CHAPTER 29

Effect of Generative AI In Industry 5.0 And Its Opportunities and Ethical Challenges

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ABSTRACT

Industry 5.0 represents the wave of upcoming changes in how factories are operating in this industry and focuses on collaborative work between machines and humans, personalized content like Ads, campaigns etc., and sustainable innovation in this transformation and change. Generative AI is an emerging technology. This paper looks at the impact that generative AI has on Industry 5.0 and how it can create opportunities for acceleration in adopting Industry 5.0 through smarter product design and accurate predictive maintenance while also studying its impact on customer experiences with the rise of personalized content. With the recent developments in the large language models (LLMs), the study shows the disruptive potential of GenAI when working with human creativity. At the same time, this paper also looks at the social and ethical challenges that come along with this change, such as concerns about data security, ownership of intellectual property, unfair biases in AI, job loss, and accountability in AI-driven decisions. This research analysis indicates that GenAI has the power to drive both sustainable and human-focused innovation for Industry 5.0, but it also brings out some difficult ethical questions.

Keywords: Generative AI; Opportunities; Challenges; Industry 5.0.

1.0 Introduction

Since Industrial Revolution, the industries have undergone constant change, constantly changing from machines to digitalization and innovation in industry 4.0. However, a new change in industry known as Industry 5.0 is emerging as the boundaries of efficiency driven by technology become apparent. Instead of replacing human capabilities, Industry 5.0 emphasizes human-centricity, sustainability, and resilience.

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DOI: 10.17492/JPI/ICISI2025/251229 *ISBN: 978-93-49790-69-8*

This contrasts with its predecessor, which placed more emphasis on automation and connectivity. In this new Industry Generative AI is an emerging technology which also helps shaping this industry. Collaborative robots, customized manufacturing, and ecologically conscious methods that put employee welfare first are important characteristics. Industry 5.0 and GenAI come together to produce a very good collaborative bond. By making personalized production of things to attract and increase customers satisfaction, sustainable innovation, and user-friendly human–machine collaborations, GenAI advances Industry 5.0 goals. It positions itself as a way to facilitate of human-centric manufacturing by making various repetitive tasks easy and automated while it also helps in creative tasks like generative design, predictive maintenance, and customized customer experiences. But there are advantages and disadvantages to this change. Although GenAI can boost efficiency, creativity, and teamwork, it also brings up issues with bias, data privacy, intellectual property, and workforce disruption. This study contributes by analyzing GenAI role in industry 5.0 and highlighting its potential, opportunities and associated challenges to this technology.

2.0 Review of Literature

Conceptual Background of Industry 5.0 and its goals along with the Integration of Generative AI in overcoming Industry 4.0's automation-centric approach, Generative Artificial Intelligence (GenAI) and Industry 5.0 represent a shift in how industries are working now making the way for a resilient and sustainable, and human-centric industrial ecosystem. This review of the literature looks at what is currently known about GenAI's contribution to Industry 5.0 transformation, while also providing information on the opportunities and problems that arise from this technological shift. The limitations of technology-driven industrial approaches with the focus on humans give rise to Industry 5.0, which emphasizes technological collaboration rather than the replacement of human capabilities (Mohammed & Skibniewski, 2023). Industry 5.0 is defined by three key pillars: human-centricity, sustainability, and resilience, in contrast to Industry 4.0's emphasis on automation and efficiency (Sai *et al.*, 2025). This change exemplifies the "Techno-Social Revolution," as defined by (Mohammed and Skibniewski 2023), in which economic growth goals are upheld while technological advancement promotes human welfare.

Using new technologies to provide prosperity beyond traditional job creation while respecting planetary boundaries, Industry 5.0 places workers' well-being at the center of production processes (Kamat, 2025). By focusing on collaborative robots (cobots), which operate alongside humans as guides and assistants rather than autonomous replacement systems, this human-centric approach sets Industry 5.0 apart from its predecessor

DOI: 10.17492/JPI/ICISI2025/251229 *ISBN: 978-93-49790-69-8*

(Mohammed & Skibniewski, 2023). The capabilities of artificial intelligence have advanced significantly with generative AI, which goes beyond conventional pattern recognition and decision-making to facilitate the creation of original content and creative problem-solving (Iqbal *et al.*, 2024). The technology comprises different architectures such as diffusion models, Transformer-based models, Variational Autoencoders (VAEs), and Generative Adversarial Networks (GANs), each of which has distinct capabilities for producing new content in a variety of domains (Şahin & Karayel, 2024).

Recent advancements in large language models (LLMs) have shown impressive abilities to comprehend context, produce responses that resemble those of a human, and assist with challenging problem-solving tasks (Kusetogullari *et al.*, 2024). The market estimates show that the global GenAI market in manufacturing is projected to reach around $6.4 billion by 2032, growing at a compound annual growth rate of 41.0%, demonstrating the rapid growth of GenAI applications (Sai *et al.*, 2025).

Industry 5.0's incorporation of GenAI offers significant potential for value generation in a number of areas. Process automation, content creation, decision-making optimization, and supply chain process improvement are some of the primary value creation mechanisms identified by Prado and Mantovani (2025). While promoting sustainable innovation practices, these capabilities help organizations attain greater productivity, improved creativity, and better knowledge management.

GenAI's uses in manufacturing also include predictive maintenance, where AI programs examine sensor data to find trends and abnormalities that allow for proactive maintenance planning and reduce equipment downtime (Sai *et al.*, 2025). According to Iqbal *et al.* (2024), generative design tools enable engineers to experiment with various design iterations in product design and development, based on particular constraints. This yields optimal solutions that strike a balance between functionality, aesthetics, and manufacturability.

Through three different perspectives—the proxy view (AI as a replacement for human tasks), the tool view (AI as an enhancement of human capabilities), and the ensemble view (AI as a component of integrated systems)—Marvi *et al.* (2025) highlight the role of GenAI in improving organizational capabilities. This development shows how GenAI has advanced from basic automation to intricate collaborative systems that support the human-centric tenets of Industry 5.0.

Despite its revolutionary potential, integrating GenAI into Industry 5.0 comes with a number of difficulties that need to be carefully considered. Jain *et al.* (2024) list several risk categories, such as data poisoning, adversarial attacks, privacy threats, and vulnerabilities in AI models. These security issues are especially important in industrial settings where data integrity and system dependability are crucial.

DOI: 10.17492/JPI/ICISI2025/251229 *ISBN: 978-93-49790-69-8*

The deployment of GenAI raises a number of difficult ethical issues pertaining to transparency, accountability, and bias reduction. According to Jesse *et al.* (2024), thorough governance frameworks that address algorithmic bias, data privacy, and the openness of AI decision-making processes are necessary for the responsible deployment of AI. The difficulty is increased by the requirement to preserve competitive advantages while striking a balance between innovation and morality.

Several research gaps that need to be addressed are revealed by the current literature. Studies on the long-term effects of integrating GenAI in manufacturing settings are very low, especially when it comes to worker well-being and sustainability results. The creation of standardized metrics for measuring GenAI's contribution to Industry 5.0 goals and sector-specific implementation strategies also require further study.

Comprehensive frameworks that address the complexity of implementing GenAI across various organizational contexts and industrial sectors are also needed, according to the literature. Future studies should concentrate on creating workable rules for the responsible application of GenAI that strike a balance between creativity, morality, and the well-being of people.

3.0 Relevance of the Study

Manufacturing's quick transition to Industry 5.0 marks a turning point in industrial history, moving the emphasis from total automation to a framework that is resilient, sustainable, and human-centered (Mohammed & Skibniewski, 2023). New technologies that enhance human creativity, enhance personalization, and promote environmental stewardship are necessary for this human-machine collaboration model. With its distinctive capabilities for content creation, predictive analytics, and self-governing decision-making, generative artificial intelligence (GenAI) has become a disruptive technology that is perfectly suited to support the main goals of Industry 5.0.

However, little is known about how GenAI can be integrated with Industry 5.0 principles, despite its obvious potential to revolutionize product design, speed up predictive maintenance, and facilitate individualized customer interactions. Without providing a comprehensive understanding of how GenAI can propel the human-centric, sustainable innovation that characterizes Industry 5.0, the literature currently in publication primarily discusses discrete applications, such as generative design in manufacturing (Iqbal *et al.*, 2024) or security threats in AI systems (Jain *et al.*, 2024). Extensive systematic reviews demonstrate the strategic value of GenAI across industries (Şahin & Karayel, 2024; Prado & Mantovani, 2025), but there is a significant knowledge gap about all the influence of organizational, technological, and ethical aspects required for responsible GenAI

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deployment in Industry 5.0 settings. Both academia and industry can benefit from this study. It fills a glaring gap in the cross-disciplinary literature by providing academics with an organized framework that combines GenAI technologies with Industry 5.0 principles. It provides practitioners with practical advice on how to use GenAI to improve customer experiences, precise predictive maintenance, and smarter product design—all the while navigating organizational, legal, and ethical challenges. In doing so, this research helps companies create human-centered, sustainable, and resilient industrial systems that can prosper in the face of swift technological change.

This study adds to the strategic knowledge required to responsibly harness the disruptive potential of GenAI by bridging technological capabilities with human values. This ensures that Industry 5.0's promise of a sustainable, collaborative future is realized.

4.0 Objectives

This study focuses to investigate the integration of Generative Artificial Intelligence (GenAI) and its applications the Industry 5.0, focusing on both aspects of its transformative potential and inherent challenges. The specific objectives are:

1. To examine how GenAI technologies such as generative design, predictive maintenance, and large language models can accelerate the adoption of Industry 5.0 by enhancing human–machine collaboration
2. To identify and analyze the key opportunities presented by GenAI applications across multiple industrial domains, including manufacturing, project management.
3. To assess the critical challenges associated with GenAI deployment in Industry 5.0 contexts, including data security risks, intellectual property concerns, algorithmic bias, and potential workforce displacement.

5.0 Research Methodology

This study investigates the incorporation of Generative AI (GenAI) within the Industry 5.0 framework using a mixed-methods approach based on a systematic literature review and qualitative synthesis. Two essential steps make up the methodology, which draws from twelve primary sources:

1. Systematic Literature Review: We conducted a comprehensive review of peer-reviewed articles, industry reports, and doctoral theses mentioned in the references part of the document. Databases searched include IEEE Xplore, ScienceDirect, and Google Scholar, using keywords such as "Industry 5.0," "generative AI," "predictive maintenance," and "human-centric manufacturing." Inclusion criteria required studies

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published between 2023 and 2025 that addressed GenAI applications, Industry 5.0 principles, or ethical challenges (Sai *et al.*, 2025; Kamat, 2025).

2. Data Extraction: From the selected literature, we extracted data on GenAI capabilities, organizational benefits, and identified risks. Categorized insights into three domains: human–machine collaboration, customer personalization, and ethical governance. By combining systematic review, thematic analysis, and case study methodologies, this research provides a comprehensive data on foundation for responsible GenAI integration within Industry 5.0.

6.0 Key Findings

The journey toward Industry 5.0 is reshaping factories into places where humans and machines work side by side, each playing to their strengths. While Industry 4.0 focused on automation and efficiency, Industry 5.0 places people back at the center of production. It envisions a workshop where collaborative robots "cobots" assist skilled craftsmen on assembly lines, and where sustainability guides every decision. Generative AI (GenAI) emerges as a powerful ally in this new era, blending data-driven precision with human creativity to unlock opportunities and, at the same time, presenting challenges that demand thoughtful solutions.

Human–Machine Collaboration - At the core of Industry 5.0 lies teamwork between humans and machines. GenAI gives cobots a shared language—instructions and feedback expressed in natural language—so that a worker can say, "Fine-tune the grip here," and instantly receive adjustments to the cobots motion. This fluid interaction builds trust and breaks down barriers between man and machine (Mohammed & Skibniewski, 2023). Instead of rigid programming, GenAI systems learn from human experts' corrections, continually refining their performance.

Predictive Maintenance and Sustainability - One of GenAI's most prominent and immediate benefits is in prediction of maintenance meaning it can get trained on specific sets to understand and predict future issues that can be generated. Traditional upkeep relies on fixed schedules or reactive repairs after equipment fails. GenAI changes the game by sifting through mountains of sensor data, spotting subtle patterns that foreshadow breakdowns. Maintenance teams receive alerts days or weeks in advance, allowing them to replace parts or recalibrate machinery before production ever slows. This not only cuts costly downtime but also extends equipment lifespan, aligning perfectly with Industry 5.0's emphasis on resource efficiency (Sai *et al.*, 2025).

Smarter Product Design - Innovation are no longer just a human thing and the old way of trial and error. Generative design tools, powered by GenAI, can generate thousands of design variations in the blink of an eye, each optimized for weight, strength, or cost.

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Engineers at companies like Autodesk feed the software their performance requirements—load capacity, material constraints, even aesthetic preferences—and within minutes, a suite of viable prototypes emerges (Iqbal *et al.*, 2024). Humans then step in, selecting and refining the most promising designs.

Personalizing Customer Experiences - Industry 5.0 doesn't stop at the factory gate. GenAI extends its transformative reach into customer engagement, crafting personalized experiences that strengthen brand loyalty. In online retail, for example, generative AI chatbots guide shoppers through complex product lines, answering questions in real time and suggesting items based on individual preferences and past behavior. Customers can even upload photos—of themselves or their living spaces—and see virtual "try-on" previews that mirror real-life fit and style (Penzurov, 2023). This level of interactivity not only boosts satisfaction but also reduces returns, streamlining logistics and cutting costs.

Unfolding Opportunities

1. Accelerated Innovation: The creative power of GenAI makes human inventors free from daily small and repetitive tasks, design tasks, leaving them free to focus on higher-level innovation.
2. Enhanced Agility: With predictive maintenance and real-time production insights, companies can pivot quickly when markets shift or supply chain disruptions arise.
3. Data-Driven Decisions: GenAI transforms raw factory and customer data into actionable insights—spotting trends, predicting demand, and guiding strategy with unprecedented precision.

Confronting the Challenges: No technological advancement can be made without looking at its flaws. GenAI poses serious ethical and operational challenges that must be addressed:

- Data Security and Privacy: GenAI thrives on vast datasets—often containing sensitive customer or operational information. Companies must guard this data against breaches and misuse, implementing strong encryption and strict access controls (Jain *et al.*, 2024).
- Intellectual Property: When an AI system generates designs or content, questions of ownership arise. Clear policies are needed to assign rights and royalties fairly between human creators and AI-driven innovations (Jesse *et al.*, 2024).
- Algorithmic Bias: AI mirrors its training data. If historical records contain biases—against certain demographics or regions—GenAI systems can perpetuate or even amplify those injustices.
- Accountability: When an AI-driven system makes a costly mistake—whether a flawed design or a customer service gaffe—who is responsible? Organizations need governance frameworks that define clear accountability for AI decisions and incorporate human-in-the-loop checks (Smith *et al.*, 2024).

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Towards Responsible Integration: The goal of Industry 5.0 is to collaborate with machines rather than to replace them. If companies also establish a foundation of ethical AI governance and ongoing learning, GenAI can be a useful tool and guide for human-centered, sustainable innovation. The main outcomes of this are human-AI cooperation, industry-related accountability, and empowerment.

By adopting these guidelines, companies can take advantage of GenAI's disruptive potential to bring about a new era of more intelligent product design, robust operations, and enhanced customer experiences—all the while managing the moral dilemmas that accompany such revolutionary change.

7.0 Implications of the Study

This research highlights that Generative AI can truly supercharge Industry 5.0's promise of human-centered, sustainable manufacturing—if it's handled thoughtfully Policymakers and industry leaders must collaborate on clear, agile guidelines that keep pace with GenAI's rapid evolution. These rules should protect data privacy, ensure fair ownership of AI-generated designs, and guard against bias—so that innovation doesn't come at the cost of equity or trust (Jain *et al.*, 2024; Jesse *et al.*, 2024).

On the shop floor, GenAI-driven predictive maintenance can become a game-changer for uptime and efficiency, while AI-powered generative design tools will spark fresh ideas in minutes—saving days or even weeks of prototypes (Iqbal *et al.*, 2024; Sai *et al.*, 2025). The bigger picture is this: GenAI offers a path to more resilient, creative, and eco-friendly production—but only if businesses commit to responsible implementation, continuous learning, and a genuine partnership between humans and machines.

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DOI: 10.17492/JPI/ICISI2025/251229 *ISBN: 978-93-49790-69-8*