Interdisciplinary Systems for Global Management
Vol. 1 (2025), No. 1, pp. 29-51
DOI: https://doi.org/10.55578/isgm.2508.003

ARTICLE

Transforming Manufacturing from Industry 4.0 to Industry 6.0: A Comprehensive Review, Gap Analysis, and Strategic Framework

Attia Hussien Gomaa [1,*]

[1] *Benha University, Cairo, Egypt*

[*]Corresponding author. Email: attia.goma@feng.bu.edu.eg

Received: 14 August 2025, Accepted: 19 August 2025, Published: 22 August 2025

Abstract

Industry 6.0 represents a pivotal advancement in the evolution of manufacturing-surpassing the automation and cyber-physical integration of Industry 4.0 and the human-centric ethos of Industry 5.0. It is founded on the principles of consciousness, circularity, and resilience, positioning manufacturing as a catalyst for human flourishing, ecological regeneration, and adaptive intelligence. This study offers a comprehensive review of more than 90 peer-reviewed publications that explore the transition from Industry 4.0 to 6.0, synthesizing key conceptual foundations, enabling technologies, and strategic imperatives. It proposes a strategic framework for implementing Industry 6.0, anchored in core principles of conscious intelligence, ethical design, and global equity. The framework is organized around five strategic pillars: technological convergence, ethical governance, inclusive transformation, organizational agility, and sustainability. These are supported by cross-cutting enablers such as innovation ecosystems, human-centric competencies, and coherent policy frameworks. The study further presents a phased roadmap for implementation, outlines expected outcomes-including empathetic artificial intelligence and regenerative industrial systems-and illustrates real-world applicability through forward-looking scenarios. Together, these elements provide a visionary yet actionable blueprint for policymakers, industry leaders, and researchers to co-create ethical, resilient, and sustainable industrial futures guided by moral intelligence, empathy, and planetary stewardship.

Keywords: Industry 4.0; Industry 5.0; Industry 6.0; Conscious Manufacturing; Circular Economy; Resilient Systems; Modern Manufacturing; Continuous Improvement

1. INTRODUCTION

The global industrial landscape is undergoing a profound transformation, driven by technological convergence, socio-economic disruption, and escalating environmental challenges. This shift is dismantling traditional models and calling for a reimagining of how value is created and governed in an increasingly volatile and complex world. Historically as illustrated in Figure 1 and Table 1, the successive industrial revolutions-from mechanization in Industry 1.0 and electrification in Industry 2.0 to automation in Industry 3.0 and digitalization in Industry 4.0-have redefined industrial operations with a strong focus on productivity, efficiency, and scalability [1-3]. Industry 4.0, in particular, introduced disruptive technologies such as cyber-physical systems, the Industrial Internet of Things (IIoT), artificial intelligence (AI), blockchain, and digital twins. Despite its transformative capabilities, however, Industry 4.0 has been criticized for contributing to workforce displacement, social fragmentation, algorithmic opacity, and ecological degradation [4-7].

In response to these shortcomings, Industry 5.0 has emerged as a human-centric, values-driven paradigm that seeks to harmonize technology with human dignity, ethical governance, and planetary sustainability [3,8,9]. Rather than automating away human involvement, it fosters collaborative intelligence-leveraging human creativity, emotional intelligence, and decision-making in synergy with intelligent machines. Industry 5.0 moves beyond the techno-centric ethos of its predecessor by

https://doi.org/10.55578/isgm.2508.003

embedding ethical purpose and inclusive innovation into the fabric of industrial systems. It redefines performance metrics not only in terms of efficiency or cost but through enhanced societal well-being, sustainability, and co-created value [10,11].

Building on this foundation, the emerging paradigm of Industry 6.0 envisions a conscious, circular, and resilient industrial future. Unlike earlier revolutions that prioritized mechanistic efficiency, Industry 6.0 seeks to integrate emotional AI, ethical reasoning, self-awareness, and regenerative principles into the very architecture of industrial systems. It is enabled by advanced technologies including artificial general intelligence (AGI), quantum computing, neuroadaptive systems, brain–computer interfaces, and bio-cybernetic integration 12]. Industry 6.0 is not a mere technological evolution, but a paradigmatic leap toward intelligent ecosystems that learn, adapt, self-regulate, and prioritize human and planetary flourishing. This calls for a redefinition of manufacturing not only as a process of physical transformation but as a platform for social innovation, ethical governance, and emotional co-evolution.

A strategic foundation for this evolution has already been laid by Gomaa [13-20], who has introduced integrated frameworks aligning Lean, Six Sigma, and maintenance excellence with Industry 4.0 technologies. These include Lean 4.0 and LSS 4.0 for real-time continuous improvement, Maintenance 4.0 and RCM 4.0 for predictive asset integrity, Smart Maintenance powered by digital twins, and SCM 4.0 Excellence for transparent, resilient supply chains. These frameworks not only optimize operational efficiency but also act as stepping stones toward Industry 5.0 and 6.0 by promoting agility, integration, and cross-functional intelligence. However, transitioning from technological efficiency to ethical consciousness requires more than digital tools-it necessitates a fundamental reorientation of industrial values, design philosophies, and organizational cultures [21,22].

Yet, Industry 5.0 remains nascent, facing significant implementation barriers. Among them are cybersecurity vulnerabilities, algorithmic bias, regulatory fragmentation, resistance to change, and the lack of interdisciplinary integration [23-25]. Overcoming these challenges demands a multidimensional transformation supported by five foundational pillars: (1) human-centric systems that prioritize inclusion and well-being; (2) collaborative intelligence enabling synergistic human-machine interactions; (3) ethical engineering that embeds moral reasoning into technology; (4) regenerative design supporting circular economy principles; and (5) resilience thinking that fosters adaptive, antifragile responses to disruption and crisis.

Industry 6.0 expands this vision by embedding emotional intelligence, ethical consciousness, and ecological awareness into future industrial ecosystems. It emphasizes emotionally intelligent systems enabled by affective computing and brain-machine interfaces; circularity through closed-loop systems, blockchain traceability, and digital product passports; and real-time resilience powered by self-healing networks and decentralized analytics [2,9]. These ecosystems are capable not only of optimizing performance but of dynamically adapting to uncertainty while maintaining ethical alignment with human and environmental values.

Moreover, Industry 6.0 introduces a transformative governance architecture rooted in decentralized autonomy, inclusive participation, and transparent decision-making. Technologies such as human digital twins, distributed ledgers, and smart contracts create systems where individuals are empowered not as passive actors, but as co-creators of value. In this paradigm, innovation becomes participatory, systems become empathic, and industrial success is measured by well-being, creativity, and planetary health. The manufacturing sector evolves into a dynamic, ethically governed ecosystem that supports lifelong learning, emotional well-being, and social resilience.

This paper reviews the evolution from Industry 4.0 to Industry 6.0, highlighting Industry 6.0 as the next frontier-going beyond digital optimization to embrace systemic consciousness, ethical intelligence, and sustainable transformation. A strategic framework is proposed to guide this transition, built on five foundational pillars and supported by emerging technologies.

The paper is organized as follows: Section 2 presents the literature review; Section 3 examines research gaps; Section 4 outlines the strategic framework for Industry 6.0 implementation; and Section 5 concludes with key insights and directions for future research.

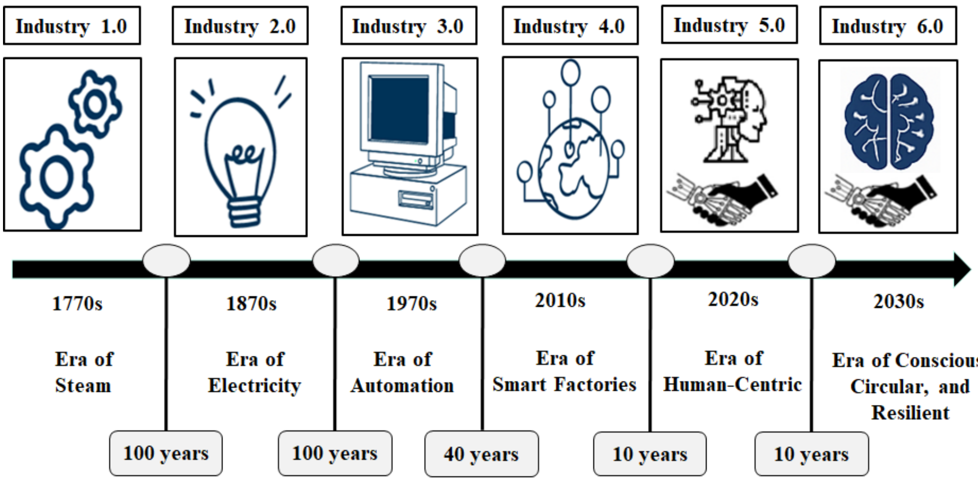

Figure 1. Evolution from Industry 1.0 to Industry 6.0

Table 1. Evolution of Industrial Revolutions.

#	Period	Era Designation	Core Transformation
1	1770s	Industry 1.0 – Mechanization	Steam and water power enabled the shift from manual labor to mechanized production.
2	1870s	Industry 2.0 – Electrification and Mass Production	Electric power and assembly lines facilitated standardized, large-scale manufacturing.
3	1970s	Industry 3.0 – Automation and Digitalization	Electronics, computers, and automation enhanced precision, efficiency, and process control.
4	2010s	Industry 4.0 – Smart and Connected Systems	IoT, AI, and cyber-physical systems enabled real-time, autonomous, data-driven operations.
5	2020s	Industry 5.0 – Human-Centric and Sustainable Collaboration	Human–machine synergy, ethical AI, personalization, and sustainability became central.
6	2030s (anticipated)	Industry 6.0 – Conscious, Circular, and Regenerative Systems	AGI, quantum computing, emotional AI, and circular economy will shape adaptive, ethical, and resilient ecosystems.

2. LITERATURE REVIEW ON THE EVOLUTION FROM INDUSTRY 4.0 TO INDUSTRY 6.0

This literature review examines the evolutionary progression from Industry 4.0 to Industry 6.0, reflecting a strategic shift from automation-centric models to intelligent, human-focused, and regenerative industrial ecosystems. Industry 4.0 laid the foundation with smart manufacturing technologies—such as the Internet of Things (IoT), cyber-physical systems, and advanced analytics—driving efficiency, automation, and productivity to enhance shareholder value [26]. Industry 5.0 built upon these advances by reintroducing the human element, emphasizing collaborative intelligence, ethical artificial intelligence, and sustainable innovation to foster inclusive and responsible value creation [27]. Looking ahead, Industry 6.0 represents a transformative paradigm characterized by conscious, circular, and adaptive systems. It integrates emerging technologies-such as Artificial General Intelligence (AGI), quantum computing, emotional AI, and bio-cybernetic platforms—while embedding ethical intelligence, decentralized governance, and regenerative design principles into core industrial strategies. This shift aims to align technological advancement with moral purpose, socio-environmental resilience, and long-term planetary well-being [8].

2.1. Review of Industry 4.0

Industry 4.0 (I4.0), first introduced in Germany in 2011, represents a paradigm shift in industrial production, characterized by the convergence of advanced digital technologies such as cyber-physical systems (CPS), the Industrial Internet of Things (IIoT), artificial intelligence (AI), machine learning (ML), robotics, big data analytics, cloud computing, and digital twins [28-30]. These technologies collectively enable the creation of intelligent, interconnected production environments where machines, systems, and humans interact in real time to exchange data, make decentralized decisions, and drive operational efficiency [31].

By embedding intelligence and connectivity into manufacturing processes, Industry 4.0 enhances operational agility, enabling dynamic optimization, self-regulating systems, and predictive control. These capabilities align closely with Lean principles by supporting the elimination of waste, improving flow, and enhancing value stream integration [32,33]. However, the paradigm's emphasis on automation and digital autonomy has raised concerns about workforce displacement, loss of tacit knowledge, and declining human engagement—posing socio-technical challenges that require a rethinking of human roles in digital factories [34,35].

Technological pillars such as autonomous robotics, additive manufacturing, augmented reality, and advanced analytics enable mass customization, efficient resource utilization, and evidence-based decision-making [36]. Predictive maintenance systems, powered by digital twins and ML algorithms, allow for continuous condition monitoring, early fault detection, and optimized maintenance scheduling—improving asset reliability and minimizing lifecycle costs [37]. Furthermore, smart machines and digitally augmented operators support agile, reconfigurable production systems capable of rapidly adapting to changing demand and product variability while maintaining high levels of quality and productivity [38].

Global implementation of Industry 4.0 is being led by strategic national programs, including Germany's Industrie 4.0 and China's Made in China 2025, with developed economies spearheading the transition toward smart manufacturing [39]. The global Industry 4.0 market, valued at $66.7 billion in 2016, is projected to surpass $227 billion by 2025, underscoring its widespread industrial and economic impact [40]. Nevertheless, widespread adoption is hindered by challenges such as high capital investment, cybersecurity vulnerabilities, interoperability barriers between IT and operational technologies, and the urgent need for digital upskilling [41].

From a systems integration perspective, Industry 4.0 promotes vertical integration within the enterprise-linking design, production, logistics, and service systems—and horizontal integration across value networks, thereby enabling smart, end-to-end supply chains [42,43]. These capabilities foster the development of smart factories: highly automated, data-driven, and adaptive manufacturing environments that leverage intelligent sensing, decentralized control, and real-time analytics to optimize performance [44].

Beyond operational performance, Industry 4.0 also contributes to sustainability by improving energy efficiency, reducing material waste, and enhancing workplace safety through automated hazard detection and risk-aware systems [45,46]. However, growing concerns about the ecological footprint of digital infrastructure, the generation of electronic waste, and emerging issues around data ethics and algorithmic bias have prompted calls for more inclusive, responsible innovation models [7]. These limitations are accelerating the shift toward Industry 5.0, which emphasizes ethical governance, human-centric design, and circular economy principles. This next-generation paradigm incorporates collaborative robotics (cobots), edge computing, emotional AI, and regenerative systems to create resilient, sustainable, and human-aligned industrial ecosystems [6,47].

2.2. Review of Industry 5.0

The evolution from Industry 4.0 to Industry 5.0 signifies not only a technological transition but also a paradigmatic transformation in industrial philosophy. Industry 4.0 focused on automation, digitalization, and operational efficiency using technologies such as cyber-physical systems (CPS), IoT, big data analytics, and cloud computing. However, it often neglected human-centricity, ethical governance, and sustainability. In response, Industry 5.0 redefines progress by prioritizing human well-being, inclusivity, and ecological regeneration, offering a more holistic approach to innovation [3].

At its core, Industry 5.0 emphasizes collaborative intelligence—fusing human intuition and creativity with machine precision and AI capabilities. This approach moves beyond full automation, utilizing technologies such as AI, cobots, AR, and emotion-aware interfaces to support shared decision-making and co-creation [48-50]. Human agency is preserved, and lean-agile systems become more flexible and resilient [51]. Emotionally intelligent and context-aware digital tools enable ergonomic and intuitive interactions, strengthening the human role in adaptive manufacturing systems [52].

Industry 5.0 drives a shift from mass production to mass personalization. Through modular design and digital platforms, firms deliver customized products while preserving lean efficiency. This is achieved via waste elimination, value stream mapping, lead time reduction, and real-time adaptability [53-56]. The concept of Sustainable Lean Performance Potential (SLPP) becomes central, ensuring decentralized control and agile responses to disruption. These characteristics empower organizations to remain lean, resilient, and customer-centric amid dynamic global challenges [57-59].

Unlike Industry 4.0's focus on digital literacy and automation skills, Industry 5.0 fosters broader human capabilities-including critical thinking, creativity, emotional intelligence, and ethical reasoning. The workforce is envisioned not just as system operators but as strategic co-creators within regenerative industrial ecosystems [60-62]. This transformation supports inclusive and meaningful work environments aligned with human dignity and social value creation.

While grounded in Industry 4.0's digital infrastructure-such as CPS, IoT, digital twins, and cloud-edge systems-Industry 5.0 integrates novel technologies like explainable AI, human-in-the-loop control, and emotion-aware computing. For instance, digital twins evolve from diagnostic tools into emotionally enriched and ethically guided decision systems [63,64]. In healthcare, Abdel-Basset et al. [22] employed a hybrid MCDM model under a neutrosophic environment, demonstrating that AI and cloud computing are the most impactful technologies. Their findings reinforce the value of human-centric digital tools in building intelligent, responsive, and resilient systems.

In conclusion, Industry 5.0 represents a strategic shift toward a balanced, ethical, and inclusive industrial future. It builds on the digital foundation of Industry 4.0 while advancing a new model of conscious innovation-one that integrates human-centricity, sustainability, and collaborative intelligence. This evolution paves the way for regenerative, adaptable, and socially aligned manufacturing ecosystems that prioritize both performance and planetary well-being [3].

2.3. Review of Industry 6.0

The progression from Industry 4.0 to Industry 6.0 signifies a paradigmatic transformation in industrial thought-transitioning from digitally optimized systems to intelligent, ethical, and regenerative ecosystems. While Industry 4.0 emphasized cyber-physical integration, real-time analytics, and operational efficiency, Industry 5.0 introduced a human-centric orientation focused on collaboration, creativity, and sustainability. Building on these foundations, Industry 6.0 envisions an integrative model that fuses emotionally and ethically intelligent artificial intelligence (AI), Human Digital Twins (HDTs), and decentralized, purpose-driven systems. This transformation embodies a convergence of technological evolution with human values and ecological consciousness, redefining industry as a platform for conscious value creation and planetary stewardship.

The technological infrastructure underpinning this evolution illustrates a layered progression. Industry 4.0 deployed the Internet of Things (IoT), cyber-physical systems (CPS), cloud computing, and early digital twins, focusing on automation and predictive maintenance [65]. Industry 5.0 advanced this model with edge-cloud architectures, collaborative robotics, and emotion-aware AI, enabling human-in-the-loop, context-aware systems [66]. Industry 6.0 represents a convergence of breakthrough capabilities—Artificial General Intelligence (AGI), quantum computing, Human Digital Twins, and Digital Twin 4.0—facilitating the simulation of emotional dynamics, ethical reasoning, and regenerative behaviors in industrial ecosystems [67].

The human-AI relationship also evolves profoundly. In Industry 4.0, human roles were primarily supervisory, with AI supporting optimization and nascent sustainability efforts. Workforce development focused on digital literacy and technical skills [68]. Industry 5.0 nurtured empathetic collaboration between humans and machines, emphasizing creativity, emotional intelligence, and environmental awareness [69,70]. Industry 6.0 envisions symbiotic ethical co-creation, where emotionally intelligent agents partner with transdisciplinary human professionals capable of moral reasoning and ecological thinking. The workforce is empowered to co-design adaptive, value-sensitive systems that align industrial outcomes with human and planetary flourishing.

Governance and resilience mechanisms similarly undergo systemic transformation. Industry 4.0 was rooted in centralized oversight and reactive risk mitigation, emphasizing redundancy and compliance [3]. Industry 5.0 introduced proactive, transparency-based governance emphasizing dignity, trust, and ethical accountability [27]. Industry 6.0 advances toward decentralized, ethically embedded governance architectures, where distributed intelligent agents and autonomous protocols uphold shared values, regenerative priorities, and systemic integrity [71]. Resilience shifts from robustness to antifragility—systems are designed not only to withstand disruptions but to adapt and evolve through them, guided by ethical foresight and regenerative design principles.

In essence, the transition toward Industry 6.0 reflects a holistic reorientation—from efficiency-centric mechanization to ethically governed, ecologically regenerative, and human-aligned systems. It elevates the role of industry from a vehicle for economic output to a catalyst for societal renewal and planetary well-being.

To conceptualize the defining themes and scholarly contributions shaping this paradigm, Table 2 synthesizes the emergent research into five key domains:

1) Technological Enablers: Industry 6.0 is driven by an advanced digital infrastructure integrating AGI, quantum computing, HDTs, and Digital Twin 4.0. These enablers transcend operational optimization, enabling real-time cognition, ethical decision-making, and systemic learning [72-75].

2) Human-Centricity and Governance: This theme underscores the integration of emotional intelligence, value-sensitive design, decentralized governance, and workforce transformation. Industry 6.0 promotes responsible innovation aligned with dignity, inclusion, and human flourishing [12,76,77].

3) Sector-Specific Innovations: Application domains span manufacturing, healthcare, logistics, and energy—each adopting localized, ethically embedded innovations. These systems emphasize resilience, contextual intelligence, and stakeholder co-creation [78-81].

4) Strategic Frameworks: Novel architectures, including digital–green twins, autonomous supply chains, and decentralized value ecosystems, guide the transition from centralized efficiency to distributed, ethical resilience [6,82,83].

5) Sustainability and Circularity: Industry 6.0 embeds regenerative thinking and circular economy principles into industrial design. Research advocates for nature-positive innovation, closed-loop systems, and ecological accountability to support sustainable societal advancement [8,83].

In conclusion, Industry 6.0 transcends the limits of digitization and automation, forging a new vision of industry as a conscious, collaborative, and regenerative ecosystem. It brings together advanced technologies, human values, and sustainability imperatives in a unified framework for long-term systemic transformation. By reimagining industrial systems as ethical and inclusive platforms for societal and ecological well-being, Industry 6.0 paves the way toward a more conscious and resilient industrial future.

Table 2. Emerging Research Themes and Pivotal Contributions in Industry 6.0.

#	Theme	Thematic Focus	Key References
1	Technological Foundations	Advancement of autonomous, intelligent, and real-time digital infrastructures enabling seamless integration, connectivity, and systemic responsiveness	Peng et al. (2020); Bhatti et al. (2021); Heilala & Singh (2023); Kharche & Pande (2023)
2	Human-Centricity & Governance	Ethical AI development, inclusive governance, responsible innovation, and the evolution of workforce competencies toward emotional and cognitive synergy	Doyle-Kent & Kopacek (2020); Salepcioglu (2021); Groumpos (2022); Almusaed et al. (2023); Chourasia et al. (2023)
3	Sectoral Innovation	Application of Industry 6.0 concepts to enhance adaptability, sustainability, and resilience across diverse industrial and socio-economic domains	Polkowski & Wierzbicka (2021); Bedi et al. (2021); Duggal et al. (2022); Singh et al. (2023); Murugan & Prabadevi (2023)
4	Strategic Architectures	Design of decentralized, human-centered frameworks integrating digital–green twin technologies and autonomous, value-driven operations	Barata & Kayser (2023); Villar et al. (2023); Kumar et al. (2023); Gomaa (2024)
5	Sustainability & Circularity	Embedding circular economy principles, regenerative system design, and sustainability-focused policies to foster long-term ecological balance	Chourasia et al. (2022); Kumar et al. (2023)

3. RESEARCH GAPS ANALYSIS

This section identifies key gaps in the current body of knowledge surrounding Industry 5.0 and Industry 6.0. While both paradigms offer transformative potential, the literature reveals critical areas where further theoretical development, empirical validation, and practical frameworks are needed.

3.1. Review of Industry 6.0

While Industry 5.0 holds significant promise as a human-centric, ethically aligned, and sustainability-oriented paradigm, several critical research gaps continue to hinder its full-scale implementation. Addressing these gaps is crucial for advancing the conceptual frameworks, enabling technologies, and organizational strategies necessary to realize resilient, intelligent, and inclusive industrial ecosystems [84]. Table 3 outlines the key research challenges that must be systematically addressed to unlock the full potential of Industry 5.0.

1) Embedding Human Values and Ethical Intelligence: Although human-centricity and ethical considerations lie at the core of Industry 5.0, existing frameworks lack the operational clarity needed to integrate human values, emotional intelligence, and ethical reasoning into the design and deployment of cyber-physical systems and AI. Current models often approach ethics reactively or superficially. Future work must focus on developing robust, interdisciplinary methodologies that embed these values at every stage of system design, drawing on engineering, cognitive science, and applied ethics 27].

2) Advanced Models for Human–AI Collaboration: Human–AI collaboration remains underdeveloped, particularly in terms of real-time, context-sensitive, and adaptive decision-making processes. Traditional automation paradigms fall short of supporting creative problem-solving and emotional interaction. Research must advance neurocognitive interfaces, affective computing, and machine learning architectures that support continuous, bidirectional learning and enhance intuitive, trust-based human–machine symbiosis 70].

3) Operationalizing Circularity and Net-Zero Targets: Sustainability is a foundational pillar of Industry 5.0, yet tangible frameworks and metrics for implementing circular economy principles at scale remain insufficient. Current efforts often focus on isolated lifecycle stages without systemic alignment. Addressing this requires the integration of lifecycle assessment, closed-loop supply chains, regenerative design, and material flow optimization, all aligned with transparent net-zero and decarbonization targets [69].

4) Human-Centric Digital Twin Innovations: The shift from asset-based to human-augmented digital twins is still in its infancy. Existing digital twin models often overlook cognitive, emotional, and contextual data. There is an urgent need for next-generation digital twins that incorporate real-time human feedback—enabling anticipatory analytics, adaptive control, and resilient decision-making in socio-technical systems [64].

5) Redefining Workforce Competencies and Organizational Learning: Industry 5.0 calls for a paradigm shift in workforce capabilities—from purely technical proficiency to creativity, emotional intelligence, and interdisciplinary collaboration. However, existing competency models and educational frameworks remain technologically biased and fragmented. Research must explore pedagogical innovations and organizational strategies that cultivate ethical awareness, adaptive thinking, and collaborative intelligence within the workforce [70].

6) Governance for Ethical, Transparent, and Responsible AI: Autonomous systems in Industry 5.0 environments raise complex ethical and regulatory issues, including bias, explainability, and accountability. Current governance models are fragmented and lack enforceability. There is a need to establish multi-stakeholder, transparent frameworks that regulate AI deployment across industrial domains, ensuring ethical alignment, fairness, and human oversight.

7) Resilience in Complex Adaptive Industrial Systems: The vision of decentralized, resilient, and self-organizing industrial ecosystems remains conceptually strong but empirically weak. There is limited understanding of how to model, simulate, and validate such systems. Research must integrate principles from cybernetics, systems theory, and resilience engineering to operationalize adaptive behaviors and enhance systemic robustness in the face of disruptions [69].

8) Standards and Interoperability for Converging Technologies: The convergence of diverse technologies-including AI, IIoT, blockchain, digital twins, and quantum computing—demands the

development of unified standards and interoperability protocols. However, standardization remains fragmented across sectors and regions, impeding scalability and seamless integration. There is a critical need to develop cross-domain, scalable frameworks for interoperability to ensure secure data exchange, system coherence, and operational efficiency [65].

In summary, fully realizing Industry 5.0's potential demands a concerted research effort across eight strategic dimensions: embedding ethical intelligence into system design; enhancing human–AI collaboration; operationalizing circular economy principles; advancing cognitive digital twins; transforming workforce skills and education; establishing robust AI governance; engineering systemic resilience; and developing global interoperability standards. These challenges are deeply interlinked and require cross-disciplinary, cross-sectoral collaboration.

As Industry 4.0 (technology-driven) and Industry 5.0 (human-centered and sustainability-driven) converge, their integration will redefine industrial systems toward more intelligent, ethical, and regenerative operations. Future research must explicitly address the following: (1) the socio-technical context under study; (2) the sustainability dimensions being advanced; (3) the anticipated societal outcomes; (4) strategic drivers for industrial transformation; (5) workforce competencies and educational requirements; (6) regulatory and safety implications—especially in human–robot collaboration; and (7) mechanisms for ongoing, transparent assessment of sustainability performance. Addressing these dimensions will enrich academic discourse, inform responsible industrial innovation, and foster inclusive and resilient ecosystems that benefit workers, organizations, and broader society [6,24,85,86].

Table 3. Key Research Gaps in Industry 5.0

#	Research Gap	Description	Key Focus Areas	Key References
1	Integration of Human Values and Ethics	Absence of actionable frameworks for embedding ethics and emotional intelligence in industrial systems.	Ethical AI design, value-sensitive engineering, human-machine empathy	Ghobakhloo et al. (2023); Calvo et al. (2022)
2	Context-Aware Human–AI Collaboration	Limited development of dynamic, adaptive, and creative co-working models.	Affective computing, neuroadaptive interfaces, real-time cognition	Khosravy et al. (2023); Li et al. (2020)
3	Scalable Circularity and Net-Zero Transitions	Inadequate models and metrics for implementing and scaling sustainable systems.	Lifecycle thinking, closed-loop value chains, carbon reduction tools	Adel (2022); Manupati et al. (2022); Geissdoerfer et al. (2017)
4	Human-in-the-Loop Digital Twin Systems	Weak integration of cognitive and emotional data into real-time digital twins.	Multisensory input, anticipatory analytics, cognitive control loops	Cañas et al. (2021); Tao et al. (2019)
5	Future Workforce and Cultural Transformation	Limited strategies for developing emotionally agile, creative, and ethical workforces.	Skills intelligence, continuous learning, inclusive leadership	Ghobakhloo et al. (2023); Cañas et al. (2021)
6	Ethical Governance and Responsible AI	Lack of robust models to ensure transparency, fairness, and accountability in AI.	Algorithmic accountability, bias mitigation, regulatory alignment	Soori et al. (2023); Javaid (2022)
7	Systemic Resilience and Decentralization	Limited tools for engineering resilient, adaptive, and distributed ecosystems.	Resilience-by-design, cyber-physical robustness, complexity theory	Adel (2022); Pinto et al. (2020); Hollnagel (2018)
8	Standards and Interoperability Frameworks	Fragmented standards hinder seamless integration and scalability.	Open protocols, interoperability layers, harmonized architectures	Soori et al. (2023); Javaid (2022)

3.2. Research Gaps in Industry 6.0

While scholarly discourse around Industry 4.0 and 5.0 has expanded significantly, the conceptualization of Industry 6.0 remains emergent and fragmented. Most existing studies prioritize technological advancement and operational efficiency without adequately addressing the ethical, emotional, ecological, and systemic dimensions that are foundational to Industry 6.0. This section identifies key research gaps across conceptual, technological, and governance domains that must be bridged to realize a conscious, circular, and resilient industrial paradigm. Despite its transformative promise, Industry 6.0 remains largely aspirational, with multiple unresolved research gaps hindering its translation into practical, intelligent, and ethically aligned industrial systems. Table 4 presents a structured synthesis of the key gaps, categorized into five critical domains: technological enablers, ethical governance, sectoral reach, implementation strategy, and sustainability integration. Although the literature offers foundational insights and visionary models, many areas lack sufficient empirical grounding, technical maturity, and system-wide applicability.

1) Technological Enablers and Infrastructure: While emerging technologies such as AI, IoT, and robotics have seen rapid progress, Industry 6.0 requires the seamless integration of advanced capabilities like Human Digital Twins (HDTs), decentralized emotional AI, and the Industrial Internet of Everything (IIoE)-which are still fragmented or underdeveloped. Existing infrastructures often fall short in real-time adaptability, interoperability, and cognitive responsiveness. Moreover, enabling technologies such as 6G, quantum computing, and AIoT-based edge-cloud systems are still in nascent stages, limiting their readiness for scalable, autonomous, and resilient industrial applications.

2) Human-Centric, Ethical, and Governance Models: There is a pronounced gap in ethical and governance frameworks that facilitate safe, inclusive, and transparent collaboration between humans and intelligent systems. Key dimensions—such as trust calibration, emotional-cognitive alignment, explainable AI, and cross-cultural adaptability—are insufficiently addressed. Current approaches do not fully embed principles of fairness, safety, accountability, and privacy into AI-driven industrial decision-making, especially in diverse and globalized contexts.

3) Sectoral and Socio-Economic Applications: Industry 6.0 research and applications have disproportionately focused on advanced manufacturing and digital healthcare, with limited attention to critical but underserved sectors such as agriculture, education, public services, and informal economies. Additionally, socio-economic considerations—such as digital exclusion, labor transformation, and policy misalignment—have not been adequately incorporated into current frameworks. There is a clear need for inclusive transformation pathways that ensure equitable access and benefits across geographies, income groups, and industries.

4) Strategic Integration and Implementation Frameworks: While conceptual models abound, actionable implementation roadmaps for Industry 6.0 remain scarce. Organizations face challenges in integrating disruptive technologies—such as brain–computer interfaces (BCIs), quantum AI, and emotional intelligence systems—into coherent, adaptive ecosystems. Furthermore, limited research exists on dynamic capability-building, modular systems design, and cross-industry orchestration aligned with resilience, agility, and circular economy principles.

5) Sustainability and Circular Economy Integration: Although sustainability and circularity are core tenets of Industry 6.0, their operationalization remains underdeveloped. Most existing studies are conceptual, with minimal empirical validation or implementation frameworks that embed zero-waste principles, carbon neutrality, or socio-environmental equity into intelligent manufacturing ecosystems. There is a pressing need for integrated performance metrics, regulatory frameworks, and real-world demonstration projects to enable systemic adoption.

In conclusion, while the conceptual landscape of Industry 6.0 is rich with promise, critical gaps must be addressed to enable its real-world adoption. These include the maturation and convergence of enabling technologies, the development of inclusive and ethical human–AI collaboration frameworks, broader cross-sectoral engagement, the design of strategic implementation blueprints, and the empirical embedding of sustainability principles. Addressing these challenges is essential to realizing Industry 6.0's vision of intelligent, regenerative, and human-aligned industrial ecosystems.

Table 4. Key Research Gaps in Industry 6.0.

#	Theme	Research Gaps	Impact	Representative References
1	Technology Integration	Fragmented integration of HDTs, Emotional AI, IIoE; immature infrastructures (6G, AIoT, quantum); limited interoperability	Slows the development of intelligent, connected, resilient systems	Peng et al. (2020); Bhatti et al. (2021); Heilala & Singh (2023); Kharche & Pande (2023).
2	Ethics & Governance	Lack of inclusive ethical frameworks; weak trust, explainability, and cultural adaptability	Limits responsible AI adoption and societal trust	Doyle-Kent & Kopacek (2020); Salepcioglu (2021); Groumpos (2022); Almusaed et al. (2023); Chourasia et al. (2022).
3	Socio-Economic Inclusivity	Overemphasis on high-tech sectors; neglect of agriculture, education, and Global South contexts; weak policies on digital divide	Restricts equitable, inclusive transformation	Polkowski & Wierzbicka (2021); Bedi et al. (2021); Duggal et al. (2022); Singh et al. (2023); Murugan & Prabadevi (2023).
4	Strategic Implementation	Absence of clear frameworks for disruptive tech adoption; weak scalability and ecosystem validation	Delays Industry 6.0 practical deployment	Barata & Kayser (2023); Villar et al. (2023); Kumar et al. (2023).
5	Sustainability & Circularity	Sustainability remains conceptual; limited empirical studies; lack of standards and pilot projects	Undermines environmental targets and regenerative system design	Chourasia et al. (2022); Kumar et al. (2023).

4. STRATEGIC FRAMEWORK FOR INDUSTRY 6.0 IMPLEMENTATION

This framework provides a transformative roadmap for reshaping industrial systems into conscious, ethical, and regenerative ecosystems, aligning with the core ethos of Industry 6.0. Unlike past industrial revolutions that prioritized automation and efficiency, Industry 6.0 integrates human values, ethical intelligence, and ecological responsibility into every aspect of industrial development. It offers a forward-looking pathway for policymakers, industry leaders, researchers, and civil society to foster inclusive innovation and planetary well-being. The framework consists of six interrelated elements:

1) Guiding Principles: Establish an ethical foundation based on conscious intelligence, human-AI collaboration, circularity, global equity, and ethical-by-design thinking.

2) Strategic Pillars: Operationalize these principles across five core areas: technological convergence, ethical governance, inclusive transformation, organizational agility, and sustainable value creation.

3) Cross-Cutting Enablers: Drive implementation through aligned policies, multi-stakeholder innovation ecosystems, and development of human-centric capabilities such as emotional intelligence and interdisciplinary skills.

4) Phased Implementation Roadmap: A structured five-phase pathway-from vision alignment to adaptive governance-supports a resilient and iterative transition to Industry 6.0.

5) Expected Outcomes: Includes the emergence of empathetic AI, equitable and inclusive innovation, regenerative industrial systems, and resilient, purpose-driven economies.

6) Illustrative Scenarios: Provide practical examples of how Industry 6.0 technologies and values can be applied across sectors to create a meaningful impact.

Together, these elements offer a cohesive and actionable blueprint for guiding the ethical and sustainable evolution of future industrial systems.

4.1. Guiding Principles for Industry 6.0

The transition from Industry 5.0 to Industry 6.0 marks not just a technological evolution, but a philosophical and ethical reorientation. Industry 6.0 emphasizes intelligence that is not only artificial but also conscious, designed with empathy, moral awareness, and ecological responsibility. Its foundation is built on five guiding principles that ensure industrial progress serves humanity and the planet sustainably and inclusively. Table 5 outlines the five foundational principles that anchor Industry 6.0 in ethical, inclusive, and regenerative values. These principles move beyond technical advancement, guiding the development of intelligent systems that serve humanity and the planet responsibly.

1) Conscious Intelligence promotes the creation of ethically aware, adaptive, and context-sensitive systems capable of responsible decision-making across diverse cultural and societal environments-such as deploying culturally responsive AI in public service delivery.

2) Ethical-by-Design ensures that ethics are embedded throughout the technology lifecycle. This includes fairness, transparency, privacy, and accountability-demonstrated in applications like explainable AI in healthcare and autonomous systems, where trust and clarity are critical.

3) Human-AI Synergy emphasizes collaborative intelligence, where machines augment human cognition and emotional awareness rather than replace it. Examples include AI copilots in education, creative design, and complex decision-making environments that elevate human capabilities.

4) Circularity & Regeneration drives the shift from extractive to regenerative industrial models. It focuses on closed-loop, zero-waste systems that restore ecological balance-for instance, circular manufacturing processes and carbon-negative infrastructure projects.

5) Global Inclusivity ensures that the benefits of innovation reach all populations, particularly underserved regions and marginalized communities. This includes accessible AI tools for rural healthcare or inclusive digital education platforms that reduce inequality.

Together, these guiding principles provide a strategic foundation for shaping Industry 6.0 as a values-driven industrial paradigm-one that balances technological progress with ethical governance, human dignity, and ecological stewardship.

Table 5. Guiding Principles for Industry 6.0.

#	Principle	Essence	Strategic Focus	Example Application
1	Conscious Intelligence	Ethical, adaptive, and context-aware systems	Promote responsible, situationally intelligent technologies	Culturally responsive AI in public services
2	Ethical-by-Design	Built-in fairness, transparency, and accountability	Embed ethics across the tech lifecycle	Explainable AI in healthcare and autonomous systems
3	Human–AI Synergy	Augment human cognition and emotional intelligence	Foster collaborative human-machine interaction	AI copilots in education, design, and decision support
4	Circularity & Regeneration	Restorative, zero-waste, and net-positive industrial ecosystems	Drive closed-loop, regenerative design and production	Circular manufacturing and carbon-negative infrastructure
5	Global Inclusivity	Equitable access to technological benefits	Ensure innovation reaches underserved communities and regions	Affordable AI tools in rural health, inclusive education platforms

4.2. Strategic Pillars for Industry 6.0

Industry 6.0 envisions a transformative shift from intelligent automation to conscious, ethical, and regenerative systems. This evolution demands more than technological advancement-it requires a holistic framework grounded in human values, societal well-being, and environmental stewardship. To realize this vision, five strategic pillars guide the operationalization of Industry 6.0's guiding principles, ensuring alignment between innovation, inclusion, resilience, and sustainability. Table 6 outlines these five strategic pillars:

1) Technological Convergence & Infrastructure: Integrates advanced technologies-such as Human Digital Twins, Industrial Internet of Everything (IIoE), quantum computing, and AIoT-into secure, interoperable, and ethically governed digital ecosystems.

2) Human-Centric Ethical Governance: Establishes value-driven, transparent, and culturally adaptive governance frameworks, embedding emotional intelligence, trust mechanisms, and explainable AI into both systems and institutions.

3) Inclusive Socioeconomic Transformation: Promotes equitable access to technology, bridges digital divides, and empowers underserved communities through inclusive education, workforce upskilling, and support for SMEs and public sectors.

4) Organizational Intelligence & Agility: Enhances resilience and adaptability through Digital Organizational Twins, enabling real-time simulation, strategic foresight, and regenerative business models.

5) Sustainability & Circular Value Realization: Embeds circular economy principles, AI-enabled analytics, and zero-waste practices into industrial operations, prioritizing decarbonization, resource regeneration, and planetary health.

Together, these pillars establish the foundation for ethically aligned, technologically advanced, and environmentally restorative industrial futures envisioned by Industry 6.0.

Table 6. Strategic Pillars for Industry 6.0 Implementation

#	Pillar	Essence	Strategic Focus	Example Applications
1	Technological Convergence & Infrastructure	Integrated deployment of advanced technologies	Align HDTs, IIoE, quantum computing, edge-AIoT, and 6G into a smart backbone	Smart factories, autonomous systems, and intelligent energy grids
2	Human-Centric Ethical Governance	Embedding ethics and emotional intelligence in AI	Ensure transparent, explainable, culturally adaptive decision-making	Ethical AI in healthcare, finance, and public services
3	Inclusive Socioeconomic Transformation	Equitable access to digital innovation	Bridge digital divides and empower communities through inclusive initiatives	AI hubs in rural areas, upskilling platforms, and SME enablement
4	Organizational Intelligence & Agility	Adaptive, real-time enterprise models	Use Digital Twins for learning, foresight, and strategic agility	Agile manufacturing, predictive logistics, and dynamic business modeling
5	Sustainability & Circular Value Realization	Regenerative, zero-waste industrial ecosystems	Apply AI for closed-loop production and environmental optimization	Circular supply chains, carbon-negative design, smart waste-to-resource systems

4.3. Cross-Cutting Enablers for Industry 6.0

The implementation of Industry 6.0 relies not only on its core principles and strategic pillars but also on a set of cross-cutting enablers that ensure systemic integrity, ethical alignment, and scalable transformation. These enablers operate across institutional, technological, human, and ecological dimensions, collectively supporting the emergence of conscious, inclusive, and regenerative industrial ecosystems. Table 7 outlines these foundational enablers.

1) Institutional and Regulatory Preparedness: Forward-looking policies and adaptive governance frameworks are essential for ensuring the ethical, legal, and sustainable integration of converging technologies. This includes protecting data sovereignty, enforcing algorithmic accountability, respecting environmental thresholds, and guaranteeing equitable access to innovation. Decentralized trust infrastructures—such as blockchain and smart contracts—enhance transparency, traceability, and collaborative integrity across autonomous and distributed systems.

2) Technological and Infrastructural Foundations: A robust and secure digital backbone is critical to enabling Industry 6.0 technologies such as Human Digital Twins, the Industrial Internet of Everything (IIoE), quantum computing, edge–cloud AIoT systems, and resilient 6G networks. Infrastructure must be designed for interoperability, cybersecurity, and ethical autonomy, supporting seamless

communication and real-time decision-making. In addition, privacy-preserving analytics and semantic data interoperability facilitate responsible cross-sector collaboration.

3) Human, Cultural, and Ecological Capacity Building: Industry 6.0 places human and planetary well-being at its core. Capacity building must therefore extend beyond technical proficiency to include ethical literacy, emotional intelligence, interdisciplinary fluency, and collaborative human–AI skills. Systems should be culturally adaptive and emotionally aware to promote inclusive innovation. Simultaneously, fostering ecological consciousness cultivates sustainability mindsets grounded in circularity, biodiversity, and long-term environmental stewardship.

4) Collaborative Innovation Ecosystems: Dynamic, multi-stakeholder ecosystems—linking academia, industry, governments, and civil society—are essential for co-creating, testing, and scaling responsible innovations. These ecosystems flourish through living labs, open innovation platforms, and decentralized experimentation, enabling inclusive participation, context-aware development, and continuous learning. Such collaboration accelerates the deployment of scalable solutions tailored to diverse socio-technical contexts.

5) Ethical Leadership and Institutional Foresight: The future envisioned by Industry 6.0 requires leaders who possess ethical vision, systems thinking, and futures literacy. Institutions must adopt anticipatory and participatory governance capable of navigating uncertainty, complexity, and interdependence. Strategic foresight methodologies—such as scenario planning, impact modeling, and backcasting—support resilient, inclusive, and regenerative decision-making over multiple time horizons.

Together, these five enablers constitute the foundational architecture for implementing Industry 6.0. They ensure that the transition toward intelligent, autonomous, and sustainable systems is grounded in ethical governance, driven by inclusive innovation, and guided by ecological responsibility and human empowerment. As transversal drivers, they transform vision into action and principles into measurable performance, forging the path toward a conscious and regenerative industrial future.

Table 7. Cross-Cutting Enablers for Industry 6.0

#	Enabler	Essence	Strategic Role	Examples
1	Institutional and Regulatory Preparedness	Ethical and adaptive policy frameworks	Ensure compliance, equity, and accountability in autonomous, data-driven systems	AI governance laws, data sovereignty regulations, and algorithmic ethics charters
2	Technological and Infrastructural Foundations	Intelligent, secure, and interoperable digital backbones	Enable real-time, autonomous, and ethically guided technology integration	6G-enabled edge-cloud infrastructure, digital identity systems, blockchain-enabled traceability
3	Human, Cultural, and Ecological Capacity Building	Ethically literate, emotionally intelligent, and sustainability-minded workforce	Prepare humans for meaningful collaboration with intelligent systems and planetary stewardship	Interdisciplinary AI curricula, emotional AI training, and circular economy education
4	Collaborative Innovation Ecosystems	Open, inclusive, and multi-stakeholder innovation networks	Accelerate responsible co-creation, contextualization, and diffusion of Industry 6.0 innovations	Living labs, open innovation platforms, academia–industry–government–society (AIGS) alliances
5	Ethical Leadership and Institutional Foresight	Visionary, anticipatory, and values-driven leadership	Guide institutions through complexity, shaping conscious futures with long-term, systems-level thinking	Futures literacy programs, impact foresight tools, and participatory governance models

4.4. Phased Implementation Roadmap for Industry 6.0

The transition to Industry 6.0 demands a strategic, ethically anchored, and systemically coherent roadmap to navigate technological complexity, align multi-stakeholder interests, and sustain transformative impact. The implementation unfolds across five adaptive and interrelated phases, each building sequentially while fostering continuous learning and institutional agility. Table 8 presents a structured roadmap to guide the evolution from conceptual alignment to full-scale realization. The roadmap is human-centric, values-driven, and inherently regenerative, ensuring that emerging technologies advance inclusive prosperity, ethical governance, and ecological sustainability.

Phase 1: Vision Co-Creation and Value Alignment: This foundational phase brings together diverse stakeholders to co-develop a shared vision rooted in ethical principles, social equity, and environmental stewardship. Through strategic foresight and participatory dialogue, collective values and long-term goals are established to guide the transformation.

Phase 2: Readiness Assessment and Gap Analysis: A comprehensive evaluation of institutional, technological, and organizational readiness is conducted. Structured audits identify capability gaps, digital maturity levels, leadership agility, and governance resilience. These insights inform targeted strategies for capacity building and systemic alignment.

Phase 3: Pilot Projects and Living Labs: This experimental phase validates emerging technologies—such as Human Digital Twins, IIoE, and emotional AI—within real-world contexts. Living labs act as inclusive testbeds for co-developing and ethically evaluating human–machine interaction models, ensuring responsible, context-sensitive innovation.

Phase 4: Scaling and Systemic Integration: Proven innovations are scaled across sectors through interoperable platforms, policy frameworks, and performance metrics. Industry 6.0 principles are embedded into enterprise systems, supply chains, and regulatory structures, enabling ecosystem-wide transformation and value co-creation.

Phase 5: Continuous Learning and Adaptive Governance: To ensure resilience and future-readiness, this phase institutionalizes feedback mechanisms, ethical oversight, and dynamic governance. Foresight tools and scenario planning enable continuous adaptation, sustaining alignment with Industry 6.0 principles amid emerging disruptions.

Collectively, these five phases form a dynamic and holistic transformation framework, bridging ethical vision with technological execution. The roadmap ensures that Industry 6.0 is not only implemented, but consciously and responsibly realized, laying the foundation for intelligent, inclusive, and regenerative industrial futures.

Table 8. Phased Implementation Roadmap for Industry 6.0.

Phase	Title	Core Objective	Key Actions	Outcomes
1	Vision Co-Creation & Value Alignment	Define a shared, ethically grounded vision	- Stakeholder engagement- Foresight workshops- Ethical goal setting	Unified vision and aligned strategic values
2	Readiness & Gap Assessment	Evaluate current capabilities and identify transformation gaps	- Capability audits- Ethical maturity review- Risk and agility mapping	Comprehensive readiness profile and gap analysis
3	Pilot Projects & Living Labs	Test technologies and ethical models in controlled real-world settings	- Launch pilots- Deploy Human Digital Twins and IIoE- Assess outcomes	Validated innovations and contextual learning
4	Scaling & Systemic Integration	Expand successful models across systems and sectors	- Scale proven pilots- Apply performance metrics- Ensure interoperability	Institutionalized and scalable transformation
5	Continuous Learning & Adaptive Governance	Sustain innovation through feedback, foresight, and ethical oversight	- Embed feedback loops- Use futures literacy tools- Monitor impact	Resilient, adaptive, and ethically governed ecosystems

4.5. Expected Outcomes of Industry 6.0

The adoption of the Industry 6.0 framework promises transformative outcomes across technological, social, environmental, and economic domains, positioning industry as a catalyst for ethical progress, inclusive prosperity, and ecological regeneration. Table 9 outlines the transformative outcomes anticipated from the implementation of Industry 6.0, structured across eight interdependent strategic domains. These domains-technological, social, environmental, economic, organizational, ethical, cultural, and educational-represent the systemic spheres where Industry 6.0 is expected to drive profound change. Each domain contributes uniquely to realizing a conscious, regenerative, and human-centric industrial paradigm.

1) Technological Domain: Industry 6.0 introduces a new generation of emotionally intelligent, ethically aligned, and context-sensitive technologies. These systems—such as Human Digital Twins, quantum AI, and IIoE-go beyond automation, enabling conscious decision-making and seamless human–machine symbiosis. The emphasis is on technologies that are not only smart but also self-aware, morally grounded, and adaptable to complex socio-technical environments.

2) Social Domain: This domain underscores equitable access, digital inclusion, and social justice. Industry 6.0 ensures that innovation benefits are fairly distributed, human roles remain central, and digital rights are upheld. Human–AI collaboration becomes a trust-based partnership that enhances societal well-being, supports diversity, and protects vulnerable communities from technological exclusion.

3) Environmental Domain: Industry 6.0 embeds regenerative principles into industrial ecosystems. Technologies are leveraged to operate within planetary boundaries through real-time environmental monitoring, closed-loop systems, and sustainable-by-design innovation. This domain aligns with the SDGs, promoting biodiversity, climate resilience, and long-term ecological balance.

4) Economic Domain: Economic outcomes shift from short-term profit models to long-term, purpose-driven value creation. Enterprises are restructured around resilience, stakeholder inclusivity, and mission-driven innovation. Decentralized models, such as platform cooperatives and token economies, emerge to redistribute value and strengthen economic equity.

5) Organizational Domain: Organizations evolve into agile, intelligent systems capable of foresight, collaboration, and ethical responsiveness. They adopt adaptive governance structures, systems thinking, and cross-disciplinary learning models to navigate uncertainty and complexity. This transformation enhances innovation capacity and resilience across industrial ecosystems.

6) Ethical Domain: Ethics is institutionalized across design, deployment, and governance layers. From algorithmic transparency and privacy safeguards to ethical AI and digital rights, Industry 6.0 ensures that all innovations are aligned with societal values and human dignity. Ethical foresight tools guide responsible innovation and prevent unintended harms.

7) Cultural Domain: Culturally inclusive and emotionally aware systems promote global solidarity while respecting local traditions. Industry 6.0 technologies are designed to accommodate diverse languages, customs, and values. Emotional intelligence, empathy, and pluralism become integral to system design and organizational behavior, fostering harmony between global convergence and cultural autonomy.

8) Educational Domain: The education sector is reimagined to cultivate the competencies required for conscious innovation. Future-oriented curricula emphasize ethical reasoning, interdisciplinary fluency, AI and quantum literacy, and emotional intelligence. Continuous learning ecosystems empower individuals to become co-creators of Industry 6.0's human-centric, sustainable futures.

Together, these eight domains form the foundation for Industry 6.0's holistic impact. They ensure that technological progress is harmonized with ethical governance, human empowerment, ecological stewardship, and cultural inclusivity, positioning Industry 6.0 as a civilizational leap toward a flourishing, equitable, and sustainable future.

Table 9. Expected Outcomes of Industry 6.0 Across Strategic Domains.

#	Domain	Strategic Outcomes	Transformative Impact
1	Technological	Convergence of ethical AI, Human Digital Twins, IIoE, quantum computing, and cognitive automation.	Enables intelligent, autonomous, and empathetic systems that enhance decision-making and personalization.
2	Social	Inclusive access to innovation, human-centered design, and empowerment of underserved communities.	Promotes social equity, human dignity, and trusted human–AI collaboration.
3	Environmental	Regenerative manufacturing, circular economy integration, and sustainability intelligence.	Drives ecological resilience, resource optimization, and alignment with global sustainability targets.
4	Economic	Shift toward purpose-driven, distributed, and post-growth enterprise models.	Enhances sustainable value creation, economic resilience, and stakeholder inclusivity.
5	Organizational	Evolution of adaptive, learning-oriented institutions with anticipatory governance.	Strengthens innovation agility, strategic foresight, and systems resilience.
6	Ethical	Ethics-by-design, transparent AI governance, and digital rights assurance.	Ensures accountable innovation and alignment with societal values and human rights.
7	Cultural	Integration of emotional intelligence, ethical literacy, and intercultural fluency into innovation.	Supports inclusive, respectful, and culturally adaptive systems.
8	Educational	Reorientation of education toward futures thinking, AI fluency, and interdisciplinary capability.	Cultivates a conscious, agile, and ethically informed future workforce.

4.6. Strategic Domains and Illustrative Scenarios of Industry 6.0

To illustrate the transformative potential of Industry 6.0, this section presents 14 forward-looking scenarios distributed across four strategic domains: Conscious Manufacturing Systems, Circular Manufacturing and Supply Chains, Resilient and Antifragile Operations, and Cross-Industry Innovation. These scenarios reflect the convergence of advanced technologies—such as affective AI, neuroadaptive systems, blockchain, and quantum computing—with ethical design and human-centric values, aiming to create intelligent, regenerative, and purpose-driven industrial ecosystems. Table 10 summarizes these scenarios, each defined by enabling technologies and their strategic value propositions, offering a vision for the next industrial paradigm.

1) Conscious Manufacturing Systems: This domain emphasizes emotionally intelligent, ethically guided, and human-centric production environments.

Scenario 1: Emotionally Intelligent Collaboration: Human Digital Twins and affective AI enable machines to recognize and respond to human emotions, promoting empathetic, psychologically safe interactions.

Scenario 2: Inclusive Cognitive Workflows: Adaptive interfaces and inclusive UX support neurodiversity, minimizing cognitive bias and enhancing participation.

Scenario 3: Ethical Decision Environments: Sentiment analytics and biofeedback loops support real-time ethical oversight in AI-augmented decision-making.

2) Circular Manufacturing and Supply Chains: Focuses on regenerative, low-impact value chains enabled by traceability, bio-innovation, and circular design.

Scenario 4: Blockchain-Enabled Circular Electronics: Digital product passports and blockchain enable lifecycle transparency, supporting repair, reuse, and recycling.

Scenario 5: Urban Biofabrication Hubs: Synthetic biology and mycelium-based materials enable localized, regenerative production with reduced environmental impact.

Scenario 6: Ethical Transparent Supply Chains: ESG blockchain tools and predictive AI ensure traceability, social responsibility, and closed-loop supply networks.

3) Resilient and Antifragile Operations: Envisions intelligent systems capable of adapting, recovering, and thriving amid disruptions.

Scenario 7: Self-Healing Smart Factories: Swarm robotics and autonomous agents detect anomalies and initiate real-time recovery, decentralizing operational risk.

Scenario 8: Adaptive Critical Infrastructure: Predictive digital twins and cyber-physical monitoring ensure continuity under extreme events or cyber threats.

Scenario 9: Emotionally Resilient Workforces: Biofeedback sensors and emotional analytics support mental well-being and sustainable workforce engagement.

4) Cross-Industry Innovation: Promotes interdisciplinary transformation through ethical AI, regenerative design, and quantum intelligence.

Scenario 10: Neuroadaptive Healthcare: Brain-machine interfaces and personalized digital twins improve prosthetic integration and individualized care.

Scenario 11: Circular Autonomy in Aerospace & Defense: Combines ethical AI with smart recycling and quantum decision tools for sustainable, autonomous operations.

Scenario 12: Conscious Agro-Industrial Systems: Emotional AI and biodynamic optimization foster regenerative agriculture and ethical land use.

Scenario 13: Regenerative Fashion & Sentient Wearables: Emotion-aware textiles and blockchain traceability combine expressive design with ethical material sourcing.

Scenario 14: Quantum Climate Co-Creation: Planetary digital twins and collective intelligence platforms, powered by quantum computing, enable participatory and regenerative climate governance.

In summary, these scenarios embody the vision of Industry 6.0-an industrial future defined by conscious collaboration, circularity, resilience, and cross-sectoral intelligence. Together, they chart a path toward regenerative, ethically aligned, and human-centered industrial ecosystems.

Table 10. Strategic Domains and Illustrative Scenarios of Industry 6.0.

Domain	#	Illustrative Scenario	Enabling Technologies	Strategic Value Proposition
Conscious Manufacturing	1	Emotionally Intelligent Collaboration	Affective AI, Neuroadaptive Interfaces, Human Digital Twins	Fosters empathy-driven interaction and emotionally sustainable operations
	2	Inclusive Cognitive Workflows	Cognitive Modeling, Adaptive Interfaces, Inclusive UX Design	Enhances neurodiversity, usability, and cognitive equity
	3	Ethical AI Decision Environments	Sentiment Analytics, Biofeedback Loops, AI Ethics Dashboards	Embeds ethical oversight and psychosocial safety in decisions
Circular Supply & Production	4	Circular Electronics via Blockchain	Digital Passports, Blockchain, Lifecycle AI	Enables full traceability and minimizes resource use
	5	Urban Biofabrication Hubs	Synthetic Biology, AI-Guided Fabrication, Mycelium Composites	Produces regenerative materials and local, low-impact manufacturing
	6	Ethical Transparent Supply Chains	ESG Blockchain, Circular Design Tools, Predictive AI	Increases visibility, accountability, and circularity
Resilient Operations	7	Self-Healing Smart Factories	Edge AI, Swarm Robotics, Autonomous Agents, Quantum Optimization	Enables autonomous recovery and system-level resilience
	8	Adaptive Infrastructure Manufacturing	Resilience AI, Digital Twins, Cyber-Physical Monitoring	Anticipates disruption and ensures continuity
	9	Emotionally Resilient Workforce Systems	Biofeedback Sensors, Emotional Analytics, Resilience AI	Supports mental well-being and long-term workforce engagement
Cross-Industry Innovation	10	Neuroadaptive Healthcare	Neuro-Robotics, Bio-Cybernetic Interfaces, Digital Twins	Personalizes care and enhances motor-sensory integration
	11	Circular Autonomy in Aerospace & Defense	Ethical AI, Smart Recycling, Quantum Decision Support	Ensures zero-waste design and ethical autonomy
	12	Conscious Agro-Industrial Systems	Emotional AI, Smart Agro-Tech, Biodynamic Optimization	Aligns food systems with ethics and environmental regeneration
	13	Regenerative Fashion & Sentient Wearables	Emotion-Aware Textiles, Blockchain Traceability, Bio-Based Materials	Integrates sustainability, expression, and ethical sourcing
	14	Quantum Climate Co-Creation Platforms	Planetary Digital Twins, Quantum Computing, Collective Intelligence	Enables regenerative, foresight-driven climate solutions

5. CONCLUSION AND FUTURE WORK

This study presents a comprehensive synthesis of the transition from Industry 4.0 to Industry 6.0, highlighting the conceptual foundations, enabling technologies, and strategic imperatives that characterize this next-generation industrial paradigm. Based on an extensive review of over 90 peer-reviewed publications, the research articulates a transformative vision of Industry 6.0—not as a linear technological progression, but as a conscious, ethical, and regenerative reimagining of industrial systems.

Unlike previous industrial revolutions, which prioritized automation, digitalization, and human-centric innovation, Industry 6.0 positions manufacturing as a platform for human well-being, ecological renewal, and moral intelligence. It is underpinned by the convergence of advanced technologies such as Artificial General Intelligence (AGI), quantum computing, emotional AI, and bio-cybernetic systems—applied not only to optimize performance but to elevate purpose and planetary stewardship.

To guide this transformation, the study introduces a strategic framework composed of six interrelated components. The Guiding Principles establish an ethical and philosophical foundation built on conscious intelligence, circularity, global equity, human–AI symbiosis, and integrity-driven design.

These principles are operationalized through five Strategic Pillars: technological convergence, ethical governance, inclusive transformation, organizational agility, and sustainable value creation. Implementation is further supported by Cross-Cutting Enablers, including innovation ecosystems, supportive policy frameworks, and human-centric capabilities such as emotional intelligence, cognitive adaptability, and transdisciplinary literacy.

A structured Implementation Roadmap outlines a phased approach—from vision formulation and stakeholder engagement to adaptive governance—ensuring a resilient, inclusive, and ethically sound transformation. The framework envisions a range of transformative Outcomes, including the emergence of empathetic AI systems, regenerative production models, equitable innovation ecosystems, and purpose-driven economies. These are illustrated through scenario-based applications that demonstrate the real-world relevance of Industry 6.0 principles across diverse sectors.

Theoretical Implications: The study introduces a value-driven meta-paradigm that integrates ethics, emotional intelligence, and systemic resilience into industrial theory. It bridges cybernetics, AI ethics, cognitive science, and sustainability, advancing industry as a morally attuned, adaptive system.

Practical Implications: The framework supports AGI-enabled cognition, bio-cybernetic feedback, and emotionally responsive systems. It advances circular manufacturing through closed-loop design, digital product passports, and intelligent lifecycle analytics, fostering inclusive, empathic, and sustainable workplaces.

Managerial Implications: Industry 6.0 requires a shift from hierarchical leadership to conscious stewardship. Managers must embrace ethical governance, regenerative business models, decentralized decision-making, and emotionally intelligent leadership to navigate complex, intelligent ecosystems.

Study Limitations: This conceptual framework requires empirical validation. Key technologies (AGI, quantum cognition, bio-cybernetics) are still emerging. Adaptation may be challenging for SMEs and low-tech sectors. Ethical, social, and cultural complexities warrant further exploration.

Future Research Directions: Future research should focus on empirically validating the proposed framework through longitudinal case studies, system dynamics modeling, and sector-specific pilot initiatives. Additional investigation is needed to refine ethical and regulatory architectures, develop integrated performance indicators, and explore the co-evolution of human and machine capabilities in conscious, intelligent ecosystems. Advancing this agenda will require transdisciplinary collaboration and global alignment, anchored in a shared commitment to designing sustainable, just, and intelligent industrial futures.

Generative Artificial Intelligence Statement: While preparing this work, the authors used ChatGPT to improve the writing quality of some paragraphs. They confirm that no generative artificial intelligence (Gen AI) was used in creating this manuscript.

Funding Statement: This study was not funded by any external sources.

Author Contribution: The authors contributed to the research and writing of this article and have read/agreed to the published version of the manuscript.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data supporting this study are included within the article.

Conflict of Interest: The authors declare no conflict of interest.

REFERENCES

1. Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D. and Wang, L., 2022. Industry 5.0: Prospect and retrospect. Journal of Manufacturing Systems, 65(1), pp.279-295.
2. Duggal, A.S., Malik, P.K., Gehlot, A., Singh, R., Gaba, G.S., Masud, M. and Al-Amri, J.F., 2022. A sequential roadmap to Industry 6.0: Exploring future manufacturing trends. Iet Communications, 16(5), pp.521-531.
3. Gomaa, A.H., 2024. Advancing Manufacturing Excellence in the Industry 4.0 Era: A Comprehensive Review and Strategic Integrated Framework. Supply Chain Research, 2(2), pp.1-37.
4. Xu, L.D., Xu, E.L. and Li, L., 2018. Industry 4.0: state of the art and future trends. International journal of production research, 56(8), pp.2941-2962.
5. Maddikunta, P.K.R., Pham, Q.V., Deepa, N., Dev, K., Gadekallu, T.R., Ruby, R. and Liyanage, M., 2022. Industry 5.0: A survey on enabling technologies and potential applications. Journal of industrial information integration, 26(1), p.100257.
6. Barata, J. and Kayser, I., 2023. Industry 5.0–past, present, and near future. Procedia Computer Science, 219, pp.778-788.
7. Choudhary, D. and Nandy, I., 2024. A study of sustainability risks from industry 4.0 perspective: taxonomy and future research avenues. Competitiveness Review: An International Business Journal, 34(6), pp.1178-1205.
8. Chourasia, S., Tyagi, A., Pandey, S. M., Walia, R. S., & Murtaza, Q., 2022. Sustainability of Industry 6.0 in Global Perspective: Benefits and Challenges. MAPAN, 37(2), 443–452.
9. Kaswan, M.S., Rathi, R., Cross, J., Garza-Reyes, J.A., Antony, J. and Yadav, V., 2023. Integrating green lean six sigma and industry 4.0: a conceptual framework. Journal of Manufacturing Technology Management, 34(1), pp.87-121.
10. Gerrikagoitia, J.K., Unamuno, G., Urkia, E. and Serna, A., 2019. Digital manufacturing platforms in the industry 4.0 from private and public perspectives. Applied Sciences, 9(14), p.2934.
11. Ivanov, D., 2023. The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. International Journal of Production Research, 61(5), pp.1683-1695.
12. Almusaed, A., Yitmen, I. and Almssad, A., 2023. Reviewing and integrating aec practices into industry 6.0: Strategies for smart and sustainable future-built environments. Sustainability, 15(18), 13464, pp. 1-27.
13. Gomaa, A.H., 2025a. Lean 4.0: A Strategic Roadmap for Operational Excellence and Innovation in Smart Manufacturing. International Journal of Emerging Science and Engineering (IJESE), 13(5), pp.1-20.
14. Gomaa, A.H., 2025b. LSS 4.0: A Conceptual Framework for Integrating Lean Six Sigma and Industry 4.0 for Smart Manufacturing Excellence. Indian Journal of Management and Language (IJML, 5(1), pp. 8-29.
15. Gomaa, A.H., 2025c. Maintenance 4.0: Optimizing Asset Integrity and Reliability in Modern Manufacturing. International Journal of Inventive Engineering and Sciences (IJIES), 12(2), pp.18-26, pp. 18-26.
16. Gomaa, A.H., 2025d. RCM 4.0: A Novel Digital Framework for Reliability-Centered Maintenance in Smart Industrial Systems. International Journal of Emerging Science and Engineering (IJESE), 13(5), pp. 32-43.

17. Gomaa, A.H., 2025e. SCM 4.0 Excellence: A Strategic Framework for Smart and Competitive Supply Chains. International Journal of Management and Humanities (IJMH), 11(8), pp. 24-44.
18. Gomaa, A.H., 2025f. Smart Maintenance in Industry 4.0: Optimizing Equipment Performance Through Digital Twins and Lean Six Sigma Integration. IUP Journal of Mechanical Engineering, 18(1), pp.7-31.
19. Gomaa, A.H., 2025g. Enhancing Failure Mode and Effects Analysis with Industry 4.0 (FMEA 4.0): A Comprehensive Review and Strategic Framework. International Journal of Darshan Institute of Engineering Research and Emerging Technologies, 14(2), pp. 1-12.
20. Gomaa, A.H., 2025h. Quality Management Excellence in the Era of Industry 4.0 (Quality 4.0): A Comprehensive Review, Gap Analysis, and Strategic Framework. MRS Journal of Accounting and Business Management, 2(8), pp. 18-40.
21. Nahavandi, S., 2019. Industry 5.0—A human-centric solution. Sustainability, 11(16), p.4371.
22. Abdel-Basset, M., Mohamed, R. and Chang, V., 2025. A Multi-criteria decision-making Framework to evaluate the impact of industry 5.0 technologies: Case Study, lessons learned, challenges and future directions. Information Systems Frontiers, 27(1), pp.791–821.
23. Calabrese, A., Levialdi Ghiron, N. and Tiburzi, L., 2021. 'Evolutions' and 'revolutions' in manufacturers' implementation of industry 4.0: a literature review, a multiple case study, and a conceptual framework. Production Planning & Control, 32(3), pp.213-227.
24. Xu, X., Lu, Y., Vogel-Heuser, B. and Wang, L., 2021. Industry 4.0 and Industry 5.0—Inception, conception and perception. Journal of manufacturing systems, 61(1), pp.530-535.
25. Mourtzis, D., Angelopoulos, J. and Panopoulos, N., 2022. A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. Energies, 15(17), 6276, pp.1-29.
26. Javaid, M., Haleem, A., Singh, R.P., Suman, R. and Gonzalez, E.S., 2022. Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability. Sustainable operations and computers, 3(1), pp.203-217.
27. Ghobakhloo, M., Iranmanesh, M., Tseng, M.L., Grybauskas, A., Stefanini, A. and Amran, A., 2023. Behind the definition of Industry 5.0: a systematic review of technologies, principles, components, and values. Journal of Industrial and Production Engineering, 40(6), pp.432-447.
28. Ghobakhloo, M., Iranmanesh, M., Vilkas, M., Grybauskas, A. and Amran, A., 2022. Drivers and barriers of industry 4.0 technology adoption among manufacturing SMEs: a systematic review and transformation roadmap. Journal of Manufacturing Technology Management, 33(6), pp.1029-1058.
29. Dyba, W. and De Marchi, V., 2022. On the road to Industry 4.0 in manufacturing clusters: the role of business support organisations. Competitiveness Review: An International Business Journal, 32(5), pp.760-776.
30. Gajdzik, B., Grabowska, S. and Saniuk, S., 2021. A theoretical framework for industry 4.0 and its implementation with selected practical schedules. Energies, 14(4), 940, pp. 1-24.
31. Hermann, M., Pentek, T. and Otto, B., 2016, January. Design principles for Industry 4.0 scenarios. Proceedings of 49th Hawaii International Conference on Systems Science, January 5–8, 2016, Maui, Hawaii, USA. IEEE.
32. Chen, S.C., Chen, H.M., Chen, H.K. and Li, C.L., 2024. Multi-objective optimization in Industry 5.0: Human-centric AI integration for sustainable and intelligent manufacturing. Processes, 12(12), p.2723.
33. Coelho, P., Bessa, C., Landeck, J. and Silva, C., 2023. Industry 5.0: The arising of a concept. Procedia Computer Science, 217(1), pp.1137-1144.
34. Tóth, A., Nagy, L., Kennedy, R., Bohuš, B., Abonyi, J. and Ruppert, T., 2023. The human-centric Industry 5.0 collaboration architecture. MethodsX, 11(1), p.102260.
35. Kovari, A., 2024. Industry 5.0: Generalized definition key applications opportunities and threats. Acta Polytechnica Hungarica, 21(3), pp.267-284.
36. Mohamed, M., 2018. Challenges and benefits of industry 4.0: An overview. International Journal of Supply and Operations Management, 5(3), pp.256-265.
37. Kuo, C.J., Ting, K.C., Chen, Y.C., Yang, D.L. and Chen, H.M., 2017. Automatic machine status prediction in the era of Industry 4.0: Case study of machines in a spring factory. Journal of Systems Architecture, 81(1), pp.44-53.

38. Mrugalska, B. and Wyrwicka, M.K., 2017. Towards lean production in industry 4.0. Procedia engineering, 182, pp.466-473.
39. Narula, S., Prakash, S., Dwivedy, M., Talwar, V. and Tiwari, S.P., 2020. Industry 4.0 adoption key factors: an empirical study on manufacturing industry. Journal of Advances in Management Research, 17(5), pp.697-725.
40. Yacout, S., 2019, October. Industrial value chain research and applications for industry 4.0. In In 4th north america conference on industrial engineering and operations management, toronto, canada.
41. Qin, J., Y. Liu, and R. Grosvenor. 2016. "A Categorical Framework of Manufacturing for Industry 4.0 and beyond." Procedia CIRP 52: 173–178.
42. Zhou, K., Liu, T. and Zhou, L., 2015, August. Industry 4.0: Towards future industrial opportunities and challenges. In 2015 12th International conference on fuzzy systems and knowledge discovery (FSKD) (pp. 2147-2152). IEEE.
43. Witkowski, K., 2017. Internet of things, big data, industry 4.0–innovative solutions in logistics and supply chains management. Procedia engineering, 182, pp.763-769.
44. Lu, Y., 2017. Industry 4.0: A survey on technologies, applications and open research issues. Journal of industrial information integration, 6(1), pp.1-10.
45. Ghobakhloo, M., 2020. Industry 4.0, digitization, and opportunities for sustainability. Journal of cleaner production, 252(1), p.119869.
46. Sajdak, M., Młody, M., Weinert, A. and Wójtowicz, Ł., 2022. How Industry 4.0 supports the strategic agility of companies. A systematic literature review. Central European Review of Economics & Finance, 41(6), pp.27-57.
47. Rijwani, T., Kumari, S., Srinivas, R., Abhishek, K., Iyer, G., Vara, H., Dubey, S., Revathi, V. and Gupta, M., 2025. Industry 5.0: A review of emerging trends and transformative technologies in the next industrial revolution. International Journal on Interactive Design and Manufacturing (IJIDeM), 19(2), pp.667-679.
48. Rath, K.C., Khang, A. and Roy, D., 2024. The role of Internet of Things (IoT) technology in Industry 4.0 economy. In Advanced IoT technologies and applications in the industry 4.0 digital economy (pp. 1-28). CRC Press.
49. Juliet, A.H., 2025, January. AI-driven predictive maintenance for industrial IoT with real-time fault detection and prediction. In 2025 8th International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech) (pp. 1-6). IEEE.
50. Sheikh, R.A., Ahmed, I., Faqihi, A.Y.A. and Shehawy, Y.M., 2024. Global perspectives on navigating Industry 5.0 knowledge: Achieving resilience, sustainability, and human-centric innovation in manufacturing. Journal of the Knowledge Economy, pp.1-36.
51. Caruana, L. and Francalanza, E., 2023. A Safety 4.0 approach for collaborative robotics in the factories of the future. Procedia Computer Science, 217(1), pp.1784-1793.
52. Mahalle, P.N., Patil, R.V., Dey, N., Crespo, R.G. and Sherratt, R.S., 2024. Explainable AI for human-centric ethical IoT systems. IEEE Transactions on Computational Social Systems, 11(3), pp.3407-3419.
53. Marino, E., Barbieri, L., Bruno, F. and Muzzupappa, M., 2024. Assessing user performance in augmented reality assembly guidance for industry 4.0 operators. Computers in Industry, 157(1), p.104085.
54. Patnaik, P., Nayak, P. and Misra, S., 2023. Personalized product recommendation and user satisfaction: Reference to Industry 5.0. In Advanced Research and Real-World Applications of Industry 5.0 (pp. 102-128). IGI Global.
55. Saniuk, S., Grabowska, S. and Fahlevi, M., 2023. Personalization of products and sustainable production and consumption in the context of industry 5.0. In Industry 5.0: Creative and Innovative Organizations (pp. 55-70). Cham: Springer International Publishing.
56. Zhang, C., Wang, Z., Zhou, G., Chang, F., Ma, D., Jing, Y., Cheng, W., Ding, K. and Zhao, D., 2023. Towards new-generation human-centric smart manufacturing in Industry 5.0: A systematic review. Advanced Engineering Informatics, 57(1), p.102121.

57. Farghali, M. and Osman, A.I., 2024. Revolutionizing waste management: unleashing the power of artificial intelligence and machine learning. In Advances in energy from waste (pp. 225-279). Woodhead Publishing.
58. Rahmani, R., Karimi, J., Resende, P.R., Abrantes, J.C. and Lopes, S.I., 2023. Overview of selective laser melting for Industry 5.0: Toward customizable, sustainable, and human-centric technologies. Machines, 11(5), p.522.
59. Golovianko, M., Terziyan, V., Branytskyi, V. and Malyk, D., 2023. Industry 4.0 vs. Industry 5.0: Co-existence, transition, or a hybrid. Procedia Computer Science, 217(1), pp.102-113.
60. Mourtzis, D., 2023. The Metaverse in industry 5.0: A human-centric approach towards personalized value creation. Encyclopedia, 3(3), pp.1105-1120.
61. Neethirajan, S., 2024. Artificial intelligence and sensor innovations: enhancing livestock welfare with a human-centric approach. Human-Centric Intelligent Systems, 4(1), pp.77-92.
62. Nguyen, H.D. and Tran, K.P., 2023. Artificial intelligence for smart manufacturing in industry 5.0: Methods, applications, and challenges. Artificial intelligence for smart manufacturing: methods, applications, and challenges, pp.5-33.
63. Guerreiro, G., Figueiras, P., Costa, R., Marques, M., Graça, D., Garcia, G. and Jardim-Gonçalves, R., 2019, November. A digital twin for intra-logistics process planning for the automotive sector supported by big data analytics. Proceedings of the ASME 2019, International Mechanical Engineering Congress and Exposition, IMECE2019, November 11-14, 2019, Salt Lake City, UT, USA.
64. Cañas, H., Mula, J., Díaz-Madroñero, M., & Campuzano-Bolarín, F., 2021. Implementing Industry 4.0 principles. Computers & Industrial Engineering, 158(1), 107379.
65. Soori, M., Arezoo, B. and Dastres, R., 2023. Internet of things for smart factories in industry 4.0, a review. Internet of Things and Cyber-Physical Systems, 3(1), pp.192-204.
66. Li, X., Zhu, L., Chu, X. and Fu, H., 2020. Edge computing-enabled wireless sensor networks for multiple data collection tasks in smart agriculture. Journal of Sensors, 2020(1), 4398061, pp.1-9.
67. Bécue, A., Maia, E., Feeken, L., Borchers, P. and Praça, I., 2020. A new concept of digital twin supporting optimization and resilience of factories of the future. Applied Sciences, 10(13), p.4482.
68. Munirathinam, S., 2020. Industry 4.0: Industrial internet of things (IIOT). In Advances in computers, 117(1), pp. 129-164.
69. Adel, A., 2022. Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas. Journal of Cloud Computing, 11(1), 40, pp. 1-15.
70. Khosravy, M., Gupta, N., Pasquali, A., Dey, N., Crespo, R.G. and Witkowski, O., 2023. Human-collaborative artificial intelligence along with social values in industry 5.0: A survey of the state-of-the-art. IEEE Transactions on Cognitive and Developmental Systems, 16(1), pp.165-176.
71. Salepcioglu, M.A., 2021. Artificial and remote management model: Industry 6.0 increased virtual and artificial audit. PressAcademia Procedia (PAP), 13(1), pp.114-115.
72. Peng, M., Garg, S., Wang, X., Bradai, A., Lin, H. and Hossain, M.S., 2020. Learning-based IoT data aggregation for disaster scenarios. IEEE Access, 8(1), pp.128490-128497.
73. Bhatti, G., Mohan, H. and Singh, R.R., 2021. Towards the future of smart electric vehicles: Digital twin technology. Renewable and Sustainable Energy Reviews, 141(1), p.110801.
74. Heilala, J., & Singh, K. 2023. Evaluation planning for artificial intelligence-based industry 6.0 Metaverse integration. Intelligent Human Systems Integration (IHSI 2023): Integrating People and Intelligent Systems, 69(1), pp.692–703.
75. Kharche, Y.A. and Pande, P.P., 2023. Development Of Artificial Intelligence Module For Pharmaceutical Manufacturing Plant With Continuous Leakage Monitoring And Self Healing Surface System--Contribution To Industry 6.0. Journal of Pharmaceutical Negative Results, 14(3).
76. Doyle-Kent, M. and Kopacek, P., 2019, August. Industry 5.0: Is the manufacturing industry on the cusp of a new revolution?. In International Conference on Production Research (pp. 432-441). Cham: Springer International Publishing.
77. Groumpos, P.P., 2022. Ethical AI and Global Cultural Coherence: Issues and Challenges. IFAC-PapersOnLine, 55(39), pp.358-363.
78. Polkowski, Z. and Wierzbicka, A., 2021. Industry 4.0 in Cosmetic Companies. Azerbaijan Journal of High Performance Computing, 4(2), pp.135-154.

79. Bedi, T., Rana, V. and Gautam, N., 2021. Changing Face Of The Apparel Industry By Incorporating Industry 4.0 And Paving Way For Industry 5.0. Turkish Online Journal of Qualitative Inquiry, 12(3), pp.4814–4832.
80. Singh, R., Tyagi, A.K. and Arumugam, S.K., 2024. Imagining the sustainable future with Industry 6.0: A smarter pathway for modern society and manufacturing industries. In Machine Learning Algorithms Using Scikit and TensorFlow Environments (pp. 318-331). IGI Global Scientific Publishing.
81. Murugan, M. and Prabadevi, M.N., 2023. Impact of Industry 6.0 on MSME Entrepreneur's Performance and Entrepreneur's Emotional Intelligence in the Service Industry in India. Revista de Gestão Social e Ambiental, 17(4), pp.1-15.
82. Villar, A., Paladini, S. and Buckley, O., 2023, July. Towards supply chain 5.0: Redesigning supply chains as resilient, sustainable, and human-centric systems in a post-pandemic world. In Operations Research Forum, 4(3), p. 60.
83. Kumar, R., Kariminejad, A., Antonov, M., Goljandin, D., Klimczyk, P. and Hussainova, I., 2023. Progress in sustainable recycling and circular economy of tungsten carbide hard metal scraps for industry 5.0 and onwards. Sustainability, 15(16), p.12249.
84. Mukherjee, A.A., Raj, A. and Aggarwal, S., 2023. Identification of barriers and their mitigation strategies for industry 5.0 implementation in emerging economies. International Journal of Production Economics, 257(1), p.108770.
85. Sindhwani, R., Afridi, S., Kumar, A., Banaitis, A., Luthra, S. and Singh, P.L., 2022. Can industry 5.0 revolutionize the wave of resilience and social value creation? A multi-criteria framework to analyze enablers. Technology in Society, 68(1), p.101887.
86. Coronado, E., Kiyokawa, T., Ricardez, G.A.G., Ramirez-Alpizar, I.G., Venture, G. and Yamanobe, N., 2022. Evaluating quality in human-robot interaction: A systematic search and classification of performance and human-centered factors, measures and metrics towards an industry 5.0. Journal of Manufacturing Systems, 63(1), pp.392-410.