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CIRCULAR ECONOMY APPLIED TO INDUSTRIAL COMPONENT RECOVERY: CONTRIBUTIONS TO SUSTAINABILITY AND COMPETITIVENESS IN BRAZILIAN INDUSTRY

Economia Circular Aplicada à Recuperação de Componentes Industriais: Contribuições para a Sustentabilidade e a Competitividade na Indústria Brasileira

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ABSTRACT | The growing demand for more efficient and sustainable production processes has led industries to seek alternatives capable of reducing operational costs without compromising the technical performance of equipment. In this context, industrial component recovery stands out as a strategy aligned with the principles of the circular economy, promoting asset lifespan extension, reducing raw material consumption, and minimizing waste generation. This study aims to discuss industrial component recovery from the perspective of sustainability and industrial competitiveness, demonstrating that this practice goes beyond traditional maintenance and constitutes an asset management strategy. The research is characterized as a narrative literature review, complemented by a technical-applied discussion based on the author's professional experience in the metallurgical sector. The analysis demonstrates that component recovery can generate significant economic and environmental benefits when supported by engineering criteria, maintenance planning, and technical assessment of operational conditions. Furthermore, this practice shows convergence with circular economy principles, particularly regarding the rational use of natural resources and increased production efficiency. It is concluded that industrial component recovery represents an important tool for organizations seeking to reconcile economic performance, technological innovation, and sustainability, constituting a promising field for future research in production engineering, mechanical engineering, and industrial management.

Keywords | Circular economy; Industrial component recovery; Industrial sustainability; Asset management; Production engineering; Competitiveness.

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RESUMO | A crescente demanda por processos produtivos mais eficientes e sustentáveis tem levado a indústria a buscar alternativas que reduzam custos operacionais sem comprometer o desempenho técnico dos equipamentos. Nesse contexto, a recuperação de componentes industriais destaca-se como uma estratégia alinhada aos princípios da economia circular, promovendo o prolongamento da vida útil de ativos, a redução do consumo de matérias-primas e a minimização da geração de resíduos. O presente estudo tem como objetivo discutir a recuperação de componentes industriais sob a perspectiva da sustentabilidade e da competitividade industrial, demonstrando que essa prática extrapola a manutenção tradicional e constitui uma estratégia de gestão de ativos. A pesquisa caracteriza-se como uma revisão narrativa da literatura, complementada por uma discussão técnico-aplicada baseada na experiência profissional do autor no setor metalúrgico. A análise evidencia que a recuperação de componentes pode gerar benefícios econômicos e ambientais relevantes quando fundamentada em critérios de engenharia, planejamento da manutenção e avaliação técnica das condições operacionais. Além disso, observa-se convergência entre essa prática e os princípios da economia circular, especialmente no que se refere ao uso racional de recursos naturais e ao aumento da eficiência produtiva. Conclui-se que a recuperação de componentes industriais representa uma importante ferramenta para organizações que buscam conciliar desempenho econômico, inovação tecnológica e sustentabilidade, constituindo um campo promissor para futuras pesquisas em engenharia de produção, engenharia mecânica e gestão industrial.

Palavras-chave | economia circular; recuperação de componentes industriais; sustentabilidade industrial; gestão de ativos; engenharia de produção; competitividade.

1 INTRODUCTION

In recent decades, global industry has undergone profound transformations driven by the need to increase productivity, reduce operational costs, and respond to growing demands for environmental sustainability. The intensification of global competition, fluctuations in raw material prices, and the adoption of stricter environmental policies have encouraged companies to reassess their production models and devote greater attention to the efficient management of industrial assets.

Traditionally, the replacement of worn components has been considered the safest alternative to ensure the operational continuity of production systems. However, this practice involves high acquisition costs, increased consumption of natural resources, greater energy demand for manufacturing new components, and higher generation of industrial waste. From a sustainability perspective, this linear production model, based on extracting, producing, using, and disposing, has become increasingly incompatible with the economic and environmental challenges faced by contemporary industries.

Within this scenario, the circular economy has emerged as a model capable of promoting more efficient use of available resources. Unlike the traditional linear system, the circular economy seeks to preserve the value of materials and products for as long as possible through strategies such as reuse, remanufacturing, recovery, and recycling. This approach has been widely discussed by international organizations, governments, and research institutions as an alternative capable of reconciling economic growth, environmental preservation, and technological innovation.

Among the strategies associated with this concept, industrial component recovery stands out. Through appropriate engineering processes, components subjected to wear can recover their functional characteristics and return to operational conditions, reducing the need for complete replacement. In addition to benefits related to the reduction of raw material consumption, this practice contributes to lowering operational costs, extending equipment lifespan, and decreasing solid waste generation.

From the perspective of production engineering and mechanical engineering, component recovery should be understood as part of a broader asset management strategy. Maintenance moves beyond a purely corrective function and becomes integrated into strategic decisions related to operational performance, production system reliability, and organizational competitiveness. Therefore, component recovery represents not only a technical solution but also a tool to support industrial sustainability and optimize production processes.

Despite the widespread application of this practice across several industrial sectors, a significant portion of the scientific literature remains focused on describing technological processes used for surface recovery and restoration of components, while aspects related to economic, environmental, and strategic impacts remain relatively less explored. This gap highlights the need to expand discussions regarding the role of component recovery within the principles of the circular economy and contemporary industrial management.

Furthermore, the strengthening of international standards related to asset management, environmental management, and operational efficiency reinforces the importance of integrated approaches capable of reconciling economic performance with environmental responsibility. Component recovery fits into this context by enabling greater utilization of existing resources, contributing to waste reduction and increasing organizational competitiveness.

Considering this scenario, this article aims to discuss industrial component recovery as an engineering-based circular economy strategy, analyzing its contribution to sustainability, industrial competitiveness, and efficient asset management. For this purpose, a narrative review of national and international scientific literature is conducted, complemented by a technical-applied discussion based on the author's professional experience, seeking to integrate concepts of engineering, sustainability, circular economy, and industrial management from an interdisciplinary perspective.

1.1 Research Problem

Although industrial component recovery is widely used across different productive sectors, there is still limited integration between literature addressing its technical aspects and studies discussing its impacts on sustainability, circular economy, and industrial competitiveness.

Within this context, this study seeks to answer the following research question:

How can industrial component recovery contribute to strengthening the circular economy, increasing sustainability, and enhancing the competitiveness of Brazilian industry?

1.2 Hypothesis

This study is based on the hypothesis that industrial component recovery, when supported by technical engineering criteria and integrated into asset management practices, constitutes a strategy capable of extending equipment lifespan, reducing operational costs, minimizing environmental impacts, and strengthening industrial competitiveness, while remaining aligned with circular economy principles.

1.3 General Objective

To analyze industrial component recovery as a circular economy strategy applied to engineering, discussing its contributions to sustainability, efficient asset management, and the competitiveness of Brazilian industry.

1.4 Specific Objectives

To present the fundamentals of circular economy applied to the industrial environment.

To discuss the role of component recovery in managing the life cycle of industrial assets.

To analyze the economic and environmental benefits of recovery compared to component replacement.

To relate component recovery to the concepts of maintenance, reliability, and asset management.

To identify challenges and perspectives for expanding the adoption of this strategy in Brazilian industry.

2 THEORETICAL BACKGROUND

2.1 Circular Economy

The predominant economic model throughout much of the industrialization process was structured around a linear production logic, characterized by the stages of raw material extraction, manufacturing, consumption, and disposal. Although this system has driven industrial development over recent decades, it has also contributed to increased exploitation of natural resources, waste generation, and greenhouse gas emissions, becoming progressively incompatible with contemporary environmental and economic challenges.

As an alternative to this model, the concept of the circular economy has gained prominence as an economic system designed to maintain products, components, and materials at their highest level of utility and value for the longest possible period. Unlike the linear economy, the circular economy prioritizes strategies aimed at reducing the consumption of natural resources, recovering materials, restoring components, and reintegrating these elements into production cycles.

According to the Ellen MacArthur Foundation, one of the leading international organizations dedicated to the subject, the circular economy is based on three fundamental principles: eliminating waste and pollution from the design stage, keeping products and materials in use for as long as possible, and regenerating natural systems. These principles represent a significant transformation in the way industries manage their assets, shifting the focus from simple equipment replacement toward strategies capable of preserving technical and economic value.

Within the industrial environment, this transformation has encouraged companies to adopt practices such as remanufacturing, component recovery, predictive maintenance, technological modernization, and integrated equipment life cycle management. These strategies reduce the need for manufacturing new components, decrease raw material consumption, and contribute to greater operational efficiency.

Industrial component recovery is directly incorporated into this context by enabling worn parts to return to adequate operating conditions through specific engineering processes. In addition to reducing costs, this practice contributes to decreasing the disposal of metallic materials and minimizing the environmental impacts associated with the production of new components.

Another relevant aspect of the circular economy is related to increasing organizational resilience. Companies that invest in asset recovery and reuse become less dependent on fluctuations in raw material markets, supplier availability, and costs associated with acquiring imported equipment. This characteristic becomes strategically important in industrial sectors that operate with high-value equipment or whose replacement depends on long manufacturing lead times.

In this scenario, engineering plays an essential role by developing technical solutions capable of restoring the functional performance of components, ensuring operational reliability and compliance with safety requirements. Therefore, component recovery should no longer be understood solely as a maintenance activity but rather as a management practice aligned with circular economy principles, simultaneously contributing to economic, environmental, and operational gains.

2.2 Industrial Sustainability

Sustainability has become one of the main pillars of business competitiveness in recent decades. More than simply complying with legal requirements or responding to societal demands, incorporating sustainable practices has become a strategy capable of increasing production efficiency, reducing costs, and strengthening the institutional image of organizations.

Within the industrial context, sustainability involves balancing economic performance, environmental responsibility, and social development, a concept known as the **Triple Bottom Line**. This approach assumes that sustainable companies must generate positive financial

results while minimizing environmental impacts and contributing to the development of the communities in which they operate.

Industrial component recovery demonstrates strong alignment with this model by enabling the extension of equipment lifespan, reducing the need for extraction of new natural resources, and significantly decreasing industrial waste generation. In addition, component reuse reduces the energy consumption associated with manufacturing new parts, contributing to lower indirect greenhouse gas emissions.

In recent years, the adoption of policies based on **ESG criteria (Environmental, Social, and Governance)** has further increased the relevance of sustainability within the business environment. Investors, consumers, and regulatory bodies have increasingly valued organizations capable of demonstrating effective commitment to sustainable practices, encouraging investments in technologies focused on energy efficiency, circular economy, and responsible management of productive resources.

Within this context, industrial component recovery represents a solution capable of integrating economic and environmental objectives, reinforcing the importance of engineering as an instrument for innovation and sustainable development.

2.3 Industrial Asset Management

The increasing complexity of production processes has made asset management one of the main tools for ensuring operational continuity and competitiveness within industrial organizations. Equipment is no longer considered merely a production resource but has assumed a strategic role within companies, directly influencing productivity, quality, safety, and financial performance indicators.

According to the **ISO 55000 series of standards**, asset management corresponds to the set of coordinated activities through which organizations obtain value from assets throughout their entire life cycle. This approach considers aspects related to equipment acquisition, operation, maintenance, recovery, and disposal, aiming to maximize technical and economic performance.

From this perspective, decisions regarding component replacement or recovery are no longer exclusively operational and become part of the strategic planning process of organizations. The choice between acquiring new equipment or recovering an existing component should consider factors such as investment costs, operational availability, failure-related risks, environmental impacts, and remaining useful life expectancy.

Within this context, industrial component recovery represents an alternative capable of extending asset life cycles without compromising functionality. When supported by appropriate technical criteria, this practice enables organizations to reduce investments in new equipment, decrease operational downtime, and optimize financial returns from existing assets.

Another relevant aspect is related to the concept of **Life Cycle Cost (LCC)**, widely used in production engineering. This model considers not only the equipment acquisition cost but

also all expenses associated with operation, maintenance, recovery, and disposal throughout its useful life. Therefore, components that initially appear to represent a lower cost may become economically less advantageous when analyzed throughout their complete life cycle.

Thus, industrial component recovery should be understood as a strategic asset management tool, enabling organizations to balance operational performance, environmental sustainability, and economic efficiency.

2.4 Industrial Component Recovery

The wear of mechanical components is an unavoidable phenomenon in virtually all industrial systems. The continuous action of mechanical stresses, abrasion, corrosion, fatigue, impacts, and high temperatures causes dimensional and structural changes capable of compromising equipment performance over time.

Historically, the replacement of worn components has represented the most commonly adopted solution by industries. However, increasing manufacturing costs, the scarcity of certain raw materials, and the need to reduce environmental impacts have encouraged the development of technologies aimed at recovering these components.

Industrial recovery comprises a set of processes designed to restore the functional characteristics of worn parts, enabling their return to operating conditions specified in the original design. Among the techniques employed are metallic coatings, welding processes, recovery machining, metallization, heat treatments, and different surface engineering technologies.

Regardless of the process applied, recovery must always comply with technical criteria related to the component's mechanical properties, operating conditions, dimensional requirements, and quality standards required for its application.

It is important to emphasize that recovery, repair, and remanufacturing represent distinct concepts. While repair generally aims to restore the immediate operation of a specific piece of equipment, recovery seeks to restore specific functional characteristics of the component. Remanufacturing, in turn, involves broader processes capable of returning equipment performance to levels comparable to those of a new product.

From the perspective of the circular economy, all these strategies contribute to extending the utilization period of productive resources, reducing the need for manufacturing new components and significantly decreasing industrial waste generation.

In addition to environmental benefits, several studies demonstrate that component recovery can represent an economically advantageous alternative compared to complete replacement, particularly in applications involving high-value components or parts that are difficult to replace.

However, the decision between recovering or replacing a component must be based on a careful technical assessment. Factors such as wear intensity, structural condition, operational requirements, associated costs, and safety criteria must be individually analyzed to ensure equipment reliability after recovery.

Therefore, engineering plays a fundamental role in this process by providing technical criteria capable of identifying safe limits for the application of recovery technologies and ensuring that recovered components demonstrate performance compatible with their operational purpose.

2.5 Industrial Maintenance and Reliability

Industrial maintenance has undergone significant evolution in recent decades, moving from a predominantly corrective activity toward a strategic function focused on increasing reliability and availability of production systems. Currently, competitive companies develop maintenance programs capable of anticipating failures, reducing operational interruptions, and optimizing the performance of industrial assets.

Traditionally, corrective maintenance prevailed in most organizations, being performed only after failures occurred. Although this approach presents lower initial planning costs, it frequently results in significant losses caused by unexpected production interruptions, increased downtime, and the need for emergency replacement of components.

With the advancement of engineering techniques, preventive and predictive maintenance models have gained prominence. Preventive maintenance is based on periodic inspections and scheduled interventions, while predictive maintenance uses monitoring techniques to identify early signs of equipment degradation, enabling interventions before failures occur.

Within this scenario, component recovery becomes an important tool supporting maintenance strategies. Components identified during early stages of wear can be recovered during planned shutdowns, preventing catastrophic failures and significantly reducing intervention costs.

Another relevant concept is operational reliability, defined as the probability that a given piece of equipment will perform its intended function during a specific period under previously established conditions. The higher the reliability of assets, the lower the occurrence of unexpected failures and the greater the efficiency of production processes.

The integration between planned maintenance, asset management, and component recovery allows organizations to increase equipment availability, reduce waste, and improve industrial competitiveness, reinforcing the importance of engineering in decision-making processes related to asset life cycles.

2.6 Preventive Maintenance as a Strategy for Industrial Component Recovery

Preventive maintenance has become one of the main strategies for ensuring the reliability, availability, and longevity of industrial assets. Unlike corrective maintenance, which is performed only after failures occur, preventive maintenance is based on planned interventions carried out at previously established intervals or according to the analysis of equipment operating conditions. This approach enables the early identification of wear

mechanisms, significantly reducing the probability of unexpected failures and extending component lifespan.

Within the context of industrial component recovery, preventive maintenance plays a decisive role. The early identification of surface wear, deformations, cracks, corrosion, or loss of mechanical properties allows engineering interventions to be performed before irreversible structural damage occurs. Therefore, components that would traditionally be discarded can be recovered through appropriate technological processes, returning to operating conditions compatible with their original technical requirements.

From the perspective of maintenance engineering, recovering a component does not simply represent a reduction in acquisition costs. It is a technical decision based on inspections, metallurgical assessments, dimensional analyses, and reliability criteria that ensure safe equipment performance after recovery. Thus, preventive maintenance should no longer be understood merely as an operational activity but rather as a strategic element in the management of industrial asset life cycles.

Another relevant aspect concerns intervention planning. Preventive maintenance enables recovery activities to be scheduled during previously defined shutdown periods, reducing production impacts and avoiding costs associated with unplanned interruptions. In addition, it promotes better utilization of specialized labor, optimization of spare parts inventories, and greater predictability of maintenance investments.

Under the principles of the circular economy, preventive maintenance constitutes one of the most efficient mechanisms for extending the use of productive resources. By enabling components to be recovered before severe failures occur, the need for manufacturing new equipment is reduced, raw material consumption decreases, and environmental impacts associated with industrial processes are minimized.

Therefore, preventive maintenance should be understood as an integrating element between engineering, sustainability, and industrial competitiveness, forming the technical foundation that enables efficient component recovery programs and sustainable asset management.

2.7 Maintenance Planning and Asset Life Cycle Management

The efficiency of industrial component recovery programs is directly related to maintenance planning and industrial asset life cycle management. Organizations that adopt structured maintenance strategies are able to establish technical criteria for defining the ideal moment for component recovery, replacement, or disposal, reducing operational costs and increasing equipment reliability.

Within this context, life cycle management considers all stages through which an asset passes, from acquisition to final decommissioning. This approach allows maintenance decisions to be based not only on the current condition of equipment but also on economic, operational, environmental, and strategic factors.

The adoption of performance indicators, maintenance history records, failure analyses, and operational condition monitoring enables the identification of degradation trends and the planning of interventions before critical failures occur. Consequently, component recovery becomes part of a permanent asset management policy, replacing emergency decisions with planned and technically supported actions.

Another benefit of maintenance planning is the optimization of costs throughout the equipment life cycle. Preventive component recovery often presents significantly lower costs than complete replacement, especially in high-value equipment or systems whose replacement depends on imports or long manufacturing lead times.

From this perspective, integrated maintenance management contributes to increasing operational availability, reducing production losses, and improving organizational competitiveness, reinforcing the strategic role of engineering in decision-making related to industrial assets.

2.8 Economic, Operational, and Environmental Benefits of Preventive Maintenance

The implementation of structured preventive maintenance programs generates benefits that extend beyond the simple reduction of corrective maintenance costs. Its effects directly influence productivity, operational reliability, environmental sustainability, and business competitiveness.

From an economic perspective, planned component recovery reduces investments in the acquisition of new equipment, decreases expenses resulting from unexpected failures, and enables better allocation of financial resources dedicated to maintenance activities. In addition, it reduces losses associated with emergency shutdowns, which are frequently responsible for significant operational damages.

From an operational standpoint, equipment subjected to preventive maintenance programs presents greater availability, lower failure rates, and improved reliability throughout its service life. Scheduled interventions reduce impacts on production and improve the utilization of installed capacity, contributing to greater efficiency in industrial processes.

Environmental benefits also deserve emphasis. Component recovery significantly reduces raw material consumption, decreases the generation of metallic waste, and lowers the energy demand required for manufacturing new parts. Consequently, there is an indirect reduction in greenhouse gas emissions associated with industrial production processes.

Furthermore, companies that adopt policies focused on preventive maintenance and component recovery strengthen their sustainability practices and increase their alignment with **ESG principles (Environmental, Social, and Governance)**, demonstrating commitment to the rational use of natural resources and the reduction of environmental impacts resulting from their operations.

Taken together, these benefits demonstrate that preventive maintenance represents a strategy capable of integrating economic performance, environmental responsibility, and operational excellence, becoming a fundamental element for organizations seeking sustainable growth.

2.9 Challenges for Implementing Preventive Maintenance and Component Recovery

Although the benefits of preventive maintenance and industrial component recovery are widely recognized, their implementation still faces technical, economic, and organizational challenges. Many companies remain associated with predominantly corrective maintenance models, in which interventions occur only after failures become evident, increasing operational costs, reducing equipment availability, and compromising the reliability of production processes.

One of the main challenges is related to organizational culture change. The implementation of preventive programs requires managers and technical teams to understand maintenance as a strategic investment rather than merely a cost center. This paradigm shift requires planning, commitment from senior management, and active participation of professionals involved in equipment operation and maintenance.

Another relevant factor concerns the need for technical qualification of teams responsible for inspections and decisions related to component recovery. The correct identification of wear mechanisms, interpretation of non-destructive testing results, metallurgical analyses, and dimensional evaluations require qualified professionals capable of applying technical criteria that ensure the safety and reliability of recovered equipment.

The investments required for implementing monitoring systems, acquiring inspection instruments, developing performance indicators, and adopting maintenance management software must also be considered. Although these investments may represent significant initial costs, several studies demonstrate that the benefits obtained throughout the asset life cycle largely compensate for the resources invested.

Another important challenge is related to the standardization of recovery procedures. To ensure that recovered components achieve performance compatible with their applications, processes must be conducted according to technical specifications, applicable standards, and strict quality control criteria. The absence of standardized procedures may compromise component reliability and reduce the expected benefits of recovery.

Despite these challenges, there is a growing trend toward adopting preventive programs integrated with asset management practices. The search for greater operational efficiency, waste reduction, and stronger sustainability practices encourages industrial organizations to invest in strategies that prioritize planned interventions and technically supported component recovery.

2.10 Integration Between Preventive Maintenance, Asset Management, and Circular Economy

The analysis of the concepts presented demonstrates that preventive maintenance, component recovery, and asset management constitute complementary elements of a single strategy aimed at increasing industrial efficiency and sustainability in production processes. When developed in an integrated manner, these practices enable the extension of equipment lifespan, reduction of operational costs, and optimization of natural resource utilization.

Component recovery can only achieve satisfactory results when preceded by structured inspection and monitoring programs. Preventive maintenance provides the information required to identify the appropriate timing for interventions, reducing the occurrence of catastrophic failures and increasing the possibilities for technical recovery of components.

This integration directly strengthens circular economy principles by reducing the need for manufacturing new parts, minimizing material disposal, and encouraging the rational use of productive resources. Therefore, preventive maintenance moves beyond an operational activity and becomes a strategic instrument capable of promoting sustainable development and business competitiveness.

Furthermore, organizations that incorporate structured asset management programs demonstrate greater planning capacity, improved operational performance, and increased predictability of maintenance investments. This approach contributes to higher equipment reliability, reduced production losses, and stronger competitive positioning in increasingly demanding markets.

Within this context, the integration between preventive maintenance, component recovery, and circular economy represents a natural evolution of contemporary industrial engineering. More than simply extending asset lifespan, this strategy contributes to the development of production models that are more efficient, sustainable, and prepared to address the technological and environmental challenges of the coming decades.

3 METHODOLOGY

3.1 Research Nature

This research is characterized as an applied study, as it seeks to analyze scientific knowledge related

to preventive maintenance, industrial component recovery, and circular economy, aiming to understand its practical application within the industrial environment. Applied research seeks to generate knowledge capable of contributing to the solution of real problems faced by organizations, especially those related to the efficient management of industrial assets.

Regarding its objectives, this study presents an exploratory and descriptive nature. Exploratory research enables a broader understanding of the subject by identifying concepts, trends, and existing relationships between preventive maintenance, component recovery,

and industrial sustainability. Descriptive research allows the organization, interpretation, and systematic presentation of this information, establishing connections among the different elements analyzed.

Regarding the research approach, a qualitative method was adopted, considering that the main objective is to interpret concepts, strategies, and practices related to maintenance engineering and asset management, without the use of statistical techniques for data processing.

3.2 Methodological Procedures

The development of this research was based on a narrative literature review, complemented by document analysis and a technical-applied discussion grounded in the author's professional experience in the metallurgical sector.

Books, scientific articles, technical standards, institutional documents, and publications related to industrial maintenance, reliability, component recovery, asset management, sustainability, and circular economy were consulted. The selection of sources prioritized materials recognized by the scientific community and publications capable of providing theoretical support for the objectives established in this research.

In addition to the literature review, the author's professional experience was used as a complementary element for interpreting the findings, allowing the concepts discussed in the literature to be related to practices observed in industrial environments. This approach contributes to connecting scientific foundations with real situations encountered in maintenance processes and component recovery activities.

3.3 Information Analysis

The information obtained was organized according to the main thematic axes of the research: preventive maintenance, industrial component recovery, asset management, operational reliability, and circular economy.

The analysis was conducted through an interpretative approach, seeking to identify convergences between theoretical references and practices adopted in industrial environments. The comparison between different approaches enabled an understanding of how structured preventive maintenance programs can influence operational efficiency, reduce maintenance costs, and strengthen strategies focused on industrial sustainability.

The interpretation of the information also considered the economic, environmental, and operational impacts resulting from component recovery, enabling the development of an integrated perspective regarding the contribution of this practice to increasing organizational competitiveness.

3.4 Research Limitations

As with any research based on a narrative literature review, this study presents limitations related to the availability of consulted sources and the impossibility of fully generalizing its results to all industrial sectors.

Furthermore, the specific characteristics of equipment, production processes, and technologies employed may influence the applicability of component recovery strategies, requiring individualized technical assessments for each operational context.

However, these limitations do not compromise the proposed objectives, since the research aims to provide a theoretical and technical-applied analysis of the importance of preventive maintenance as a strategic element for component recovery and the strengthening of circular economy principles within the industrial environment.

4 RESULTS AND DISCUSSION

4.1 Preventive Maintenance as the Foundation for Industrial Component Recovery

The analysis developed throughout this research demonstrates that preventive maintenance represents the main mechanism capable of enabling efficient industrial component recovery programs. Unlike corrective maintenance, which acts after failures occur, preventive maintenance allows the early identification of dimensional changes, surface wear, corrosion processes, deformations, and other degradation mechanisms before they permanently compromise the structural integrity of components.

This proactive approach significantly expands the possibilities for technical recovery of parts, enabling engineering interventions to be performed at an appropriate stage while preserving essential mechanical characteristics required for the safe return of components to operational conditions.

From this perspective, component recovery should no longer be considered merely an economic alternative to component replacement but rather a direct consequence of the existence of structured preventive maintenance programs. The greater the ability to monitor industrial assets, the greater the opportunities for recovery and the lower the need for premature disposal of components.

In addition to economic aspects, this approach strengthens equipment operational reliability by reducing the risks of unexpected failures and contributing to greater stability in production processes.

4.2 Component Recovery as a Strategic Asset Management Tool

Component recovery should be understood as an integral part of strategic industrial asset management. The decision to recover or replace a component cannot be based exclusively on the immediate cost of intervention; it must consider factors related to

operational performance, reliability, equipment availability, environmental impact, and total life cycle cost.

The results obtained from the literature demonstrate that organizations adopting structured recovery policies can significantly reduce investments allocated to the acquisition of new components, particularly in high-value equipment or systems where replacement involves extended manufacturing lead times.

From this perspective, structured preventive programs enable better utilization of existing assets, extending their service life without compromising safety requirements or operational performance.

This approach is directly aligned with the principles established by modern asset management, in which the objective is not merely to keep equipment operating but to maximize the value obtained from each asset throughout its entire life cycle.

4.3 Economic Impacts of Preventive Maintenance and Component Recovery

The economic benefits resulting from planned component recovery occur at different levels of industrial management. Reducing the need to acquire new equipment represents only one of the advantages observed.

Structured preventive maintenance programs also contribute to reducing costs associated with emergency shutdowns, minimizing production losses, optimizing spare parts inventories, and improving organizational financial planning.

Another relevant aspect concerns increased equipment operational availability. Components recovered before critical failures occur allow production processes to continue with fewer unplanned interruptions, directly influencing productivity and operational efficiency indicators.

Furthermore, the predictability provided by planned interventions enables better utilization of human and financial resources allocated to maintenance activities, reducing waste and increasing the return on investments made.

4.4 Contributions to Circular Economy and Industrial Sustainability

Industrial component recovery presents a strong relationship with circular economy principles by promoting the extension of productive asset lifespan and reducing the need for manufacturing new components.

By recovering parts subjected to wear, the consumption of raw materials is reduced, industrial waste generation is minimized, and the environmental impacts associated with extraction, manufacturing, transportation, and disposal processes are decreased.

This strategy also contributes to reducing the energy consumption required for the production of new components, favoring an indirect reduction in greenhouse gas emissions and strengthening corporate policies focused on sustainability.

Within this context, preventive maintenance represents an essential instrument for implementing circular economy practices in industry, since only the early identification of wear mechanisms enables components to be recovered before becoming technically or economically unfeasible.

Therefore, maintenance engineering assumes a strategic role not only in preserving operational reliability but also in promoting sustainable industrial development.

4.5 Integrated Discussion of Results

The integrated analysis of the results demonstrates that preventive maintenance, component recovery, and asset management constitute inseparable practices within contemporary industrial engineering.

Although frequently addressed independently, these strategies present a high level of complementarity. Preventive maintenance provides the necessary information for identifying degradation processes; component recovery transforms this information into concrete actions capable of extending asset lifespan; and asset management incorporates these decisions into the strategic planning of organizations.

The practical experience observed in industrial environments demonstrates that companies implementing consistent preventive programs show greater capacity to recover components, reduce operational costs, increase equipment availability, and strengthen their competitiveness.

Therefore, preventive maintenance should not be understood merely as an equipment preservation activity, but rather as a strategic element responsible for enabling component recovery, strengthening circular economy practices, and generating economic, operational, and environmental benefits for organizations.

5 CONCLUSIONS

This study aimed to analyze industrial component recovery from the perspective of the circular economy, highlighting the importance of preventive maintenance as a strategic element for efficient industrial asset management.

The analysis demonstrated that structured preventive maintenance programs significantly expand the possibilities for component recovery by enabling the identification of wear mechanisms before irreversible failures occur. This approach reduces operational costs, increases equipment availability, strengthens production process reliability, and contributes to the more efficient use of industrial resources.

From a sustainability perspective, it was observed that component recovery represents an important instrument for reducing raw material consumption, decreasing waste generation, and strengthening circular economy principles. By extending the lifespan of industrial assets, organizations are able to reduce environmental impacts without compromising technical performance or operational safety.

Another aspect identified concerns the strategic role of maintenance engineering. Beyond performing technical interventions, preventive maintenance provides essential information for decision-making processes related to component recovery, replacement, and equipment life cycle management. In this way, engineering contributes directly to the development of production models that are more efficient, sustainable, and competitive.

It can therefore be concluded that preventive maintenance represents the main link between component recovery, asset management, and circular economy. Its adoption enables organizations to transform activities traditionally focused only on equipment preservation into strategies capable of generating economic, operational, and environmental value.

As a perspective for future research, it is recommended that case studies involving different industrial sectors be developed, allowing quantitative measurement of the gains obtained through structured preventive maintenance and component recovery programs, as well as the assessment of their impacts on reliability, sustainability, and competitiveness indicators.

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Márcio Galvani Antonelli is a Mechanical Engineer with experience in industrial maintenance, industrial component recovery, asset management, and maintenance engineering. His professional work focuses on developing strategies related to the circular economy, industrial sustainability, operational reliability, and equipment life cycle optimization. His research interests include the application of engineering solutions to enhance the competitiveness of Brazilian industry through improved operational efficiency, cost reduction, and the sustainable use of resources.