DIGITAL TRANSFORMATION IN THE MANAUS FREE TRADE ZONE: IMPACTS AND CHALLENGES OF IMPLEMENTING INDUSTRY 4.0 TOWARDS SOCIETY 5.0

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ABSTRACT

This article explores how the implementation of Industry 4.0 technologies in the Manaus Industrial Estate (PIM) can enable the transition to Society 5.0, aligning industrial efficiency, technological innovation and social welfare. The research adopts a mixed approach, combining qualitative and quantitative methods, with the application of a case study and field research. The results show that 75% of the companies surveyed have already started initiatives aimed at Society 5.0, mainly focused on areas such as Production/Operations and Information Technology. However, challenges such as a lack of skilled labor, resistance to change and high costs still limit the transformative potential of these technologies. Concrete benefits have been identified, including cost reduction, greater connectivity and customer satisfaction. This study proposes an integrative model that aligns the adoption of Industry 4.0 technologies with the principles of Society 5.0, highlighting strategies such as professional training, tax incentives and collaboration between companies and educational institutions. It concludes that digital transformation in the PIM has significant potential to promote

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technological innovation and social inclusion, positioning the Manaus Free Trade Zone as a global benchmark in sustainable and socially responsible development.

Keywords

Industry 4.0; Society 5.0; Manaus Free Trade Zone; Manaus Industrial Estate; Digital Transformation; Sustainability.

1 INTRODUCTION

Industry 4.0, often referred to as the Fourth Industrial Revolution, is a transformative milestone in the global industrial landscape. This paradigm is characterized by the integration of advanced technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, advanced robotics and cyber-physical systems (CPS), promoting automation, connectivity and efficiency at unprecedented levels (Schwab, 2016). In Brazil, the Manaus Free Trade Zone (ZFM) emerges as a peculiar case, being an important economic hub that simultaneously faces structural challenges and seeks to align itself with the demands of an increasingly digitalized global market.

Created in 1967 with the aim of promoting economic and social development in the Amazon, the ZFM has established itself as one of the region's main industrial engines, covering diverse sectors such as electronics, chemicals and two-wheelers (Silva & Silva, 2017). However, the technological modernization of local industries has become a requirement for the ZFM to maintain its relevance on the global stage. In this context, the digital transformation driven by Industry 4.0 technologies is not just an opportunity, but a necessity to ensure the competitiveness of the Manaus Industrial Estate (PIM).

The transition to Society 5.0, a concept introduced in Japan, presents a promising horizon for integrating technological advances with human and social needs (Fukuyama, 2018). This vision proposes an inclusive and sustainable digital economy that uses technologies such as AI and IoT not only for economic gain, but also to solve social challenges such as inequality, poor infrastructure and climate change (Deguchi et al., 2020). In this way, aligning the principles of Industry 4.0 with the goals of Society 5.0 becomes essential for transforming the ZFM into a model of sustainable and innovative development.

Justification

The relevance of this research lies in the need to modernize the Manaus Industrial Estate in the face of competitive pressures and the challenges posed by globalization and economic digitalization. Although the ZFM represents a significant portion of the Brazilian economy

and plays a strategic role in job creation and environmental preservation, many of its production processes remain outdated in relation to global trends (CNI, 2018). In addition, the transition to Society 5.0 can contribute to tackling social and structural problems that have limited the region's full development for decades.

Investing in the implementation of Industry 4.0 technologies in the PIM will not only increase its productivity and efficiency, but will also create the conditions to align industrial growth with social welfare, in line with the principles of Society 5.0. Initiatives such as process automation, the use of real-time data and professional training can reduce regional inequalities and position the ZFM as an example of a sustainable and innovative economy.

In this context, this study seeks to explore how the implementation of Industry 4.0 technologies in the Manaus Industrial Estate (PIM) can enable the transition to Society 5.0, aligning industrial efficiency, technological innovation and social welfare.

The research seeks to understand the impacts of these technologies on industrial operations, with a focus on productivity gains, efficiency and sustainability, while assessing the challenges and opportunities related to training the workforce and adapting to new technological paradigms. It also investigates collaborative initiatives between industries, government and educational institutions, seeking innovative solutions to social issues, such as urban mobility and health, which can be tackled using digital technologies.

Finally, the study proposes an integrative model that aligns the adoption of Industry 4.0 technologies with the principles of Society 5.0, promoting a more inclusive and innovative economy, capable of transforming the Manaus Free Trade Zone into an example of sustainable and socially responsible development.

2. THEORETICAL FRAMEWORK

2.1 Industry 4.0

2.1.1 Definition and origin

Industry 4.0, also known as the Fourth Industrial Revolution, symbolizes a new paradigm in industrial production, characterized by the integration of advanced digital technologies into production processes. Officially introduced in Germany in 2011 during the Hannover Fair, the initiative was designed to modernize the industrial sector and make it more competitive in a digitalized global environment (Kagermann, Wahlster & Helbig, 2013).

The evolution of previous industrial revolutions highlights the distinctions of Industry 4.0. While the First Industrial Revolution (Industry 1.0) marked mechanization driven by steam,

Industry 2.0 brought mass production powered by electricity. In Industry 3.0, automation and the use of computers advanced production lines. Industry 4.0, however, connects machines, systems and products via digital networks, allowing processes to be adaptable and managed in real time (Schwab, 2016).

2.1.2 Main technologies

The core of Industry 4.0 lies in emerging technologies that integrate the physical and digital worlds, promoting automation, connectivity and personalization. The main technologies include:

- **Internet of Things (IoT):** IoT connects physical devices to the internet, allowing data to be collected and exchanged in real time. In smart factories, IoT sensors monitor and adjust operations automatically, optimizing production processes (Xu, He & Li, 2014).
- **Cyber-Physical Systems (CPS):** Integrate physical and computational processes for real-time control and monitoring, making it possible to adapt machines to production demands (Lee et al., 2015).
- **Big Data and Analytics:** Analyzing large volumes of data in real time offers insights for strategic decisions, optimizing efficiency and identifying potential flaws in processes (Chen, Chiang & Storey, 2012).
- **Artificial Intelligence (AI) and Machine Learning:** AI allows machines to learn from data, resulting in predictive maintenance, automated quality control and continuous adjustments to operations (Jordan & Mitchell, 2015).
- **Automation and Advanced Robotics:** Collaborative robots (cobots) perform complex tasks, increasing productivity and improving worker safety (Bahrin et al., 2016).
- **Blockchain:** Widely used for security and traceability, especially in supply chains, ensuring transparent and secure transactions (Kavalikov & Lagrange, 2018).

2.1.3 Impacts on Manufacturing

Industry 4.0 is transforming manufacturing with significant impacts:

1. **Increased productivity:** Smart, connected and autonomous machines operate continuously, reducing downtime (Schwab, 2016).
2. **Reduced operating costs:** Predictive maintenance and automation reduce labor costs and material waste (Porter & Heppelmann, 2014).
3. **Flexibility and customization:** Customized mass production becomes feasible, allowing companies to meet specific consumer demands (Bahrin et al., 2016).
4. **Improved product quality:** Sensors and real-time monitoring identify defects, ensuring high quality standards (Jordan & Mitchell, 2015).
5. **Sustainability:** More efficient processes reduce emissions and energy consumption, promoting environmentally responsible practices (Stock & Seliger, 2016).

Despite the advantages, challenges include high start-up costs, the need for robust infrastructure and resistance to change on the part of workers, as well as cybersecurity concerns (Caniato et al., 2018).

2.1.4 Industry 4.0 in the Brazilian Context and in the Manaus Free Trade Zone

In Brazil, the adoption of Industry 4.0 is at an early stage, but has significant potential, especially in the Manaus Free Trade Zone (ZFM). The Manaus Industrial Pole (PIM), the core of the ZFM, concentrates industries covering sectors such as electronics and chemicals, whose modernization is essential to maintain global competitiveness (Silva & Silva, 2017).

The ZFM faces particular challenges, such as logistical limitations and a lack of advanced technological infrastructure. However, the adoption of technologies such as IoT and automation can increase efficiency and reduce costs. Investments in training and digital infrastructure, including high-speed networks and big data solutions, are key to the success of digital transformation in the region (CNI, 2018).

In addition, Industry 4.0 in the ZFM can promote sustainability, using technologies to reduce carbon emissions and minimize waste, aligning with the principles of Society 5.0 and contributing to the social and environmental development of the Amazon (Fukuyama, 2018).

2.2 Society 5.0

2.2.1 Concept and development

Society 5.0, a concept introduced by the Japanese government in 2016 in the 5th Science and Technology Basic Plan, represents a new stage in human development, focused on integrating technological advances with social welfare. Unlike Industry 4.0, whose central objective is to optimize industrial processes and economic efficiency, Society 5.0 places human beings at the center of innovations, using technologies such as the Internet of Things (IoT), Artificial Intelligence (AI) and Big Data to solve social problems such as inequality, population ageing and climate change (Fukuyama, 2018).

Historically, Society 5.0 is seen as the natural evolution of previous societies:

- **Society 1.0:** Hunting and gathering;
- **Society 2.0:** Agriculture;
- **Society 3.0:** Industrial revolution;
- **Society 4.0:** Age of information and digitalization.

Society 5.0 emerges as a fusion between the physical, digital and biological worlds, promoting a super-intelligent and inclusive society. This paradigm expands the possibilities of Industry 4.0, applying its technologies to areas such as health, urban mobility, education and sustainability (Deguchi et al., 2020).

2.2.2 Enabling Technologies

The technologies of Society 5.0 are the same as those of Industry 4.0, but their use is geared towards social and sustainable applications. Among the most relevant are:

- **Artificial Intelligence (AI):** Central to Society 5.0, AI automates processes and analyzes large volumes of data, with applications ranging from the personalization of education to improvements in the health system, such as early diagnosis and remote monitoring of patients (Roser & Nakamura, 2020).
- **Internet of Things (IoT):** Essential for creating smart cities, IoT connects devices and systems, enabling the efficient management of urban resources such as transportation, energy and waste (Zanella et al., 2014).
- **Big Data:** Allows for a better understanding of people's needs, planning public policies based on predictive analysis and ensuring the efficient use of resources (Gubbi et al., 2013).
- **Robotics: This** goes beyond industry and is gaining prominence in areas such as health, with robots to assist the elderly, and transportation, with autonomous vehicles (Deguchi et al., 2020).
- **Augmented Reality (AR) and Virtual Reality (VR):** Offer solutions for training, education and realistic simulations, with applications ranging from immersive educational environments to remote support for healthcare professionals (Schwab, 2016).

These technologies enable the creation of an environment where technological innovations solve everyday problems while promoting social inclusion and sustainability.

2.2.3 Benefits and challenges

Society 5.0 has numerous benefits, including the following:

1. **Improved quality of life:** Applications such as digital health and smart urban mobility increase accessibility to essential services, promoting greater well-being for populations (Fukuyama, 2018).
2. **Social inclusion:** Technology is used to eliminate barriers, creating accessible solutions for people with disabilities, the elderly and marginalized populations (Roser & Nakamura, 2020).
3. **Environmental sustainability:** Technologies such as IoT and Big Data help optimize the use of natural resources, promoting cleaner cities with a smaller ecological footprint (Deguchi et al., 2020).

However, the implementation of Society 5.0 faces significant challenges:

- **Unequal access to technology:** In peripheral regions or those with limited infrastructure, ensuring access to enabling technologies is a challenge, especially in developing countries.
- **Cyber security:** Increased interconnectivity increases exposure to cyber attacks, requiring strict digital security protocols (Roser & Nakamura, 2020).
- **Professional qualifications:** Society 5.0 requires workers trained to deal with advanced and complex technologies, requiring investment in education and retraining (Schwab, 2016).

2.2.4 Applications in the Brazilian and Global Contexts

Japan is leading the way in implementing Society 5.0, with initiatives ranging from autonomous vehicles to assistive robots for elderly care. These solutions are being developed to address challenges such as population aging and labor shortages (Deguchi et al., 2020).

In Brazil, although Society 5.0 is not yet widely discussed, there are initiatives that incorporate its principles. Examples include:

- **Smart urban mobility:** In cities like São Paulo, IoT systems are used to manage traffic and improve public transportation.
- **Digital health:** Telemedicine has gained prominence during the COVID-19 pandemic, demonstrating the potential of technologies to expand access to medical care in remote areas (Roser & Nakamura, 2020).
- **Sustainability:** Smart city projects, such as Curitiba, integrate Big Data and IoT to manage urban resources more efficiently.

These applications demonstrate the transformative potential of Society 5.0, especially when adapted to challenging contexts such as Brazil.

2.3 Digital transformation

2.3.1 Definition and strategies

Digital transformation refers to the integration of digital technologies into all aspects of an organization, resulting in fundamental changes in the way businesses operate and generate value for customers. More than adopting technological tools, digital transformation implies a complete reassessment of business models, organizational structures and corporate cultures (Bharadwaj et al., 2013).

According to Rogers (2016), digital transformation is not a one-off process, but an ongoing one, encompassing the modernization of technological infrastructure, the reinvention of business processes and the adaptation of organizational strategies to the demands of an increasingly digitized environment. In the industrial context, this includes the use of technologies such as Big Data, IoT, AI and automation to optimize operations and promote innovations in products and services.

Successful digital transformation strategies usually include:

1. **Digitization of operational processes:** Task automation and data integration reduce costs and improve efficiency (Bharadwaj et al., 2013).
2. **Product and service innovation:** The use of technologies such as AI and Big Data makes it possible to develop personalized products aligned with consumer demands in real time (Schwab, 2016).
3. **Creation of digital business models:** Innovative companies take advantage of digital platforms to generate new sources of revenue, such as subscription services or online marketplaces (Rogers, 2016).
4. **Training and cultural change:** Digital transformation requires skilled workers and an organizational culture that values innovation and adaptability (Westerman, Bonnet & McAfee, 2014).

2.3.2 Role in Industry 4.0 and Society 5.0

Digital transformation is a central element in both Industry 4.0 and Society 5.0, serving as a bridge between industrial efficiency and social progress. In the context of Industry 4.0, it enables automation, connectivity and personalization through technologies such as cyber-physical systems, IoT sensors and AI. These advances enable the creation of smart factories that monitor and optimize production in real time (Lasi et al., 2014).

In Society 5.0, digital transformation transcends the industrial environment to improve people's quality of life. Enabling technologies are applied in areas such as health, education and urban mobility, promoting social inclusion and sustainability (Deguchi et al., 2020). For example:

- In healthcare, telemedicine platforms enable remote care, while AI helps diagnose and monitor patients.
- In smart cities, connected sensors optimize traffic, reduce energy consumption and improve waste management (Zanella et al., 2014).

2.3.3 Applications in the Manaus Free Trade Zone

In the Manaus Free Trade Zone (ZFM), digital transformation has great potential to modernize the Manaus Industrial Hub (PIM), increasing its competitiveness in the global market. Local industries can adopt technologies such as IoT and Big Data to monitor the efficiency of operations, reduce waste and improve sustainability (Silva & Silva, 2017).

In addition, digital transformation in the PIM can facilitate the integration of local industries into global value chains, increasing their attractiveness to foreign investors. For example:

- **Predictive maintenance:** The use of IoT sensors and AI can predict machine failures, reducing unplanned downtime and operating costs.
- **Advanced automation:** Collaborative robots can be used for repetitive tasks, allowing workers to focus on higher value-added activities.
- **Professional** training**:** Training programs in digital technologies are essential to prepare the local workforce for the demands of Industry 4.0 and Society 5.0 (CNI, 2018).

However, the implementation of the digital transformation in the ZFM faces significant challenges, such as the need for a robust technological infrastructure and the shortage of skilled labor. Government investment in digital connectivity, such as high-speed networks, and the creation of partnerships between companies and educational institutions are key to overcoming these barriers.

Digital transformation can also contribute to the sustainability of the Amazon region. Technologies such as Big Data and blockchain can trace the origin and environmental impact of ZFM products, strengthening its reputation on the international market. In addition, the digitalization of production processes can reduce the consumption of natural resources and the emission of pollutants, in line with the principles of the circular economy (Stock & Seliger, 2016).

3. Methodology

3.1 Research Categorization

The methodology used in this study follows a sound scientific approach, combining different data collection and analysis techniques. Based on the classification proposed by Gil (2010), the research can be categorized as follows:

1. **Objectives:**
   The research is exploratory and descriptive in nature. It is exploratory in that it seeks to understand how Industry 4.0 is being implemented at the Manaus Industrial Estate (PIM) and what challenges are faced in this process. At the same time, it is descriptive in that it details the impacts of this implementation in economic, social and environmental terms, as well as strategies to enable the transition to Society 5.0.

2. **Procedures:**

   This study uses two main methods:

   - **Case study:** Focused on PIM companies that have already adopted or are in the process of adopting Industry 4.0 technologies.
   - **Field research:** Including primary data collection through semi-structured interviews and questionnaires applied to PIM managers and workers. In addition, a comprehensive literature review was carried out to provide a theoretical basis for the analysis.

3. **Data approach:**

   A multi-method

   approach was adopted, integrating qualitative and quantitative data.

   - The **quantitative aspect** included the analysis of the questionnaires applied in the field, using descriptive statistics to identify patterns and trends.
   - The **qualitative aspect** was based on semi-structured interviews with PIM specialists and managers, exploring perceptions and experiences related to digital transformation.

3.2 Literature review

The literature review was the initial stage of the methodology and aimed to build the theoretical basis for analyzing the impacts and challenges of Industry 4.0 in the Manaus Industrial Hub (PIM), as well as the transition to Society 5.0. This review focused on relevant studies related to the topic, organized into three broad areas:

1. **Industry 4.0:**

   The survey looked at the key technologies of Industry 4.0, such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, automation and cyber-physical systems. Their impact on production processes was analyzed, including improvements in operational efficiency, mass customization and cost reduction. In addition, the challenges to implementing these technologies have been highlighted, such as the high initial costs, the need for robust technological infrastructure and the qualification of the workforce (Schwab, 2016; Kagermann, Wahlster & Helbig, 2013).

2. **Society 5.0:**

   The review explored the concept of Society 5.0, developed in Japan, as a model of

society centered on human beings and supported by technological innovations. The interrelationships between Industry 4.0 and Society 5.0 were analyzed, highlighting how technology can be used to tackle social problems such as economic inequalities, climate change and accessibility to essential services (Fukuyama, 2018; Deguchi et al., 2020).

3. **International case studies:**
   Examples of best practice in other countries were analyzed to identify successful models for implementing Industry 4.0 technologies. Particular attention was paid to cases involving emerging economies or industrial contexts similar to that of the PIM, offering insights into how to overcome structural barriers and adapt technological solutions to regional particularities (Porter & Heppelmann, 2014).

The literature review also included analysis of the benefits of digital transformation in terms of productivity, sustainability and social inclusion. Finally, it consolidated the state of the art on the application of digital technologies in the industrial environment, providing a solid basis for the subsequent stages of the research.

3.3 Case Study

The case study was selected as a central methodological approach due to its ability to investigate contemporary phenomena within their real contexts. This methodology was applied to analyze companies in the Manaus Industrial Hub (PIM) that are already implementing or in the process of adopting Industry 4.0 technologies. The case study provided a detailed understanding of the challenges and opportunities involved in this process.

1. **Company selection:**
   The participating companies were chosen on the basis of criteria such as:
   - Adoption of Industry 4.0 enabling technologies, such as the Internet of Things (IoT), advanced automation, artificial intelligence (AI) and big data.
   - The relevance of these technologies to industrial production and their impact on operations.
     The selection criteria aimed to ensure the representativeness of different industrial sectors within the PIM, including electronics, chemicals and metallurgy.
2. **Interviews with managers and experts:**
   To enrich the case study, semi-structured interviews were conducted with managers and experts from the selected companies. The interviews focused on:
   - Identify perceived benefits of Industry 4.0 technologies.

- Explore operational challenges related to the implementation of these technologies.
- Map solutions and strategies adopted to overcome structural and cultural barriers.

3. **Purpose of the Case Study:**

   The study sought to provide detailed, practical insights into the best practices and challenges faced in integrating digital technologies into the unique context of PIM. This data served as the basis for impact analysis and for proposing strategies aimed at accelerating the transition to Society 5.0.

The use of case studies helped to contextualize the results, highlighting regional specificities and the practical implications of adopting Industry 4.0 technologies in the PIM.

3.4 Field research

Field research complemented the case study, allowing primary data to be collected directly from workers, managers and other stakeholders at the Manaus Industrial Estate (PIM). This approach was essential to understanding the perceptions and experiences related to the implementation of Industry 4.0 and the transition to Society 5.0.

1. **Questionnaires:**

   Questionnaires with open and closed questions were developed and applied to a representative sample of workers and managers from different companies in the PIM. The questionnaires sought to:

   - Capturing perceptions about the impacts of Industry 4.0 on the workplace.
   - Identify challenges faced during the adoption of digital technologies.
   - To assess expectations regarding the transition to Society 5.0.
     The quantitative data collected was analyzed using descriptive statistics to identify patterns and trends.

2. **Interviews:**

   Semi-structured interviews were conducted with managers and workers directly involved in the automated processes, as well as experts in industrial technology. This qualitative approach allowed for a deeper exploration of:

   - Perceived benefits of enabling technologies.
   - Solutions adopted to overcome challenges such as the lack of professional qualifications and structural limitations.
   - Visions on the role of digital technologies in promoting social welfare and productive efficiency.

3. **Data Collection Process:**

   Data collection was carried out in two stages:

- **Stage 1:** Application of questionnaires, ensuring the representativeness of different industrial sectors within the PIM.
- **Stage 2:** Conducting interviews, providing a practical and detailed insight into the impacts of technologies in the local context.

4. **Data Analysis:**

   The primary data was analyzed in an integrated manner:

   - The quantitative analysis used descriptive statistics to identify relevant correlations and trends.
   - The qualitative analysis was based on content analysis techniques, allowing the identification of emerging themes and patterns in the interviewees' responses.

The field research provided a solid basis for assessing the economic, social and environmental impacts of Industry 4.0 in the PIM, as well as contributing to the formulation of practical strategies for the transition to Society 5.0.

3.5 Impact Analysis

Impact analysis was a central component of the research, assessing how the adoption of Industry 4.0 technologies affects the economic, social and environmental dimensions at the Manaus Industrial Estate (PIM). This stage was based on the data collected during the case study and field research, providing a comprehensive view of the benefits and challenges faced.

1. **Economic Impact:**

   The economic analysis focused on the effects of enabling technologies on:

   - **Productivity and efficiency:** Industry 4.0 technologies, such as automation and IoT, have helped to reduce operating costs and increase production efficiency in PIM companies.
   - **Creating business opportunities:** Digitalization has opened up new markets and enabled more agile business models connected to global demands.
   - **Cost reduction:** It has been observed that technologies such as predictive maintenance and real-time monitoring systems have significantly reduced costs related to operational failures.

2. **Social Impact:**

   Automation and digitalization have had both positive and challenging social impacts:

   - **Generation of skilled jobs:** The adoption of digital technologies has created demands for trained professionals, encouraging the qualification of the local workforce.

- **Changes in the professional profile:** Despite new opportunities, there have been challenges related to the replacement of traditional jobs with functions that require greater technical qualifications.
- **Improved working conditions:** The automation of repetitive and dangerous tasks has helped to reduce occupational risks, promoting a safer environment.

3. **Environmental Impact:**

   Sustainability was another point evaluated, with emphasis on:

   - **Reducing emissions:** The use of technologies such as big data and IoT has made it possible to optimize industrial processes, reducing energy consumption and carbon emissions.
   - **Waste minimization:** Digital processes have facilitated the adoption of sustainable practices, such as the circular economy, reducing material waste.
   - **Clean and efficient solutions:** Companies that have adopted advanced automation have reported greater efficiency in the use of natural resources.

4. **Analysis methodology:**

   The analysis was structured on the basis of the data obtained in the previous stages:

   - Quantitative indicators, such as cost reduction and increased productivity, were measured using descriptive statistics.
   - Qualitative results, such as perceptions of social and environmental impacts, were assessed through content analysis of the interviews.

The impact analysis provided an integrated view of the benefits and challenges associated with Industry 4.0 in the PIM, underpinning the strategic proposals presented in the subsequent stages.

3.6 Proposed Strategies

Based on the results of the literature review, the case study and the field research, this stage of the research proposes practical strategies to overcome the challenges identified and speed up the transition of the Manaus Industrial Estate (PIM) to Society 5.0. The strategies were formulated taking into account regional particularities and the specificities of companies in the context of the Manaus Free Trade Zone.

1. **Drawing up a Roadmap for the Transition:**

   An action plan structured in stages was developed to guide the PIM in adopting Industry 4.0 technologies and preparing for the challenges of Society 5.0. The main guidelines include:

   - **Technological infrastructure:** Investments in digital connectivity, such as high-speed networks and big data systems, are essential to enable advanced automation.

- **Professional training:** Partnerships with educational institutions to offer training in enabling technologies such as IoT, AI and automation.
- **Government incentives:** Public policies to support companies in acquiring innovative technologies, reducing financial barriers for small and medium-sized companies.

2. **Practical Recommendations for PIM Companies:**

   Based on the best practices observed in international case studies and local analysis, specific actions were suggested for companies:

   - **Modular automation:** Adopt scalable solutions that allow the gradual integration of Industry 4.0 technologies, minimizing initial costs.
   - **Focus on sustainability:** Prioritize technologies that reduce energy consumption and promote environmentally responsible practices, in line with the circular economy.
   - **Digital integration:** Using blockchain and IoT-based systems to improve traceability and efficiency in supply chains.

3. **Recommendations for Public Policies:**

   The role of government and regulatory institutions was highlighted as key to fostering technological innovation and promoting social and economic development:

   - **Tax and financial incentives:** Tax reductions for companies that invest in digital technologies and sustainable practices.
   - **Digital inclusion programs:** Initiatives to bring connectivity and technological training to the most isolated populations in the Amazon region.
   - **Fostering research and innovation:** Supporting R&D projects that connect universities, companies and research centers to create local technological solutions.

4. **Sustainability and Social Inclusion:**

   The strategies were aligned with the principles of Society 5.0, integrating technological advances with human well-being:

   - **Community projects:** Developing initiatives that use technology to solve social problems such as urban mobility, health and education.
   - **Regional partnerships:** Encourage collaborations between PIM companies to promote an innovative and sustainable ecosystem.

The proposals presented aim to transform the PIM into a reference model for the integration of Industry 4.0 and Society 5.0, simultaneously promoting industrial competitiveness and social development.

3.7 Expected contributions

The contributions of this research cover three main dimensions: theoretical, practical and social, offering a broad and integrated view of the impacts of Industry 4.0 and the transition to Society 5.0 in the context of the Manaus Industrial Estate (PIM).

1. **Theoretical Contributions:**
    - This study contributes to the advancement of academic literature by exploring the integration between the concepts of Industry 4.0 and Society 5.0 in a specific context of emerging economies.
    - The detailed analysis of the challenges and opportunities faced by PIM provides relevant insights into how to adapt these technologies to regional realities.
    - The development of an integrative model that takes into account the particularities of the ZFM can serve as a reference for future studies in other industrial centers with similar characteristics.
2. **Practical Contributions:**
    - The research offers practical and direct recommendations for PIM companies, helping them to implement Industry 4.0 technologies and adapt to the demands of Society 5.0.
    - The strategies proposed, such as the transition roadmap and the recommendations for professional training, can be applied immediately, contributing to the modernization of local industries.
    - Economic, social and environmental impact analyses provide concrete data to support business decisions and public policies aimed at innovation and sustainability.
3. **Social Contributions:**
    - The research highlights the potential of digital technologies to reduce socio-economic inequalities in the Amazon region, promoting digital inclusion and human development.
    - Suggested solutions, such as telemedicine projects and digital education, could significantly improve the quality of life of the local population, especially in remote areas.

- By aligning the principles of Society 5.0 with the needs of the PIM, the research reinforces the role of technological innovation as an engine for sustainable and socially inclusive development.

These contributions demonstrate the relevance of the study not only for theoretical advancement, but also for practical application and social impact. By connecting the concepts of Industry 4.0 and Society 5.0 to the realities and challenges of the PIM, this research proposes solutions that can transform the Manaus Free Trade Zone into an exemplary model for integrating industrial competitiveness and social development.

4. Results and Discussion

4.1 Results

The survey of companies in the Manaus Industrial Estate (PIM) revealed important aspects about the adoption of Industry 4.0 practices and preparation for Society 5.0. These results have been organized into the following categories:

4.1.1 Preparing for Society 5.0

Around **75% of companies** reported having started projects related to the transition to Society 5.0. The main initiatives are concentrated in areas such as Production/Operations and Information Technology (IT). However, **12.5% of companies** have not yet started specific activities, and another **12.5%** are planning long-term implementations.

4.1.2 Main objectives

Companies' objectives reflect a combination of economic and social goals:

- **Increased operational efficiency:** cited as an isolated objective by **25%** and in combination with others by **62.5%**.
- **Product and service innovation:** Highlighted by **12.5%** as a key priority.
- **Environmental sustainability and improving the customer experience:** cited as complementary in some answers.

4.1.3 Challenges faced

The main barriers to the implementation of Society 5.0 were:

- **Lack of skilled labor:** Identified by **62.5%** of companies.
- **Resistance to change:** cited by **50%**.
- **High implementation costs:** Also mentioned by **50%**.

- Inadequate infrastructure and regulatory issues were highlighted, but less frequently.

4.1.4 Benefits observed

Although **50% of the companies** have not yet realized tangible benefits, the positive impacts reported include:

- Reduced operating costs.
- Faster and more connected processes.
- Improved product quality and customer satisfaction.

4.1.5 Technologies used or planned

The most cited technologies were:

- **Big Data and Data Analysis:** Used or planned by **50%** of companies.
- **Artificial Intelligence (AI) and Internet of Things (IoT):** Highlighted as pillars for modernization.
- Technologies such as robotics, automation and augmented/virtual reality were mentioned by a smaller proportion.

4.2 Discussions

The results obtained corroborate the theoretical framework and highlight the challenges and opportunities faced by PIM companies in the technological transition. This discussion was organized into the following dimensions:

4.2.1 Technological readiness and maturity

Although the majority of companies have started the transition to Society 5.0, the inequality in the stages of preparation reflects the lack of uniform access to resources and training. This is in line with the literature, which emphasizes the need for a robust digital infrastructure to support technological transformation.

4.2.2 Strategic Objectives

The objectives of the PIM companies show a convergence between the principles of Industry 4.0 (efficiency and innovation) and Society 5.0 (sustainability and human focus). However, the lack of structured strategies compromises the maximization of benefits.

4.2.3 Structural challenges

Challenges such as a lack of skilled labor, resistance to change and high costs are widely discussed in the literature on Industry 4.0. Overcoming these obstacles requires investment in professional training, economic incentives and improved infrastructure.

4.2.4 Benefits and impacts

The benefits reported confirm the expectations surrounding advanced technologies. However, the lack of clear metrics to assess medium and long-term impacts prevents a more robust analysis of the progress made.

4.2.5 Technologies as enablers

The technologies mentioned, such as IoT, Big Data and AI, reaffirm their central role in digital transformation. However, the disparity in responses shows that many companies are still exploring possibilities, without a consolidated implementation.

5. Conclusions

Based on the results of the research and the discussions developed, it is possible to conclude that the implementation of Industry 4.0 at the Manaus Industrial Estate (PIM) represents a strategic opportunity to promote technological innovation and the transition to Society 5.0. This process, although challenging, has significant potential to transform the region's industrial and social environment.

5.1 Main findings

The main findings of this research stand out:

1. **Company preparation:**
    - **75% of companies** have already started specific actions to adopt practices in line with Society 5.0, focusing on areas such as Production/Operations and Information Technology (IT).
2. **Main Motivations:**
    - The objectives identified include product/service innovation, increased operational efficiency and improvements in the quality of life of workers and customers. These objectives reflect a convergence between the pillars of Industry 4.0 and the humanized values of Society 5.0.

3. **Challenges faced:**
    - The main challenges include a lack of skilled labor, resistance to change and high implementation costs. These factors highlight the need for professional training and economic incentives to accelerate the digital transformation.
4. **Benefits Observed:**
    - Companies that have implemented technologies have reported benefits such as cost savings, greater customer satisfaction and more agile and connected processes.
5. **Support and Partnerships:**
    - Collaboration between companies, universities and startups emerged as a critical factor for the success of the initiatives, reinforcing the importance of an innovation ecosystem.

5.2 Recommendations

Based on the conclusions, the following recommendations are suggested to facilitate the transition to Society 5.0 in the context of PIM:

1. **Investments in education and training:**
    - Develop specific professional qualification programs in line with the demands of Industry 4.0 and Society 5.0. Partnerships with local educational institutions are essential to train workers in the use of technologies such as IoT, AI and Big Data.
2. **Public Incentive Policies:**
    - Establish tax incentives and credit lines for companies that invest in enabling technologies and sustainable practices.
3. **Promoting Collaborative Innovation:**
    - Encourage partnerships between companies, universities and startups to foster the creation of technological solutions adapted to regional needs.
4. **Technological infrastructure:**
    - Expand investments in digital infrastructure, such as high-speed networks and advanced data systems, to support the implementation of technologies.

5. **Adoption of Sustainability Indicators:**
    - Develop clear metrics to assess the environmental, economic and social impacts of Industry 4.0 practices, ensuring alignment with the principles of Society 5.0.

5.3 Suggestions for future work

The research suggests the following directions for future studies:

1. **Socio-economic impact:**
    - Investigating how digital transformation can reduce regional inequalities and promote greater social inclusion in the Manaus Free Trade Zone.
2. **Development of Sustainable Models:**
    - Create business models based on the circular economy and the reduction of industrial waste in the context of the PIM.
3. **Analysis of costs and benefits:**
    - Economically evaluate the investments required for the transition to Society 5.0, comparing them with the long-term benefits.
4. **Detailed Case Studies:**
    - Investigate companies that have already implemented advanced practices, highlighting critical success factors and lessons learned.
5. **Integration of Intelligent Urban Mobility:**
    - Explore how digital technologies can be applied to improve mobility in the region, promoting efficiency and sustainability.

5.4 Final considerations

The challenges of implementing Industry 4.0 and the transition to Society 5.0 in the Manaus Free Trade Zone are complex, but the results show that the transformative potential is significant. The combined efforts of the public, private and academic sectors can position the PIM as a global example of technological integration and sustainable development.

Society 5.0 offers a vision of the future in which innovation and well-being go hand in hand. The Manaus Free Trade Zone, with its strategic position, is prepared to lead this movement, becoming a model of how the digital revolution can drive socio-economic transformation and environmental preservation.

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