

LCDB 7007 - Research Principles and Philosophy

**A Critical Literature Review and Philosophical Analysis on Strategic Operations
Transformation in Manufacturing: How Circular Economy and Industry 5.0 Integration Can
Shape Managerial Decision-Making, Process Redesign, and Sustainable Performance.**

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Abstract

Purpose: This report presents a detailed critical literature assessment of research on strategic operations transformation in manufacturing using circular economy concepts and Industry 5.0 frameworks undertaken between 2021 and 2026. The review investigates how these paradigms affect managerial decision-making, process redesign, and organisational sustainability performance, while also critically analysing the epistemological, ontological, and ethical features of the research.

Design/Methodology/Approach: A systematic literature study was undertaken across many databases in Google Scholar, generating 30+ peer-reviewed studies published between 2021 and 2026. The review employed thematic synthesis to identify both converging and divergent perspectives on technology adoption, circular economy implementation, and Industry 5.0 transformation. Critical philosophical analysis looks into the underlying assumptions, research paradigms, and ethical considerations discovered in specific investigations. Gao et al. (2026), a large study on Industry 4.0 and organisational sustainability performance, receives a full methodological assessment.

Findings: A recent study shows that Industry 4.0 technologies (IoT, AI/ML, Digital Twins) play an important role as mediators between strategic purpose and long-term production outcomes. Adoption of the circular economy remains scattered, with impediments to implementation covering institutional, technological, and organisational dimensions. The human-centric paradigm of Industry 5.0 is emerging as a counterpoint to technology-centrism, but empirical data tying human-centricity to performance is still limited. Critical analysis detects positivist epistemological dominance while mainly ignoring interpretivist and critical realist viewpoints that are vital for comprehending context-embedded organisational transformation.

Originality/Value: This overview combines theoretical literature with critical philosophical analysis, resulting in a DBA-level grasp of research paradigms in manufacturing transformation. It finds considerable study gaps in non-Western contexts, longitudinal investigation of implementation sustainability, and ethical aspects of technological governance in manufacturing.

Keywords: circular economy, Industry 5.0, operations transformation, sustainable manufacturing, research philosophy, epistemology, ethical governance

Introduction

Manufacturing companies must balance operational efficiency, environmental stewardship, and social responsibility (Gao et al., 2026). Nassar (2026) argues that traditional linear production methods of extraction, production, consumption, and disposal are no longer sustainable due to resource scarcity, increased regulation, and stakeholder demands for corporate sustainability. Since 2021, two converging frameworks have gained prominence: the Circular Economy (CE) focuses on resource loop closure and waste valorisation, while Industry 5.0 prioritises human-centric, sustainable, and resilient manufacturing systems (Rejeb *et al.*, 2025).

This revolution goes beyond technical adoption. Bratovičić (2025) proposes a new approach to managerial decision-making that combines data-driven analytics with human judgement, redesigns processes to balance efficiency and circularity, and incorporates economic, environmental, and social performance measures. However, scholarly study on this change remains scattered across disciplines, with divergent epistemological frameworks, inconsistent empirical validation, and insufficient critical evaluation of underlying philosophical assumptions.

The report fills this gap by synthesising studies released between 2021 and 2026 on strategic operations transformation in manufacturing through circular economy and Industry 5.0 integration. Aside from a review of the literature, the study critically evaluates the epistemological, ontological, and ethical foundations of this research corpus, making a contribution to DBA-level scholarship on operational research philosophy. A detailed case study of one prominent empirical study exemplifies how philosophical orientation influences methodological choices, validity claims, and practical relevance.

Method for Conducting the Literature Review

Search Strategy and Databases

A systematic literature review was undertaken following PRISMA guidelines. Primary searches were conducted in Google Scholar using keyword combinations: ("circular economy" OR "circular business model") AND ("manufacturing" OR "operations") AND ("Industry 4.0" OR "Industry 5.0"); ("sustainable manufacturing" OR "green manufacturing") AND ("digital transformation" OR "Industry 4.0"); ("operations transformation" OR "business process redesign") AND ("sustainability" OR "circular economy"). Secondary searches targeted specific technology domains (AI, digital twins, IoT) and conceptual frameworks (supply chain resilience, sustainable performance, managerial decision-making).

Inclusion Criteria

Peer-reviewed journal articles and conference proceedings published 2021-2026; English language; empirical studies (qualitative, quantitative, or mixed-methods); explicit focus on manufacturing, operations, or supply chain contexts; engagement with sustainability, circularity, or Industry 4.0/5.0 frameworks.

Exclusion Criteria

Editorials, opinion pieces, and commentaries; research before 2021; purely theoretical conceptual papers with no empirical basis; non-English publications; studies focusing on service sectors without a manufacturing operations setting.

Analytical Procedure

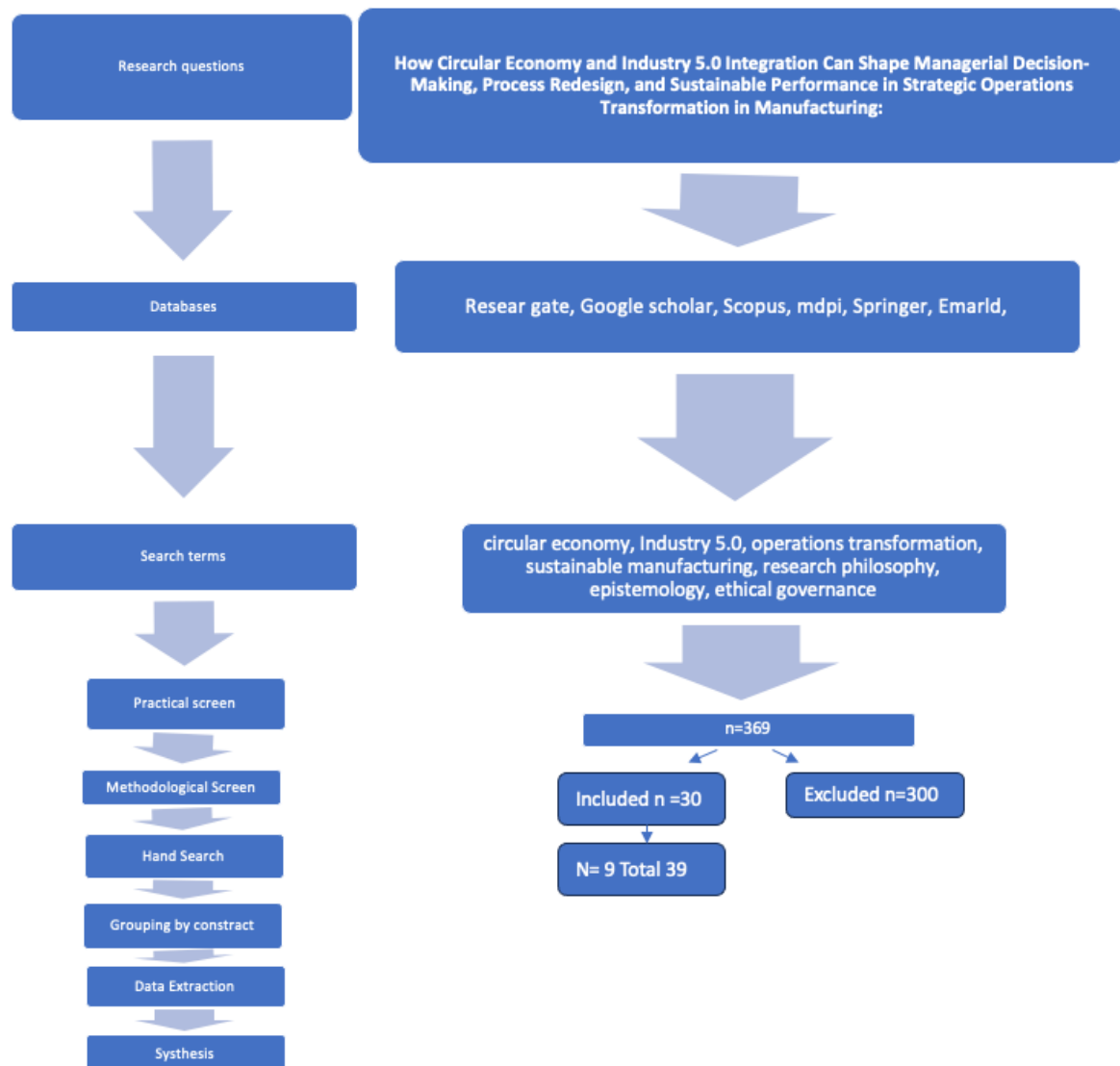
Following systematic screening (369 records evaluated, 39 included following quality assessment), findings were synthesised using theme analysis. Iterative open coding revealed themes such as technological integration pathways, circular economy implementation mechanisms, process redesign methodologies, human-centric organisational factors, long-term performance outcomes, implementation barriers and enablers, and epistemological and ontological positioning.

Philosophical analysis investigated each study's underlying assumptions about the nature of manufacturing reality (ontology), how valid knowledge about transformation is formed (epistemology), and what values and ethical frameworks govern research and practice (axiology). Positive versus interpretivist versus critical realist paradigmatic posture was studied in depth, as well as the consequences for validity claims and practical applicability.

Limitations of the Review Approach

The review is geographically biased toward industrialised nations and manufacturing sectors (automotive, aerospace, pharmaceuticals), with little coverage of emerging economies' manufacturing environments. A language restriction to English may preclude useful research from non-Anglophone regions. Publication bias toward quantitative, statistically significant findings may result in underrepresentation of qualitative insights and null findings. The 2021-2026 timeframe encompasses an expanding discipline; nevertheless, long-term confirmation of discoveries is still incomplete.

Figure 1: Prisma flow diagram for literature review



(Source: Created by Microsoft Word)

Critical Literature Review

Theme 1: Strategic integration of digital technology

Industry 4.0 technologies such as IoT, AI/ML, Digital Twins (DT), and Big Data Analytics have emerged as critical infrastructure for operational transformation (Gao et al., 2026). Research produced between 2021 and 2026 progressively views these technologies as mediators, transforming strategy purpose into sustainable effects. Gao et al. (2026), using structural equation modelling on 719 Chinese manufacturing firms, show that IoT integration, AI adoption, digital twin usage, and green technology adoption all contribute to sustainable manufacturing practices (SMP), which improves organisational sustainability performance (OSP). This mediation model shows that technology adoption creates benefits only when implemented through systematised sustainable practices, a significant finding suggesting that simply acquiring technology yields insufficient returns (Gao et al., 2026).

Similar mediation patterns appear in supply chain research. Digital green transformation capability allows greater long-term performance through the sequential mediation of green process innovation and sustainable supply chain agility (Yarkarami, 2025). Notably, data governance quality moderates these connections, implying that technology infrastructure is ineffective without governance structures that ensure data transparency and responsible use. This epistemic shift from technology determinism to context-dependent technological efficacy reflects the rising realisation that implementation effectiveness is contingent on organisational preparation rather than technological expertise (Gao et al., 2026).

Digital twins need special attention because they demonstrate technology's role in connecting sustainability goals with practical realities. Real-time simulation capabilities allow manufacturers to assess resource utilisation, waste output, and lifecycle implications prior to physical deployment, hence facilitating predictive maintenance and decreasing unscheduled downtime (Gao et al., 2026). Nassar and Abbas (2025) demonstrate digital twin applications in poultry production, revealing how predictive capabilities improve both operational efficiency and resource conservation, but their research highlights a technology-practice gap in which theoretical potential exceeds actual implementation.

Theme 2: Impact of Digital technologies

The literature highlights a number of technologies that can aid circular transformation.

Artificial intelligence and machine learning: Artificial intelligence (AI) and machine learning (ML) technologies have the potential to significantly improve the efficiency, dependability, and long-term viability of industrial and operational operations. Their ability to assess huge amounts of historical and real-time data enables businesses to support more accurate demand forecasting, allowing resources, materials, and production capacity to be better aligned with expected demand. Furthermore, predictive maintenance models can detect trends that suggest future equipment problems before they occur, allowing businesses to plan maintenance ahead of time and reduce unexpected downtime. AI and machine learning can also aid with defect identification by recognising abnormalities and departures from typical operating circumstances, allowing businesses to respond to problems faster and reducing the likelihood of substantial operational disruptions.

Beyond maintenance and defect detection, these technologies can help with process optimisation by finding inefficiencies and suggesting changes to operating settings. AI-powered energy management can also assist companies in monitoring and optimising energy consumption, potentially lowering needless usage and associated expenses. Furthermore, AI and machine learning can aid with recovery planning by assessing probable disruption situations and assisting businesses in developing more effective solutions to operational disruptions. Collectively, these competencies can improve decision-making, strengthen operational resilience, and boost the efficiency with which existing resources and assets are used. Adoption of AI and machine learning may benefit to both operational performance and sustainability goals by reducing material and energy waste, avoiding downtime, and enhancing asset utilisation (Gao et al., 2024).

However, the usefulness and dependability of algorithms are strongly reliant on the quality, completeness, and representativeness of the data used to train them. If the underlying data is insufficient, obsolete, incomplete, or impacted by past biases, AI systems may provide incorrect or inappropriate recommendations. This is especially important in circular economy and product lifecycle decisions, where algorithms may depend on previous patterns to determine whether things should be repaired, remanufactured, recycled, or disposed.

As a result, judgements based on incorrect statistics can exacerbate current inefficiencies rather than identifying the most sustainable or economically viable solution. Furthermore, machine learning models can occasionally yield confusing or difficult-to-interpret results, raising concerns about openness and

accountability. For example, a manager may be unable to effectively explain why an AI system deemed a specific product unfit for remanufacturing and instead recommended disposal. This lack of explainability can make it difficult for businesses to justify automated judgements to employees, customers, regulators, or other stakeholders, especially if those decisions have substantial financial, environmental, or ethical implications. According to NIST (2024), the dependability, openness, and explainability of AI systems are critical factors when integrating AI into organisational decision-making processes.

Internet of Things: IoT sensors can play a crucial role in monitoring and improving the performance of industrial machinery and production processes. These sensors can continuously collect real-time data on machine performance, energy consumption, material flow, operating conditions, and product quality. By providing accurate and up-to-date information, IoT technology enables organisations to identify inefficiencies, detect potential faults, and make informed decisions about production operations. Real-time monitoring can also support predictive maintenance by identifying early warning signs of equipment failure, allowing maintenance to be scheduled before a major breakdown occurs. This can help reduce unplanned downtime, extend the operational lifespan of machinery, lower maintenance costs, and improve overall productivity. In addition, the data collected throughout the equipment and production lifecycle can support lifecycle management, helping organisations optimise resources, improve efficiency, and maintain consistent product quality over time.

Another important concern is cybersecurity, which might become a target for unauthorised access, hacks, or misuse due to the vast volume of data generated by connected workplace systems. Interoperability introduces additional hurdles when diverse technologies and systems are unable to communicate efficiently, thereby lowering efficiency and increasing safety hazards. Furthermore, problems about data ownership must be addressed, notably who has the authority to access, store, analyse, and distribute information generated by workers and workplace sensors. A human-centric strategy necessitates suitable regulatory and organisational structures to ensure that workers' data is obtained legitimately, used appropriately, stored securely, and protected from unauthorised surveillance or abuse (Abraha, 2025).

Blockchain: Blockchain technology can improve the traceability, transparency, and verification of material provenance throughout supply chains. Blockchain, by generating a secure and tamper-resistant digital record of materials and products, can give stakeholders accurate information about the origin, movement, ownership, and transformation of resources throughout their lifecycle. This has the potential to greatly aid the establishment of circular supply chains, in which resources are retained, reused, refurbished, and recycled for as long as feasible.

Blockchain might be used to record the percentage of recycled content in items, changes in product ownership, the history and composition of individual components, and how things are treated at the end of their useful life. Such information could increase supply-chain accountability while also allowing businesses, consumers, and recyclers to make more educated material reuse and recovery decisions.

As a result, blockchain-based traceability systems could help to increase transparency and facilitate the move from linear production and consumption models to more circular methods (Meier, Gruchmann, and Ivanov, 2023).

However, blockchain does not inherently guarantee data accuracy. It may retain an incorrect or misleading entry indefinitely. Energy consumption, governance structure, and practical scalability must all be considered.

Digital twins and life-cycle data:

Digital twins can provide detailed virtual representations of industrial processes, products, and supply chains, allowing managers to monitor, assess, and optimise operations in a simulated environment before making changes to real-world systems. Organisations can examine the potential repercussions of process changes, uncover inefficiencies, and anticipate dangers by simulating various operational scenarios without disturbing ongoing production. Furthermore, digital twins can help managers achieve sustainability goals by allowing them to assess the environmental impact of various tactics, such as changes in production processes, resource usage, energy use, and supply-chain topologies. This ability to test and analyse multiple scenarios allows for more informed decision-making while lowering the environmental and financial risks associated with implementing untested modifications (Singh et al., 2024).

The completeness and currency of the data determine its usefulness. A digital twin that just reflects the factory and ignores suppliers, transportation, usage, and end-of-life stages may provide an incomplete assessment of sustainability.

Theme 2: Transformation of linear to circular economy

Although the use of the circular economy in industry has expanded dramatically since 2021, implementation remains dispersed and often superficial. Bressanelli et al. (2022) introduce the Smart Circular Sustainability (SCS) paradigm for chicken production, which integrates circular economy concepts with digital innovation and risk management, illustrating how CE extends beyond waste reduction to systemic value optimisation. Based on this approach, Nassar (2026) presents the Smart Circular Sustainability (SCS) paradigm for chicken production, which combines the circular economy, digital innovation, and risk management to optimise resource utilisation, minimise waste, and improve system resilience. Their findings reveal a substantial difference between "textbook" circularity applications that neglect trade-offs (increased energy consumption, toxic byproducts) and evidence-based implementation based on rigorous sustainability assessment (Alizad, Haddad, and Salonitis, 2026).

Circular business model implementation faces severe challenges at the institutional, supply chain, and firm levels. The key impediments are regulation and government incentives, followed by supply chain collaboration gaps and inadequate material flow tracking (Rossi, Lermen, and Echeveste, 2025). These hurdles are not just technical, but fundamentally structural, reflecting institutional misalignments between linear economic incentives and circular goals. Italian manufacturing firms that succeed in circular transformation demonstrate specific dynamic capabilities sensing emerging market signals, seizing opportunities through collaboration, and reconfiguring resources toward circular models—which provide an ontological foundation for understanding CE transition as organisational learning rather than technological substitution (Franco and Giannoccaro, 2025).

A critical study finds that CE research frequently employs a rationalist ontology, assuming that CE benefits (resource efficiency, cost reduction, market distinction) are self-evident and constraints are mostly surmountable by technical solutions and incentive alignment. This positivist framing overlooks the inherent interests, power dynamics, and cultural resistances that define organisational fields shaped by century-long linear economy structuring (Robertson, Rahimy, & Bort, 2026). Paradox theory provides an alternative interpretivist lens, revealing how firms encounter materially grounded contradictions (for example, durability versus recyclability in product design) that reverberate through organisations as learning, belonging, and organising paradoxes that require ongoing navigation rather than resolution (Robertson, Rahimy, and Bort, 2026).

Theme 3: Process Redesign and Operational Efficiency

Business process redesign, when combined with Lean Thinking and ICT integration, emerges as a formidable transformation methodology. Yahata et al. (2025) redesigned a healthcare radiology department using BPR's radical structural transformation, Lean's continuous improvement, and ICT's real-time data visualisation, resulting in a 75% cycle time reduction, 15% inventory optimisation, and increased cost efficiency. This integrated lean methodology, verified across numerous organisational contexts, reveals that transformative change involves both synchronised technical redesign and iterative improvement, neither of which alone is sufficient.

Supply chain resilience is becoming increasingly important in post-pandemic manufacturing contexts, relying on dynamic capabilities and operational agility rather than static optimisation. Qader et al. (2025) found that Industry 4.0 technologies improve supply chain resilience by providing real-time visibility, predictive capabilities, and adaptive reconfiguration in the Pakistani pharmaceutical and Chinese automobile industries. Critical analysis highlights a tension between supply chain visibility technologies and increased surveillance of labour and lower-tier suppliers. This raises ethical concerns about who benefits from resilience and how vulnerability is distributed throughout the supply chain ecosystem (Diaz-Elsayed, Morris, & Schoop, 2020).

Theme 4: Strategic Decision-Making and human-centric operation

A significant change toward human-centred production has gained traction, particularly in Industry 5.0 frameworks. Kure's (2025) study on the role of strategic human resource management in Ethiopian manufacturing decision-making found that textile industries have higher HR strategic engagement than capital-intensive chemical sectors, indicating that the perceived importance of human capital varies by context. According to Kure (2025), strategic integration of human resources demands sectoral and institutional change rather than just transferring standardised practices.

Human-centricity is explicitly prioritised by Industry 5.0 at the process, system, and management levels. According to Chen et al. (2024), digital technologies can promote collaboration between humans and machines while also posing risks such as job displacement and algorithmic management, which can limit autonomy. Nasir et al. (2025) provide a comprehensive framework for human-centric Industry 5.0, which addresses operator safety, occupational health, human-robot collaboration at the process level, ergonomic design and production planning at the system level, and ethical business practices and inclusive culture at the management level. This multi-level perspective fills a fundamental vacuum in previous Industry 4.0 literature, which mostly viewed "human" as a restricted synonym for machine operators, leaving out designers, consumers, and public stakeholders.

Theme 5: Integration of Sustainable Performance factors

Measuring sustainable performance now includes environmental, social, and economic factors, mirroring the UN Sustainable Development Goals framework. However, integration continues to be a contentious issue. Gao et al. (2026) describe organisational sustainability performance as originating from Industry 4.0 technology through sustainable manufacturing practices, while noting that their measurements evaluate firm-level efficiency benefits rather than definite SDG fulfilment. This key caveat highlights the epistemic difference between operationalised measures and aspirational sustainability goals, which stems from positivism's preference for quantitative, firm-level achievements over systemic ecological or social transformation.

Big Data Analytics and AI adoption improve green supply chain collaboration, but their impact on long-term sustainability is unknown (Rashid et al., 2024). This shows that implementing sustainability at the

organisational level may have unintended consequences; firm-level efficiency improvements could shift costs to supply chain partners, communities, or ecosystems. According to interpretivist and critical realist researchers studying stakeholder engagement practices in Swedish manufacturing organisations, transitioning to the circular economy necessitates not only operational redesign but also a fundamental reconceptualisation of engagement practices from linear stakeholder management to circular stakeholder engagement, which includes broader constituencies, expanded issues, and levelled influence dynamics (Fobbe and Hilletoft, 2022).

Theme 6: Challenges of Implementation

Despite significant research investment and technological competence, the circular economy and Industry 5.0 deployment face ongoing challenges. According to a recent systematic review (Swarnakar et al., 2026), main hurdles include unclear strategy frameworks, low resources, skills shortfalls, misaligned organisational culture, and fragmented regulations. Notably, these hurdles go beyond technical domains; they are fundamentally organisational, institutional, and cultural. This recognition moves the analytical focus from technology-centric to organisation-centric explanations, resulting in a significant epistemological shift with far-reaching policy and practice ramifications.

Geographic and sectoral diversity in implementation performance indicates that universal frameworks do not properly lead localised transformation. Pakistani pharmaceutical firms, Indian manufacturing contexts, Chilean SMEs, and Chinese automotive sectors each have unique barriers and adaptive responses that reflect institutional environments, supply chain structures, and competitive dynamics (Qader et al., 2025). This diversity necessitates contextualised, adaptive approaches rather than standardised transformation playbooks, implying that study design must interact intimately with individual organisational and institutional settings rather than attempting decontextualised generalisations.

Synthesis

Quantitative studies give valuable information regarding the linkages between technology capabilities, CE practices, and performance, but they frequently fail to prove causal direction. Qualitative research can provide context and meaning, but it may have limited generalisability. Review studies can map the field, but they cannot determine organisational effects. A mixed-methods and critical-realist research program could address these limitations by integrating measured performance outcomes with qualitative investigations into mechanisms and contexts. Longitudinal designs would be especially useful because strategic transformation is a process, not a single adoption choice.

As a result, the synthesis lends support to a research perspective that views CE-I5.0 integration as a socio-technical revolution. Ontologically, manufacturing systems include material, technological, organisational, and social aspects. Epistemologically, no single approach can fully express them. Axiologically, sustainability and human-centricity are value-laden commitments rather than neutral variables. This provides a strong rationale for a critical-realist and pragmatic orientation in DBA research: critical realism promotes the explanation of underlying mechanisms and contextual conditions, whereas pragmatism promotes the use of methods that answer the practical research question rather than favouring one method over another.

Research Gaps

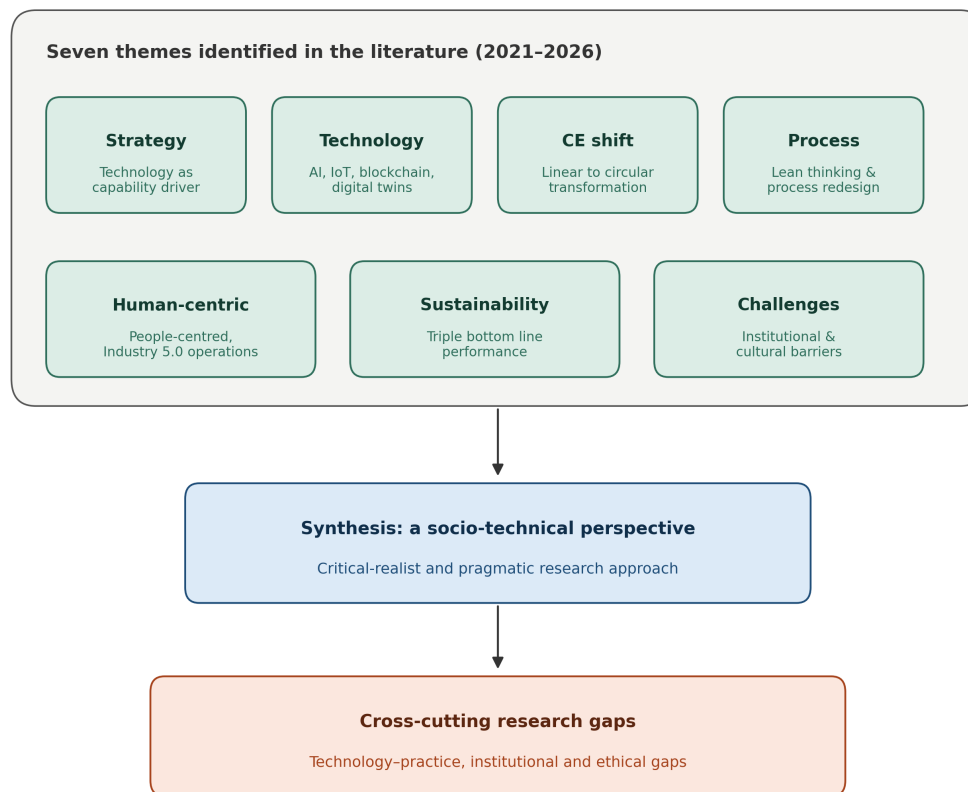
Integrating the 2021-2026 literature reveals several converging insights:

- (1) Technology serves as a necessary but insufficient prerequisite for sustainable transformation; hence, there is a research vacuum in understanding how technology can assure sustainable transformation.
- (2) Circular economy implementation necessitates systemic alignment at the institutional, supply chain, and organisational levels; hence, there is a shortage of research strategies that can advise on these parameters.
- (3) Human-centric approaches are increasingly regarded as key rather than peripheral, resulting in a lack of coordination with technology growth, which contrasts with the fundamentals of Industry 5.0.
- (4) There is a gap between technological capability and organisational execution. AI, IoT, digital twins, blockchain, and analytics have all been highlighted as facilitators in research, but few studies have investigated how these technologies affect routines, structures, authority, and decision rights.
- (5) There is a gap between technological capability and organisational execution. Research has highlighted AI, IoT, digital twins, blockchain, and analytics as facilitators, but few studies have looked at how these technologies affect routines, hierarchies, authority, and decision rights.
- (6) There is a philosophical gap: while human-centricity and ethics are growing more popular, they are less usually used in the design of empirical studies.

There is an additional gap in managerial decision-making. Most research implies that more knowledge leads to better decisions. Managerial decisions are influenced by experience, organisational politics, professional norms, incentives, institutional pressures, and bounded rationality, among other factors. Digital decision-support systems can improve information quality by emphasising measurable features. If a dashboard prioritises energy efficiency and throughput, managers may unintentionally undervalue worker well-being or community impact. The epistemological quandary is thus not only whether the data are right, but also what types of knowledge emerge and which are marginalised.

However, some critical gaps are revealed, such as limited research on non-Western manufacturing contexts and emerging economy implementation pathways; scarcity of longitudinal studies assessing implementation sustainability over multi-year periods; underdeveloped ethical frameworks addressing technology governance, labour implications, and just transition concerns; and insufficient integration of critical realist and interpretivist perspectives examining how organisational.

Figure 2: Thematic analysis framework for the selected topic



(Source: Created by Microsoft PowerPoint)

Philosophical and Methodological Analysis

Overview of the Study

Gao et al. (2026) conduct an empirical study on how Industry 4.0 technologies, such as AIA, DTU, IoT Integration, and GTA, improve Organisational Sustainability Performance (OSP) via Sustainable Manufacturing Practices (SMP). The study, which is based on the Natural Resource-Based View (NRBV) and Dynamic Capabilities Theory (DCT), combines structural equation modelling across survey data from 719 Chinese manufacturing enterprises to examine direct and mediated correlations while also investigating the moderating roles of contextual factors.

The study's significance derives from its integrated modelling of multiple Industry 4.0 technologies, which fills a significant gap in previous research that examined technologies in isolation, as well as its explicit treatment of sustainable manufacturing practices as a mediating mechanism for translating technological capability into sustainability outcomes. The study, published in Scientific Reports, shows today's quantitative rigour in manufacturing transformation research.

Ontology and Epistemology of the Study

Ontological Positioning: Gao et al. (2026) employed a realist ontology, assuming that organisational sustainability performance, manufacturing practices, and technology adoption are objective realities independent of observer perspective. This realism is moderately critical rather than naive; the authors acknowledge that sustainability performance emerges from organisational action rather than existing as a natural fact, but they believe that such organisational phenomena can be meaningfully measured and modelled using validated survey instruments and statistical techniques.

The study implicitly implies that sustainable manufacturing practices are a constant, measurable construct in which organisations either do or do not employ measures such as waste reduction, energy efficiency optimisation, and resource conservation to a quantifiable extent. This ontological framing improves statistical power and generalisability but may obscure how "sustainable" is constructed, challenged, and reinterpreted across organisational contexts. A manufacturing company's claimed adoption of "sustainable practices" may conceal a variety of underlying processes, including true systemic transformation, symbolic compliance with external pressures (greenwashing), or measurement distortion that reflects social desirability bias rather than behavioural change.

Epistemological Framework: Gao et al. (2026) adhere to a post-positivist epistemology. Hypothesis testing, controlled variable measurement, and statistical inference generate knowledge—methodology indicative of post-positivism's retaining of positivist empirical convictions while conceding fallibility and probabilistic rather than absolute knowledge claims. The authors define measurement models, evaluate structural relationships, offer confidence intervals and p-values, and use advanced statistical procedures (partial least squares-SEM) that mirror current quantitative social science norms.

This epistemological approach prioritises knowledge claims based on quantifiable, generalisable patterns discovered through large-sample survey techniques. As a result, the study provides robust insights into the average effects of Industry 4.0 technology on production practices and performance across Chinese manufacturing sectors. However, key knowledge domains remain unavailable under this epistemology. How do managers comprehend sustainability demands? Why do businesses adopt or reject certain practices despite apparent rationality? How can organisational cultures influence implementation? What unexpected outcomes result from technological adoption? These problems, which are critical to understanding transformation, are analytically peripheral in positivist epistemology.

Axiology and Researcher Positionality

Values Embedded in Research: The axiology of Gao et al. (2026), as well as their embedded value commitments, emphasises technical efficacy, organisational performance optimisation, and environmental/sustainability contribution. The study's purpose is to advance "UN SDGs 9 and 12," which relate firm-level sustainability achievements to global development goals. Gao et al. (2026) argue that integrating technology innovation with organisational practices is the key to achieving sustainability.

Axiology does not address important problems like equity, justice, or power distribution. The study does not look at whether Industry 4.0 adoption has distinct effects across supply chain tiers, labour categories, or geographic regions. It does not investigate potential dislocations (workforce displacement, vulnerability concentration) associated with technology adoption. According to Amirkhizi et al. (2025), the assumption is that organisational-level sustainability improvements are unambiguous and do not consider any externalities or distributional repercussions.

Researcher Positionality: Gao et al. (2026) make no clear mention of their positionality, the researchers' social places, interests, or any biases that influence research design and interpretation. This lack is consistent with post-positivist standards that emphasise impartial objectivity. However, significant positioning is inferentially evident: the researchers are from Chinese institutions; the study

focuses solely on Chinese firms; the theoretical framework (NRBV, DCT) reflects dominant Western management theory; and the conclusion prioritises technology adoption and organisational capability development as solutions. This posture creates blind spots, such as limited exposure to Chinese-specific institutional frameworks, labour governance, and state industrial policy, which significantly impact factory change (Bai *et al.* 2025).

Methodological Quality: Reliability, Validity & Trustworthiness

Internal Reliability and Validity: Gao *et al.* (2026) establish strong internal validity by employing demanding measuring methodologies. Multi-item scales with reported Cronbach's alpha >0.70 , construct validity validated using convergent and discriminant analysis, and rigorous model definition indicate that the measured constructs accurately describe the intended phenomena. Statistical testing demonstrates that all four technology aspects have significant direct effects on SMP and mediated effects on OSP, with effect sizes and confidence ranges accurately stated.

The cross-sectional survey approach, while providing large-sample statistical power, limits causal inference. The authors assert "effects"; however, they cannot conclusively prove whether technology adoption predates sustainability practice adoption, or whether enterprises that are already following sustainable practices invest in technology. Longitudinal study designs would improve causal claims; yet, practical and budgetary constraints limit their usage in manufacturing research.

External Validity and Generalizability: There are various reasons that limit the study's generalisability. The sample composition focuses on Chinese enterprises from a variety of industrial sectors; whether the findings apply to Western manufacturers with distinct institutional frameworks, labour governance, and regulatory contexts is questionable. The demand for survey replies on sensitive sustainability measures may result in social desirability bias, with enterprises over-reporting sustainable operations. Survey tools measure reported behaviour; actual implementation and effects may differ significantly (Roxas and Lindsay 2012).

Response rate and sample representativeness are underreported, making it impossible to determine the amount of potential sampling bias. Firms that are already advanced in sustainability implementation, have relatively mature technology adoption, or operate in ecologically sensitive industries or regions may make up a disproportionate share of the sample. Such selection effects may exaggerate the reported correlation between technological uptake and sustainability performance.

Qualitative Trustworthiness Considerations: Trustworthiness requirements differ across post-positivist quantitative and qualitative research methodologies. Gao *et al.* (2026) do not use qualitative credibility tactics such as member checking, peer debriefing, or negative case analysis, demonstrating the methodological contrasts between quantitative and qualitative research. Nonetheless, including such qualitative validation procedures may increase confidence in the findings by offering a better understanding of participants' viewpoints and experiences. It would be particularly useful to investigate how interviewed managers perceive the survey results, as well as whether reported levels of technology adoption and sustainable practices align with qualitative assessments of real implementation procedures, organisational issues, and impediments.

Ethical Considerations

Research Conduct Ethics: Gao et al. (2026) have little explicit ethical discussion. Standard protocols (informed consent, confidentiality, and institutional review approval) are likely followed, but not documented in the publication. This reflects widespread journal publication rules that emphasise space limits; nonetheless, ethics are rendered invisible, potentially normalising deficient ethical scrutiny.

Broader Ethical Dimensions: More importantly, the report raises but does not completely address critical ethical concerns about technology governance and a fair transition. Increased Industry 4.0 adoption may have serious effects for workers, particularly those who are vulnerable to job loss or deskilling as industrial processes become more automated (Ghobakhloo et al., 2025). Similar problems apply to communities affected by industrial development, as well as lower-tier supply-chain providers who may be required to embrace new technology despite a lack of commensurate financial, technical, or organisational resources. These potential distributional repercussions are crucial to consider when assessing the ethical implications of Industry 4.0, but they are outside the scope of the study's analytical methodology.

Furthermore, the study's focus on "Chinese businesses" strikes a balance between identifying specific Chinese manufacturing contexts and generalising conclusions. This ambiguity creates ethical concerns about whether prescriptive advice developed in Chinese industrial contexts are appropriate for diverse institutional, labour, and regulatory environments. The perception of universality may obscure context-specificity, misinforming practitioners and policymakers.

Critical Appraisal

Strengths: Gao et al. (2026)'s integrated modelling of many technology variables is a significant step forward from siloed technology studies. The explicit modelling of SMP as a mediating mechanism emphasises how technology leads to outcomes, which is an important theoretical contribution. Large-sample quantitative rigour leads to statistically solid results. Rather than technical determinism, the NRBV/DCT theoretical framework places an appropriate priority on firm strategic capability development.

Limitations: While post-positivist epistemology generates statistical power, it does not provide for an understanding of implementation processes, organisational interpretation, or context-dependent adaptation. Cross-sectional design limits causal inference. Surveys introduce social desirability and recollection biases. The geographic and temporal limits of Chinese enterprises in the 2020s limit generalisability. Insufficient focus on ethical dimensions and power disparities.

Alternative Approaches: An interpretive case study methodology examining implementation processes, management decision-making, and worker experiences across 3-5 contrasting Chinese firms would provide complementary insights into the "how" and "why" questions that the quantitative study can only address through structural relationships. A critical realist approach would openly look at how technological adoption interacts with institutional power structures, labour governance, and the larger political economy to shape manufacturing transformation (Zhang et al., 2026). Longitudinal tracking of technology uptake and sustainability practice implementation over 5 years would strengthen causal claims and measure the longevity of improvements.

Implications for the Present Study

This critical review acknowledges the value of Gao et al. (2026) 's contribution while emphasising its limits. Their discovery that Industry 4.0 technology can improve organisational sustainability performance by mediating the role of sustainable manufacturing practices is a strong and practical contribution. However, the study also demonstrates the limitations of a primarily positivist epistemological approach to understanding the complexities of organisational change. Manufacturing organisations are more than just technical systems; they are also socio-technical environments in which technology interacts with power dynamics, organisational meanings, values, and human activities. As a result, understanding strategic operations transformation necessitates more epistemological pluralism, combining quantitative analysis of relationships and patterns with qualitative approaches that investigate organisational meaning, interpretivist perspectives on lived experiences, and critical analysis of how transformation affects various stakeholders and whose interests it ultimately serves.

Discussion and Contribution

Findings: The literature from 2021 to 2026 demonstrates that manufacturing operations change is fundamentally multidimensional, technological, organisational, institutional, and human, necessitating integrated rather than siloed studies. When entrenched in systematic sustainable practices and governance frameworks, digital technologies serve as enablers; yet, technology alone does not drive sufficient transformation. Circular economy concepts provide compelling reasoning for resource efficiency and waste valorisation, but their execution faces inherent institutional resistance and necessitates systemic alignment beyond individual enterprises. The human-centric emphasis of Industry 5.0 corrects the technology-centrism of Industry 4.0, but its implementation is still in its early stages and is being challenged (Djebbouri et al., 2025).

Critical philosophical analysis demonstrates how epistemic choices influence which transformation processes become visible and understandable. Positivist techniques wonderfully expose technical efficacy, statistical correlations, and generalisable patterns that are crucial for policy and investment decisions. However, they under-represent the interpretive processes by which organisational actors develop meaning around sustainability, contest transformation paths, and generate unanticipated outcomes. Interpretivist study on how managers negotiate opposing demands, employees adapt to new roles, and communities undergo transformation provides complementary insights. Critical realist analysis reveals how structural power relations permit and hinder transformation possibilities, providing necessary depth.

Implications for Managerial Practice: Practitioners using operational transformation strategies should be aware of numerous ramifications, which are followed below -

1. Technology adoption necessitates concurrent development of organisational capabilities, governance structures, data systems, workforce competences, and management practices that translate technological potential into real-world outcomes (Gao et al., 2026). Investment in technology without concomitant capability development produces poor results.
2. Circular economy transition necessitates systemic alignment across the regulatory environment, supply chain alliances, and internal procedures; incremental improvement within linear frameworks is insufficient (Swarnakar et al., 2026).
3. Inclusive stakeholder participation, which includes workers, suppliers, customers, and community members, impacts the validity and sustainability of improvements beyond the initial implementation phase.
4. Contextual adaptation is critical; given that manufacturing transformation pathways vary significantly among sectors, geographic locations, firm sizes, and institutional settings, one-size-fits-all methods are doomed to fail (Wu et al., 2024).
5. Just transition, which includes managing workforce displacement, supporting skill development, and guaranteeing equitable distribution of transformation gains, is an ethical necessity in addition to business logic (Emmerling et al., 2025).
6. Finally, long-term transformation sustainability necessitates including human values such as worker well-being, safety, and development possibilities alongside efficiency measurements (Fernández Intriago, L. et al., 2025).

Theoretical Contributions and Gaps: Contemporary research advances various theoretical dimensions. The Natural Resource-Based View (NRBV) correctly highlights environmental limits and sustainability as justifications for strategic capability development, moving beyond the resource-based view's narrow focus on competitive advantage. Dynamic Capabilities Theory explains how companies detect emerging opportunities, seize transformational events, and reallocate resources to new business models. Instead of assuming technical resolution, Paradox Theory explains how organisations manage the inherent conflicts embedded in circular product design and sustainable transformation.

However, considerable theoretical holes remain. Existing research gives a limited understanding of how legislative frameworks, customer expectations, technical standards, and competitive pressures jointly create organisational fields and industrial sectors, enabling and constraining transition. More research is needed to understand how opposing institutional logics, such as market efficiency, environmental stewardship, and social responsibility, interact and, in some cases, integrate inside manufacturing companies. Similarly, the impact of professional communities such as engineering, operations management, and sustainability practitioners on the pathways used to achieve transformation has received scant attention. Although institutional theory provides essential frameworks for studying these dynamics, its application to manufacturing transformation is still relatively unexplored (Dagilienė, Varaniūtė, and Banionienė 2024).

Furthermore, the temporal dynamics and procedures by which transformation occurs are largely understudied. Much of the present research gives cross-sectional insights, resulting in a limited understanding of how transformation occurs and progresses across time. Greater focus is consequently required to explore how early transformation initiatives shape subsequent changes in organisational culture, as well as how first implementation experiences may either enable or hinder later phases of transformation. Adopting processual and narrative views could bring valuable insights by viewing transformation as a dynamic and context-dependent process rather than a static organisational outcome. Such approaches may also uncover underlying change mechanisms and sequences that are frequently concealed in quantitative research methodologies.

Methodological Implications: Diverse research designs help us comprehend more. Quantitative large-sample research generates statistical patterns and generalisability, which are critical for making policy and investment decisions. Qualitative case study research provides a comprehensive contextual understanding of implementation processes, decision-making logics, and unexpected outcomes. Mixed-methods designs that combine several data sources and analytical tools provide especially powerful insights. Longitudinal research monitoring implementation over numerous years exposes implementation trajectories, unexpected consequences, and the sustainability of improvements.

Manufacturing operations research should be characterised by epistemological pluralism, which recognises that diverse methods of knowing create distinct discoveries, each with strengths and limitations. Positivist methodologies, interpretivist case studies, critical realism, structural analysis, and participatory action research all highlight different aspects of transforming reality. Rather than rivalry, methodological diversity allows for a more complete understanding.

Furthermore, better integration of ideas from other disciplines (engineering, management, organisational psychology, sociology, political economy) improves explanatory capacity and practical usefulness.

Conclusion

One of the major challenges and opportunities facing contemporary capitalism is the reform of manufacturing operations to incorporate circular economy and Industry 5.0 principles. The literature from 2021-2026 shows significant progress in understanding technical enablers, organisational implementation channels, and performance results. Industry 4.0 technologies (IoT, AI/ML, digital twins, and big data analytics) serve as required but insufficient conditions for long-term transformation. The move to a circular economy necessitates systemic alignment at the institutional, supply chain, and organisational levels, yet it faces persistent challenges reflecting rooted interests and cultural resistances. The human-centric emphasis of Industry 5.0 provides an important correction to technology-centrism, albeit operationalisation and empirical validation are still in progress.

A critical analysis of research philosophy demonstrates the epistemic dominance of post-positivist techniques, which produce statistically robust but contextually limited findings. Alternative epistemologies, such as interpretivism's emphasis on meaning-making and critical realism's focus on structural power, reveal features that positivism ignores. Despite their importance in transforming legitimacy, the ethical features of technology governance, equitable transition, and distributional repercussions have received scant attention.

Looking ahead, some research topics deserve special attention. Geographic and sectoral diversification extends beyond China-focused manufacturing research to rising economies and varied industrial sectors. Longitudinal investigation over 5-10 years to determine implementation durability and unexpected repercussions. Integration of critical perspectives on how power dynamics, institutional frameworks, and conflicting logics promote and hinder transformation. Deeper engagement with ethical issues such as technological governance, worker agency, and just transition. Workers, community

members, and frontline practitioners serve as co-researchers rather than subjects in participatory research methods.

Finally, strategic operations transformation is successful not only through technology sophistication, but also through alignment of technological competence, organisational readiness, institutional support, stakeholder involvement, and human-centred values. Manufacturing organisations embarking on this transformation journey benefit from research that combines quantitative rigour with qualitative depth, technological understanding with social consciousness, and aspirational sustainability commitments with an honest acknowledgement of implementation complexity.

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