© February 2026| IJIRT | Volume 12 Issue 9 | ISSN: 2349-6002

# The Rise of Industry 6.0: An Analysis and Comprehensive Review of Technological Shift

Ms. Kajal Sharma[1], Dr. Nirali C Dave[2]
[1]Teaching Assistant, Vanita Vishram Women's University, Surat, Gujarat
[2]Assistant Professor, Vanita Vishram Women's University, Surat, Gujarat

**Abstract - Technological breakthroughs, economic pressures, and changing societal expectations have all led to several revolutions in industrial systems. New organisational structures and industrial paradigms were introduced at every level, from Industry 1.0's mechanisation to Industry 2.0's mass production, automation, and digitalisation. Industry 5.0 emerged with its focus on human-centeredness, ethical AI, and long-term cooperation. While Industry 4.0 focused on data-driven automation and cyber-physical systems, its technology-centric orientation revealed constraints on sustainability, resilience, and human well-being. In keeping with the concept of Society 6.0, Industry 6.0 is developing as a post-digital socio-technical paradigm that seeks to strike a balance between industrial autonomy, moral governance, human values, and long-term societal sustainability. Advanced artificial intelligence, autonomous robots, decentralised cognitive manufacturing, and system design focused on sustainability set it apart. The current review systematically examines Industry 6.0 by synthesising recent peer-reviewed literature to analyse its key enabling technologies, human-centric and sustainability dimensions, managerial and policy implications, and open research challenges that influence its future industrial adoption.**

**Index Terms — Industry 6.0, Society 6.0, Human-Centric Artificial Intelligence, Digital Twins, Cyber-Physical Systems, Intelligent Robotics, Digital Transformation.**

## I. INTRODUCTION

Through technological advances and shifting value-creation models, industrial revolutions have consistently altered production systems and socioeconomic structures. Each paradigm changed how labour, capital, and technology interacted, influencing social effects and production. To view Industry 6.0 as a progressive response to previous industrial restrictions rather than a singular technical revolution, it is imperative to trace this history [11][19].

The late eighteenth century saw the emergence of the First Industrial Revolution (Industry 1.0), which signalled the shift from artisanal production to mechanised manufacture driven by steam and water. Industrial systems continued to rely mostly on human labour, localised infrastructure, and manual supervision, which limited scalability and operational flexibility even as productivity increased [19].

Industry 2.0 made mass manufacturing and international supply chains possible by using assembly-line methods, electrification, and standardised parts. Although this paradigm greatly increased productivity and decreased expenses, it depended on strict hierarchical control, restricted worker autonomy, and mostly ignored social and environmental sustainability issues [11][17].

Electronics, information technology, and programmable logic controllers (PLCs) drove the Third Industrial Revolution (Industry 3.0), which improved automation, precision, and operational efficiency [8]. But manufacturing processes continued to be rigid and centralised, making it difficult to respond to new needs like customisation, sustainability, and market volatility [10].

By combining cloud computing, big data analytics, the Industrial Internet of Things (IIoT), and cyber-physical systems (CPS), Industry 4.0 brought about a significant revolution that allowed for predictive maintenance and real-time monitoring [8]. Excessive automation, diminished human agency, ethical issues with AI, worker displacement, and a lack of alignment with long-term sustainability goals are among the difficulties, according to research [1][11].

As a result, Industry 5.0 was born, emphasising sustainability, resilience, and human-centricity. This paradigm encourages ethical AI, human-robot cooperation, and socially conscious production systems by redefining people as cooperative partners rather than machine operators [1][18]. Particularly in complicated and unpredictable situations, human creativity and contextual intelligence are acknowledged as crucial supplements to automation [1].

Industry 6.0 is emerging as the next evolutionary stage, building on previous industrial advances. It is characterised by decentralised, AI-driven cognitive manufacturing systems where ethical governance, sustainability, and regulatory compliance are intrinsically embedded within operational intelligence, allowing accountability to be a built-in system capability rather than an external constraint [6][20].

Intelligent digital twins, autonomous and cooperative robots, generative artificial intelligence, blockchain-based trust mechanisms, and human-aware systems are all included in Industry 6.0, according to recent studies [2][4]. Together, these technologies allow for continuous feedback, adaptive optimisation, and system resilience throughout industrial value chains, all while maintaining human oversight, moral judgement, and ethical reasoning [14][20]. Crucially, Industry 6.0 is strongly related to the larger concept of Society 6.0, in which industrial and technical advancement promotes environmental responsibility, social inclusion, and general human well-being [19]. Industry 6.0 seeks to address global issues like resource shortages, demographic upheavals, and climate change through resilient and sustainable industrial systems by fusing economic performance with the generation of social value [21][22].

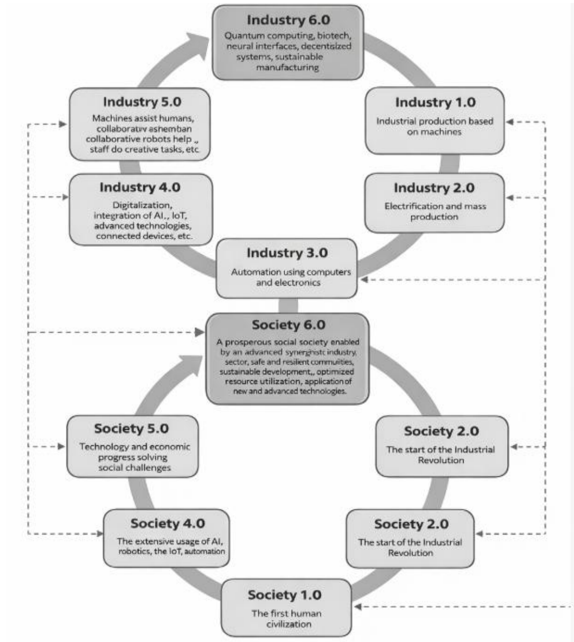


Figure 1. Evolution of Industry 1.0–6.0 shows how social growth (Society 1.0–6.0) and industrial change are more aligned [1].

## II. REVIEW METHODOLOGY

This study examines recent scholarly research on Industry 6.0 and its predecessor industrial paradigms using a qualitative literature synthesis technique. Based on their significance to digital transformation, human-centric manufacturing, sustainability, and Industry 6.0, twenty-three peer-reviewed journal publications, conference papers, and reputable review studies published between 2020 and 2025 were chosen. The chosen literature was categorised into five main areas after thematic analysis: the evolution of the industrial paradigm; enabling and emerging digital technologies; human-centric and ergonomic aspects; sustainability and integration of the circular economy; and management, social, and policy implications. This theme framework facilitates a methodical synthesis of many viewpoints and emphasises how previous research as a whole advances our knowledge of Industry 6.0.

Table-1 Technology-Focused Studies

| Ref. | Paper Title | Category | Core Focus | Scope |
|---|---|---|---|---|
| [2] | Industry 6.0: Vision, technical landscape, and opportunities | Technology | Presents a detailed technical roadmap of Industry 6.0. It includes AI, CPS, blockchain, and improved networking technologies. | Industry 6.0 system reference architectures and interoperability standards. |
| [4] | Generative AI and swarm robotics for Industry 6.0 | Technology | Enables decentralised, adaptable production environments by introducing heterogeneous robotic swarms and generative AI. | Autonomous swarms' scalability, coordination systems, and safety assurance. |
| [6] | Theoretical foundations of Industry 6.0 control | Technology | Uses clever digital twins to propose decentralised AI-driven production control. | large-scale industrial implementation and performance evaluation. |
| [8] | Cyber-physical systems review | Technology | Examines the control techniques and CPS architectures that are the basis of smart manufacturing systems. | CPS is evolving towards sustainable, human-centred Industry 6.0 systems. |
| [14] | Deep generative digital twins | Technology / Sustainability | Uses digital twins with unsupervised deep learning for energy management and predictive monitoring. | Real-time industrial deployment and explainable AI integration |
| [20] | Blockchain, IoT, and AI integration | Technology / Sustainability | Focuses on data security, trust, and transparency in Industry 6.0 environments. | Safe designs that are both scalable and interoperable. |

Table 2: Human Factors and Human–AI Collaboration

| Ref. | Paper Title | Category | Core Focus | Scope |
|---|---|---|---|---|
| [1] | Human-centred and sustainable AI in Industry 5.0 | Human-Factors / Sustainability | Examines human-centred, ethical, and transparent AI foundations while emphasising societal responsibility and trust. | Quantitative measures for large-scale industrial validation and ethical AI. |
| [7] | Human-centric digital twins | Human-Factors / Sustainability | Incorporates human interaction, behaviour, and thought processes into digital twin models. | standardised digital twin architectures with a person in the loop. |
| [13] | Human–AI interaction research agenda | Human Factors / Policy | Outlines the main obstacles to secure, comprehensible, and reliable human-AI systems. | Usability standards and legal frameworks. |
| [15] | Ergonomic and human factors in manufacturing | Human Factors | Examines ergonomics as a factor in sustainability, safety, and productivity. | AI-powered ergonomic monitoring and evaluation systems. |
| [16] | Human factors in sustainable manufacturing | Human Factors / Sustainability | Links ergonomics to worker well-being, sustainability, and system reliability. | Quantitative performance indicators with an emphasis on individuals. |
| [18] | From automation to collaboration | Human Factors | Examines the shift to human-machine cooperation. | Examines the shift to collaborative human-long-term workforce adaptability and skill transformation research systems of robots. |
| [22] | Human-centric and resilient manufacturing | Human Factors / Sustainability | Emphasises human welfare, flexibility, and resilience in production systems. | Models for measuring and validating resilience. |
| [23] | Human–technology interaction in Industry 6.0 | Human Factors / Social | investigates transdisciplinary cooperation between humans and technology in Industry 6.0 settings. | Investigates multidisciplinary human-technology cooperation in Industry 6.0 settings. |

Table 3: Sustainability and Circular Economy

| Ref. | Paper Title | Category | Core Focus | Scope |
|---|---|---|---|---|
| [5] | AI-driven transformations in manufacturing | Sustainability / Technology | Focusses on sustainable value chains while examining AI-enabled changes in Industry 4.0–6.0. | Frameworks for implementing the circular economy powered by AI |
| [9] | AEC practices in Industry 6.0 | Management/ Sustainability | Applies the concepts of Industry 6.0 to the built environment and construction. | Confirmation of cross-sector sustainability and alignment of policies. |
| [7] | Digital transformation and leadership | Management/ Sustainability | Demonstrates how company culture and leadership may support long-term success. | Transitions to Industry 6.0 are supported by leadership models. |
| [21] | Sustainable smart manufacturing beyond 5.0 | Sustainability / Technology | Examines clever and energy-efficient manufacturing methods. | Validation of carbon-neutral and net-zero manufacturing. |

Table 4: Management and Organisational Perspectives

| Ref. | Paper Title | Category | Core Focus | Scope |
|---|---|---|---|---|
| [3] | Industry 6.0 as an emerging research field | Management / Bibliometric | Gives bibliometric proof that Industry 6.0 is an interdisciplinary field of study. | longitudinal evaluations and empirical case studies |
| [10] | AI-driven digital twins for manufacturing | Technology / Management | Demonstrates the use of digital twins as instruments for strategic decision support. | Integration with systems for making business decisions. |
| [11] | From Industry 4.0 to Industry 6.0 | Management | Utilises management fashion theory to analyse paradigm changes. | Studies on organisational adoption dynamics and resistance. |
| [12] | Marketing management theory 6.0 | Management / Social | Extends the Industry 6.0 concept to value generation and customer interaction. | Industry-specific empirical validation of Marketing 6.0. |

Table 5: Social, Policy, and Governance Perspectives

| Ref. | Paper Title | Category | Core Focus | Scope |
|---|---|---|---|---|
| [19] | Industry 6.0 and Society 6.0 | Social / Policy | Relates the advancement of industry to inclusion and societal well-being. | Frameworks for Industry 6.0 governance that are driven by policy. |

## III. EVOLUTION FROM INDUSTRY 4.0 TO INDUSTRY 6.0

The shift from exclusively automation-driven efficiency to human-centric, sustainable, and value-oriented systems is reflected in the transition from Industry 4.0 to Industry 6.0. Digitalisation, connection, and increasing productivity through intelligent and automated technology were the primary focus of Industry 4.0. Industry 5.0 restored the value of human participation in industrial processes by introducing human–machine collaboration and system resilience to offset the drawbacks of over-automation [2][5]. Building on these advancements, Industry 6.0

offers a holistic socio-technical paradigm that incorporates cognitive intelligence, decentralised control, sustainability-by-design, and ethical artificial intelligence. This strategy seeks to bring technical development into line with social responsibility, human values, and long-term sustainability standards [11][19].

A: Industry 4.0: Smart, Connected, and Data-Driven Manufacturing

The integration of cloud computing, data analytics, cyber-physical systems, and the Industrial Internet of Things to enable intelligent, connected, and data-driven production settings is what defines the fourth industrial revolution, or Industry 4.0. Through autonomous control, real-time system monitoring, and machine-to-machine communication, its main goal is to increase operational efficiency, flexibility, and productivity. Applications like predictive maintenance and digital twins have been extensively documented in the literature [8][10]. Furthermore, through real-time data integration and analytics, Industry 4.0 has made it possible to optimise supply chain coordination [11]. However, a number of studies point out that Industry 4.0 places a high priority on technology optimisation, frequently disregarding sustainability and ethical considerations as secondary goals and placing human operators as passive supervisors [18]. Calls for more human-centric and value-oriented industrial paradigms beyond Industry 4.0 have grown as a result of these constraints [21].

B: Industry 5.0: Human-Centric and Collaborative Manufacturing

As a result of Industry 4.0's emphasis on technology, Industry 5.0 emerged, redefining individuals as vital components of sophisticated industrial systems. Industry 5.0, which integrates computational intelligence with human creativity, experience, and ethical judgement to enhance personalisation, resilience, and worker well-being, emphasises tight human–machine collaboration rather than replacing human labour [1][15]. In addition to improving trust, autonomy, and worker happiness, enabling technologies, including collaborative robots, human-aware and explainable AI, adaptive human–machine interfaces, and ergonomic workplace design, contribute to safer, more inclusive, and flexible production environments [13][18]. Furthermore, Industry 5.0 promotes sustainability through tackling environmental consciousness, workforce inclusiveness, and social responsibility [15]. Large-scale autonomy and system-level cognition are, however, constrained by their reliance on shop-floor-level intelligence and mostly centralised control structures [2][11]. The shift to Industry 6.0, a more decentralised, cognitively sophisticated, and sustainability-governed paradigm, is driven by these limitations [16].

C: Industry 6.0: Cognitive, Decentralised, and Sustainable Manufacturing

Industry 6.0 is a next-generation industrial paradigm that integrates cognitive intelligence, autonomous decision-making, and sustainability-by-design, going beyond the digital automation of Industry 4.0 and the human-centric collaboration highlighted in Industry 5.0. Industry 6.0 offers decentralised, self-learning, and robust manufacturing ecosystems through the integration of intelligent digital twins, cyber-physical intelligence, swarm robotics, generative artificial intelligence, and blockchain-based trust mechanisms [2][4]. In order to support adaptive and context-aware production processes, intelligence is dispersed among machines, digital entities, and human actors [6][9]. System design incorporates social, ethical, and environmental considerations. Predictive analytics, zero-defect manufacturing, and resource-efficient production that is in line with the circular economy and ESG-compliant governance frameworks are further made possible by artificial intelligence [1][5]. Additionally, explainable AI and human digital twins facilitate co-intelligent human involvement, establishing Industry 6.0 as a basis for socially conscious and inclusive industrial development in line with Society 6.0 [7][19]. This alignment is further reinforced by socio-technical integration and human-centric resilience [22][23].

## IV. ENABLING TECHNOLOGIES FOR INDUSTRY 6.0

One characteristic of Industry 6.0 is the clear incorporation of social, ethical, and environmental values into the design of industrial systems. Predictive analytics, zero-defect manufacturing, mass customisation, and resource-efficient production are all made possible by artificial intelligence, which also supports circular economy practices and governance frameworks that are in line with ESG and CSRD [1][5]. Workers engage with cognitive systems through decentralised decision-making, explainable AI, and human digital twins in an evolving co-intelligent human participation model [7][13]. By facilitating sustainable and socially conscious economic growth, this human-machine symbiosis closely synchronises Industry 6.0 with the overarching goal of Society 6.0 [19][22].

A: Artificial Intelligence and Machine Learning:
Artificial intelligence (AI) and machine learning (ML) power Industry 6.0's cognitive underpinnings, facilitating autonomous perception, ongoing learning, and adaptive decision-making across production systems. Industry 6.0 uses self-learning and generative AI models capable of autonomous planning, real-time reconfiguration, and intelligent resource allocation in highly customised environments, in contrast to Industry 4.0, when AI mainly supported monitoring, prediction, and optimisation [2][14]. By optimising energy use, material efficiency, waste reduction, and circular economy practices across value chains, AI also supports sustainability [5][21]. One characteristic of Industry 6.0 is its ethical and human-centred approach, where AI supports human decision-making through transparent and explicable processes under constant human supervision, especially in situations where sustainability and safety are crucial [1][13]. As a result, AI in Industry 6.0 operates in socio-technical production environments as a responsible and cooperative agent [5][22].

B: Cyber-Physical Systems and Industrial Internet of Things (IIoT):
The fundamental technical underpinnings of Industry 6.0 are the Industrial Internet of Things (IIoT) and Cyber-Physical Systems (CPS), which combine computational intelligence, communication networks, and physical industrial assets. Whereas CPS facilitates real-time sensing, control, and autonomous machine interaction, IIoT allows for constant data interchange and extensive connection throughout industrial and supply-chain ecosystems [8].CPS designs transition from centralised control to decentralised, AI-enabled systems in Industry 6.0, enabling context-aware and localised decision-making that improves fault tolerance, scalability, and resilience [6][10]. In order to enable human-centric and ecologically responsible production, recent studies further highlight the direct integration of human input, safety limitations, and sustainability objectives into CPS control logic [19][21].

C: Digital Twins and Human Digital Twins:
Through real-time data interchange, digital twins (DTs) are virtual representations of physical assets and processes that stay in constant sync with actual systems. Predictive maintenance, fault diagnosis, scenario analysis, and lifecycle optimisation within decentralised manufacturing systems are made possible by AI-enabled digital twins in Industry 6.0, which transform from monitoring tools into intelligent entities capable of simulation, prediction, and autonomous decision support [6][10]. Adaptive intelligence and self-learning skills are further improved by sophisticated generative and cognitive digital twin models [14]. The creation of Human Digital Twins (HDTs), which mimic human physical, cognitive, and behavioural characteristics, including ergonomics, workload, and physiological states, is a significant advancement that promotes safe and flexible human–machine cooperation [7][15]. The human-centric and sustainable vision of Industry 6.0 [1][22] is further reinforced by collaborative and sustainable industrial frameworks [18].

D: Distributed Computing (Edge, Fog, Cloud):
Distributed computing architectures that include edge, fog, and cloud layers allow decentralised intelligence in Industry 6.0. Near cyber-physical systems, sensors, and robotics, edge computing facilitates real-time control, low-latency processing, and privacy-sensitive activities [2][8]. While cloud platforms provide for large-scale data storage and long-term learning capabilities, fog computing offers localised coordination, analytics, and workload management [6][10]. This layered computing paradigm improves system scalability, robustness, and operational flexibility through federated learning, adaptive work distribution, and closer interaction with AI-driven digital twins and CPS [4][14]. Consequently, Industry 6.0 production systems perform better in terms of sustainability, energy efficiency, and resilience.

E: Advanced Robotics and Additive Manufacturing:
Flexible, adaptable, and human-collaborative production systems are made possible by sophisticated robots and additive manufacturing in Industry 6.0. In

addition to lowering physical workload and enhancing productivity and operational safety, robotic swarms, autonomous mobile robots, and collaborative robots provide safe human–machine interaction, decentralised task execution, and dynamic system reconfiguration [4][18]. By facilitating quick prototyping, localised and customised production, and material-efficient construction, additive manufacturing enhances these capabilities and supports sustainability and circular economy goals [5][21]. The combination of robots, additive manufacturing, and AI-driven design improves overall system resilience, production agility, and innovation potential in highly dynamic industrial settings [22].

### F: Blockchain, Cybersecurity, and Trust Technologies:

Blockchain and cutting-edge cybersecurity technologies are essential for building trust, transparency, and system security in decentralised and data-intensive Industry 6.0 ecosystems [20]. Blockchain's immutable records, safe data interchange, and end-to-end traceability across intricate value chains make ethical AI governance, sustainability reporting, and regulatory compliance possible [2][19]. Trust-enabling technologies boost alignment with ESG and CSRD standards while improving accountability, coordination, and cybersecurity when combined with AI, IIoT, and digital twins [3][11][13].

## V. HUMAN – CENTRIC AND ERGONOMIC CONSIDERATIONS

Human-centricity is a defining principle of Industry 6.0, distinguishing it from earlier efficiency- and automation-focused paradigms. Within AI-driven and cyber-physical systems, humans are regarded as active collaborators, supervisors, and ethical decision-makers. Successful implementation requires the integration of human factors, ergonomics, trust, and cognitive support into system design and governance frameworks [1], [15]. These requirements are further reinforced by sustainability-oriented and resilient manufacturing perspectives emphasised in recent studies [18][22][23].

### A: Human–AI Collaboration and Interaction

Collaboration between humans and AI, where intelligent technologies enhance rather than replace human skills, is what defines Industry 6.0. In safety-critical settings, trust and influence depend on transparency, explainability, flexibility, and intuitive engagement [1][13]. In sophisticated industrial contexts, bidirectional learning improves productivity, safety, and system resilience by allowing people to oversee AI while systems adjust to human preferences [18][22].

### B: Ergonomics and Workplace Design

An essential component of Industry 6.0, ergonomics has a direct impact on the long-term comfort, safety, and well-being of employees. System dependability is decreased by poor ergonomic design, which increases physical strain, cognitive overload, and human mistakes [15][16]. With the use of AI, sensors, and human-centred digital twins, Industry 6.0 facilitates proactive, data-driven ergonomic optimisation. This allows for ongoing workstation monitoring and adaptive modification to improve sustainability and productivity [7][14] and [21].

### C: Trust, Transparency, and Explainability

The adoption of human-centric Industry 6.0 relies strongly on trust in intelligent systems, where transparency, explainability, and predictable behaviour are critical for effective human–AI collaboration [1][13]. Explainable AI is particularly important in safety-critical and ethical contexts to bridge human understanding of algorithmic decisions [14][19]. Beyond transparency, trust also depends on robust data governance, cybersecurity, accountability, and ethical oversight, supported through supervision, traceability, and auditability mechanisms [20][23].

### D: Cognitive Load and Skill Transformation

Industry 6.0 shifts work from labour-intensive tasks to cognitively demanding interaction with AI systems, digital twins, and autonomous platforms, increasing cognitive load despite efficiency gains. This calls for context-aware decision assistance that is in line with human cognition and user-friendly interfaces [7][13]. Rapid worker skill change is therefore necessary, with a focus on digital literacy, AI supervision, and multidisciplinary capabilities through ongoing, human-centred reskilling programs [11][18]and [22].

E: Human-Centric Resilience and Well-Being

Human-centric resilience in Industry 6.0 refers to the capacity of industrial systems to endure disturbances while preserving both human welfare and operational continuity. Systems that incorporate participatory decision-making and human adaptability are more resilient to shocks and failures [22][19]. Industry 6.0 enhances adaptive resilience by integrating ethical reasoning and human judgement into decentralised control [6][14]. Furthermore, it is becoming more widely acknowledged that worker safety, mental health, and well-being are important factors that affect sustainability and productivity [15][16] and [21].

## VI.SUSTAINABILITY AND CIRCULAR ECONOMY INTEGRATION

Sustainability is no longer a secondary goal but rather a fundamental design element in Industry 6.0, where environmental, economic, and social sustainability are directly integrated into system architecture, operational control, and decision-making. Industry 6.0 incorporates intelligent, data-driven, and human-centric manufacturing to promote long-term resilience, in contrast to previous paradigms that relied on end-of-pipe solutions [5][17]. Through real-time energy optimisation, predictive maintenance, waste reduction, and lifecycle evaluation, artificial intelligence and digital twins provide proactive sustainability management [6][10]. Digital traceability, decentralised production, and sophisticated manufacturing technologies further promote closed-loop material flows, remanufacturing, and product life extension [4][9]. Industry 6.0 is positioned as a robust, regenerative, and socially conscious industrial framework by virtue of these features [1][11].

## VII. MANAGEMENT AND POLICY IMPLICATIONS

Industry 6.0 is a fundamental shift in industrial management and governance that goes beyond technology development to incorporate ethical responsibilities, environmental objectives, and human-centric values into decision-making processes. By matching intelligent technology with organisational and societal goals, it prioritises long-term value generation in contrast to efficiency-driven paradigms [3][11]. According to the research, there is a move toward decentralised and adaptive governance that is backed by AI-driven analytics and digital twins. This calls for new leadership skills, learning-oriented cultures, and productive human–AI collaboration [6][14]. At the policy level, Industry 6.0 presents important questions about cybersecurity, data governance, and ethical AI, necessitating adaptable and reliable regulatory frameworks [1] [13]. The necessity of sustainability-focused and ESG-aligned policy initiatives within Industry 6.0 ecosystems is further highlighted by the close connection between industrial transformation and social well-being [5][19].

## VIII. RESEARCH GAPS AND FUTURE DIRECTIONS

Large-scale Industry 6.0 deployment is still constrained by substantial research gaps, despite growing conceptual maturity. The majority of research is conceptual or simulation-based, and there is currently a dearth of empirical and longitudinal validation of AI-, digital twin-, and decentralised control systems in actual production contexts [1][3]. There is a dearth of standardised criteria for evaluating human-AI collaboration, ergonomics, worker well-being, and trust [7][15]. Although ethical AI and explainability are widely acknowledged as essential, practical governance and compliance frameworks remain immature [13][19]. There are still issues with interoperability in distributed computing, digital twins, AI, and CPS [2][10]. Additionally, there is also a dearth of empirical data in favour of workforce reskilling, sustainability-by-design, and flexible policy frameworks that comply with CSRD and ESG regulations [11][18].

| Research Dimension | Identified Research Gap | Evidence from Literature | Scope |
|---|---|---|---|
| Empirical Validation | Most research has limited practical relevance and is conceptual, exploratory, and simulation-based. | Lack of significant deployments across industrial sectors and long-term case studies | Long-term evaluations, comparative industry case studies, and pilot projects for Industry 6.0 architecture [1][3][6] |
| Human-Centric Performance Metrics | Lack of quantifiable and defined metrics for human-centricity. | Dependency on qualitative or fragmented measures of collaboration, trust, and well-being | creation of unified human-centric KPIs that incorporate resilience, skill adaptability, cognitive burden, and trust in AI [7][13][15][16][18][22]. |
| Ethical AI and Governance | Ethical and explainable AI is largely discussed at a conceptual level. | Restricted operational models for ethical reasoning, responsibility, and explainability | Restricted operational models for ethical reasoning, responsibility, and explainability |
| Technology Integration and Interoperability | Disjointed research on enabling technologies without comprehensive integration | Insufficient knowledge about the coordinated implementation of distributed computing, blockchain, digital twins, AI, and CPS | Creating interoperable reference architectures and assessing cybersecurity risks, fault tolerance, and resilience [2][4][8][10][14][20] |
| Workforce Transformation and Skills | Inadequate empirical data on training and reskilling approaches that work. | The majority of discussions about skill development and workforce adaptability are conceptual. | Research on human digital twins, AI-supported training platforms, and adaptive learning systems for skill improvement [11][18][22] |
| Sustainability and Circular Economy | Sustainability-by-design promises are only partially validated. | There are a few quantifiable connections between observable environmental effects, circular flows, and AI optimisation. | Validation of circular economy plans throughout value chains and integration of lifecycle evaluation with real-time digital twins [5][17][21] |
| Policy and Governance | Early-stage and dispersed policy studies | Absence of specific regulatory frameworks for decentralised AI-powered industrial systems | Comparative and long-term policy research on cross-sector cooperation, public-private governance, and adaptive regulation [19, 23] |

## IX. CONCLUSION

This paper traces the history from Industry 1.0 to Industry 6.0, highlighting a paradigm change from automation-centric production toward human-centric, sustainable, and ethically controlled industrial systems [1][23]. According to the research, Industry 6.0 is a socio-technical framework that combines digital twins, artificial intelligence, decentralised intelligence, and human-machine cooperation to create industrial ecosystems that are sustainable and resilient [2][5]. The literature continuously highlights sustainability, human considerations, and governance as fundamental design principles [15][18] even while technologies like AI, cyber-physical systems, sophisticated robotics, distributed computing, and blockchain offer the technological underpinning [4][14]. The necessity for transdisciplinary and longitudinal research is underscored by persistent gaps in empirical validation, ethical AI implementation, interoperability, workforce transformation, and policy alignment [3][11]and [19].

## REFERENCES


[1] B. Martini, D. Bellisario, and P. Coletti, “Human-centred and sustainable artificial intelligence in Industry 5.0: Challenges and perspectives,” Sustainability, 2023.

[2] A. Verma, V. K. Prasad, A. Kumari, P. Bhattacharya, G. Srivastava, K. Fang, W. Wang, and T. R. Gadekallu, “Industry 6.0: Vision, technical landscape, and opportunities,” IEEE Access, 2023.

[3] M. M. Roshid, A. Waaje, and R. Karim, “Industry 6.0 as an emerging research field: A systematic and bibliometric analysis,” in Proc. Int. Conf. on Industry 6.0, Turkey, 2025.

[4] A. Lykov, M. Altamirano Cabrera, M. Konenkov, V. Serpiva, K. F. Gbagbe, A. Alabbas, A. Fedoseev, L. Moreno, M. H. Khan, Z. Guo, and D. Tsetserukou, “Industry 6.0: New generation of industry driven by generative AI and swarm of heterogeneous robots,” Robotics and Computer-Integrated Manufacturing, 2024.

[5] A. Fernández-Miguel, F. E. García-Muiña, S. Ortíz-Marcos, M. Jiménez-Calzado, A. P. Fernández del Hoyo, and D. Settembre-Blundo, “AI-driven transformations in manufacturing: Bridging Industry 4.0, 5.0, and 6.0 in sustainable value chains,” Sustainability,2023.

[6] A. Fernández-Miguel, S. Ortíz-Marcos, M. Jiménez-Calzado, A. P. Fernández del Hoyo, F. E. García-Muiña, and D. Settembre-Blundo, “Toward the theoretical foundations of Industry 6.0: A framework for AI-driven decentralised manufacturing control,” Applied Sciences,2023.

[7] M. Krupaš, E. Kajáti, C. Liu, and I. Zolotová, “Towards a human-centric digital twin for human–machine collaboration,” Sensors, 2023.
[8] S. J. Oks et al., “Cyber-physical systems in the context of Industry 4.0: A review,” IEEE Access, 2020.
[9] A. Almusaed, I. Yitmen, and A. Almssad, “Reviewing and integrating AEC practices into Industry 6.0,” Preprints, Aug. 2023.
[10] P. Uhlemann, C. Lehmann, and R. Steinhilper, “AI-driven digital twins for manufacturing,” Computers in Industry,2023.
[11] S. Heusinkveld, J. Benders, and R. van den Berg, “From Industry 4.0 to Industry 6.0,” Technological Forecasting and Social Change,2023.
[12] P. Kotler, H. Kartajaya, and I. Setiawan, “New marketing management theory 6.0,” Journal of Business Research,2023.
[13] J. M. Carroll, A. Hussain, and E. L. Fong, “Human–AI interaction research agenda,” ACM Computing Surveys, 2023.
[14] E. G. Kaigom, “Deep generative and discriminative digital twin for Industry 6.0,” IEEE Access, 2023.
[15] B. Hasanain, “The role of ergonomic and human factors in sustainable manufacturing,” Journal of Manufacturing Systems, 2023.
[16] V. Firescu and D. Filip, “Human factors and ergonomics in sustainable manufacturing systems,” Sustainability, 2023.
[17] M. Asif, L. Yang, and M. Hashim, “Digital transformation and leadership in manufacturing,” Sustainability, 2022.
[18] M. A. Shabur, A. Shahriar, and M. A. Ara, “From automation to collaboration,” Journal of Cleaner Production, 2023.
[19] M. Dixit and U. Shanker, “Industry 6.0 and Society 6.0,” Journal of Industrial Information Integration,2023.
[20] A. Singh, S. Goyat, and A. Panwar, “Blockchain, IoT, and AI integration for Industry 6.0,” Future Internet, 2023.
[21] Y. Kim, “Sustainable smart manufacturing technologies beyond Industry 5.0,” Journal of Manufacturing Processes, 2022.
[22] A. Alves, R. Pereira, and J. Santos, “Human-centric and resilient manufacturing systems,” Journal of Cleaner Production, 2024.
[23] A. Almusaed, I. Yitmen, and A. Almssad, “AEC–human–technology interaction in Industry 6.0 environments,” Preprints, 2023.