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The process of innovation in solid waste management

Abstract

The treatment of solid waste is still a major challenge for modern society. The reality is that there is a great deficiency in the collection and correct disposal of urban and industrial solid waste, resulting in high levels of pollution on the planet. Given this scenario, it is necessary to invest in technology and innovation, although much has already been done regarding the correct treatment of solid waste, but much can still be done. To mitigate this problem, innovation processes must be adopted in the treatment of solid waste, which involves several steps and approaches, aiming to improve efficiency, reduce environmental impacts, and promote sustainability. Implementing innovative strategies requires a coordinated commitment between different sectors of society, continuous investment in new technologies, and a cultural shift towards how waste is perceived and managed. This article, based on a systematic review of literature, presents the main innovative actions and technologies present in the world and the importance of investment in this sector for the future of solid waste management. Regarding the development of this research, the result obtained is considered promising because it was possible to identify, among the practices of innovation and solid waste management described in the literature, which can be implemented by civil society, government agencies, and companies in a coordinated way. This result opens space for future studies aiming at the use of these practices for the successful development of innovation in organizations.

Keywords: Innovation; Innovation management; Solid Waste Management; Environmental Impacts.

O processo de inovação na gestão de resíduos sólidos

Resumo

O tratamento de resíduos sólidos ainda se apresenta como um grande desafio para a sociedade moderna. A realidade é que existe uma grande deficiência na coleta e na

destinação correta de resíduos sólidos urbanos e industriais, resultando em elevados índices de poluição no planeta. Diante deste cenário, é preciso que se invista em tecnologia e inovação, embora muito já se tenha feito com relação ao tratamento correto de resíduos sólidos, mas muito ainda se pode fazer. Para mitigar este problema, deve-se adotar processos de inovação no tratamento de resíduos sólidos, que envolve diversas etapas e abordagens, visando a melhorar a eficiência, reduzir os impactos ambientais e promover a sustentabilidade. A implementação de estratégias inovadoras requer um compromisso coordenado entre diferentes setores da sociedade, investimento contínuo em novas tecnologias e uma mudança cultural em relação à forma como os resíduos são percebidos e gerenciados. Este artigo, elaborado a partir de uma revisão sistemática da literatura, apresenta as principais ações de inovação e tecnologias que estão presentes no mercado e a importância do investimento neste setor para o futuro da gestão de resíduos sólidos. Com relação ao desenvolvimento desta pesquisa, o resultado obtido é considerado promissor, pois foi possível identificar, dentre as práticas de inovação e gestão de resíduos sólidos descritas na literatura, quais podem ser implementadas pela sociedade civil, órgãos governamentais e empresas de forma coordenada. Esse resultado abre espaço para estudos futuros visando a utilização dessas práticas para o sucesso do desenvolvimento da inovação nas organizações.

Palavras-chave: Inovação; Gestão da inovação; Gestão de Resíduos Sólidos; Impactos Ambientais.

Introduction

In contemporary society, innovation is one of the key drivers of social and economic development across countries and regions. According to Mota (2011), although innovation is often associated with research and development (R&D), it is a broader concept intrinsically linked to the application of knowledge. Innovation requires a commitment to educational practice, serving as a backdrop for the construction of new knowledge, driven not by prevailing paradigms but by lived and reimagined organizational activities. This dynamic is considered one of the fundamental pillars of entrepreneurial innovation.

In modern society, when innovation is guided by sustainability and aligned with sustainable entrepreneurship, it plays a vital role in the transition toward an economy with positive social and environmental impacts and increasingly sustainable production cycles (DEMIREL et al., 2019). The development of Sustainable Business Models (SBMs) is not only of interest to the academic community, but also to business professionals and public policymakers (BOCKEN et al., 2019).

With the advent of new technologies, many companies have sought innovative ways to monitor the generation and destination of their waste. This includes efforts to adopt cleaner treatment techniques or methods that reduce or eliminate waste generation altogether. Despite technological and managerial advances in recent decades, the management of solid waste remains a significant challenge, particularly in developing countries, where it continues to pose obstacles to the implementation of effective public policies (BOCKEN et al., 2019).

According to Brazil's National Solid Waste Policy [PNRS - *Política Nacional de Resíduos Sólidos*] – Law 12,305 of 2010 – solid waste management comprises a set of activities carried out directly or indirectly across various stages, including storage, collection, transportation, transfer, treatment, final disposal of waste, and environmentally sound disposal of non-recoverable materials (REIS, FRIEDE e LOPES, 2017). The legislation stipulates that decision-making must aim to find integrated solutions that consider political, economic, environmental, cultural, and social dimensions, under the principle of sustainable development and with active social participation (Brazil, 2010).

However, even a decade after the establishment of this legal framework, Brazil continues to dispose of approximately 25% of its municipal and industrial solid waste in inadequate sites such as open dumps and recycles only 1.7% of its municipal solid waste through sorting and recycling processes.

Given this context, this study seeks to examine the role of innovation in solid waste management processes, particularly in the context of the transition toward a more sustainable society. The central research question guiding this investigation is: "*What are the best innovative practices in solid waste treatment?*" The main objective is to identify the key innovation-related factors in the solid waste management sector. This study aims to contribute theoretically to expanding academic discussions and research on innovation in waste management practices.

This article is structured as follows: first, the theoretical framework is presented, covering the concepts of innovation, solid waste management, and the challenges associated with solid waste. The next section details the research methodology, followed by the analysis and discussion of the findings. Finally, there are the conclusions, as well as limitations, and suggestions for future research.

Theoretical Review

Innovation Concept

According to the Oslo Manual, published by the Organization for Economic Co-operation and Development [OCDE - *Organização para a Cooperação e Desenvolvimento Econômico*] (OCDE, 2018), considered a global reference for concepts and methodology to analyze innovation in companies, innovation can be defined as:

> *"...a new or improved product or process (or a combination of both) that differs significantly from the company's previous products or processes and that has been introduced to the market or put into use by the company" (OCDE, 2018).*

A The dynamic proposed by the concept of Innovation in Business Models (IBM), emphasizes the ability of organizations to design new business models or transform existing ones (GEISSDOERFER et al., 2018). Innovation is considered a key factor for the full embrace of sustainability, and in this sense, it should serve as a strategic tool within the business model (AGHION et al., 2009).

According to the Brazilian Innovation Law, the definition of innovation is quite broad and focuses primarily on technological innovation. It is generally described as the introduction of novelty or improvement within the productive environment that results in new products, processes, or services (CHRISTENSEN, 2012). However, innovation goes beyond this technical scope; it involves transforming an idea into a creative solution. Thus, innovation is essential for companies of all sizes and sectors, and indeed for an entire country. It is one of the main engines of growth, whether in the productive sector, education, government, healthcare, public safety, or infrastructure (AGHION et al., 2009).

As it is possible to innovate in different contexts, both innovation researchers and public policymakers have adopted a broader definition of the concept in order to better analyze its characteristics, the frequency with which it occurs within companies, and the conditions that enable it. To distinguish between innovation as a process and as an outcome, the Oslo Manual adopts the concepts of innovation activities (the process) and business innovation (KLOSOWSKI et al, 2023). The definition of these terms is:

- **Innovation activities**: encompass all development, financial, and commercial activities undertaken by a company that are intended to result in an innovation for the company.
- **Business innovation**: refers to a new or significantly improved product or business process (or a combination of both) that differs substantially from the company's previous products or processes and has been introduced to the market or implemented within the company.

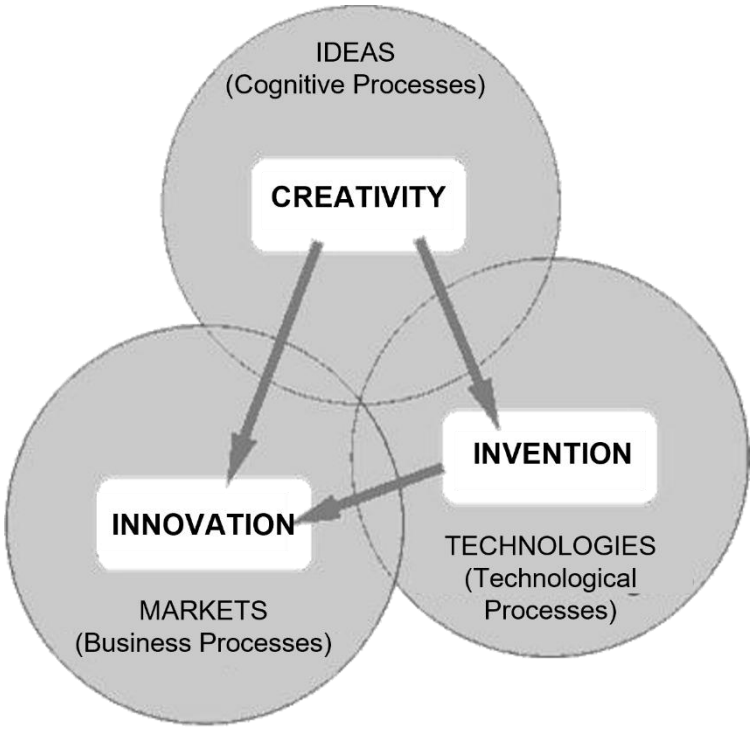
The Oslo Manual, according to Klosowski et al (2023), defines four types of innovation: product, process, marketing, and organizational innovation. The term product includes, in its definition, new forms of services offered in the market. Process innovation refers to production processes, logistics activities, and after-sales services. Product and process innovation are central concepts for defining and analyzing innovation and organizational outcomes, namely:

- **Product innovation:** it is the introduction of a new or significantly improved good or service relating to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, embedded software, user-friendliness, or other functional features.

- **Process innovation:** it is the implementation of a new or significantly improved production or delivery method. This encompasses **major changes in techniques, equipment, and/or software**.
- **Marketing innovation:** it is the implementation of a new marketing method involving significant changes in product design or packaging, product positioning, promotion, or pricing strategies.
- **Organizational innovation:** it is the implementation of a new organizational method in the company's business practices, workplace organization, or external relations.

According to Barney (2002), the technological innovation process involves the mobilization and coordination of both internal and external resources and actors. Internally, this includes departments such as R&D, marketing, operations, human resources, finance, and new business development. Externally, it encompasses stakeholders such as customers, suppliers, research institutions, and funding agencies, as illustrated in Figure 1.

Figure 1 – Strategic Management Model of Technological Innovation.



Source: Adapted from Barney. (2002)

Innovation is a key element in achieving sustained revenue growth and serves as an important differentiator for increasing a company's profit margins. No organization can grow solely through cost reduction and reengineering. Essential components of an innovation-driven culture

include flexibility, integration, efficiency, productivity, value creation, management, and market gains (DE OLIVEIRA MORAIS et. al, 2018).

When combined with knowledge, innovation has become a vital factor for organizational survival, being credited as the driving force behind organizational success and growth, and ultimately contributing to national economic development (MORAIS, MARIA, and OLIVEIRA, 2021).

Solid Waste Management

Solid waste management refers to the process of planning, implementing, monitoring, and controlling the handling of solid waste in order to reduce environmental impacts and improve public health. Its primary goal is to minimize the amount of waste contaminating natural resources such as rivers, lakes, and oceans, while also reducing environmental degradation. Furthermore, solid waste management seeks to decrease the volume of waste sent to landfills and increase the proportion of waste that is recycled or reused (CAVALCANTI, FERNANDES, 2015).

Solid waste should be regarded as one of the most serious public health and environmental challenges currently. The consequences of improper handling and disposal have both direct and indirect effects on human health and the survival of ecosystems. The environmental and social costs to society resulting from the production, handling, and inappropriate disposal of waste are substantial and continue to grow (MARTI, PUERTAS, 2021).

Figure 2 – Solid Waste Management.

Source: Adapted from the National Solid Waste Policy – PNRS (BRAZIL, 2010)

According to the National Solid Waste Policy – PNRS (BRAZIL, 2010), integrated solid waste management refers to a set of actions aimed at finding sustainable solutions for waste management. These actions must necessarily involve political, economic, environmental, cultural, and social dimensions, along with social oversight, in order to ensure integrated and sustainable management.

Since its enactment, the National Solid Waste Policy has served as the main legal instrument for regulating solid waste management in Brazil. However, many public administrators have faced significant challenges in implementing the law at the state and municipal levels.

Solid waste management in developing countries still requires considerable attention. These countries often face critical difficulties at the municipal management level, such as limited financial and administrative capacity, and insufficient technical expertise in managing public sanitation services, selective waste collection, and waste treatment (JACOBI; BESEN, 2011).

Challenges and Issues in Urban Solid Waste Management

The Bill of Law No. 12,305/2010 is concise and establishes guidelines, instruments, responsibilities, and prohibitions for the management of solid waste in the country.

According to the 2023 report Panorama of Solid Waste in Brazil, published by the Brazilian Association of Waste and Environment [ABREMA - *Associação Brasileira de Resíduos e Meio Ambiente*], it is estimated that in 2022, each Brazilian generated an average of 1.04 kg of Municipal Solid Waste per day. Applying this figure to the population reported by the 2022 Demographic Census, approximately 77.1 million tons of Municipal Solid Waste were generated in the country in that year. This corresponds to more than 211 thousand tons of waste produced per day, or about 380 kg per capita per year. Of the total Municipal Solid Waste generated in Brazil in 2022, approximately 93% was properly collected, which amounts to over 196 thousand tons collected daily. While this number seems high, it is important to highlight that the remaining 7%, which were not collected, represent over 5 million tons of improperly disposed waste, posing significant risks to both the environment and public health.

Furthermore, ABREMA (2022), reports that around 61% of the Municipal Solid Waste collected in Brazil in 2022 was sent to sanitary landfills, totaling 43.8 million tons. The Southeast and South regions achieved higher-than-average performance, with more than 70% of their collected waste properly directed to sanitary landfills.

However, solid waste management in Brazil still faces numerous problems and challenges that hinder the implementation of effective and sustainable practices. Some of the main challenges are outlined in Table 1.

Table 1 – Challenges in Solid Waste Management.

Challenges	Descriptors
1. Increase in Waste Generation	Population Growth and Urbanization: The increase in population and urban expansion lead to higher solid waste generation. Changes in Consumption Patterns: Economic growth and lifestyle changes result in greater consumption of disposable goods and packaging, thereby increasing the volume of waste.
2. Insufficient Infrastructure	Lack of Adequate Facilities: Many cities lack sufficient infrastructure for the collection, treatment, and proper disposal of waste. Inefficient Collection: Waste collection systems are often inefficient and fail to effectively cover all urban areas, especially in informal settlements and hard-to-reach locations.
3. Low Recycling Rates	Insufficient Source Segregation: The lack of proper waste segregation at the source hampers recycling processes. Limited Recycling Market: Recycling markets are often underdeveloped, frequently due to low demand or low market value for recycled materials.
4. Economical Challenges	Insufficient Funding: Lack of financial resources to invest in waste treatment technologies and improve existing infrastructure. High Costs: Elevated costs associated with the collection, transportation, treatment, and final disposal of waste.
5. Environmental and Public Health Impacts	Pollution: Improper waste disposal can lead to soil, water, and air pollution. Public Health: Poorly managed waste can attract disease vectors such as rats and mosquitoes and contribute to various public health issues.
6. Legislation and Regulation	Lack of Effective Regulation: In some areas, there is either an absence of appropriate legislation or insufficient implementation and enforcement of existing laws. Conflicts of Interest: Challenges in coordination among different levels of government and stakeholders.
7. Awareness and Education	Low Public Awareness: The general population is often unaware of the importance of proper waste segregation and the benefits of recycling. Insufficient Education: A lack of effective educational programs to promote sustainable waste management practices.
8. Technologies and Innovation	Adoption of New Technologies: Challenges in adopting and implementing new waste treatment technologies, often due to high initial costs and limited technical expertise. Maintenance and Operation: Difficulties in operating and maintaining waste treatment facilities, particularly in resource-constrained areas.
9. Management and Planning	Inefficient Planning: A lack of long-term strategic planning for waste management. Stakeholder Coordination: Challenges in coordinating among stakeholders, including government agencies, the private sector, and communities.
10. Socioeconomic Inequality	Unequal Access to Waste Management Services: Low-income communities often have limited access to proper waste collection and treatment services. Inequitable Exposure to Risk: Vulnerable communities are more frequently exposed to the risks associated with poor waste management.

Source: Adapted from the Solid Waste Panorama Report in Brazil (2023).

The treatment and management of solid waste must be approached with caution and careful planning, primarily due to their environmental impact (SANTIBAÑEZ-AGUILAR et al., 2013). Two important processes for solid waste treatment, recycling and composting,

are emphasized in both the technical-scientific literature and the National Solid Waste Policy (BRASIL, 2010).

To address these challenges, an integrated approach is essential, including effective public policies, investments in infrastructure and technology, education and awareness programs, and effective coordination among all stakeholders involved.

Methodology

The methodological procedures guiding this study, in relation to its objectives, are grounded in theoretical frameworks. For this research, a systematic literature review was adopted as the method, characterized by a rigorous search for studies related to the search terms, following a specific protocol and analyzing the located studies (FERENHOF; FERNANDEs, 2016).

Regarding the nature of the research, this qualitative study is a basic investigation aimed at generating new knowledge to advance the themes of “Innovation and Solid Waste” without a specific practical application.

According to Marconi and Lakatos (2009), this approach is based on investigating and unveiling inseparable aspects that allow for a detailed description of investigations, attitudes, and behavioral trends, seeking to understand and interpret the relationships regarding the complexity of the problem without the use of empirical or statistical tests.

Results and discussion

The main objective of solid waste management is to mitigate the generation of waste produced by the population and industrial sector, promote environmental quality, and foster sustainability, in addition to supporting sustainable economic productivity (KARAK et al., 2012). Understanding the characteristics of solid waste generation is a fundamental starting point for this, as it assists in complying with legislation as well as in the management and planning of collection, treatment, and final disposal actions (CAMPOS, 2012).

Several factors can contribute to effectively reducing the increasing volume of solid waste generated, provided they are implemented in an articulated and comprehensive manner.

The application of innovation processes in solid waste treatment involves various stages and approaches aimed at improving efficiency, reducing environmental impacts, and promoting sustainability.

As a result of the bibliographic survey conducted in this study, it was possible to list some innovative strategies and practices that can be implemented. These practices are presented in Table 2.

Table 2 – Innovative strategies and practices applied to the innovation process in solid waste treatment.

Innovative Practices	Descriptors	Authors
1. Advanced Treatment Technologies	Anaerobic Digestion: Uses microorganisms to break down organic matter in the absence of oxygen, producing biogas (methane) which can be used as a renewable energy source and as biofertilizer. Gasification and Pyrolysis: Convert organic waste into syngas and bio-oil through thermal processes, enabling the generation of energy and valuable chemical products. Mechanical-Biological Treatment: Combines mechanical and biological processes to sort and treat waste, increasing the efficiency of recycling and composting.	BONAFIN, DA SILVA, KORF, (2022). LADEIRA, PACHECO, (2023). WALCANAIA (2022). MEDEIROS et al (2022).
2. Automation and Digitalization	Sensors and IoT (Internet of Things): Implementation of sensors in waste bins and collection trucks to monitor waste levels in real time, optimize collection routes, and enhance waste management efficiency. Digital Platforms: Applications that coordinate recycling efforts between consumers and companies, facilitating proper waste segregation and selective collection.	DO VAL BUGELLI, SCUR, (2023). CALDEIRA et al (2024). BUENO, TORRES, (2022)
3. Circular Economy	Product Design for Recycling: Development of products and packaging that are easier to recycle, disassemble, and reuse, thereby minimizing waste generation. Industrial Symbiosis: Collaboration among companies from different sectors to use the waste from one process as raw material for another, promoting resource reuse.	LIMA (2023). CALDEIRA et al (2024). DO VAL BUGELLI, SCUR, (2023).
4. Social and Educational Innovation	Education and Awareness Campaigns: Educational programs aimed at informing the public about the importance of proper waste separation and the benefits of recycling and composting. Community Participation: Initiatives that encourage active community involvement in waste management, such as door-to-door selective collection programs and voluntary drop-off points.	COELHO et al.(2022). RIZARDI, VICENTE (2020). PIRES, ALPERSTEDT, (2022)

Innovative Practices	Descriptors	Authors
6. Public-Private Partnerships	Strategic Collaborations: Partnerships between governments, private companies, NGOs, and academic institutions to develop and implement innovative solutions in solid waste management. R&D investments: Funding for research and development aimed at creating new technologies and more efficient and sustainable waste treatment methods.	LIMA, (2023). HUMBERT, KUPSCH FILHO, (2020). THOMÉ, DINIZ, RAMOS, (2016). SABRI, HANYIA, JABER, (2012)
7. Innovative Business Models	Subscription-Based Services: Models in which consumers pay for the use of products rather than ownership, encouraging product return and recycling at the end of their life cycle. Waste-as-Resource Enterprises: Businesses that view waste as a valuable resource, creating new products from recycled materials and promoting the circular economy.	ALVES, GONÇALVES, (2019). DE OLIVEIRA et al.(2021). BAUM, DE SOUZA, (2023).

Source: Developed by the Authors (2024).

Quantifying the solid waste generated in urban areas is hindered by the continued practice of improper disposal, although this situation has significantly improved after the Law 12,305/2010. In rural areas, this task is even more complex due to the additional challenge of the absence or insufficiency of collection systems (IPEA, 2012).

Solid waste collection in Brazil is also closely linked to economic factors, as there are considerable costs associated with ensuring the regular execution of this service. These challenges demand an integrated approach involving governments, organizations, and civil society in order to promote sustainable urban solid waste management (MONTEIRO et al, 2024).

The National Solid Waste Policy establishes the guidelines for the management and handling of solid waste, including waste reduction, recycling, and reuse. These guidelines, commonly referred to as the “3 Rs” of sustainability, define effective solid waste management as essential to reducing environmental impacts, improving quality of life, and promoting sustainable development (DOS SANTOS, VAN ELK, 2021).

Solid waste management is a complex process that requires the collaboration of multiple factors. Proper planning, along with the implementation of appropriate policies, programs, and services, is essential to ensure the effective handling of solid waste. Technological innovation in waste management seeks alternatives for the proper disposal of materials, avoiding practices that could harm society both financially and environmentally, while also ensuring control over each stage of the management process.

As outlined in various studies reviewed in this research, waste management involves mapping processes, analyzing the types of waste generated at each stage,

classifying and quantifying this waste, assessing storage practices, and identifying how and where final disposal takes place.

Final Considerations

The studies presented and discussed herein offer insight into the strategies and innovative practices applied to the process of innovation in solid waste treatment in Brazil and worldwide. However, significant challenges remain regarding the effective implementation of the guidelines established by the National Solid Waste Policy in Brazil.

As it is a concept that is spreading and that causes disruptive changes in society, the process of innovation in solid waste treatment and its large-scale implementation raises important reflections. Among them are how to reintegrate the volume of waste generated at the end of a production chain back into its beginning, how to transform each type of waste into a new resource, and how to enable the transition from a traditional linear model to a circular and economically sustainable model.

Given this context, adopting innovation as a key element emerges as an established model for the healthy coexistence between the economy and the environment. Aiming to structure a system in which products and materials are valorized, the selection of raw materials, product design, and the utilization of by-products become essential aspects of this new production paradigm. It is important to note that solid waste collection in Brazil is also directly linked to economic factors, as there are costs associated with the periodic execution of this process. Although waste management efforts have improved significantly in recent years, many opportunities for enhancement remain, one of which lies in the implementation of innovation and development in these processes.

Thus, this study emphasizes that the mechanisms employed to promote solid waste management function as interconnected building blocks, which further increase the use of recyclable resources while reducing waste and simultaneously driving revenue growth. Last but not least, it is clear that innovation in solid waste treatment is not merely a “fleeting trend” but rather a global convergence that is gaining ground in society and is widely debated at both national and international levels.

Due to the research theme being situated within the Brazilian context, this study faces certain limitations. These are related to the availability of documents and articles with incomplete or outdated data, the significant variability in the composition of solid waste across different regions, and the difficulty in ensuring the long-term financial sustainability of innovative projects.

As a suggestion for future research, it is recommended to investigate the reintegration of solid waste into production processes through reuse and recycling, which could reduce costs for organizations, decrease the extraction of raw materials, and benefit society as a whole.

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