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Literature Review on the Role of Mechanical Engineering in Supporting the Industrial Revolution 5.0

Idzani Muttaqin
Universitas Islam Kalimantan MAB Banjarmasin., Indonesia

Email : idzanimuttaqin@gmail.com

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ABSTRACT

The Industrial Revolution 5.0 marks a paradigm shift from full automation to symbiotic collaboration between humans and machines, emphasizing a human-centric approach, sustainability, and the integration of intelligent technologies. In this context, the role of mechanical engineering has undergone a significant transformation, from merely designing mechanical systems to becoming a multidisciplinary bridge between digital technology and human needs. This study aims to review the literature related to the contribution of mechanical engineering in supporting intelligent manufacturing systems, human-machine collaboration, and the application of sustainability principles such as circular economy and eco-design. Using a qualitative literature study method, data were obtained from indexed academic sources in the last decade and analyzed using a thematic approach. The results of the study indicate that mechanical engineering must integrate artificial intelligence, the Internet of Things (IoT), and cyber-physical systems to support adaptive and efficient production. In addition, the development of cobots requires expertise in safety-based and ergonomic design. In terms of the environment, mechanical engineers are required to apply the principles of product life cycle engineering and low-emission technologies. This transformation creates cross-field challenges that require new competencies and a systemic approach. Therefore, a comprehensive literature review is a strategic basis for formulating the direction of adaptive and sustainable mechanical engineering development in the Industry 5.0 era.

Keywords: Human-Machine Collaboration; Mechanical-Engineering; Sustainable Manufacturing

INTRODUCTION

The Industrial Revolution 5.0 marks a paradigm shift from a fully automated technological approach to a symbiotic collaboration between humans and machines. No longer solely oriented towards efficiency and productivity as in the 4.0 era, the Industrial Revolution 5.0 emphasizes the importance of human-centric innovation, namely the development of technology that considers human values, empathy, and sustainability (Musarat et al., 2023). In the midst of this transformation, the role of mechanical engineering has expanded, not only as the foundation of mechanical and manufacturing systems, but also as a bridge between intelligent technology and dynamic human needs. This creates new challenges for mechanical engineers to design systems that are not only functional and efficient, but also intuitive, safe, and able to adapt to user variability.

In this context, mechanical engineering can no longer stand alone as a discipline, but must integrate the principles of systems engineering, artificial intelligence, and human ergonomics. For example, the development of cobots (collaborative robots) in a modern work environment requires a deep understanding of human-machine interaction, including sensory aspects, adaptive actuation, and occupational safety (Rijwani et al., 2025). The Industrial Revolution 5.0 pushes mechanical engineering out of its conventional zone from only designing machines to participating in creating an ethical, inclusive, and sustainable technological ecosystem. Therefore, a literature review of the role of mechanical engineering in this era is essential to formulate the direction of scientific development and engineering practice that is responsive to changes in the times.

The transformation of mechanical engineering in the Industrial Revolution 5.0 era is not just a technical shift, but a profound paradigm shift. Mechanical engineering must now act as an integrator agent between classical mechanics and intelligent digital technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and cyber-physical systems. The traditional role of mechanical engineers, which previously focused on structural design, heat transfer, or motion mechanisms, has now evolved into a more complex role involving automated system programming, industrial big data management, and AI-based simulation modeling. This combination creates epistemological challenges: disciplinary boundaries are becoming increasingly blurred, and mechanical engineers are required to have cross-field competencies. In practice, this can be seen in the development of smart manufacturing, where production systems are able to respond adaptively to real-time data and feedback from the human work environment (Broo et al., 2022). This means that mechanical engineering competency is not only about mastering mechanical formulas, but also understanding how a machine becomes an intelligent entity integrated into a dynamic industrial ecosystem.

Furthermore, the development of collaborative robots (cobots) clearly reflects how this transformation demands a multidisciplinary approach. It is not enough to just design actuators and sensors, mechanical engineers must now consider aspects of human-machine interaction involving cognitive psychology, user interfaces, and ethical-based work safety. Cobots are designed to work alongside humans, not replace them, so their mechanical design must take into account responsiveness, flexibility, and the ability to learn from human work patterns. A study by Setiyo & Rochman (2023) emphasized that the implementation of cobots requires collaboration between mechanical engineering, electrical engineering, and computer science in order to achieve synergy between efficiency and work safety. Thus, the transformation of the role of mechanical engineering cannot be separated from the need for a systemic and collaborative approach in addressing the complexity of future industrial technology. The Industrial Revolution 5.0 is not just about smarter automation, but about how humans and machines complement each other in creating sustainable added value.

The urgency of literature review in mechanical engineering is getting stronger along with the emergence of technological disruption in the Industrial Revolution 5.0. Amidst the complexity of contemporary industrial challenges, sectoral and fragmented research has proven to be inadequate to respond to the needs of interconnected and rapidly changing industrial systems. Therefore, a comprehensive literature review is crucial to identify knowledge gaps in the development of mechanical technology integrated with digital systems. For example, there is an urgent need to understand how mechanical engineering can contribute to creating real-time data-based manufacturing systems, AI-assisted design, and predictive technology in machine maintenance. Recent literature such as that presented by Taj & Zaman (2022) shows that the integration of intelligent technology and basic principles of mechanical engineering still requires more systematic research mapping. Without a strong literature review, technology development in the Industrial Revolution 5.0 risks becoming experimental and undirected, making it difficult to be widely adopted by the industrial sector.

Furthermore, literature not only functions as a mapping of scientific discourse, but also as a tool to evaluate the success and failure of previous technology implementations. In this context, literature reviews act as a reflective medium that can reveal methodological biases, limitations of existing systems, and best practices from various global industrial sectors. Although many companies have adopted the principles of Industry 4.0, only a small number are able to carry out comprehensive integration due to the lack of technological and human resource readiness. This emphasizes that in order to welcome the Industrial Revolution 5.0, literature is needed that is not only descriptive, but also analytical and prospective, capable of providing a strategic roadmap for the development of adaptive and human-centric mechanical engineering. Thus, the need for critical, up-to-date, and multidisciplinary literature reviews is the main foundation for the birth of relevant and sustainable mechanical engineering innovations.

The concept of sustainability in the Industrial Revolution 5.0 is no longer just an additional element, but rather a main pillar in the design and implementation of future industrial systems. In this context, mechanical engineering has a strategic position in reducing the environmental impact of the manufacturing process through more efficient and environmentally friendly system engineering. One of the main contributions of mechanical engineering is in the development of energy-efficient systems and low-carbon manufacturing technologies, which enable the saving of natural resources and the reduction of carbon emissions without sacrificing productivity. As explained by Islam et al (2025), the application of life cycle engineering and eco-design in mechanical engineering allows product optimization from the design stage to recycling, so that the entire product life cycle can be utilized optimally with minimal environmental impact. However, the challenges faced are not only technical, but also structural, where the sustainability approach is often not a priority in the industrial planning and decision-making process. Therefore, the role of mechanical engineers must develop into change agents who are able to integrate sustainability perspectives into every stage of engineering and production.

In addition, mechanical engineering also plays a vital role in supporting the circular economy principle, which is becoming increasingly relevant amidst the resource crisis and increasing global ecological pressures. Through innovations in modular design, remanufacturing technologies, and predictive maintenance systems, mechanical engineers can extend the useful life of products and reduce industrial waste. The integrated circular economy approach in mechanical engineering practice not only improves material efficiency but also creates new economic value through reduced operational costs and green business opportunities. However, the adoption of sustainable technologies in industry still faces obstacles in the form of cultural resistance, lack of regulations that encourage green innovation, and limited technical knowledge among industry players. Therefore, further literature and research are needed to strengthen scientific arguments and prove that sustainability is not only a moral imperative, but also a profitable business strategy. Within the framework of Industry 5.0, mechanical engineering is no longer just an answer to technical problems, but must be part of an ecological solution that shapes the future of an ethical and sustainable industry

METHOD

This study uses a qualitative approach with a literature review method as the main technique in data collection and analysis. The literature review was chosen because the topic being studied focuses on mapping scientific discourse and developing theoretical concepts related to the transformation of the role of mechanical engineering in facing the challenges and opportunities of the Industrial Revolution 5.0. This method allows researchers to identify, critically review, and synthesize the results of previous studies in order to produce in-depth understanding and reveal research gaps that are still open.

The data studied in this study were obtained from various relevant secondary scientific sources, such as internationally indexed journal articles (Scopus, Web of Science), conference proceedings, academic books, and official institutional reports (e.g. NIST and OECD) published in the last 10 years (2014–2024). Inclusion criteria include publications that explicitly discuss mechanical engineering, intelligent manufacturing technology, human-machine system integration, and industrial sustainability within the framework of the Industrial Revolution 5.0. The literature collection procedure was carried out through a systematic search using databases such as ScienceDirect, IEEE Xplore, and Google Scholar with keywords such as "mechanical engineering", "Industry 5.0", "sustainable manufacturing", and "human-machine collaboration". The data obtained were analyzed using thematic analysis techniques, namely by grouping information based on main themes such as the transformation of the role of mechanical engineering, human-machine collaboration, and contributions to industrial sustainability. The analysis was carried out critically by assessing the suitability of the methodology, the strength of the arguments, and the theoretical contributions of each literature. With this approach, research is expected to be able to provide a comprehensive conceptual map regarding the strategic role of mechanical engineering in the Industry 5.0 era and encourage more relevant research directions in the future.

RESULT AND DISCUSSION

Transformation of the Role of Mechanical Engineering in the Industry 5.0 Ecosystem

1. Integration of Mechanical Engineering with Digital Technology and Artificial Intelligence

The integration of mechanical engineering with digital technology and artificial intelligence (AI) has fundamentally changed the way mechanical engineering works and the scope of the profession. In the era of Industry 4.0, the boundaries between physical and digital systems are becoming increasingly blurred, driving a paradigm shift in the world of engineering. Mechanical engineering, which previously focused on mechanical design and production, must now adapt to technologies such as the Internet of Things (IoT), cyber-physical systems, and artificial intelligence that enable real-time connectivity and intelligent automation in the production process. Through this technology, the concept of smart manufacturing was born, which allows machines and production systems to make decisions autonomously based on the analysis of sensor data collected continuously. This provides high flexibility in production line management, such as the ability to quickly adjust to variations in market demand, detect operational anomalies, and dynamically organize production schedules without human intervention.

This development also encourages the implementation of various innovations such as predictive maintenance, where AI algorithms are used to predict machine failures before actual failure occurs, thereby reducing maintenance costs and operational downtime. By utilizing historical data from vibration, temperature, pressure, and power consumption sensors, machine learning algorithms can recognize component degradation patterns and provide early warnings automatically (Andriyani et al., 2024). In addition, techniques such as digital twins enable the creation of digital replicas of physical machines or systems for simulation and optimization without disrupting real operations. Digital twins not only display machine conditions in real time but also enable "what-if" scenario analysis which is very useful in strategic decision making (Ugih, 2021). On the other hand, this technology also plays an important role in optimizing energy consumption by efficiently managing equipment usage based on peak load times and ideal operational conditions. Through this integration, the entire product life cycle from design, production, distribution, to after-sales can be monitored and optimized holistically using a data-driven approach.

As a result of this integration, the role of mechanical engineers has expanded significantly. They are not only required to master the principles of mechanics and design, but also cross-disciplinary skills such as data analysis, programming, and machine learning-based algorithm development. A modern mechanical engineer must be able to read and analyze big data, use programming languages such as Python or MATLAB, and understand the structure of intelligent control-based automation systems. In the contemporary industrial environment, collaboration between mechanical engineers, data scientists, and software developers is crucial. Without an understanding of digital system architecture and machine-to-machine communication interfaces, an engineer will be left behind in designing adaptive and efficient systems.

Literature such as Handayani (2024) emphasizes that success in building a new generation production system is highly dependent on the integration of engineering knowledge with the use of digital technology. This study shows that interdisciplinary skills are core competencies in the era of industrial digital transformation. This is also reinforced by the World Economic Forum report (2020) which emphasizes that skills such as systems analysis, digital critical thinking, and mastery of Industry 4.0 technology will be important elements in the development of engineering human resources in the future. This transformation not only has implications for the adoption of new tools or hardware, but also demands changes in the way of thinking, planning, and executing industrial strategies as a whole. Therefore, the integration of mechanical engineering with digital technology is a strategic step that has a major impact, both in increasing industrial efficiency, creating added value, and strengthening global competitiveness in the modern manufacturing world. Adapting to these changes is not an option, but a necessity to survive and thrive in an increasingly digitalized and differentiated industrial landscape.

2. Human-Machine Collaboration: The Role of Mechanical Engineering in Realizing Human-Centered Systems

In the development of modern industrial systems, there has been a significant paradigm shift from an approach that is solely oriented towards machine efficiency to a more human-centered system. This shift reflects the awareness that technology must not only increase productivity, but also need to pay attention to aspects of social sustainability and human well-being in the workplace. This is reflected in the philosophy of Industry 5.0, which emphasizes synergy between advanced technology and human values. In this context, mechanical engineering has a strategic responsibility to create mechanical systems that are not only technically superior, but also in line with the psychological, physical, and social needs of humans as the main users. Such systems are designed to be able to improve the quality of life of workers, reduce physical burdens, and support human decision-making through technology that is collaborative, not competitive (Zainal et al., 2025).

One concrete form of the role of mechanical engineering in realizing a human-centered work system is the development of collaborative robots (cobots). Unlike conventional industrial robots that operate separately and require special safety systems, cobots are designed to work side by side with humans on the same production line. Cobots are equipped with sophisticated sensors that allow them to recognize human presence, adjust movement speed, and even stop automatically when they detect a risk of collision. This advantage not only increases the efficiency of the production process but also creates a safer and more flexible work environment. According to research conducted by Javaid et al. (2022), the use of cobots can significantly reduce work injuries and accelerate the adaptation time of workers to new technologies. However, this achievement can only be realized if the mechanical, control, and human interaction aspects are designed in an integrated manner.

Therefore, mechanical engineering must integrate ergonomics as part of the technical design. Ergonomics allows designers to understand the physical and cognitive limitations of humans in interacting with mechanical systems, so that the resulting product does not cause fatigue or injury. On the other hand, the concept of human-computer interaction (HCI) also needs to be implemented in the development of cobots interfaces so that they are intuitive and easy to operate by workers from various educational backgrounds and ages. In addition, adaptive sensor-based safety aspects are very important, especially in dynamic work environments that involve a lot of physical activity. Advanced cobot control systems must be able to adjust commands based on environmental changes or user responses in real time. By combining data from force, pressure, temperature, and visual sensors, this system can predict potential hazards and adjust machine behavior to avoid accidents.

Furthermore, as explained by Raharjo (2023) successful collaboration between humans and machines requires alignment between mechanical design, control software, and human work patterns. Mechanical engineering cannot work in isolation; it must collaborate closely with other fields such as work psychology, computer science, and industrial engineering to ensure that all aspects run harmoniously. In practice, this multidisciplinary approach helps create a work system that is not only efficient and productive, but also socially just and sustainable. The concept of user-centered engineering becomes important, where end users (in this case human workers) are involved in the design and testing process of the system to ensure that the technology is appropriate to real needs in the field.

Thus, the role of mechanical engineering in the Industry 5.0 era is not just to develop advanced technology, but also to bridge production efficiency and human values. This creates a new direction for a more inclusive industrial world, where technology is present to support human capacity, improve quality of life, and create a more ethical and sustainable work system. Human-machine collaboration designed with a human-centered engineering approach can be the foundation for an industrial future that is not only technically intelligent, but also socially wise.

Contribution of Mechanical Engineering to Sustainability and Circular Economy in Industry 5.0

1. Implementation of Life Cycle Engineering and Eco-Design in Mechanical Product Engineering

In recent decades, the principle of sustainability has begun to become a major concern in mechanical product engineering, especially through the Life Cycle Engineering (LCE) and Eco-Design approaches. LCE emphasizes the importance of considering all stages of a product's life cycle from raw material selection, manufacturing process, distribution, use, to recycling or final disposal to reduce negative impacts on the environment (Liang, 2023). This brings a paradigm shift in the world of mechanical engineering, where engineers no longer only focus on functional aspects and technical performance, but also on the ecological footprint of the designed product. In practice, LCE encourages the use of environmentally friendly and easily recycled materials, the development of modular designs that facilitate maintenance and extend the service life, and the use of Life Cycle Assessment (LCA) as an analysis tool to evaluate the environmental impact of a product from the design stage. For example, in the automotive industry, the application of LCA has helped manufacturers such as BMW and Toyota reduce total CO_2 emissions per vehicle through the selection of lightweight materials based on recycled aluminum and optimization of assembly processes.

In line with this, Eco-Design is a more focused approach at the early stages of product design, with the aim of reducing potential environmental impacts through material selection, production processes, and end-of-life strategies. In mechanical products, its application can be seen from efforts to design lightweight components, reuse product parts, and ease of disassembly and recycling. These strategies not only reduce energy and material consumption, but also increase economic efficiency in the long term. A study by Kong et al (2022) shows that product designs that allow for reuse and recycling of components significantly reduce total life cycle costs and extend product value in the market. In the aircraft sector, for example, the use of lightweight composite materials and modular structural designs has resulted in fuel savings of up to 20%, while reducing operational emissions. The application of eco-design is also increasingly facilitated by technological advances, such as computer-aided design (CAD) and generative design, which allow simulation of the environmental impact of various design configurations before production begins.

According to Elgazzar (2024), the LCE and Eco-Design approaches are particularly relevant in the heavy manufacturing and automotive sectors, which historically contribute to high carbon emissions and intensive exploitation of natural resources. Therefore, the application of these two principles is considered crucial in reducing the environmental impact of the mechanical engineering industry. In addition, the integration of these approaches has been shown to not only have a positive ecological impact, but also lead to long-term economic efficiency through reduced primary raw material requirements and energy costs. As global environmental regulations such as the European Green Deal and ISO 14001 increase, companies are increasingly encouraged to integrate sustainable design principles into their operational practices.

However, the implementation of LCE and Eco-Design is not without challenges. One of them is the lack of global standardization related to sustainable design, so that engineering companies or institutions often have different approaches. In addition, many professionals still do not have awareness or competence regarding the importance of environmentally friendly design, which requires training and a change in mindset from the higher education stage. Technical challenges also arise from the manufacturing side, where adjustments to the production process are needed to accommodate recycled materials and other sustainable technologies. On the other hand, there is a dilemma between performance and sustainability—for example, the use of environmentally friendly materials that may have mechanical characteristics below conventional standards. To overcome this, collaboration is needed between academics, technology providers, and industry to develop new materials and innovative fabrication methods, such as bio-based composites or additive manufacturing based on recycled metal powders, which are able to bridge technical and sustainability needs.

Despite the challenges, the implementation of LCE and Eco-Design is an important step towards a production system that is in line with the principles of a circular economy. Through designs that consider aspects of maintenance, repair, and recycling, mechanical engineering products can become part of a repeatable production cycle that is low-waste and resource efficient. Case studies from companies such as Philips and Siemens show that circular-based business models that implement sustainable design can increase consumer loyalty and create opportunities for product innovation. Thus, mechanical engineering can play a significant role in driving the transformation of the industry towards a greener and more sustainable direction. To accelerate the adoption of this principle, synergy is needed between government regulations, technological innovation, engineering education, and commitment from the industrial sector itself.

2. Energy-Saving Technologies and Predictive Maintenance as Pillars of Industrial Sustainability

The application of Life Cycle Engineering (LCE) and Eco-Design in mechanical product engineering is a strategic approach that is increasingly relevant amidst increasing awareness of environmental sustainability issues. LCE is an engineering method that considers all stages of a product's life cycle from design, production, distribution, use, to end-of-life such as recycling or disposal (Cruz & Garcia, 2024). Meanwhile, Eco-Design actively integrates environmental aspects into the product design process without neglecting technical or aesthetic performance. In the context of mechanical engineering, this approach is very important considering that this sector, such as the automotive industry and heavy manufacturing, is known to have a significant contribution to energy consumption, raw material use, and carbon emissions. Traditional mechanical products are often designed with a purely functional orientation, resulting in waste of resources, increased industrial waste, and high energy consumption during their operation.

Through the application of LCE and Eco-Design principles, engineers are encouraged to consider not only the functional aspects of a product, but also its overall ecological impact. Some of the key principles adopted include designing for recyclability, using environmentally friendly materials, increasing energy efficiency throughout the product’s lifecycle, and designing products that are easy to maintain and have a long life. For example, in automotive component design, the use of recyclable thermoplastic materials in place of heavy metals has been shown to reduce carbon emissions and simplify the end-of-life process of the product. In addition, the design for disassembly strategy facilitates the separation of components during repair or recycling, which ultimately reduces the burden of solid waste and minimizes the need for extraction of new materials. Sustainability evaluation is also further strengthened by the Life Cycle Assessment (LCA) approach, which is used to identify and quantify the environmental impacts of each stage of a product’s lifecycle, including carbon footprint, cumulative energy consumption, potential for water and soil pollution, and other impact categories such as global warming potential (GWP) and human toxicity.

Research by Sundaramoorthy et al (2023) confirms that the application of this principle in mechanical engineering has great potential to reduce the environmental footprint, especially in industries with high resource consumption. Products designed based on this approach are not only more efficient in terms of energy and material use, but also contribute to the circular economy through ease of repair and recycling. For example, in the manufacturing of machine components, the use of remanufacturing or refurbishment technology allows worn components to be refurbished and reused, reducing the need to manufacture new parts. In the transportation sector, the design of lightweight yet strong vehicles through the selection of environmentally friendly composite materials can reduce vehicle weight, thereby reducing fuel consumption and CO_2 emissions.

However, the implementation of LCE and Eco-Design in engineering practice still faces several challenges. One of them is the absence of standard standards related to sustainable design, which results in variations in approaches and non-uniformity of implementation in the field (Hauashdh et al., 2024). Several international standard initiatives such as ISO 14006 (guidelines for incorporating eco-design) do exist, but have not been widely adopted in various industries, especially in developing countries. In addition, there is still a gap in knowledge and awareness among engineering professionals, which requires the integration of this topic into the engineering education curriculum and industrial training. Many mechanical engineers still focus on technical performance-based design without considering the life cycle of materials and products. Another challenge is the need to adapt existing manufacturing technologies to comply with the principles of a circular economy, which generally requires additional investment, both in terms of production infrastructure and research and development. For example, 3D metal printing technology (additive manufacturing) which supports the use of more efficient and precise materials is still expensive and not widely accessible to small and medium industry players (Rehan, 2021). In addition, the initial cost of developing LCE-based products tends to be higher due to the need for alternative material research, life cycle simulations, and product sustainability testing, although in the long term it can provide significant environmental efficiency and added value.

Thus, the integration of Life Cycle Engineering and Eco-Design in mechanical product engineering is not only an answer to the global environmental crisis, but also a key driver in the transformation of the industry towards more responsible and sustainable practices. The application of these principles drives environmentally-based technological innovation, strengthens the competitive position of companies in an era of stringent emission regulations, and creates economic value through resource optimization. Therefore, the collective efforts of stakeholders in the engineering, industrial and public policy sectors are key to driving the widespread and effective adoption of this approach.

CONCLUSION

The transformation of the role of mechanical engineering in the Industry 5.0 ecosystem reflects a fundamental shift from conventional technical approaches to intelligent, collaborative industrial systems that are oriented towards sustainability and human values. On the one hand, the integration of mechanical engineering with digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), cyber-physical systems, and digital twins has revolutionized the manufacturing process through intelligent automation, predictive maintenance, and real-time data-driven management. This requires new competencies from mechanical engineers, namely mastery of cross-disciplinary skills that include programming, data analysis, and understanding complex systems. On the other hand, mechanical engineering also contributes significantly to realizing a human-centered industry, through the development of ergonomic systems, adaptive interfaces, and collaborative technologies such as cobots that support worker safety and comfort. This role is further strengthened by a commitment to sustainability, which is reflected in the application of the Life Cycle Engineering (LCE) and Eco-Design approaches in mechanical product engineering. These principles encourage the use of environmentally friendly materials, energy efficiency, ease of recycling, and the development of products with a long life, which supports a circular economy and a reduction in the carbon footprint of the industry. Despite challenges such as the lack of global standardization, limited technical competence in sustainability, and the need for initial investment in green technology, the success of large companies in implementing these principles proves that economic efficiency and positive ecological impact can be achieved simultaneously. Thus, the role of mechanical engineering in the Industry 5.0 era is not only as a driver of technological innovation, but also as a driver of change towards an inclusive, ethical, and sustainable industrial system.

Collaboration between industry, academia, government, and society is key to accelerating the widespread adoption of this approach. Therefore, the transformation of mechanical engineering must be directed not only at achieving technical performance, but also at making a real contribution to environmental sustainability and social welfare in the future

REFERENCES

Andriyani, W., Inayah, I., Ikhsan, Z., Dewi, S. M., Khudori, A. N., Haris, M. S., ... & Faizah, S. (2024). *TEKNOLOGI IoT PADA BIDANG PERTANIAN MODERN*. TOHAR MEDIA.

Broo, D. G., Kaynak, O., & Sait, S. M. (2022). Rethinking engineering education at the age of industry 5.0. *Journal of Industrial Information Integration*, *25*, 100311.

Cruz, J. C., & Garcia, A. M. (2024). Machine Learning for Predictive Maintenance to Enhance Energy Efficiency in Industrial Operations. *ITEJ (Information Technology Engineering Journals)*, *9*(1), 15-22.

Elgazzar, M. A. G. (2024). The impact of Eco-Design strategies in improving Industrial Product Lifecycle. *International Design Journal*, *14*(1), 381-395.

Handayani, K. (2024). Strategi adaptif untuk mempertahankan tenaga kerja di era society 5.0: Menghadapi tantangan cobot. *Jurnal Penelitian Multidisiplin Bangsa*, *1*(3), 185-200.

Hauashdh, A., Nagapan, S., Jailani, J., & Gamil, Y. (2024). An integrated framework for sustainable and efficient building maintenance operations aligning with climate change, SDGs, and emerging technology. *Results in Engineering*, *21*, 101822.

Islam, M. T., Sepanloo, K., Woo, S., Woo, S. H., & Son, Y. J. (2025). A review of the industry 4.0 to 5.0 transition: exploring the intersection, challenges, and opportunities of technology and Human–Machine collaboration. *Machines*, *13*(4), 267.

Javaid, M., Haleem, A., Singh, R. P., Rab, S., & Suman, R. (2022). *Significant applications of cobots in the field of manufacturing. Cognitive Robotics, 2, 222-233*.

Kong, L., Wang, L., Li, F., Tian, G., Li, J., Cai, Z., ... & Fu, Y. (2022). A life-cycle integrated model for product eco-design in the conceptual design phase. *Journal of Cleaner Production*, *363*, 132516.

Liang, J. S. (2023). A knowledge with ontology representation for product life cycle to support eco-design activities. *Journal of Engineering, Design and Technology*, *21*(4), 991-1026.

Musarat, M. A., Irfan, M., Alaloul, W. S., Maqsoom, A., & Ghufran, M. (2023). A review on the way forward in construction through industrial revolution 5.0. *Sustainability*, *15*(18), 13862.

Raharjo, B. (2023). Teori Etika Dalam Kecerdasan Buatan (AI). *Penerbit Yayasan Prima Agus Teknik*, 1-135.

Rehan, H. (2021). Energy efficiency in smart factories: leveraging IoT, AI, and cloud computing for sustainable manufacturing. *Journal of Computational Intelligence and Robotics*, *1*(1), 18.

Rijwani, T., Kumari, S., Srinivas, R., Abhishek, K., Iyer, G., Vara, H., ... & 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), 667-679.

Setiyo, M., & Rochman, M. L. (2023). The role of mechanical engineering in the era of industry 4.0 and society 5.0. *Mechanical Engineering for Society and Industry*, *3*(2), 54-56.

Sundaramoorthy, S., Kamath, D., Nimbalkar, S., Price, C., Wenning, T., & Cresko, J. (2023). Energy efficiency as a foundational technology pillar for industrial decarbonization. *Sustainability*, *15*(12), 9487.

Taj, I., & Zaman, N. (2022). Towards industrial revolution 5.0 and explainable artificial intelligence: Challenges and opportunities. *International Journal of Computing and Digital Systems*, *12*(1), 295-320.

Ugih Rizqi, Z. (2021). *Perancang Digital Twin Berbasis Simulasi untuk Smart Warehouse: Asset Administration Shell Framework* (Doctoral dissertation, Universitas Islam Indonesia).

Zainal, R. F., Alim, S., Arizal, A., & Purnama, R. (2025). Tinjauan Integrasi Teknologi Deep Learning Untuk Revolusi Industri Dalam Sistem Siber-Fisik. *INTER TECH*, *3*(1), 54-64.