies to support circular economy principles in an industrial setting	A framework for integrating I4.0 technology and CE practices was validated using a three-stage qualitative research approach. suggests using internet technologies, reverse logistics, additive manufacturing, and electronics reuse to advance CE. demonstrates a positive impact on the environment
58	(Nathany, 2025)	Nathany, D.	2025	Manufacturing Transformation: An Extensive Examination of Industry 4.0 Technology, Industry 5.0 Views, and Upcoming Research Paths	An in-depth analysis of Industry 5.0 integration and Industry 4.0 technologies (big data, digital twins, AI/ML, IoT, cloud, AR/VR, and blockchain). Benefits are quantified as follows: 25% growth potential and 25% breakdown reduction. Emphasises the need for sustainability and decarbonisation.
59	(Nayeri, Sazvar and Tirkolaei, 2026)	Nayeri, S.; Sazvar, Z.; Tirkolaei, E.B.	2026	Creating a circular supply chain network, improving RSPs, cutting expenses, energy use, and greenhouse gas emissions, and raising SC visibility and job development.	Provides a multi-phase circular supply chain decision-making model that integrates I5.0 and CE.
60	(Nexus, 2026)	Nexus	2026	Conceptual nexus between Industry 5.0 and the circular economy.	Useful for describing the intersection of human-centred innovation,

					sustainability, and circularity.
61	(Oliveira Neto et al., 2019)	Oliveira Neto et al.	2019	Cleaner production and SDGs in textiles.	An effective empirical illustration of circular-lean integration and sustainability outcomes.
62	(Onu, Pradhan and Mbohwa, 2023)	Onu, P., Pradhan, A., Mbohwa, C.	2023	Industry 4.0 and Beyond: Facilitating Digital Conversion and Long-Term Development in Industry X.0	Examines the development of Industry X.0, including 5G, digital twins, edge computing, and quantum computing.
63	(Padmavathi, Kanimozhi and Saminathan, 2025)	Padmavathi, V., Kanimozhi, R., Saminathan, R.	2025	Digital twin-powered smart factories: edge AI, federated learning, and real-time physics-based co-simulation	Presents a method for co-simulation in smart factories that integrates DT, Edge AI, and FL. boosts throughput by 13.2%, decreases cloud usage by 28%, and cuts latency by 35%.
64	(Peruzzini, Prati and Pellicciari, 2023)	Peruzzini, M., Prati, E., Pellicciari, M.	2023	A framework for utilising the human-automation symbiosis to create intelligent production systems for Industry 5.0	Suggests a framework for Smart Manufacturing Systems Design (SMSD) that uses human-automation symbiosis to achieve I5.0. Manufacturing entities are integrated through the usage of augmented digital twins.
65	(Gomes et al. 2004)	Gomes, C.F., Yasin, M.M. and Lisboa, J.V.	2004	Examines manufacturing performance metrics.	A good resource for traditional performance metrics before the integration of CE and Industry 5.0.

66	(Li et al., 2022)	Li, Z., Fei, F. and Zhang, G.	2024	Cloud Computing and Edge Management in Smart Manufacturing: Changing Production Through Digital Integration	Analyses the cloud-edge-tier architecture in smart manufacturing. examines cloud platforms, IoT monitoring, predictive maintenance, and real-time optimisation. Examines automobile and pharmaceutical case examples. Addresses implementation difficulties such as legacy integration, security, and skill limitations.
67	(Rahman and Chandan, 2025)	Rahman, F., Chandan, A.	2025	Innovative Strategies in the Industry 5.0: Overcoming Industry 4.0's Difficulties	Examines the transition from I4.0 to I5.0, emphasising supply chain, cybersecurity, human resource management, and technology integration.
68	(Rahmani, Jesus and Lopes, 2024)	Rahmani, R., Jesus, C., Lopes, S.	2024	Implementing Digital Transformation and Digital Twins: Exploring the Factory of the Future	A case study of Portuguese automotive businesses embracing automation and the I4.0-to-I5.0 transition. examines the use of lighter materials, additive manufacturing, artificial intelligence, and collaborative human-robot environments. demonstrates progress toward sustainable manufacturing.

69	(Raj and Atluri, 2025)	Raj, P., Atluri	2025	Cloud-Based Smart Factories: Real-Time Data Pipelines, IoT-Powered Manufacturing	Investigate cloud-based data pipeline systems for smart factories that include IoT, edge computing, and machine learning. Examine data components (ingestion, stream processing, storage, and visualisation). Showcases case studies of efficiency improvements in the automobile and pharmaceutical industries.
70	(Rathi and Kathuria, 2025)	Rathi, G.; Kathuria, S.	2025	AI and blockchain for management choices; digital twins for smart production; resource efficiency and a sustainable supply chain	Explains how AI and blockchain, two Industry 5.0 technologies, affect management choices by providing information for supply chain transparency and cost reductions.
71	(Rejeb et al., 2025)	Rejeb, A.; Rejeb, K.; Keogh, J.G.; Süle, E.	2025	I5.0-CE convergence: developing technologies for sustainability through human-centric methods.	Explores the relationship between I5.0 and CE, emphasising how new technologies can help sustainability through human-centred approaches.

72	(Ren, Boonlua and Jirawuttinunt, 2025)	Ren, B., Boonlua, S., Jirawuttinunt, S.	2025	Industry 5.0: Digital Transformation and ESG Rating in China's Manufacturing Sector	Determines the relationship between 360 Chinese firms' DT and ESG ratings from 2010 to 2022.
73	(Rüßmann et al., 2015)	Rüßmann et al.	2015	Landmark Industry 4.0 report.	Provides the fundamental technology rationale upon which Industry 5.0 grew.
74	(Santiago et al., 2025)	Santiago et al.	2025	CE, sustainable supply chain management, and CSR.	Useful for governance, supply chain integration, and the transition to Industry 5.0.
75	(Negri et al., 2020)	Negri, M., Cagno, E., Colicchia, C. and Sarkis, J.	2020	Demands robust and sustainable supply chains.	Helpful in demonstrating why efficiency-based models are insufficient for future operations.
76	(Sassanelli et al., 2019)	Sassanelli et al.	2019	Examines circular economy performance assessment approaches.	Useful for measuring performance, selecting indicators, and spotting fragmentation in CE metrics.
77	(Shabur, Shahriar and Ara, 2025)	Shabur, M.A.; Shahriar, A.; Ara, M.A.	2025	I5.0 and green technologies for eco-friendly production; CE principles (reuse, recycling, and remanufacturing) for environmental footprints; humans as fundamental decision-makers.	Explains how I5.0 reduces its impact on the environment by using energy-efficient systems, renewable energy, and green technologies.

78	(Shafique, Adeel and Rashid, 2024)	Shafique, M.N.; Adeel, U.; Rashid, A.	2024	I5.0 technology capabilities and long-term performance are mediated and moderated by CE, an empirical mechanism	Demonstrates that CE practices serve as a moderator and mediator between I5.0 technology capabilities and long-term performance.
79	(Shamsuddoha et al., 2024)	Shamsuddoha, M.; Kashem, M.A.; Nasir, T.; Hossain, N.U.I.	2024	Real-time agile decision-making is made possible by IoT, AI, and data analytics; production changes dynamically, productivity and waste reduction.	Explains how real-time data collection, quick decision-making, and dynamic modifications to manufacturing processes are made possible by I5.0 technologies (IoT, AI, and data analytics). These characteristics are found to improve production and reduce waste. Supports the data-driven managerial decision-making dimension, as well as the relationship between I5.0 technology capacity and operational performance results.
80	(Sharma et al., 2024)	Sharma, A., Singh, S. K., Kumar, S., et al.	2024	Industry 5.0 with IoT-enabled smart farming	Examines IoT, digital twins, AI, and remote sensing as examples of I5.0 integration in agriculture. Showcases sensor-based agricultural monitoring, cognitive algorithms for predictive maintenance, and autonomous decision-making. demonstrates I5.0's dramatic potential for precision agriculture and sustainability.

81	(Lewis, M.A., 2019)	Lewis, M.A.	2019	Foundational operations strategy text.	Useful for establishing the foundation of strategic operations, trade-offs, performance goals, and process decisions.
82	(Spring, M. and Araujo, L., 2017.)	Spring, Araujo	2017	Challenges to a product-centric operations strategy.	Helpful for thinking beyond linear manufacturing and towards servitization and process reform.
83	(Štefko et al., 2025)	Štefko, R., Frajtova-Michalikova, K., Straková, J., et al.	2025	Digital twin-based virtual factories and cyber-physical production systems.	Examines robotics, enterprise digital twin systems, cognitive computing, and 3D immersive virtual reality in Industry 5.0 metaverse settings. Showcases the integration of AI, IoT, and edge computing for smart production engineering. Emphasises knowledge acquisition in synthetic settings.
84	(Tavares et al., 2026)	Tavares, T.M. et al.	2026	Lean-CE integration; transition from LM tools (VSM, 5S) to strategic-philosophical integration; thorough literature assessment. Knowledge Maturity Theory	Explains the transition from the early application of Lean methods (VSM, 5S, cellular manufacturing) for CE objectives to a deliberate and thorough integration of both paradigms. Offers a knowledge maturity viewpoint on the Lean-CE relationship. Useful as a methodological counterpoint to the 5.0-CE integration literature, as well as for Part 1's analysis of how fields arise before paradigmatic synthesis.

85	(Van Erp et al., 2024)	Van Erp, T.; Carvalho, N.G.P.; Gerolamo, M.C.; Gonçalves, R.; Rytter, N.G.M.; Gladysz, B.	2024	Manufacturing strategy for I5.0: incorporating sustainability, resilience, and human-centeredness into industrial value generation; framework development.	Provides an innovative manufacturing strategy framework based on the I5.0 paradigm that includes sustainability, resilience, and human-centeredness into industrial value generation. Specifically applicable to the strategic operations transformation issue and the theoretical gap in integrated CE-I5.0 decision frameworks. Supports the draft RQ on which operational configurations are most closely related to the CE-I5.0 transformation.
86	(Xu et al., 2021)	Xu, Lu, Vogel-Heuser, Wang	2021	Examines the conceptual shift from Industry 4.0 to Industry 5.0.	Useful for conceptual genealogy and separating efficiency-first logic from human-centred industrial paradigms.
87	(Zafar et al., 2025)	Zafar, H.; Mehdi, B.U.; Sheikh, A.A.; Sahar, N.E.	2025	I5.0 shifts from linear to circular models: blockchain, AI, and IoT for real-time decision-making and transparency; implementation of circular economic strategies.	Describes how I5.0's innovation-centric and human-centred transformation accelerates the shift from linear to circular economic models that prioritise waste reduction. Smart technologies are regarded as enabling more real-time decision-making, transparency, and sustainable product design. It is proposed that technology advancements are required to implement CE approaches through material reuse, enhanced manufacturing, and new resource management channels.

88	Aivazidou, Tsolakis and Mollona (2025)	Aivazidou, E.; Tsolakis, N.; Mollona, E.	2025	CE 5.0 concept; digital technology-enabled CE operations; institutional cause-effect model; business resilience	Introduces CE 5.0 as a strategy for enhancing company resilience and environmental sustainability. Defines CE 5.0 as the design, analysis, and administration of CE-focused operations made possible by digital technologies. Critical for framing process reform in an institutional and strategic framework.
89	Atif (2023)	Atif, S.	2023	Beyond efficiency and productivity, the I5.0 strategy incorporates social responsibility, CE ideals into business models, and waste minimisation.	Argues that I5.0 goes beyond efficiency to include social responsibility. I5.0's emphasis on human capital encourages managers to enhance resource efficiency and eliminate waste. It is noted that incorporating CE principles in corporate models improves sustainable policies through process automation. This is useful for connecting I5.0's strategic aim to operational and process-level redesign.
90	Breque, De Nul and Petridis, 2021)	Breque, De Nul, Petridis	2021	Defines Industry 5.0 as a resilient, sustainable, and human-centred industrial vision.	The primary policy source for defining Industry 5.0 and connecting it to strategic operations, sustainability, and human-centred transformation.

91	Chichi and Mamad, 2025)	Chichi, O.; Mamad, M.	2025	I4.0-I5.0 digital enablers with CE values, causal-loop diagram (CLD) for decision support, and triple bottom line performance	Explains how supply chain resilience and triple-bottom-line performance can be balanced by combining I4.0 digital enablers with I5.0 human-centric, resilience-oriented, and CE concepts. For extensive investments in workforce development, CE transformations, and digital infrastructure, CLD provides a framework for decision-making. supports the resilience-focused theoretical integration of I5.0 and CE.
92	Gargari, Saeidi-Mobarakeh and Khalili (2025)	Gargari, F.J.; Saeidi-Mobarakeh, Z.; Khalili, H.A.	2025	I5.0 supply chain sustainability, circular closed-loop concepts, decision-support tools, and economic and environmental balance	Develops a thorough framework that, under I5.0 settings, synchronises supply chain networks with sustainable practices. Provides effective decision-support tools for balancing economic, technological, and environmental goals. Improves sustainability performance through circular closed-loop integration. Sub-themes related to process redesign and managerial decision-making are directly informed.

93	Guo et al. (2025)	Guo, J.; Guo, L.; Waheed, A.; Jianhua, Y.	2025	I5.0 technologies and sustainable performance; CE as a positive moderator; managerial investment decisions	The study discovers that CE practices help to mitigate the association between I5.0 technologies and long-term performance. Argues that managers must use CE to align I5.0 with sustainability goals. Provides empirical recommendations on investment decisions, resource management, and optimising organisational operations. Key quantitative evidence supporting the CE-I5.0 moderating mechanism.
94	(Kyfyak et al. 2018)	Kyfyak, V. and Lopatynskyi, Y.,	2018	Process re-engineering an	Develops a rigorous methodology for modelling company development scenarios that employs business process reengineering to boost competitiveness.
95	Majiwala et al. (2026)	Majiwala, H.; Gandhi, N.; Kant, R.; Shankar, R.	2026	I5.0-enabled circular supply chains (CSCs); MCDM framework for performance outcomes, production efficiency, and waste reduction.	Creates a hybrid MCDM framework to help managers prioritise performance outcomes from I5.0-enabled CSC deployment. The top-ranked outcomes include improved manufacturing efficiency, operational and economic performance, and waste reduction. Directly addresses the sustainable performance

					measurement gap and offers managers an empirical decision-support tool.
96	Mollik et al. (n.d.)	Mollik, M.S.; Karim, R.; Sahabuddin, M.; Eneizan, B.	N/A	I5.0-CE synergy; human-centred innovation; AI/ML for adaptive manufacturing; closed-loop supply chains; resource recovery.	Identifies the following I5.0-CE features: intelligent resource recovery, closed-loop supply chains, digital-physical integration, human-centred innovation, and sustainable product design. Demonstrates how predictive maintenance and flexible production are made possible by artificial intelligence and machine learning for longer product lifecycles.
97	(Milani et al. 2025)	Milani, F. and Lashkevich, K.	2025	Opportunities for process improvement	Conducts a systematic assessment of the literature to discover and categorise 80 different process improvement opportunities, each of which is linked to one or more of 64 possible redesign alternatives.

98	(Sikdar et al. 2014)	Sikdar, A. and Payyazhi, J.	2014	Business process management	Provides a conceptual framework for managing organisational transformation while using business process management (BPM).
99	(Dumas et al., 2018)	Dumas, M., La Rosa, M., Mendling, J. and Reijers, H.A.,	2018	Process improvement and its performance	Explains the purpose of process redesign and defines what it means to improve process performance.
100	(Zellner, G., 2013)	Zellner, G.	2013	Redesigning and improving business processes.	Develops a framework for discovering patterns in Business Process Redesign (BPR) to discover new mechanisms for redesigning and enhancing business processes.

Preliminary Literature Review

Introduction and Field Overview

Manufacturing now faces a turning point, as old ways of making things – grabbing resources, building products, then tossing them away – are seen more clearly as harmful to nature and shaky for business (Yakymyshyn, Falovych and Krauze, 2025). At the very moment factories grow smarter through digital tools like those in Industry 4.0, they also run into fresh problems: using too many materials, pushing workers aside, and falling short on long-term responsibility (Sasso, Filho and Ganga, 2024). Out of this situation come two strong ideas aiming to fix what's broken - the Circular Economy, built on keeping materials in use, slashing trash, designing for renewal; alongside it, Industry 5.0 steps forward, blending machines with care for people, environmental needs, and stronger systems (Tavares et al., 2025).

Where these paths meet lies something deeper than small change - it reshapes how makers plan, structure, and carry out their core work (Siratan et al., 2025)

Looking into early studies shows how circular economy ideas mix with Industry 5.0 tools in factories. What stands out here is that each system alone falls short; when linked, however, better results emerge - less waste, stronger profits, smoother workflows, plus healthier work lives (Setyadi, Pawirosumarto and Damaris, 2025). Attention turns toward managing supplies, shaping daily processes, using smart tech, shifting job roles, along with leadership styles that help change take root. With a close look at current findings, patterns form: real-world efforts by makers worldwide reveal stumbling blocks faced, while fresh strategies begin showing clearer paths forward (Fatema et al., 2026).

Circular Economy Practices in Manufacturing

Outlasting the take-make-waste path kicks off when things dodge landfills, kept alive through careful creation (Rajić et al., 2024). Instead of just building tough stuff, plants now craft return paths - old gear gets pulled back in before it dies. Worn-out models aren't dumped; they're fixed up, sent out again, riding systems built to guard value across seasons (Andrade et al., 2024). Real-world runs show tighter loops cut trash, stretch raw inputs further, and trim daily expenses (Sajadieh and Noh, 2025). Yet true success isn't just about new tools or approaches - it hinges on reshaping what a business sees as essential. While plenty of companies now acknowledge circular economy ideas, only a handful weave them into core strategies, usually brushing them off as quick fixes or ways to trim expenses (Huang and Zhao, 2025).

When processes get leaner, less waste shows up - turns out smarter resource handling quietly backs circular goals (Sasso, Filbo, and Ganga, 2024). Progress doesn't come from mixing ideas like ingredients; it flows from big changes that keep lifting both efficiency and sustainability (Tavares et al., 2025). Supply networks? They become key players - small adjustments ripple outward, altering buying patterns, deepening supplier trust, even sketching what happens after a product ends its run. Data pulled from shipping lanes across continents reveals firms linking purchasing to reuse plans recover quicker when disruptions hit, sidestep shortages better, while slowly building stronger connections along the way (Van and Chin, 2025).

Industry 5.0 technologies in Manufacturing

A shift is happening beyond Industry 4.0 - not wiping it out, but building alongside it, with attention turned toward people and social outcomes rarely centred in tech-only upgrades (Gaffley and Pelsner, 2025). What sets I5.0 apart isn't just gadgets; instead, it weaves together smart systems like artificial intelligence, connected sensors, live simulations, and localised data processing - alongside care for how workers feel, grow, and stay safe - with pressure to cut emissions, reuse materials, and heal ecosystems over time (Rejeb et al., 2025). Take digital twins: these are living mirror versions of factories, adjusting on the fly through constant feedback, forecasting issues before they rise, fine-tuning operations minute by minute - all while showing staff what's unfolding in ways easier to grasp and interact with (Sajadieh and Noh, 2025).

When real-world studies look at Industry 5.0 in practice, firms that blend people and machines well tend to outperform those relying only on automation - this shows up clearly in how smoothly things run (Peruzzini, Prati and Pellicciari, 2023). Instead of replacing workers, smarter setups let AI support their choices; such teamwork between humans and tech lifts performance when tackling tricky tasks, adjusting to change, or coming up with new ideas (Gomaa, 2025). Tools like virtual, augmented, and mixed reality are stepping into key roles by shaping hands-on learning spaces, linking teams across distances, and even sharpening awareness during live operations (Chu et al., 2024).

Integration of Circular Economy and Industry 5.0

The use of Circular Economy (CE) principles together with Industry 5.0 (I5.0) technologies yields benefits that multiply each other rather than just add up when it comes to manufacturing transformation (Singh et al. 2025). The digital tools help CE implementation by enabling transparency, traceability and even real-time monitoring, which are crucial features of closed-loop systems. For example, IoT sensors can trace materials throughout reverse logistics networks, blockchain can be used for creating unchangeable records of product histories that support remanufacturing decisions, and artificial intelligence can be employed for resource allocation optimisation in circular supply chains (Bhler, Schuster and Pflaum, 2025). On the other hand, CE principles guide the choice of technology deployments so that, for instance, the I5.0 digital infrastructures comply with sustainability standards and, through such technological implementations, the welfare of people is augmented rather than being compromised (Rejeb et al. 2025).

Organisational implementations make it clear that the successful CE-I5.0 integration requires the focus on technical, organisational, and cultural aspects simultaneously (Shahin, Maghanaki and Chen, 2026). Business Process Reengineering (BPR) approaches using Plan-Do-Check-Act (PDCA) cycles reveal that the moderate integration levels (with an average of 44.70% implementation) are maintained even though the necessity of transformation is recognised, which shows that there is a lot of potential for progress (Rajic et al. 2024). Case studies of the automotive, electronics, and pharmaceutical industries show that companies that view CE and I5.0 integration as separate initiatives are doomed to get minimal results, whereas companies that create explicit links between circular material flows and human-centred technology design enjoy both their sustainability and efficiency gains comprehensively (Hurta and Noskieviov, 2025).

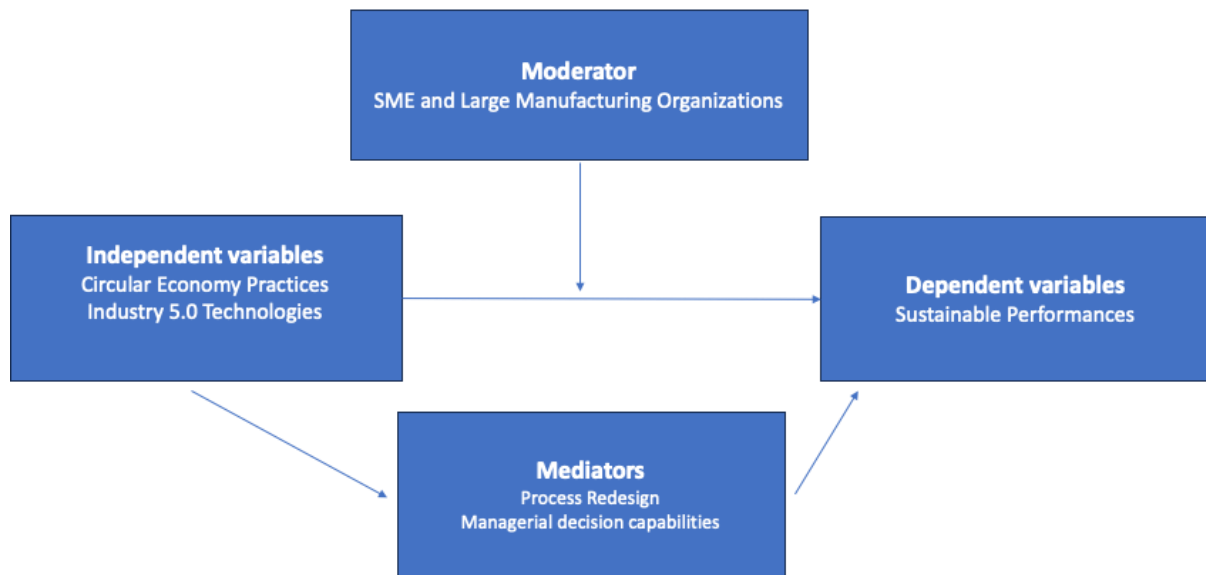
Integration Challenges

Despite the fact that there are strong theoretical reasons and proven operational benefits, manufacturing organisations still suffer from several barriers to integrating CE-I5.0 transformation (Holly et al. 2023). Besides that, external barriers such as regulatory fragmentation, lack of financial incentives and underdeveloped markets for circular materials often remain more critical even than internal ones, which indicates that even the sole efforts of a single organisation must be accompanied by a supportive policy environment (J. and Munro, 2023). Besides, technology-related barriers are represented by the following: the technology provider capabilities are not mature; the cybersecurity vulnerabilities of interconnected systems; and the problems of digital innovation integration with legacy manufacturing infrastructure (Kannan et al. 2024). Last but not least, organisational barriers may be the following: workforce competency gaps; resistance to cultural change; and lack of governance structures for cross-functional coordination necessary for integrated approaches (Hansen, Christiansen and Lassen, 2024).

Conceptual framework

The conceptual framework below is based on how the circular economy and Industry 5.0 technologies interact to influence small, medium, and large industrial organisations. The position of moderator is shared by small, medium, and large manufacturing organisations. While circular economy practices and industry 5.0 technologies are independent variables, sustainable performance is dependent. Process redesign and managerial decision-making ability serve as intermediaries. The diagram's visual presentation is demonstrated here.

Conceptual Framework



Identified Gaps

There are major gaps in the existing literature that need to be addressed through doctoral-level research. Most published studies examine either CE principles or I4.0 technologies separately; the systematic exploration of the integrated application of these and their synergistic mechanisms has remained quite limited (Trzcielinska and Trzcieliski, 2025). Philosophical development of CE-I5.0 integration, i.e. going beyond mere adoption of operational tools to strategic, culturally embeddedness, is a hardly touched area and may have considerable effects on sustainability in the long run (Tavares et al. 2025). The focus on small and medium-sized enterprises (SME) is low despite these firms accounting for the bulk of manufacturing activities worldwide and at the same time having limited resources and capabilities (Van and Chin, 2025). Also, differences between various industrial sectors in CE-I5.0 adaptation are hardly recorded, with only a few studies dealing with large manufacturers of automobiles and electronic equipment and ignoring industries like pharmaceuticals, chemicals and speciality materials (Saidi et al. 2025). No previous research has provided an empirically validated framework for how manufacturing managers make decisions when CE principles and I5.0 technologies interact concurrently. A model of managerial decision logic under joint CE-I5.0 conditions, including how managers balance efficiency, circularity, resilience, and human-centricity, is missing.

Gap Matrix

Gap Type	What is Missing?	Example from Literature	Contribution
Theoretical	There is no integrated theoretical framework for CE-I5.0, and its philosophical/strategic implications are not fully explored.	CE principles and I4.0/I5.0 technologies studied separately (Trzcielinska & Trzcieliski, 2025). Strategic and cultural embeddedness of CE-I5.0 untouched (Tavares et al., 2025)	Create an integrated CE-I5.0 theoretical framework that covers operational, strategic, and cultural dimensions.
Empirical	There is no empirically supported framework for managers to make decisions that strike a balance between human-centricity, efficiency, circularity, and resilience.	Managerial decision making under joint CE-I5.0 conditions is lacking, and no study has generated an empirically validated CE-I5.0 decision model (Nayeri et al., 2025).	Concurrently implement CE-I5.0 by empirically validating a managerial decision-making model.
Contextual	Despite their dominance in global manufacturing, there is a lack of focus on small and medium-sized enterprises (SMEs).	SMEs account for the bulk of worldwide manufacturing yet are under-researched (Van & Chin, 2025)	Utilise the CE-I5.0 framework in SME manufacturing environments with limited resources.
Sectoral	Inter-sector variations in CE-I5.0 adaptation were infrequently noted; the pharmaceutical, chemical, and speciality materials sectors were not included.	Only large auto and electronics firms studied (Saidi et al., 2025)	Expand research into the chemical, pharmaceutical, and speciality material manufacturing industries.

Draft Research Questions

1. How do manufacturing firms incorporate the concept of a circular economy into their operations while leveraging Industry 5.0 technologies to achieve both environmentally sustainable and operationally efficient outcomes? Also, what business capabilities are most important for this integration?
2. What steps can manufacturing firms take to transition from using circular economy and Industry 5.0 technologies as operational tools to integrating circular and human-centric principles into their organisational culture? In other words, how do manufacturers transition from simply human-centred values?
3. How can digital technologies, particularly artificial intelligence, digital twins, and blockchain, be developed and applied to support closed-loop material flows while also improving worker safety, skill training, and work quality?

4. Besides technological challenges, what kind of policy measures and community-level actions are the most effective in encouraging manufacturing SMEs to adopt an integrated CE - I 5.0 approach? Also, how can these frameworks be changed or modified to suit different regulatory and economic contexts?
5. How much do manufacturing-specific characteristics such as product complexity, supply chain structure, and regulatory fray influence the best strategies for CE-I5.0 integration and performance outcomes?

Conclusion

Finally, the literature study underlined how each term in the research topic is important. It also illustrated how they collaborated to assist the manufacturing sector. Strategic operation management focuses on how traditional operation management will be replaced by strategic operations, transforming the entire operational backbone of the sectors listed below. When it comes to circular economy and Industry 5.0 integration, it will help to transform the industrial industry's operational environment. This paper contributes by presenting an integrated CE-Industry 5.0 paradigm that reconceptualises managerial decision-making as a multidimensional competence balancing efficiency, circularity, and human-centeredness.

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