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APLICAÇÕES DE RESÍDUOS DA INDÚSTRIA DE PAPEL E CELULOSE EM DIFERENTES MATERIAIS: REVISÃO NARRATIVA

Applications of waste from the paper and cellulose industry in different materials: a narrative review

Gabriela Tenório de Lacerda Melo Alves[1], Maryane Gislaine Cordeiro de Queiroz[2], Karol Stein Scaburri[3], Abrahão Bernardo Rohden[4]

Resumo: Os resíduos sólidos industriais representam um desafio crescente na área ambiental, e a indústria de papel e celulose destaca-se por gerar volumes significativos de resíduos. Neste contexto, o objetivo do estudo é realizar uma revisão narrativa sobre o reaproveitamento de resíduos da indústria de papel e celulose em diferentes materiais, com foco na construção civil, indústria têxtil, agricultura e produção de embalagens à base de papel e celulose. O levantamento bibliográfico foi realizado por meio do Portal de Periódicos CAPES, utilizado como plataforma de acesso integrado a bases de dados, periódicos científicos e plataformas editoriais disponíveis no portal, e da Biblioteca Digital Brasileira de Teses e Dissertações (BDTD), considerando publicações disponíveis entre 2014 e 2024. Os resultados indicaram que o reaproveitamento dos resíduos da indústria de papel e celulose apresenta viabilidade técnica e potencial de aplicação nas diferentes vertentes analisadas, agricultura, construção civil, embalagens, tecnologias ambientais, entre outros. Embora elevada heterogeneidade entre os resíduos, métodos de processamento e indicadores avaliados, conclui-se que o reaproveitamento de resíduos da indústria de papel e celulose apresenta potencial ambiental e tecnológico, embora sejam necessários avanços na padronização terminológica, caracterização dos resíduos e avaliação do desempenho em longo prazo para ampliar sua aplicação industrial.

Palavras-chave: Resíduo industrial. Papel e celulose. Reaproveitamento.

Abstract: Industrial solid waste represents a growing environmental challenge, and the pulp and paper industry stands out for generating significant volumes of waste. In this context, the aim of this study is to conduct a narrative review on the reuse of waste from the pulp and paper industry in different materials, with a focus on civil construction, the textile industry, agriculture, and the production of paper- and cellulose-based packaging. The bibliographic survey was carried out through the CAPES Journal Portal, used as an integrated access platform to databases, scientific journals, and editorial platforms available on the portal, as well as through the Brazilian Digital Library of Theses and Dissertations (BDTD), considering publications available between 2014 and 2024. The results indicated that the reuse of waste from the pulp and paper industry demonstrates technical feasibility and potential application in the different areas analyzed, including agriculture, civil construction, packaging, and environmental technologies, among others. Despite the high heterogeneity among waste types, processing methods, and evaluated indicators, it is concluded that the reuse of waste from the pulp and paper industry presents environmental and technological potential, although advances in terminological standardization, waste characterization, and long-term performance assessment are still necessary to expand its industrial application.

Keywords: Industrial Waste. Paper and Cellulose. Reuse.

[1]Mestre em Engenharia Ambiental, Fundação Universidade Regional de Blumenau, gtlmalves@furb.br
[2]Mestre em Engenharia Civil, Fundação Universidade Regional de Blumenau, mgcqueiroz@furb.br
[3]Graduanda em Engenharia Química, Fundação Universidade Regional de Blumenau, ksaburri@furb.br.
[4]Doutor em Engenharia Civil, Fundação Universidade Regional de Blumenau, arohden@furb.br

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1 INTRODUCTION

The management of industrial solid waste (ISW) represents a constant challenge for industrial sectors, both in complying with current legal requirements and addressing the demands for investments in the environmental sector, particularly in socio-environmental initiatives (Müller *et al.,* 2022). In countries such as Brazil, ISW management faces additional barriers, including logistical challenges, due to the distances between major urban centers equipped with advanced technologies and more remote regions of the territory (Silva and Fontana, 2021).

Among industrial sectors generating waste, the paper and cellulose industry stands out for its high production volume, with residues that exhibit diverse compositions and characteristics, complicating their reuse and often resulting in their disposal in landfills (Brasil, 2022). In 2022, Brazil's cellulose production reached 25 million tons, while paper production amounted to 11 million tons, representing increases of 10.9% and 21%, respectively, compared to 2021 (IBA, 2023). Consequently, Brazil ranked among the world's top ten paper-producing countries in 2020, as reported by the Food and Agriculture Organization of the United Nations (FAO, 2021). It is noteworthy that, specifically in the state of Santa Catarina, a significant paper production of 1.9 million tons was recorded in 2022, according to data provided by the Environmental Institute of Santa Catarina (IMA, 2022). Regarding cellulose, Brazil is the second largest producer worldwide, ranking only behind the United States (IBÁ, 2023).

Considering the various environmental impacts associated with industrial activities, the objectives proposed by the Sustainable Development Goals (SDGs) aim to promote more sustainable cities and production systems. In this context, SDGs 3, 9, and 12 are particularly relevant, as they focus on ensuring responsible consumption and production while fostering social well-being. Accordingly, reducing the amount of waste generated through prevention, reduction, recycling, and reuse measures represents a positive approach to waste management and final disposal (Brasil, 2015). Moreover, according to Ervasti et al. (2016), recycling practices exert a positive effect on the environment by reducing pollutant gas emissions and enhancing sustainability through more efficient use of raw materials.

Within the paper and cellulose production processes, the reuse of post-consumer paper scraps is notable, enabling the use of this industrial residue as a by-product. Paper scraps are typically composed of recycled residues from diverse raw materials, featuring varied properties that require prior classification due to the presence of additives such as glue, kaolin, aluminum sulfate, starch, dyes, adhesives, latex, and pigments. These additives can affect the color of the paper and result in a significant volume of rejected fibers during the production process (Schneider and Mühlen, 2011; Alves *et al.*, 2012; Silva, Niemeyer, and Stolberg, 2020).

In the paper and cellulose industry, residues are generated at different stages of production, processing, recycling, and wastewater treatment. These residues may include fibrous materials, paper scraps, sludge, and other by-products with variable composition, depending on the raw material and the industrial process adopted (Simão et al., 2018). Among the industrial sectors responsible for waste generation, the paper and pulp industry stands out due to its high production volume, whose residues exhibit diverse compositions and characteristics, making their reuse more challenging (Brasil, 2022). According to the Brazilian Technical Association of Pulp and Paper (ABTCP, 2013), some Brazilian manufacturers used exclusively or almost exclusively recyclable cellulosic material, while others relied on chemically produced cellulosic material or combined both sources in their operations. Additionally, the literature highlights the potential reuse of residues from the paper and cellulose industry in sectors such as agriculture, construction, energy generation, and environmental technology, as well as their use as by-products within the industry itself (Simão et al., 2018).

In this context, the present study provides a narrative review of the applications of waste from the paper and cellulose industry in different materials, aiming to analyze the main reuse routes, application sectors, reported technical benefits, and limitations identified in the literature.

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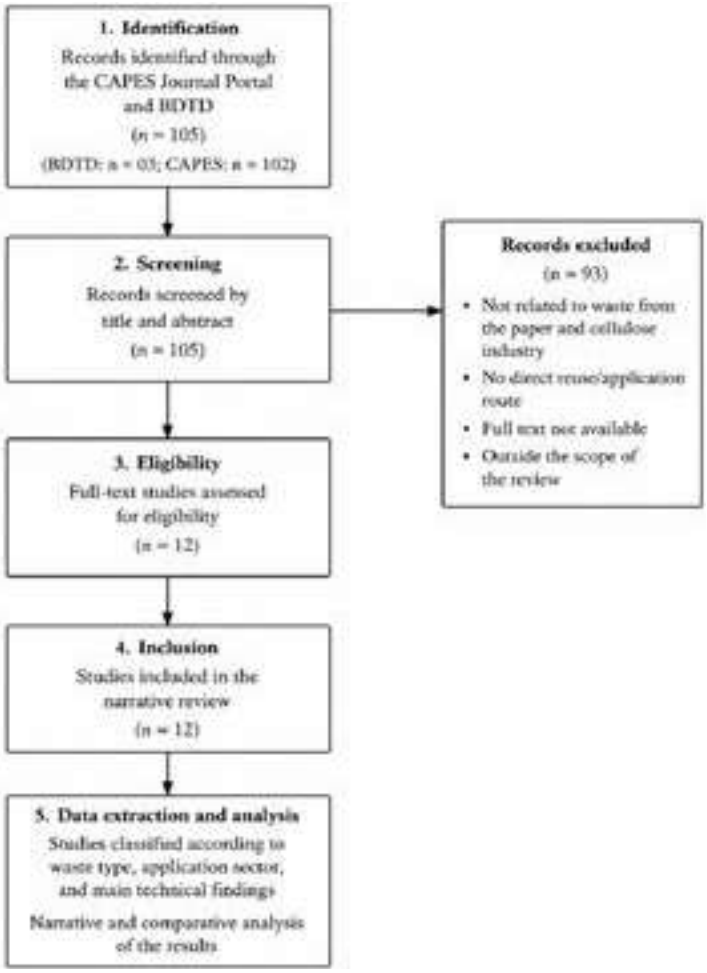
2 METHODOLOGY

This study was conducted as a narrative literature review focused on the reuse of waste from the paper and cellulose industry in different applications. The bibliographic survey was performed through the CAPES Journal Portal, considered an integrated access platform to scientific databases, journals, and publisher platforms, and through the Brazilian Digital Library of Theses and Dissertations (BDTD). The CAPES Journal Portal was selected because it provides access to multiple scientific databases and publisher platforms, including publications in Portuguese and English, allowing broader retrieval of academic literature. The BDTD was used to retrieve Brazilian theses and dissertations related to the topic. The search covered publications available between 2014 and 2024.

The search strategy was guided by the objective of identifying studies related to the reuse of waste from the paper and cellulose industry. The keywords used were “resíduo”, “aparas de papel”, “reaproveitamento”, “paper waste”, and “reuse”. The inclusion criteria were studies published in Portuguese and/or English, full-text availability, and studies whose focus was the reuse or application of waste generated in the paper and cellulose industry.

A total of 105 records were initially identified. The first screening stage was based on title and abstract reading. Records were excluded when they did not address the reuse or application of waste generated in the paper and cellulose industry, did not provide full-text access, or were not aligned with the scope of the review. At the end of the selection process, 12 studies were included for narrative and comparative analysis. The selected studies were classified according to waste type, application sector, and main technical findings.

Figure 1 - Flowchart of study selection



Source: Authors (2024).

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3 RESULTS AND DISCUSSION

3.1 CLASSIFICATION OF THE SELECTED STUDIES

Paper waste originates from multiple sources and presents diverse physicochemical characteristics, while its by-products allow for a wide range of applications (BRASIL, 2022). It can occur in different forms, such as sludge, cellulosic pulp, or separated cellulose fibers (Table 1). Although the search was conducted through the CAPES Journal Portal, the selected articles were retrieved from recognized scientific sources, including journals and publisher platforms indexed in databases such as Scopus and Web of Science.

Table 1 - Overview of the selected studies included in the narrative review.

Authors	Document type	Information source	Waste type	Application sector	Specific application
Kendrick (2019)	Dissertation	BDTD / UFPR Repository	Cellulosic pulp	Packaging	Packaging paper
Jarek (2014)	Dissertation	BDTD / UFPR Repository	Paper trimmings	Packaging	Packaging paper
Pandey et al. (2021)	Conference paper	CAPES / Scopus	Paper waste	Molded products	Eco-friendly cutlery
Duong et al. (2017)	Article	CAPES / Scopus	Cellulose fibers	Insulation materials	Thermal jacket
Gorzelańczyk et al. (2020)	Article	CAPES / Scopus	Cellulose fibers	Construction materials	Fiber-cement boards
Rezende et al. (2021)	Article	CAPES / Scopus	Cellulose fibers	Construction materials	Mortar
Fernando et al. (2023)	Article	CAPES / Web of Science	Cellulose fibers	Construction materials	Cement-based composites
Rey et al. (2023)	Article	CAPES / Scopus	Paper sludge	Construction materials	Non-structural ceramic brick blocks
Mathivanan et al. (2017)	Conference paper	CAPES / Scopus	Paper waste	Agriculture / biological processes	Vermiculture / vermicomposting
Chrysargyris et al. (2020)	Article	CAPES / Scopus	Paper waste	Agriculture	Peat substitute in growing medium
Pham et al. (2021)	Article	CAPES / Scopus	Paper waste	Environmental technology	Carbon aerogel for pollutant removal
Widowati et al. (2021)	Conference paper	CAPES / Scopus	Paper waste	Aesthetic / product design	Wig manufacturing

Source: Authors (2024).

This initial classification shows that direct comparison among studies is limited by the heterogeneity of waste types and by the lack of terminological standardization. Although the search was guided by terms related to paper trimmings and paper waste, the selected studies used different expressions to describe residues from the paper and cellulose industry, including paper waste, paper sludge, cellulosic pulp, cellulose fibers, and paper trimmings. This variation indicates that the terminology adopted in the literature is still fragmented, which reinforces the need to classify the studies according to waste type and application sector before comparing their results.

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3.2 PACKAGING

The selected studies on packaging and molded products used different paper-based residues and evaluated applications ranging from packaging papers to molded products. Kendrick (2019) investigated the use of microfibrillated cellulosic pulp in packaging papers and reported improvements in specific paper properties, including a 12% increase in tensile strength and a 30% reduction in water vapor permeability. In this case, the indicators evaluated were directly related to the performance of paper packaging applications.

Jarek (2014) addressed the sustainable reuse of residues generated in paperboard packaging companies, with emphasis on design and innovation strategies for the use of paper residues. Unlike Kendrick (2019), the study was not centered on the measurement of mechanical or barrier properties, but on the valorization of residues within the context of packaging companies. Therefore, its contribution is associated with the identification of reuse possibilities and design-oriented alternatives for paper residues.

Pandey et al. (2021) proposed the development of eco-friendly cutlery from paper waste through a molding process. The authors stated that wastepaper can be recycled to produce usable and biodegradable products, such as paper plates, cups, spoons, tiles, toys, and crafts. The study presented a compact recycling machine and indicated an estimated design efficiency of 90% and power consumption of 450 W.

Overall, the studies in this group show that paper and cellulose residues were applied to packaging papers, design-based reuse, and molded products. However, the evidence is based on different types of evaluation. In packaging paper, the reuse route was assessed through measurable material properties, such as tensile strength and water vapor permeability. In molded products, the focus was mainly on process feasibility, including equipment efficiency and energy consumption. In design-based reuse, the contribution was related to residue valorization and the identification of alternative uses, rather than to the measurement of technical performance. Therefore, although the studies indicate reuse possibilities, comparison among them is limited by the differences in residue type, processing method, final product, and performance indicators. The main limitation in this group is the absence of common technical criteria, which prevents a direct comparison of performance between studies and does not allow a generalized conclusion for all packaging and molded product applications.

3.3 CONSTRUCTION MATERIALS

The selected studies on construction materials evaluated the incorporation of residues from the paper and cellulose industry in fiber-cement boards, cement-based mortars, ceramic bricks, cement composites, and recycled composite materials. Gorzelańczyk, Schabowicz and Szymków (2020) evaluated fiber-cement materials containing recycled cellulose fibers. The authors reported that the incorporation of recycled fibers affected the mechanical behavior of the boards, especially under moisture exposure. The results indicated reductions in modulus of rupture and increased water absorption with higher recycled fiber contents.

Rezende et al. (2021) evaluated cement-based mortars reinforced with recycled waste paper cellulosic fibers. The authors reported changes in both fresh and hardened properties, including reduction in density and mechanical strength, while also indicating improved post-cracking behavior associated with the presence of fibers.

Rey, Forero-Garcia and Romero (2023) investigated the incorporation of paper sludge into hollow ceramic bricks for non-structural walls. The authors evaluated dosages of 0%, 11.1%, 12.5%, 14.3%, 16.7%, and 20% of paper sludge. According to the study, the residue used was generated during the paper manufacturing process and consisted mainly of cellulose and minerals, such as kaolin and

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limestone. The results showed that the incorporation of paper sludge did not negatively affect the mechanical response of the ceramic bricks. The mixture with 20% paper sludge reached a compressive strength of 14 MPa, while the mixtures with 11.1% and 12.5% presented the best overall performance considering strength, absorption, dimensions, and aesthetic quality.

Fernando et al. (2023), in a review on cement composites incorporating waste cellulose fibers, reported that paper-based cellulose fibers used in cement-based composites are mainly classified into two groups: waste paper sludge and paper/cardboard waste. The authors showed that the effect of these fibers on cementitious materials varies according to fiber content, dispersion, and water demand. In the studies reviewed by the authors, reductions in density were observed with the addition of waste paper fibers. However, the increase in fiber content was also associated with reductions in mechanical properties in some cases. For example, an increase in fiber content from 0% to 16% reduced bulk density from 1972 to 1063 kg/m³, while other studies cited in the review reported reductions in compressive strength and modulus values with higher fiber contents.

The same review also reported different responses depending on the incorporation level. In cement boards, the replacement of cement by paper fiber at 10%, with 5% accelerators, increased the modulus of rupture from 1.5 to 2.2 MPa and the modulus of elasticity from 0.5 to 2.5 GPa. However, when the addition of waste paper cellulose fibers increased from 10% to 20%, reductions of approximately 44% to 63% were observed in the modulus of rupture and modulus of elasticity. Thus, the data compiled by Fernando et al. (2023) indicate that paper-based cellulose fibers may contribute to density reduction and some mechanical gains at specific contents, but higher incorporation levels may reduce mechanical performance.

In addition to cementitious and ceramic materials, the selected studies also included applications in composite materials. Studies involving mixed waste of plastic and paper evaluated the mechanical and morphological behavior of composites produced from recycled residues. In this case, the paper residue was not evaluated alone, but as part of a mixed recycled matrix, which limits direct comparison with studies based on paper sludge in bricks or cellulose fibers in cement-based materials.

In this section, the results are better interpreted according to the type of matrix in which the residue was incorporated. In cementitious materials, the behavior was mainly associated with the interaction between cellulose fibers and the cement matrix, with effects on density, water absorption, modulus of rupture, modulus of elasticity, and mechanical strength. The reviewed data indicate that the incorporation level is a relevant factor, since specific contents were associated with density reduction or mechanical gains, while higher fiber contents were related to increased porosity, water demand, and reduction in mechanical performance. In ceramic bricks, the paper sludge was evaluated in a fired clay matrix, and the results were linked to compressive strength, water absorption, dimensional characteristics, and aesthetic quality. In mixed plastic-paper composites, the paper residue was not evaluated separately, which limits attribution of the observed behavior specifically to the paper fraction. Thus, the evidence indicates possible reuse routes in construction materials, but the results depend strongly on residue type, matrix composition, dosage, moisture sensitivity, and the performance criterion adopted. This heterogeneity limits direct comparison among studies and prevents a generalized conclusion for construction materials as a whole.

3.4 AGRICULTURE

The selected studies related to agriculture and biological processes evaluated paper waste in two different routes: vermicomposting and growing media.

Mathivanan et al. (2017) studied the biodegradation of paper waste using Eisenia foetida by vermicomposting technology. The authors evaluated the use of paper waste combined with organic

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residues and reported that the process contributed to paper degradation and compost production. The study also indicated earthworm growth during the process, considering size and number of worms, especially under treatment conditions that favored waste decomposition.

Chrysargyris et al. (2020) evaluated the reuse of paper as an alternative growing medium component for Brassica seedling production under nursery conditions. The authors reported that paper waste affected substrate properties, including pH and aeration. The study also evaluated plant physiological responses and indicated that the tested substrates did not cause cellular damage, based on parameters such as lipid peroxidation, hydrogen peroxide production, and antioxidant enzyme activity.

These applications differ from the previous groups because they are not organized around a common sector, but around specific product functions. In the case of carbon aerogels, paper waste was converted into a material for environmental remediation, with performance evaluated by adsorption capacity, pollutant removal, and recovery rates. In the insulation application, the cellulose-based material was assessed according to density and thermal conductivity, which are directly related to heat transfer. In wig manufacturing, the evaluation was based on product validation and acceptance, rather than on physicochemical or mechanical performance. This difference in evaluation criteria is the main limitation of this group. Although the studies show that paper waste and cellulose-based materials can be processed into products with distinct functions, the evidence is restricted to each application and does not support direct comparison among them or a generalized conclusion about material performance.

3.5 OTHERS APPLICATIONS

Other applications were identified in studies involving adsorbents, insulating materials, and aesthetic products. These studies used paper waste or cellulose-based materials in different processing routes, which resulted in distinct final products and performance indicators.

Pham et al. (2021) produced carbon-based aerogels derived from waste paper for the adsorptive removal and recovery of organic pollutants from wastewater. The authors evaluated phenol and 2-chlorophenol removal and reported maximum adsorption capacities of 238.1 and 277.8 mg g^{-1}, respectively. The study also reported that the carbon aerogel could remove approximately 80% of organic pollutants from wastewater and that recovery rates reached 207.3 mg g^{-1} for phenol and 252.1 mg g^{-1} for 2-chlorophenol.

Duong et al. (2017) evaluated cellulose aerogels for thermal insulation applications in water bottles. The authors reported low density and thermal conductivity values, indicating the use of the material as a thermal jacket. In this case, the application was not related to direct replacement of conventional paper products, but to the use of cellulose-based material in an insulating system.

Widowati et al. (2021) investigated the use of paper waste for wig manufacturing. The process involved cutting, shaping, gluing, and curling paper waste to obtain the final product. The authors reported validation indices of 97% and student approval of 87.2%, indicating acceptance of the proposed product within the evaluated context.

In this group, the studies presented different reuse routes and different performance indicators. Pham et al. (2021) focused on adsorption capacity and pollutant recovery, Duong et al. (2017) evaluated thermal insulation properties, and Widowati et al. (2021) assessed product validation and acceptance. Therefore, these studies cannot be directly compared in terms of material performance, but they show that paper and cellulose residues have been investigated in applications beyond conventional packaging, agriculture, and construction materials.

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4 CONCLUSIONS

The narrative review showed that waste from the paper and cellulose industry has been applied in different sectors, including packaging and molded products, construction materials, agriculture and biological processes, environmental technologies, insulating materials, and aesthetic products. The selected studies used different types of residues, such as paper waste, paper sludge, cellulosic pulp, cellulose fibers, and paper trimmings.

One of the main aspects observed was the lack of standardized terminology for these residues. The same general field includes materials with different origins, compositions, processing routes, and applications. Therefore, the expression “waste from the paper and cellulose industry” should be understood as a broad category, not as a single material with uniform properties.

In packaging and molded products, the indicators included tensile strength, water vapor permeability, degradation rate, process efficiency, and energy consumption. In construction materials, the main parameters evaluated were compressive strength, density, water absorption, modulus of rupture, modulus of elasticity, and morphological characteristics. In this group, the results were influenced by residue content, moisture, fiber dispersion, and matrix type. In agriculture and biological processes, the studies addressed vermicomposting and growing media, considering degradation, compost production, substrate properties, and plant physiological responses. Other applications involved adsorption capacity, pollutant recovery, thermal insulation properties, and product acceptance.

Thus, the reviewed literature indicates reuse possibilities for waste from the paper and cellulose industry, but the evidence remains fragmented. The studies differ in residue type, processing method, incorporation level, and performance indicators, which limits broad conclusions about technical feasibility. Future research should prioritize clearer identification of residue origin, standardized terminology, physicochemical characterization, comparative evaluations under similar conditions, and long-term performance assessment.

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