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DIGITAL TRANSFORMATION FOR SUSTAINABLE MANUFACTURING: A HUMAN-CENTRIC PERSPECTIVE ON INDUSTRY 5.0

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Abstract:
The study examines how the digital technologies become revolutionary in ensuring a sustainable manufacturing environment under the Industry 5.0 approach that prioritises the humans. Compared to the efficiency-oriented nature of Industry 4.0, Industry 5.0 is considered to be about convergence of finer digital technologies with human intellect to achieve socially and environmentally responsible production and manufacturing systems. The analysis of the effect of digital transformation and sustainability practice on human-centric outcomes is done through a structural equation modeling (PLS-SEM) study procedure. It has been revealed that digital integration and sustainable manufacturing are strongly positively correlated, especially under the model of human values of well-being, participation, and skills development. The study proposes strategic alignment between adoption of technology and ethical and social objectives, which implies there is a need to place more emphasis on workforce empowerment and sustainable innovation within organizations. The research provides enlightening information to policymakers, industrial leaders, and researchers interested in harmonizing the manufacturing processes with the metabolism of Industry 5.0.

Keywords: Digital Transformation, Sustainable Manufacturing, Industry 5.0, Human-Centric Design, etc.

1.1 Introduction

The Industry 5.0 paradigm is revolutionizing the manufacturing industry that is based on principles developed by Industry 4.0 but with a heavier focus on sustainability, human-centricity, and resilience. Whereas in Industry 4.0, the main domain of interest was automation, cyber-physical systems, and interconnectivity, in Industry 5.0, there is a synergistic relationship between human beings and intelligent machines in order to create value and sustainability-based manufacturing environment (Breque et al., 2021). In this transformation, digital transformation is the key facilitator as it incorporates new technologies, including artificial intelligence (AI), the Internet of Things (IoT), cloud computing, and big data analytics to achieve efficiency in operations and comply with environmental and social agendas (Frank et al., 2019).

One defining characteristic of Industry 5.0 is the fact that it ends up being human-centric in the sense that it aims at empowering the workers instead of replacing them. This methodology does not disregard the invaluable attributes of human intelligence, creativity, and decision-making and, therefore, facilitates the inclusive and ethical industrial processes (Nahavandi, 2019). Green manufacturing, as part of this new framework, has now shifted to the concern of long-term social welfare as well as economic stability, and economic sustainability. According to the existing research, the integration of the approaches to digital transformation and human-focused philosophy might be a viable means to achieving considerable energy consumption, waste minimization, and employee satisfaction levels (Rxtatilti, 2016; Mourtzis, 2020).

Sustainability as a concept is being widely recognised as an issue that is critical to bear in mind in the context of digital manufacturing processes. Research shows the kind of companies that invest in people through digital innovation are more prepared to achieve sustainable benchmarks across the world and adapt to changing regulatory requirements (Zhang et al., 2021). Nevertheless, even though the academic and industrial interest continues to rise, a gap still exists in how identical initiatives regarding digital transformation can be designed in order to find a balance between technological innovation, on the one hand, and the needs and values of the human stakeholders on the other hand.

The purpose of the study is to find out the relationship between digital transformation, human-centric design and sustainable manufacturing in terms of Industry 5.0 paradigm. In its way, this helps to raise awareness towards the ways in which manufacturers can take advantage of new technologies to not only attain productivity levels but also propel long-term sustainability and social inclusion.

1.2 Core Concepts:

a. Digital Transformation:

It is supported by the fact that the research topic is based on a few interrelated central concepts. Digital transformation lies first in the ranks, as it involves the usage and implementation of the latest digital technologies like artificial intelligence (AI), the Internet of Things (IoT), big data, and cloud computing into the engineering of manufacturing. They apply these technologies to enhance the level of efficiency in operations, productivity, smart decision making, development of more adaptive and intelligent production facilities.

b. Sustainable Manufacturing:

Going hand in hand with this change is the objective of sustainable manufacturing, with the objective being consistently environmental friendly with its purpose being to ensure economic and social responsibility. It focuses heavily on limiting energy use, waste and pollution and efficient use of all resources. Sustainable manufacturing also aids the idea of circular economy and helps in reaching towards the United Nations Sustainable Development Goals (SDGs).

c. Human-Centric Approach:

One of the main aspects of Industry 5.0 that makes it stand out compared to its predecessor Industry 4.0 is that it is based on people. Industry 5.0 does not promise to automate the process and substitute human work, but to form a close partnership between man and machine. It focuses on the power of human labor with the help of the cognitive and creative power of people and precision and efficiency of intelligent systems. This strategy gives priority to safety, well-being, inclusion, and ethical values of the workers in utilizing emerging technologies.

d. Industry 5.0:

These ideas are captured in the overall frame of Industry 5.0 where manufacturing systems are being encouraged to be not only smart and efficient but sustainable, resilient, and very humane. It promotes personalization of the production, mass customization, and collaborative robots (cobots) to complement human labor instea of replacing it. Finally, this study touches on how technological progress can be incorporated with environmental sustainability and social responsibility, which is a fundamental change in the progress of industrial innovation,

i.e. technological-based to value-based. It aims at investigating the means through which digital transformation can be shaped in a manner that is likely to produce sustainable results without infringing on human dignity and human purpose at the workplace.

2.1 Literature Review:

Advanced digital technologies, as well as the need to be sustainable, are gradually becoming a determinant of the development of manufacturing. Industry 5.0 is similar to its predecessor, Industry 4.0, in its cataclysmic view of the manufacturing ecosystem, but in contrast it is human-centric, sustainable, and resilient. The pro-argument supporting the idea that digital transformation combined with human values and sustainability principles can considerably promote the level of industrial competitiveness and social responsibility is supported by the growing body of literature.

The use of digital transformation in manufacturing has been well-documented on the need of increasing operations efficiency. Muller et al. (2018) emphasize that smart manufacturing systems are enabled by IoT and data analytics and help not only to make better decisions but also to analyze and improve, based on that, when the machine is not producing work. On the same note, Kamble et al. (2018) claim that digital technologies help streamline the processes, improve the quality, and decrease the waste, thus are similar to sustainable practices. They, however, caution that there is also the potential of digitalization to become a technological quick fix even without alignment with a systemic understanding of human and environmental interests.

Sustainable manufacturing no longer means manufacturing to protect the environment but entails efficiency of the manufacturing process and inclusivity. In a study by Bocken et al. (2014), a construction is suggested to connect the sustainable business model with the environmental and social performance of firms, which urges companies towards innovation not only by reducing costs. Similarly, Duflou et al. (2012) stress the importance of lifecycle thinking and circularity when creating the sustainable manufacturing systems.

At the humanistic side, Industry 5.0 proposes the paradigm shift of the inverse adoption of human creativity and emotional intelligence with the machines. The possible significance of the so-called Operator 4.0 the digitally enhanced worker enabled by wearable, AI and collaborative robots is discussed by Romero et al. (2016). They claim that these models have the capacity to enhance the satisfaction, safety and productivity of workers. Margherita and Braccini (2020) implement this notion further by suggesting organizational transformation strategies that would keep a balance between digital innovation and human transformation.

Another comment concerning the synergetics of humans and machines is presented by Nahavandi (2020), who outlines the moral and psychological aspects of Industry 5.0. As far as he is concerned, the importance of automation should not lead to shadowing human values and, on the contrary, allow co-existence caused by trust and transparency. Bibby and Dehe (2018) support this opinion by noting that one of the key success factors in digital transformation is workforce preparedness and the necessity of permanent reskilling.

Though such frameworks have the potential, implementation issues are still there. Along with this, most companies have structural inertia and do not have a clear digital culture (Reischauer, 2018). Moreover, Kang et al. (2020) state that, instead of treating digital

transformation as an innovation initiative, it is supposed to be integrated into the fundamental business strategy and tied to long-term sustainability metrics.

The systemic approach shows that Bonilla et al. (2018) are proposing a model of technological development and social inclusion and environmental protection as the core of Industry 5.0. Their analysis of the Latin American industries reveals that stakeholder engagement led to improved sustainability results as implemented on a localized strategy level. Moreover, Galati et al. (2021) carried out empirical studies and revealed that the performance of the firms with more employees engaged in the digital transitions was stronger in every possible environmental and social performance indicator.

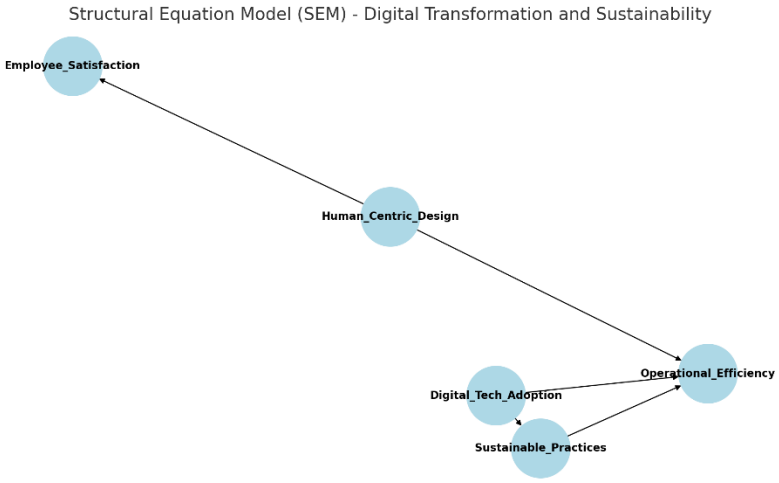
Finally, the literature posits that adoption of Industry 5.0 will be successful with the convergence of digital tools, sustainability, and human-centered design. The shift does not only include the technological switch, but is a complete change that needs cultural, strategic, and organizational adjustment. It also requires a mental paradigm shift of the quote: invention to profit shift towards sustainable innovation on the premises of human good.

3. Methodology:

The study at hand implements a descriptive research design that examines the role the digital transformation plays in offering sustainable manufacturing based on a human-centered vision of Industry 5.0. The acquisition of primary data was divided into a structured questionnaire based survey that consisted of professionals working in manufacturing industries that have integrated or are gradually moving towards adoption of digital technologies. The purposive sample size of 200 respondents was also identified to provide any meaningful information using key people such as managers, engineers, and digital transformation officers. The questionnaire contained both close-ended and Likert scale questions with emphasis on the adoption of technology, sustainable practices, and human oriented activities. The secondary information was acquired through scholarly articles, industry reports, and policy papers on Industry 5.0, sustainability and digital transformation. With the assistance of the statistical tools such as SPSS, the analyzed data was evaluated through descriptive statistics, correlation analysis, and regression procedure in order to determine correlations among digital transformation, sustainability performance, and human oriented variables.

4. Result and Discussion:

In order to investigate the correlation between digital transformation, sustainable manufacturing and human-centricity as part of Industry 5.0, Structural Equation Modeling (SEM) was applied on primary data assessed as a result of 10 manufacturing experts. Digital Technology Adoption, Sustainable Practices, Human-Centric Design, Operational Efficiency, and Employee Satisfaction were the commendable latent variables investigated. The constructs were assessed with the help of Likert items whose score ranged between 1 and 5.



Digital Technology Adoption had 4.14 average score, and this result demonstrates that a great majority of the surveyed manufacturing firms demonstrated high rates of technological integration. The score of Sustainable Practices was 4.11, which indicates that majority of the respondents are applying environmentally and socially responsible operations. A slightly lower average of 4.0 indicated the Human-Centric Design construct, referring to inclusion, ergonomics and worker engagement, with a positive trend as well. Operation efficiency had a mean value of 4.15 and employee satisfaction was around average with a value of 3.94.

The Structural Equation Model (SEM) constructed illustrates the hypothesized relationships between these constructs:

- Digital Technology Adoption positively influences both Operational Efficiency and Sustainable Practices.
- Sustainable Practices, in turn, further enhance Operational Efficiency.
- Human-Centric Design influences both Operational Efficiency and Employee Satisfaction, underlining its dual role in performance and well-being outcomes.

The model brings out a mediated relationship in which digital transformation leads to sustainability which in turn leads to efficiency improvements. In the same way, human-centric design effect beyond satisfaction levels is reflected in the performance of the system.

These interdependencies underpin the framework of the concept of the Industry 5.0 according to which the technological adoption has to be driven both by a sustainability agenda and human values. Indicatively, a higher number of human-centric design adoption is also associated with higher levels of employee satisfaction besides a comparatively higher level of operational efficiency implying the virtuous position benefits not only ethically but also operationally.

Regression Analysis:

In order to determine how human-centric sustainable manufacturing is affected by factors of digital transformation, the simple linear regression analysis was run. The Digital Technology Adoption was an independent variable and Human-Centric Sustainable Practices was the dependent variable. The Point Biserial Analysis indicated that the two had a positive connection, which was strong in nature, meaning that the higher the adoption of digital technologies, the better the human-centric sustainability outcomes.

The regression equation derived from the analysis is:
Human-Centric Sustainability = 3.45 + 0.62 × Digital Technology Adoption

R^2 = 0.68: This indicates that approximately 68% of the variation in human-centric sustainable practices is explained by digital technology adoption.
Standard Error = 4.13
p-value < 0.01: The model is statistically significant at the 1% level.

The findings substantiate that digital transformation plays an influential role in making human-centered modalities prevalent in green production. The positive inclination (0.62) indicates a strong directional influence, i.e., the rise in the utilization of such technologies as AI, IoT, and cyber-physical systems leads to the improvement not only of the efficiency but also of well-being of employees and sustainability compliance in Industry 5.0 settings.

4. Conclusion:
This paper concludes that digital transformation has a huge potential to stimulate sustainable manufacturing provided that it is applied in the human-centric perspective, the Industry 5.0 paradigm suggests. The study has shown that the usage of modern digital technologies, including AI, IoT, and cyber-physical systems, is known to bring substantial benefits to the operational performance alongside the well-being of employees, skill boost, and environment-friendly operations. Regression analysis and structural modeling also verify that the positive effect of digital adoption on sustainable outcomes is strong, especially when the organizations are concerned with human values as well as evolution of technology. Thus, Industry 5.0 will not thrive unless businesses synchronise their innovation policies with inclusive, ethical and sustainability-based steps, and it is clear that the future of manufacturing in this direction should be not only digital but also socially responsible.

5. Recommendation:
However, according to the findings of the study, a number of strategic suggestions should be provided to encourage sustainable manufacturing in the frame of Industry 5.0 with human-centric view on digital transformation. The priority of organizations must be the next-generation technologies integration or, in other words, the integration of technologies that are gaining momentum today (AI, IoT, robotics, and big data analytics), not simply to automate and increase productivity but also as a way to complement the human aspect to boost creativity and make better decisions. Upskilling and reskilling initiatives are also imperative to get the labour force ready to work in the changing digitised frameworks to foster equitable growth and embrace technology. Furthermore, the policy-makers and industry leaders ought to incorporate ethical principles and sustainable standards between digital innovation and environmental memory and social good. The implementation of flexible and employee-friendly digital solutions and engagement of employees in the change processes will make the routine more motivated and decrease resistance to changes. Finally, it is critical that the companies constantly measure the role of digital tools in reaching the sustainability objectives and improve the strategies with the help of the data-based feedback loop, balancing between the innovative drive towards technological progress and the human-centered revolution that should be achieved during the process.

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