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Study of the impact of Industry 5.0 technologies on operational excellence: Insights into agility, innovation, and sustainability

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Abstract

Industry 5.0 marks an evolution from Industry 4.0 by integrating advanced technologies such as artificial intelligence, IoT, and big data while taking a more human-oriented and sustainability-oriented approach. This new industry framework is profoundly changing operational excellence practices, driving agility, resilience, continuous innovation, and increased collaboration with customers. This study focuses on assessing the impact of Industry 5.0 technologies on several dimensions of operational excellence, namely productivity, quality, agility, innovation, customer satisfaction, resilience, and sustainability. The aim is to examine how these innovations impact contemporary industrial practices. An empirical study on the adoption and perceived impact of Industry 5.0 technologies was conducted with professionals from various industry sectors. A statistical analysis of the data collected made it possible to determine the correlations between the adoption of these technologies and the operational performance observed. The results show that the integration of Industry 5.0 technologies significantly improves process efficiency, productivity, and organizational agility. However, the effects on innovation and customer satisfaction are still limited, suggesting that these areas are being less tapped. In addition, moderate progress has been made on sustainability and resilience, including through better energy management and increased flexibility in supply chains.

Keywords: Agility, Industry 5.0, Innovation, Operational excellence, Resilience, Sustainability.

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1. Introduction

Industry 5.0 emerged as a natural evolution of Industry 4.0, responding to the need to move beyond an exclusively technological approach to integrate a more humanistic and sustainable dimension [1]. The humanization of the technological environment initiated by Industry 4.0 has indeed been a determining factor in this transition to Industry 5.0 [2]. The latter does not replace Industry 4.0 but complements it by redirecting innovation and research towards an industrial model that is more human-centered and respectful of the planet's resources [3, 4].

The transition to Industry 5.0 marks a real paradigm shift, moving from a techno-centric vision to a more inclusive approach, where societal and environmental considerations are placed at the heart of industrial innovations [5, 6]. Industry 5.0 integrates advanced technologies such as big data, artificial intelligence, the Internet of Things (IoT), and robotics, but with humans and the planet at the heart of the priorities [7].

What fundamentally distinguishes Industry 5.0 from its predecessor is the focus on values rather than just technology adoption. This transformation builds on the most disruptive technologies, identified as part of the emerging technologies, to achieve key human-centered, resilience, and sustainability goals [8]. The dramatic growth of disruptive technologies such as 6G, artificial intelligence, and cognitive computing is redefining the future of the workplace, seamlessly integrating human beings with machines and the technological environment around them [9, 10].

Nowadays, operational excellence is an unavoidable requirement for organizations looking to enhance their performance and maintain competitiveness. Outperforming in key areas of operational performance, such as increasing customer satisfaction, improving quality, increasing productivity, and maximizing operational benefits, is at the heart of operational excellence [11]. However, this transition to Industry 5.0 has major implications for industrial operations and represents an important step towards a more sustainable and resilient future [11, 12]. In doing so, it is redefining the way operational excellence is designed. Traditionally focused on eliminating inefficiencies and improving quantitative performance [13, 14], operational excellence now incorporates qualitative dimensions such as agility, resilience, continuous innovation, and co-creation with customers [14-17].

Industry 5.0 offers new opportunities to transform production and supply chain management practices, enabling companies to remain competitive while adopting more sustainable and human-centric practices [18, 19]. It is in this dynamic context that our study is situated. Although a lot of research has explored the technological aspects of this transition, empirical research on the impact of these technologies on the main aspects of operational excellence remains limited.

Therefore, the research question is: What are the implications of Industry 5.0 on operational excellence, and to what extent do Industry 5.0 technologies contribute to improving this excellence within companies? This article aims to fill this gap in the literature by analyzing the opportunities offered by these new technologies and the practical challenges that companies must face to take full advantage of them.

The main objective of this work is to examine the impact of Industry 5.0 technologies on the operational excellence of companies. Specifically, this study focuses on how the integration of these technologies can transform operational practices, with a particular focus on their effects on core aspects of operational excellence, such as efficiency, productivity, quality, reliability, agility, resilience, and innovation.

To reach these goals, a review of previous work on Industry 5.0 and operational excellence was performed upstream. This preparatory analysis provided a theoretical framework for investigating the implications of Industry 5.0 adoption on operational excellence. Then, the data was collected from a survey of operational excellence practitioners. The results are presented through a thorough analysis of the data gathered, underscoring significant findings and their implications for industrial practices. This approach is distinguished by an effort aimed at quantifying and qualifying the changes observed in industrial practices.

2. Methods

This work takes a quantitative approach to assess the impact of Industry 5.0 technologies on several aspects of operational excellence, including efficiency and productivity, quality and reliability, agility, innovation, customer satisfaction, operational resilience, and environmental sustainability. An extensive search was conducted from academic databases such as IEEE Xplore, ScienceDirect, Google Scholar, and MDPI, using keywords such as "Industry 5.0", "operational excellence", and "impact". This approach enabled the collection of relevant articles, studies, and reports, which served as the foundation for the research. A detailed analysis of the selected articles and studies was conducted, emphasizing the key elements regarding the impact of Industry 5.0 on operational excellence.

An empirical study was then conducted with 120 participants from various industrial sectors. These participants, mainly decision-makers and managers, such as directors of operational excellence and digital transformation managers, had a deep understanding of the impact of Industry 5.0 technologies on their businesses. Data was collected via a structured questionnaire. The latter included a section on the profile of the participants and companies, followed by a section devoted to the operational excellence tools and the 5.0 technologies used. Next, the questionnaire focused on seven main areas of interest from the study: process efficiency and productivity, quality and reliability, organizational agility, driving innovation, customer satisfaction, resilience, and sustainability. A 5-point Likert scale was used to assess the impact of 5.0 technologies on each of these elements.

The questionnaire was pretested with 10 experts in industrial management and digital transformation, allowing adjustments to be made based on their feedback. The reliability of the scales was verified with Cronbach's alpha, showing satisfactory internal consistency (> 0.70). The data were analyzed using descriptive statistics (means, standard deviations, etc.) and correlation tests to identify relationships between key variables, such as operational efficiency, quality, agility, innovation, and customer satisfaction. These analyses help determine factors that act as primary determinants in the overall

perceived impact of Industry 5.0 technologies. The results obtained will make it possible to formulate strategic recommendations for a more effective adoption of these technologies in various industrial contexts.

These analyses contribute to identifying the key factors shaping the perceived impact of Industry 5.0 technologies.

3. Results

The graph in Figure 1 illustrates the breakdown of the companies participating in this study by sector of industry sector, highlighting the diversity of the industries involved. The automotive and aerospace sectors account for the largest share of the sample.

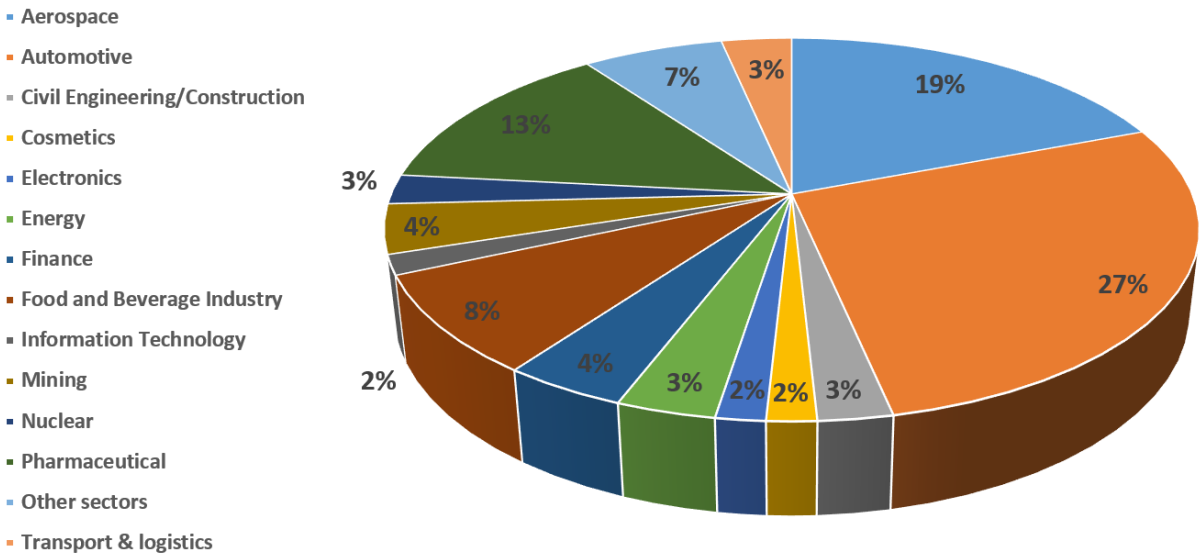

Figure 1.
Sector Representation of Surveyed Companies.

As part of this study, it is important to understand the context in which companies operate when it comes to operational excellence. The companies represented use various methodologies to improve their internal processes and achieve optimal performance, as shown in Figure 2. Among these, Lean Six Sigma is the most widely implemented method (63%), followed by Lean Management and KAIZEN (60% each). These traditional approaches aim to minimize waste and maximize process efficiency. Other methods, such as Agile Project Management (48%) and Lean Manufacturing (54%), are also popular, highlighting a need for adaptability and rapid response to market changes. Green Lean Six Sigma, adopted by 39% of companies, reflects a growing focus on sustainability goals by integrating green practices into continuous improvement strategies.

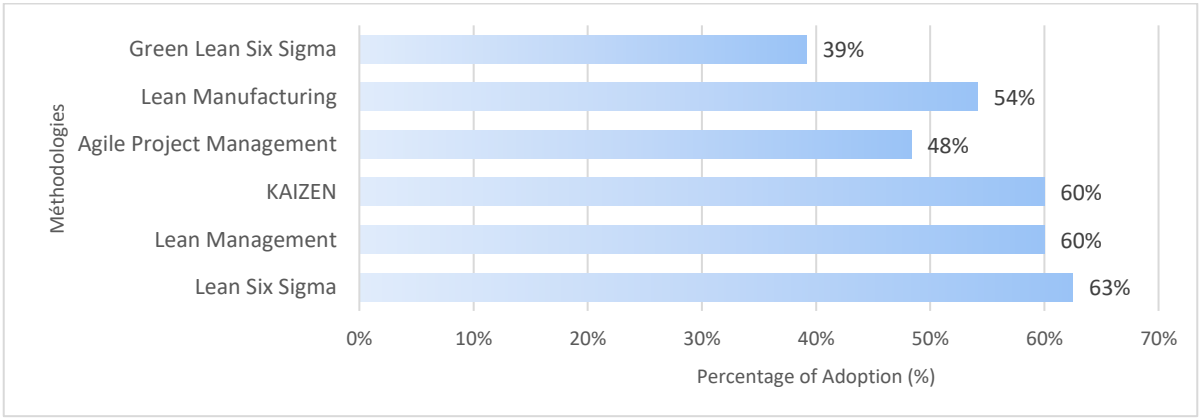

Figure 2.
Main tools, methodologies and approaches used to promote operational excellence in represented companies.

The distribution illustrated in Figure 3 shows the frequency of the main Industry 5.0 technologies implemented by the companies represented. These companies prioritize the adoption of technologies that offer robust connectivity and data analytics capabilities, such as AI, IoT, and Big Data, which are seen as key levers for digital transformation that bring immediate and tangible benefits. On the other hand, the more limited adoption of technologies such as additive manufacturing, digital twins, and cobots suggests the presence of potential challenges related to cost, integration, or technology readiness.

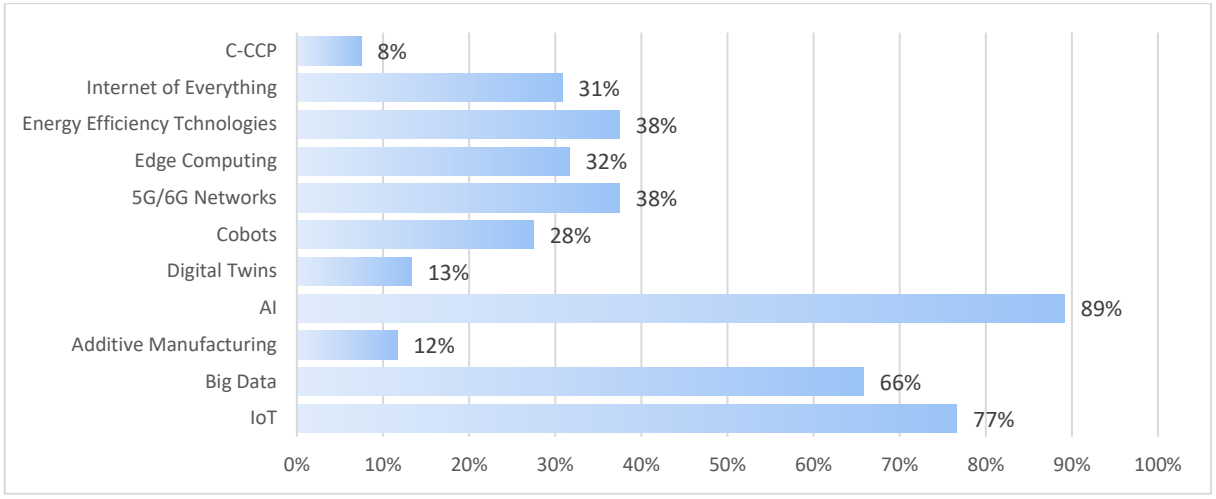

Figure 3.
Frequency of main Industry 5.0 Technologies Implemented in the represented companies.

Work Process Efficiency and Productivity: Figure 4 illustrates the various contributions of Industry 5.0 technologies to improve work process efficiency. Results indicate that real-time data collection (93%) and real-time monitoring (88%) are the most recognized contributions of Industry 5.0 technologies to improve the efficiency of work processes. This reveals a marked trend towards decision-making based on accurate and up-to-date data. Indeed, companies seem to favor technologies that allow them to have a clear and instant view of their operations, which is essential for proactive and reactive management.

However, task automation is only valued by 43% of respondents, despite its well-known benefits in terms of cost reduction and improved accuracy. This contradiction merits further exploration to understand whether the adoption of automation is held back by economic, cultural, or regulatory factors, or whether it is more dependent on technology readiness and organizational readiness.

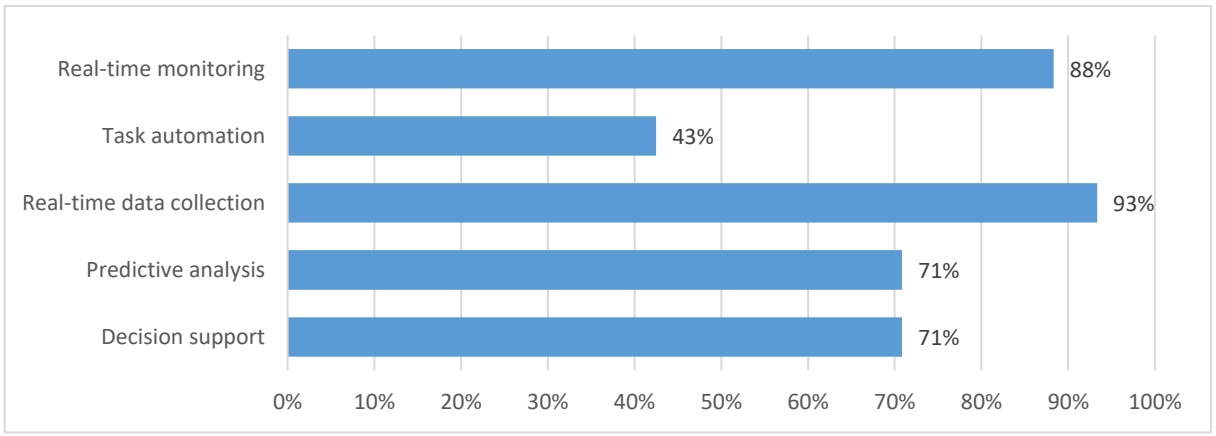

Figure 4.
Contributions of the Technologies of 5.0 to the Efficiency and Productivity of Work Processes.

Quality and reliability Improvement: The contribution of Industry 5.0 technologies to improving quality is mainly attributed to automated process monitoring (96%) and early detection of anomalies (65%), as shown in Figure 5. These findings highlight a movement toward proactive quality management approaches, where companies invest in technologies that enable rapid detection and resolution of issues before they become critical. However, real-time quality control and improved process accuracy and reliability are only 57% valued. This comparatively low figure could suggest that while technologies are available to boost quality, their adoption is not universal. This may be due to limitations in skills or resources, or a mistrust in the ability of these technologies to integrate seamlessly into existing processes.

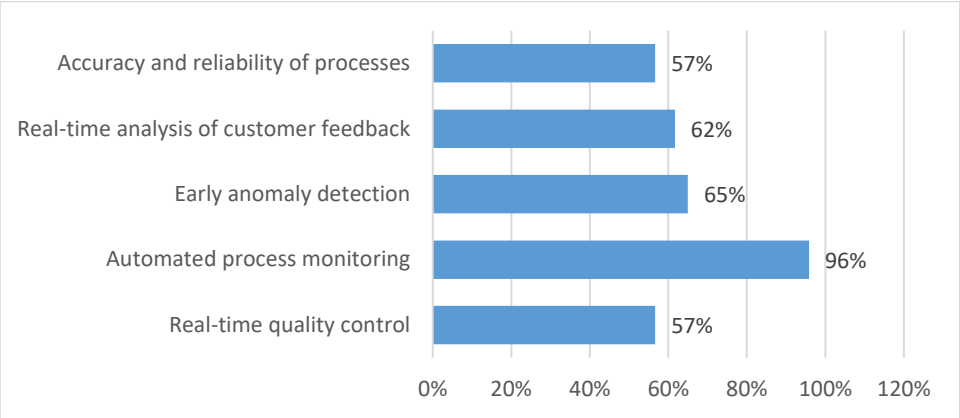

Figure 5.
Impact of industry 5.0 Technologies on quality and reliability.

Operational Agility: As shown in Figure 6, Agility in decision-making (86%) and flexibility in change management (81%) are identified as the aspects most impacted by new technologies. This trend shows that companies recognize the value of technologies that allow for rapid adaptation to changes, whether internal or external. This is consistent with the contemporary challenges of a volatile market environment, in which the capacity to respond swiftly to changes has become a key competitive advantage. However, rapid adaptability to new market demands (74%) and real-time collaboration between teams (54%) are less mentioned. This could reflect gaps in the digital tools and infrastructure available to facilitate seamless collaboration or the under-use of these technologies. Real-time collaboration might not be perceived as critical, or businesses might encounter obstacles such as organizational silos or inadequate technology infrastructure.

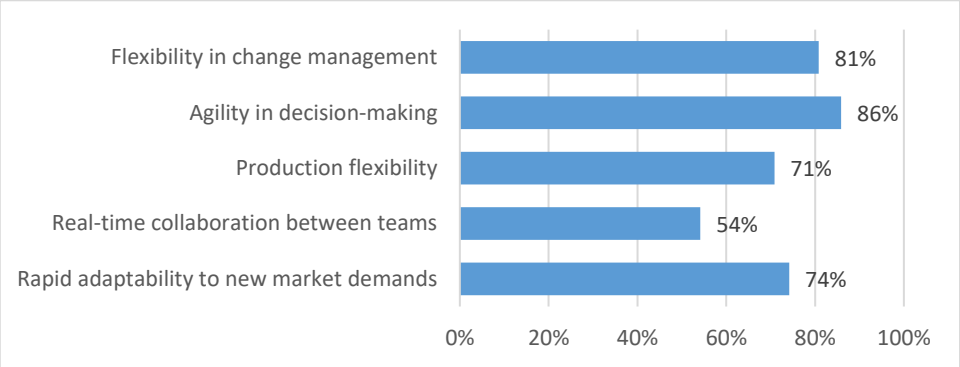

Figure 6.
Specific aspects of organizational agility have been impacted by new technologies.

Continuous Innovation: The results, illustrated in Figure 7, show that new technologies stimulate creativity (63%) and encourage technological experimentation (64%). However, access to the global innovation ecosystem is low (33%). This contrast indicates an under-tapped potential in open innovation. Although companies invest in technologies that facilitate internal innovation, they do not maximize their participation in external innovation ecosystems, such as partnerships with startups, research institutes, or other companies. This limitation may be due to a lack of confidence or skills to manage complex external collaborations, or a strategic focus more focused on proprietary innovation. This suggests a need for companies to review their innovation strategy to include more external collaboration and knowledge sharing to increase their competitiveness.

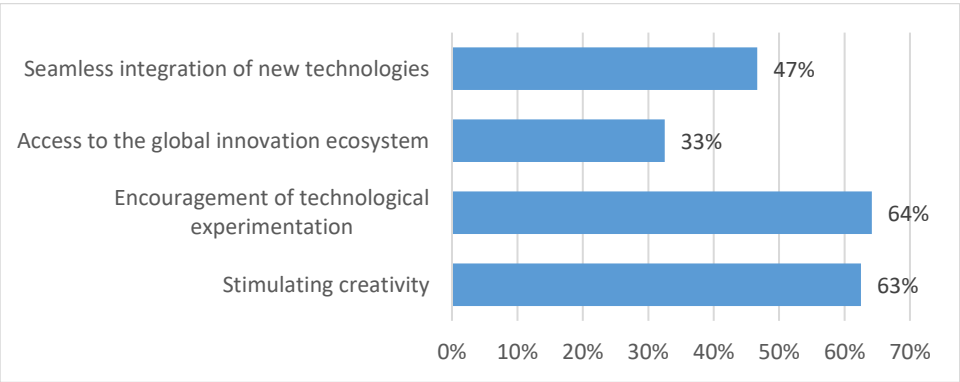

Figure 7.
New Technologies' Contribution to Promoting Ongoing Innovation in Companies.

Customer Experience: Regarding customer experience, Figure 8 illustrates the key areas for improvement thanks to Industry 5.0 technologies identified by companies. Emphasis is placed on expediting ordering and delivery processes (57%) and the ease of use of online platforms (53%). This reflects a focus on boosting operational efficiency and improving user experience. Nevertheless, personalization of interactions and offers (30%) and security of data and transactions (21%) are considerably undervalued. This disparity could suggest that companies have not yet fully harnessed technologies like artificial intelligence and data analytics to deeply enhance personalization in the customer experience. The low data security score may indicate insufficient investment or trust in current cybersecurity solutions, a critical point in an increasingly digital world where customer trust is key.

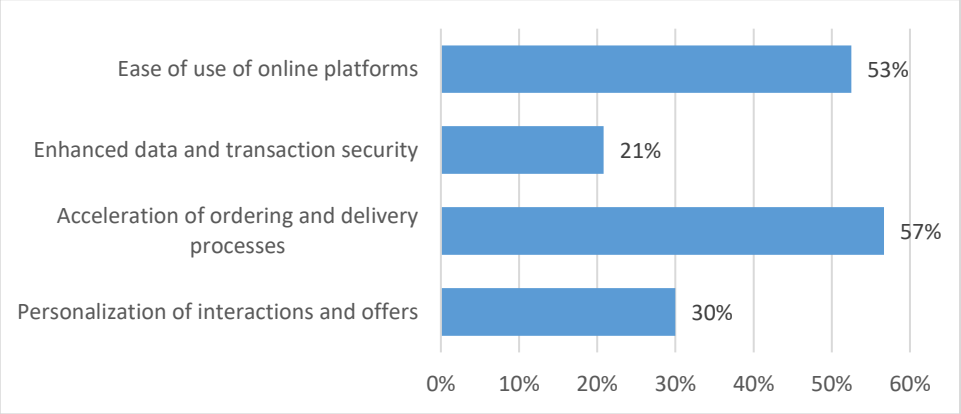

Figure 8.
Contribution of Industry 5.0 Technologies to Enhancing Customer Experience.

Sustainable Practices: As shown in Figure 9, industry 5.0 technologies are perceived to exert a substantial impact on reducing carbon footprint (76%) and implementing green technologies (63%). However, the application of data analytics for sustainability (53%) and energy efficiency improvement (50%) has lower scores, indicating partial adoption of advanced energy and analytics technologies. These findings suggest that while companies are increasingly incorporating sustainable practices, there remains untapped potential for more strategic use of analytics technologies and energy management tools. Greater adoption of these technologies could result in further gains in sustainability and operational efficiency.

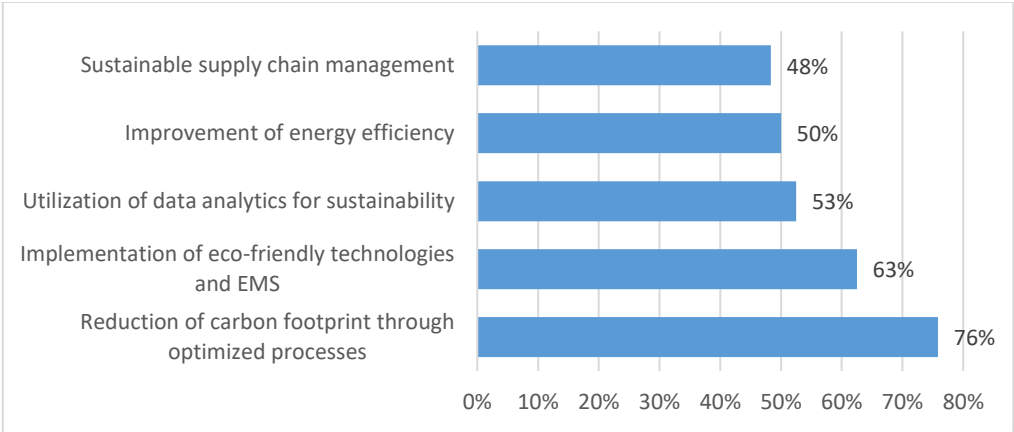

Figure 9.
Contribution of New Technologies to Sustainability.

Operational Resilience: When it comes to resilience, Figure 10 highlights that companies prioritize supply chain flexibility (65%) and remote work solutions (62%), showing their willingness to adapt to disruption. However, redundancy of critical systems (23%) and remote process automation and management (26%) receive much lower scores, which could indicate under-preparedness for crises and over-reliance on centralized or rigid systems. This trend shows that, while companies recognize the important value of resilience, they have not yet undertaken a proactive and integrated approach to building their ability to respond to crises robustly.

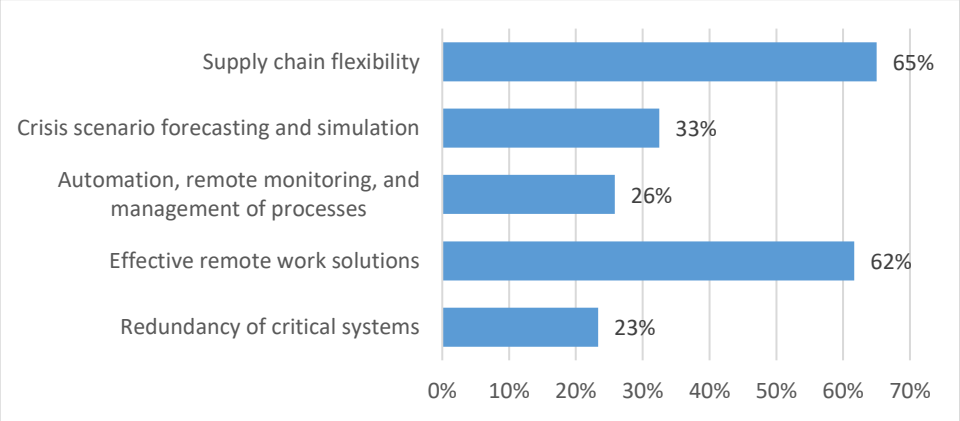

Figure 10.
Contribution of New Technologies to Strengthening Organizational Resilience.

Regarding the assessment of the impact of Industry 5.0 technologies, the results presented in Table 1 show a diversity in the level of impact of Industry 5.0 technologies on different aspects of operational excellence within the companies represented.

Table 1.
Statistical Analysis of the Impact of Industry 5.0 Technologies on Various Aspects of Operational Excellence.

		Efficiency and productivity	Quality and reliability	Organizational agility	Innovation	Customer satisfaction	Resilience	Sustainability
N	Valid	120	120	120	120	120	120	120
Mean		3.83	3.58	3.97	2.82	2.71	3.08	3.85
Std. Error of Mean		0.079	0.091	0.100	0.088	0.080	0.076	0.113
Median		4.00	4.00	4.00	3.00	3.00	3.00	4.00
Mode		4	4	5	3	3	3	5
Std. Deviation		0.863	1.001	1.100	0.961	0.873	0.832	1.241
Variance		0.745	1.003	1.209	0.924	0.763	0.692	1.540
Skewness		-0.546	-0.491	-0.859	0.608	0.070	0.392	-1.051
Std. Error of Skewness		0.221	0.221	0.221	0.221	0.221	0.221	0.221
Kurtosis		-0.184	-0.284	-0.288	0.090	0.204	0.031	0.306
Std. Error of Kurtosis		0.438	0.438	0.438	0.438	0.438	0.438	0.438
Range		3	4	4	4	4	4	4
Sum		460	429	476	338	325	369	462
Percentiles	25	3.00	3.00	3.00	2.00	2.00	3.00	3.00
	50	4.00	4.00	4.00	3.00	3.00	3.00	4.00
	75	4.00	4.00	5.00	3.00	3.00	4.00	5.00
Impact level	Level 1	0%	3%	2%	4%	8%	1%	10%
	Level 2	9%	13%	13%	37%	29%	23%	2%
	Level 3	19%	25%	12%	40%	48%	51%	20%
	Level 4	51%	43%	33%	12%	12%	20%	30%
	Level 5	21%	17%	40%	8%	3%	6%	38%

Improved business process management: Most respondents (51%) rate improving the productivity and efficiency of business processes at Level 4, with 21% at Level 5, indicating an overall positive impact of Industry 5.0 technologies on this area. The median and mode of 4 confirm that most respondents indicate a significant positive perception. The low variance (0.745) and the slightly skewed rightward distribution (Skewness: -0.546) suggest that the majority of respondents perceive a noticeable but not optimal improvement, which is in line with the gradual nature of digital transformation. Respondents see Industry 5.0 technologies as enablers of efficiency and productivity, mainly thanks to real-time monitoring and decision-making reinforced by data collection technologies, which optimize operations management.

Impact on the quality and reliability of products or services: The impact on quality and reliability is perceived in a positive but moderate way. With 43% of respondents at Level 4 and 17% at Level 5, improvement is recognized, although less pronounced than for efficiency and productivity. The less skewed distribution (Skewness: -0.491) and a higher standard deviation (1.001) indicate greater diversity in perceptions. This implies that certain companies have managed to leverage

quality control and data analytics technologies to improve their products, while others have yet to fully integrate and leverage these technologies into their production processes.

Increased operational agility: New technologies are strongly associated with improving operational agility, with 40% of responses at level 5. This perception is in line with the aims of Industry of Industry 5.0 technologies, which seeks to boost the flexibility and responsiveness of companies. The more pronounced asymmetry (Skewness: -0.859) shows a trend towards higher valuations, indicating confidence in the capabilities of technologies to increase agility. This positive perception can be attributed to the adoption of technologies that enable real-time decision-making, flexibility in change management, and better responsiveness to market changes.

Stimulation of innovation: The perceived impact on innovation is relatively low, with 40% responses at Level 3 and only 8% at Level 5. The positive skewness (Skewness: 0.608) confirms this trend towards lower scores. These findings imply that numerous companies have not yet completely leveraged the potential of technologies to drive innovation. This could result from an underutilization of emerging technologies or an organizational culture that does not sufficiently foster experimentation and open innovation.

Contribution to customer satisfaction: With a majority of responses at level 3 (48%) and a small proportion at level 5 (3%), the impact of technology on customer satisfaction is perceived as limited. A relatively symmetrical distribution around the mean (Skewness: 0.070) indicates an absence of clear consensus among respondents. This perception could be due to an incomplete implementation of personalization technologies or challenges in integrating customer-facing technology solutions.

Strengthening operational resilience: The impact on resilience is moderate, with 51% of responses at level 3. This shows that, although technologies are recognized as useful for building resilience, their current application is not yet able to overcome all disruptions. The skewness (Skewness: 0.392) towards lower values reflects potential for improvement. The low standard deviation (0.832) suggests a stronger consensus among respondents. While these recognize some benefits, such as automation and remote monitoring, the overall impact is perceived to be limited. This suggests that numerous companies could benefit from a more strategic integration of resilience technologies.

Environmental sustainability: Sustainability is one of the most favorably impacted areas, with 38% of responses at level 5 and 30% at level 4. These results demonstrate that Industry 5.0 technologies are considered essential to achieve sustainability goals. The distribution is slightly skewed towards high values (Skewness: -1.051), indicating a strong and consistent perception of the positive impact. While the high standard deviation (1.241) reveals a wide range of opinions among respondents, respondents seem to particularly value technologies that contribute to minimizing carbon footprints, increasing energy efficiency, and sustainable supply chain management. This positive perception could reflect an increased awareness of the necessity for sustainable practices and the successful integration of green technologies.

Disparities between Domains: By comparing the spread of responses between the different domains, we can identify domains where the impact of technologies is maximized or limited, as depicted in Figure 11. The percentages at Levels 4 and 5 for areas like process management (72%) and agility (73%) are relatively high, while innovation (20% for Levels 4 and 5 combined) and customer satisfaction (15%) are much lower. This indicates that, although the fact that Industry 5.0 technologies are widely adopted, their ability to foster innovation or readily enhance customer satisfaction may not be as well understood or leveraged.

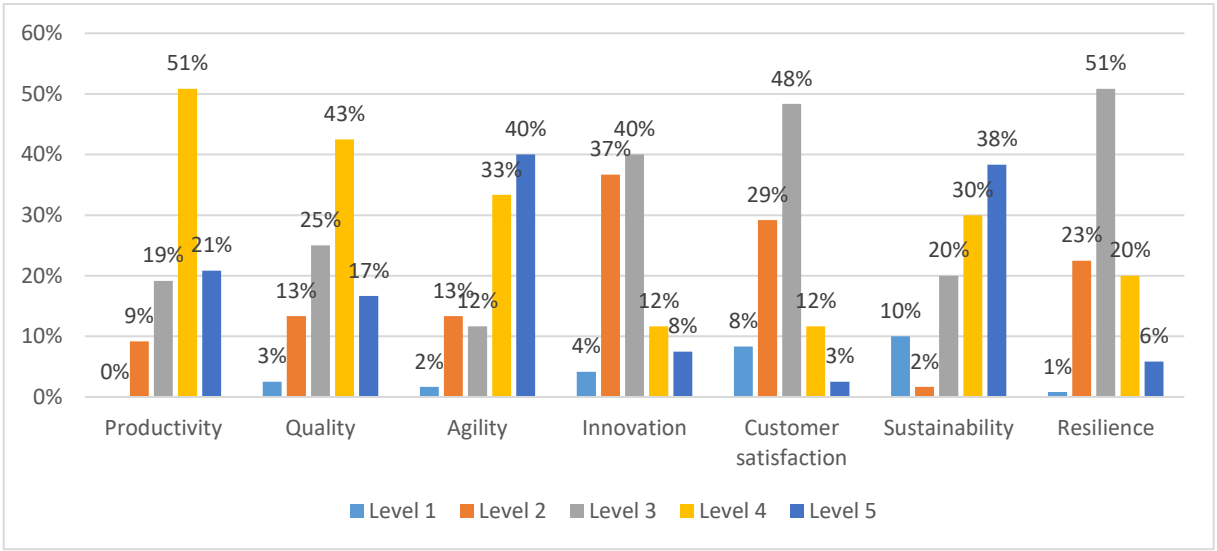

Figure 11.
Breakdown of Impact Levels of Industry 5.0 Technologies on Different Aspects of Operational Excellence.

Table 2 shows the correlations between different aspects of operational excellence, depending on the impact level of new technologies. Each aspect, such as efficiency and productivity, quality and reliability, organizational agility, innovation, customer satisfaction, resilience, and sustainability, was treated as a separate variable.

Table 2.
Analyzing the Correlations between the Dimensions of Operational Excellence.

			Efficiency and productivity	**Quality and reliability**	**Organizational agility**	**Innovation**	**Customer satisfaction**	**Resilience**	**Sustainability**
Spearman's rho	Efficiency and productivity	Correlation Coefficient	1.000	0.526**	0.445**	0.233*	0.194*	0.108	0.230*
		Sig. (2-tailed)		0.000	0.000	0.010	0.033	0.239	0.012
	Quality and reliability	Correlation Coefficient	0.526**	1.000	0.426**	0.255**	0.072	0.038	.318**
		Sig. (2-tailed)	0.000		0.000	0.005	0.434	0.679	0.000
	Organizational agility	Correlation Coefficient	0.445**	0.426**	1.000	0.088	0.216*	0.120	0.152
		Sig. (2-tailed)	0.000	0.000		0.341	0.018	0.193	0.097
	Innovation	Correlation Coefficient	0.233*	.255**	0.088	1.000	0.088	0.134	0.040
		Sig. (2-tailed)	0.010	0.005	0.341		0.337	0.146	0.661
	Customer satisfaction	Correlation Coefficient	0.194*	0.072	0.216*	0.088	1.000	0.419**	0.032
		Sig. (2-tailed)	0.033	0.434	0.018	0.337		0.000	0.728
	Resilience	Correlation Coefficient	0.108	0.038	0.120	0.134	.419**	1.000	-0.004
		Sig. (2-tailed)	0.239	0.679	0.193	0.146	0.000		0.969
	Sustainability	Correlation Coefficient	0.230*	0.318**	0.152	0.040	0.032	-0.004	1.000
		Sig. (2-tailed)	0.012	0.000	0.097	0.661	0.728	0.969	

Note: **. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

A moderate and significant positive correlation exists between the productivity and efficiency of work processes and the quality and reliability of products/services ($r = 0.526$), suggesting that companies that optimize their business processes through Industry 5.0 technologies also perceive an improvement in the quality and reliability of the products or services provided. This might be due to more efficient processes reducing defects and increasing production consistency, leading to better perceived quality.

Similarly, a moderate correlation ($r = 0.445$, $p < 0.01$) is observed between efficiency and productivity of work processes and organizational agility, implying that improving business processes through Industry 5.0 technologies is also linked to greater operational agility. Companies that optimize their processes can also adapt more quickly to market changes or new customer requirements.

The impact on product/service quality and reliability is also correlated with the impact on agility ($r = 0.426$, $p < 0.01$), highlighting that companies that perceive improved quality through technologies also see increased flexibility in their operations. Furthermore, a moderate and significant correlation between the contribution of technologies to customer satisfaction and resilience ($r = 0.419$, $p < 0.01$) suggests that technologies that raise customer satisfaction, such as through better responsiveness and quality of service, are also associated with improved resilience to disruption.

Of the 21 possible correlations between the variables examined, about half (10) are significant at the confidence level of 0.05 or 0.01. This suggests that several important relationships exist between the different aspects of operational excellence, but also that these relationships are not uniform across all dimensions studied. Some variables, such as the productivity and efficiency of work processes and the quality and reliability of products or services, show more significant correlations with other dimensions, pointing out that they are pivotal to the integration of emerging technologies. In contrast, other variables, such as resilience, show little or no significant correlations, suggesting that their relationship is less direct or that other factors are at play. The diversity in the strengths and number of these correlations indicates that the impact of Industry 5.0 technologies varies across organizational contexts and specific application areas.

4. Discussion

This study examines the impact of Industry 5.0 technologies on different aspects of operational excellence, with a focus on process efficiency, product or service quality, organizational agility, continuous innovation, customer satisfaction, organizational resilience, and environmental sustainability. Findings show that, despite the adoption of Industry 5.0 technologies perceived as beneficial, their impact varies considerably across the dimensions studied.

The results highlight the importance of real-time data gathering and analysis capabilities, backed by Industry 5.0 technologies. The seamless integration of these technologies enables decision-making based on up-to-date data, thereby optimizing efficiency, productivity, and quality of operations [20, 21]. Recent advances in areas such as AI, IoT, Cloud Computing, Big Data, and Cyber-Physical Systems have accelerated the transition to smart manufacturing, bringing major benefits with regard to sustainability, profitability, and productivity [22].

According to previous studies, Industry 5.0 leverages adaptive robots, collaborative cyber-physics systems, and human interaction and recognition technologies to improve productivity and efficiency [7, 23, 24]. However, the more moderate valuation given to this contribution within the companies studied could indicate an incomplete integration of these technologies. This could reflect constraints in skills, resources, or uncertainties about their seamless integration into existing processes. However, the human factor remains crucial, particularly regarding ownership of change and the ability to make full use of these technologies. While automation and emerging technologies significantly increase production and efficiency, human capabilities and creativity remain essential for making decisions, solving problems, and developing new ideas [21].

Improving process efficiency and productivity is seen as one of the most notable impacts of Industry 5.0. The correlations identified in this study suggest that operational efficiency is a foundation that directly influences product/service quality, organizational agility, and resilience. Concerning quality and reliability improvement, the results highlight that Industry 5.0 promotes a proactive approach focused on ongoing monitoring and prompt detection of anomalies. Organizational agility outcomes indicate that emerging technologies are perceived as significant enablers of organizational flexibility, particularly in data-driven rapid decision-making and change management. The companies represented recognize the importance of digital capabilities to quickly adapt to market fluctuations and customer requirements.

As far as environmental sustainability is concerned, this dimension appears to be among the most beneficially impacted by Industry 5.0. Advanced digital technologies help reduce carbon footprint and optimize energy efficiency, contributing to sustainable business practices. These findings are consistent with previous work collectively recognize that the driving force behind Industry 5.0 is to embed inclusive sustainability goals into the ongoing digital industrial transformation [22, 25-27].

The effect on innovation is perceived as relatively limited, indicating an under-use of emerging technologies to stimulate innovation. Companies could benefit from greater involvement in external innovation ecosystems to strengthen their competitiveness. Industry 5.0 facilitates a productive workplace that fosters innovation, skills development, and work-life balance [28].

Relating to customer experience, the results show a focus on process efficiency, such as faster orders and ease of use of online platforms but reveal an under-utilization of personalization technologies. This suggests that companies have not yet fully embraced digital solutions to deliver a differentiated customer experience, despite the potential of technologies like 3D printing and data-driven automation to create bespoke products and maximize customer satisfaction [21, 29].

Operational resilience, while recognized as an important strategic objective, is perceived as relatively underdeveloped. Low scores for redundancy of critical systems and remote process automation reflect an over-reliance on centralized and rigid systems. This indicates that businesses need to take a more proactive approach to integrating resilient technologies and

preparing for future disruptions. The decentralized systems offered by Industry 5.0 can play a key role in improving the resilience of production chains [30].

This study reveals that while Industry 5.0 technologies are widely adopted and perceived as beneficial, disparities exist in their perceived impact, particularly regarding customer satisfaction and innovation. Companies, therefore, need to further explore how these technologies can be strategically integrated to maximize their effect on all these aspects, especially by driving innovation and improving customer experience.

On a practical level, managers should be aware that adopting these technologies requires a holistic approach that goes beyond improving internal processes to also include efforts to drive innovation and improve customer satisfaction. Companies should invest in cutting-edge technologies and align these investments with well-defined organizational strategies, while considering the specific challenges related to technology integration and change management, to increase their impact on the various dimensions of operational excellence.

To strengthen innovation and resilience, in particular, specific strategies to develop internal skills, foster a culture of innovation, and integrate new technologies more closely into risk and operations management should be taken into account. Companies should also further explore open innovation and the adoption of emerging technologies to drive creativity and innovation within their organizations. Particular attention should be paid to employee training and the integration of emerging technologies into quality and sustainability management practices. In addition, it is essential to improve the integration of customer-facing technologies for personalizing offers and elevating customer satisfaction. Businesses should also invest in risk management solutions to better prepare for future disruptions.

5. Conclusion

This study highlights the differentiated impact of Industry 5.0 technologies on the various dimensions of business operational excellence. The analysis reveals that technologies are effective in improving process productivity and organizational agility. In addition, the study highlights the under-tapped potential of technology to stimulate innovation and enrich customer experience. This calls for companies to adopt a more systematic and interconnected approach to digital transformation by fully integrating these technologies into overall innovation and change management strategies. The implementation of technologies, including digital twins, additive manufacturing, and artificial intelligence, in these domains could enable companies to bolster their competitiveness over the long term.

The implementation of technologies such as digital twins, additive manufacturing, and artificial intelligence in these sectors may allow companies to bolster their competitiveness over the long term.

On a practical level, our findings suggest that policymakers need to go beyond improving existing processes to implement strategies that encourage open innovation and collaboration with external ecosystems. Particular attention must be paid to changing management and the training of employees' digital skills, which are prerequisites for the optimization of Industry 5.0 technologies. Furthermore, the proactive integration of technologies into quality, sustainability, and customer satisfaction management practices is imperative to ensure sustainable competitiveness in a rapidly changing market environment. Analyzing the barriers to the full adoption of emerging technologies is also relevant to understanding the complex dynamics that influence digital transformation on an industrial scale.

References

[1] J. Leng *et al.*, "Industry 5.0: Prospect and retrospect," *Journal of Manufacturing Systems*, vol. 65, pp. 279-295, 2022. https://doi.org/10.1016/j.jmsy.2022.09.017

[2] S. Saniuk, S. Grabowska, and M. Straka, "Identification of social and economic expectations: Contextual reasons for the transformation process of Industry 4.0 into the Industry 5.0 concept," *Sustainability*, vol. 14, no. 3, p. 1391, 2022. https://doi.org/10.3390/su14031391

[3] S. Huang, B. Wang, X. Li, P. Zheng, D. Mourtzis, and L. Wang, "Industry 5.0 and society 5.0—comparison, complementation and co-evolution," *Journal of Manufacturing Systems*, vol. 64, pp. 424-428, 2022. https://doi.org/10.1016/j.jmsy.2022.07.010

[4] X. Xu, Y. Lu, B. Vogel-Heuser, and L. Wang, "Industry 4.0 and Industry 5.0—Inception, conception and perception," *Journal of Manufacturing Systems*, vol. 61, pp. 530-535, 2021. https://doi.org/10.1016/j.jmsy.2021.10.006

[5] Z. Fatima *et al.*, "Production plant and warehouse automation with IoT and industry 5.0," *Applied Sciences*, vol. 12, no. 4, p. 2053, 2022. https://doi.org/10.3390/app12042053

[6] D. Paschek, A. Mocan, and A. Draghici, "Industry 5.0 – the expected impact of next industrial revolution," In Thriving on future education, industry, business, and society," in *Proceedings of the MakeLearn and TIIM International Conference*, 2019, pp. 15–17.

[7] P. K. R. Maddikunta *et al.*, "Industry 5.0: A survey on enabling technologies and potential applications," *Journal of Industrial Information Integration*, vol. 26, p. 100257, 2022. https://doi.org/10.1016/j.jii.2021.100257

[8] European Commission, *Directorate-general for research and innovation, & Müller, J. (2020). Enabling Technologies for Industry 5.0: Results of a workshop with Europe's technology leaders*. Luxembourg: Publications Office of the European Union, 2020.

[9] N. Chen and M. Okada, "Toward 6G internet of things and the convergence with RoF system," *IEEE Internet of Things Journal*, vol. 8, no. 11, pp. 8719-8733, 2020. https://doi.org/10.1109/JIOT.2020.3047613

[10] L. Xu, X. Zhou, Y. Tao, X. Yu, M. Yu, and F. Khan, "AF relaying secrecy performance prediction for 6G mobile communication networks in industry 5.0," *IEEE Transactions on Industrial Informatics*, vol. 18, no. 8, pp. 5485-5493, 2021. https://doi.org/10.1109/TII.2021.3120511

[11] S. Nahavandi, "Industry 5.0—A human-centric solution," *Sustainability*, vol. 11, no. 16, p. 4371, 2019.

[12] D. K. Mishra and D. Paul, "Industry 5.0: Human touch and the future," presented at the 2022 OPJU International Technology Conference on Emerging Technologies for Sustainable Development (OTCON), IEEE, 2023.

[13] M. P. Kovilage, S. T. Yapa, and C. Hewagamage, "Research areas, gaps and future research directions of operational excellence: A systematic literature review," *South Asian Journal of Business Insights*, vol. 2, no. 1, pp. 3–32, 2022. https://doi.org/10.4038/sajbi.v2i1.31

[14] A. M. Carvalho, P. Sampaio, and E. Rebentisch, "On agile metrics for operations management: measuring and aligning agility with operational excellence," in *2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2019: IEEE, pp. 1601-1605.

[15] D. Wojtkowiak and P. Cyplik, "Operational excellence within sustainable development concept-systematic literature review," *Sustainability*, vol. 12, no. 19, p. 7933, 2020. https://doi.org/10.3390/su12197933

[16] J. Antony *et al.*, "Global perspectives on operational excellence: unveiling critical failure factors and sustainable pathways," *International Journal of Quality & Reliability Management*, vol. 41, no. 10, pp. 2604-2626, 2024. https://doi.org/10.1108/IJQRM-01-2024-0013

[17] R. Henríquez-Machado, A. Muñoz-Villamizar, and J. Santos, "Sustainability through operational excellence: an emerging country perspective," *Sustainability*, vol. 13, no. 6, p. 3165, 2021. https://doi.org/10.3390/su13063165

[18] S. Nayeri, Z. Sazvar, and J. Heydari, "Towards a responsive supply chain based on the industry 5.0 dimensions: A novel decision-making method," *Expert Systems with Applications*, vol. 213, p. 119267, 2023. https://doi.org/10.1016/j.eswa.2022.119267

[19] M. Bezoui, A. T. Almaktoom, A. Bounceur, S. M. Qaisar, and M. Chouman, "Hybrid Metaheuristics for Industry 5.0 Multi-Objective Manufacturing and Supply Chain Optimization," in *2024 21st Learning and Technology Conference (L&T)*, 2024: IEEE, pp. 245-249.

[20] O. B. Akan, E. Dinc, M. Kuscu, O. Cetinkaya, and B. A. Bilgin, "Internet of everything (IoE)-from molecules to the universe," *IEEE Communications Magazine*, vol. 61, no. 10, pp. 122-128, 2023. https://doi.org/10.1109/MCOM.001.2200594

[21] D. M. Dave, "Advancing resilience and agility in manufacturing through Industry 5.0: A review of digitization, automation, and advanced analytics," *International Journal of New Technology and Research*, vol. 9, pp. 5-12, 2023. https://doi.org/10.31295/ijntr.v9i6.2321

[22] B. Rahardjo, F.-K. Wang, S.-C. Lo, and T.-H. Chu, "A sustainable innovation framework based on lean six sigma and industry 5.0," *Arabian Journal for Science and Engineering*, vol. 49, no. 5, pp. 7625-7642, 2024. https://doi.org/10.1007/s13369-023-08565-3

[23] A. Nourmohammadi, M. Fathi, and A. H. Ng, "Balancing and scheduling assembly lines with human-robot collaboration tasks," *Computers & Operations Research*, vol. 140, p. 105674, 2022. https://doi.org/10.1016/j.cor.2021.105674

[24] S. Wang, M. Guo, Y.-X. Hu, Y.-K. Chiu, and C. Jing, "Smart manufacturing business management system for network industry spin-off enterprises," *Enterprise Information Systems*, vol. 16, no. 2, pp. 285-306, 2022. https://doi.org/10.1080/17517575.2020.1722254

[25] L. Alexa, M. Pîslaru, and S. Avasilcăi, "From Industry 4.0 to Industry 5.0—an overview of European Union enterprises," *Sustainability and Innovation in Manufacturing Enterprises: Indicators, Models and Assessment for Industry 5.0*, pp. 221-231, 2022. https://doi.org/10.1007/978-981-16-7365-8_8

[26] M. Ghobakhloo, M. Iranmanesh, M. F. Mubarak, M. Mubarik, A. Rejeb, and M. Nilashi, "Identifying industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values," *Sustainable Production and Consumption*, vol. 33, pp. 716-737, 2022. https://doi.org/10.1016/j.spc.2022.08.003

[27] M. Golovianko, V. Terziyan, V. Branytskyi, and D. Malyk, "Industry 4.0 vs. Industry 5.0: Co-existence, transition, or a hybrid," *Procedia Computer Science*, vol. 217, pp. 102-113, 2023. https://doi.org/10.1016/j.procs.2022.12.206

[28] D. Guile and J. Mitchell, *Fusion skills and Industry 5.0: conceptions and challenges*. Intech Open Books. http://doi.org/10.5772/intechopen.100096, 2022.

[29] W. Xiang, K. Yu, F. Han, L. Fang, D. He, and Q.-L. Han, "Advanced manufacturing in industry 5.0: A survey of key enabling technologies and future trends," *IEEE Transactions on Industrial Informatics*, vol. 20, no. 2, pp. 1055-1068, 2023. https://doi.org/10.1109/TII.2023.3274224

[30] J. Leng *et al.*, "Towards resilience in Industry 5.0: A decentralized autonomous manufacturing paradigm," *Journal of Manufacturing Systems*, vol. 71, pp. 95-114, 2023. https://doi.org/10.1016/j.jmsy.2023.08.023