PERIODICIDADE

Four-monthly publication/ Publicação quadrimestral

CONTATO

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SOBRE O PERIÓDICO MIX SUSTENTÁVEL

O Periódico Mix Sustentável nasceu da premissa de que o projeto englobando os preceitos da sustentabilidade é a única solução possível para que ocorra a união entre a filosofia da melhoria contínua com a necessidade cada vez maior de preservação dos recursos naturais e incremento na qualidade de vida do homem. A sustentabilidade carece de uma discussão profunda para difundir pesquisas e ações da comunidade acadêmica, que tem criado tecnologias menos degradantes na dimensão ambiental; mais econômicas e que ajudam a demover injustiças sociais a muito estabelecidas.
O periódico Mix Sustentável apresenta como proposta a publicação de resultados de pesquisas e projetos, de forma virtual e impressa, com enfoque no tema sustentabilidade. Buscando a troca de informações entre pesquisadores da área vinculados a programas de pós-graduação, abre espaço, ainda, para a divulgação de profissionais inseridos no mercado de trabalho, além de entrevistas com pesquisadores nacionais e estrangeiros. Além disso publica resumos de teses, dissertações e trabalhos de conclusão de curso defendidos, tendo em vista a importância da produção projetual e não apenas textual.
De cunho essencialmente interdisciplinar, a Mix tem como público-alvo pesquisadores e profissionais da Arquitetura e Urbanismo, Design e Engenharias. De acordo com a CAPES (2013), a área Interdisciplinar no contexto da pós-graduação, decorreu da necessidade de solucionar novos problemas que emergem no mundo contemporâneo, de diferentes naturezas e com variados níveis de complexidade, muitas vezes decorrentes do próprio avanço dos conhecimentos científicos e tecnológicos. A natureza complexa de tais problemas requer diálogos não só entre disciplinas próximas, dentro da mesma área do conhecimento, mas entre disciplinas de áreas diferentes, bem como entre saberes disciplinares e não disciplinares. Decorre daí a relevância de novas formas de produção de conhecimento e formação de recursos humanos, que assumam como objeto de investigação fenômenos que se colocam entre fronteiras disciplinares.
Desafios teóricos e metodológicos se apresentam para diferentes campos de saber. Novas formas de produção produção de conhecimento enriquecem e ampliam o campo das ciências pela exigência da incorporação de uma racionalidade mais ampla, que extrapola o pensamento estritamente disciplinar e sua metodologia de compartimentação e redução de objetos. Se o pensamento disciplinar, por um lado, confere avanços à ciência e tecnologia, por outro, os desdobramentos oriundos dos diversos campos do conhecimento são geradores de diferentes níveis de complexidade e requerem diálogos mais amplos, entre e além das disciplinas.
A Revista Mix Sustentável se insere, portanto, na Área Interdisciplinar (área 45), tendo como áreas do conhecimento secundárias a Arquitetura, Urbanismo e Design (área 29), a Engenharia Civil (área 10) e, ainda, as engenharias em geral.

CLASSIFICAÇÃO QUALIS

No quadriênio 2017-2020 a revista MIX Sustentável está classificada como A3 em todas as áreas de avaliação.

MISSÃO

Publicar resultados de pesquisas e projetos, de forma virtual e impressa, com enfoque no tema sustentabilidade, buscando a disseminação do conhecimento e a troca de informações entre acadêmicos, profissionais e pesquisadores da área vinculados a programas de pós-graduação.

OBJETIVO

Disseminar o conhecimento sobre sustentabilidade aplicada à projetos de engenharia, arquitetura e design.

POLÍTICAS DE SEÇÃO E SUBMISSÃO

A) Seção Científica

Contém artigos científicos para socializar a produção acadêmica buscando a valorização da pesquisa, do ensino e da extensão. Reúne 12 artigos científicos que apresentam o inter-relacionamento do tema sustentabilidade em projetos

de forma interdisciplinar, englobando as áreas do design, engenharia e arquitetura. As submissões são realizadas em fluxo contínuo em processo de revisão por pares. A revista é indexada em sumários.org e no google acadêmico.

B) Seção Resumo de Trabalhos de Conclusão de Curso de Graduação, Iniciação Científica e Pós-graduação
Tem como objetivo a divulgação de Teses, Dissertações e Trabalhos de Conclusão de Curso na forma de resumos expandidos e como forma de estimular a divulgação de trabalhos acadêmico-científicos voltados ao projeto para a sustentabilidade.

C) Seção Mercadológica
É um espaço para resenhas e entrevistas (espaços de diálogo). Apresenta pelo menos duas entrevistas com profissionais atuantes no mercado ou pesquisadores de renome, mostrando projetos práticos que tenham aplicações na esfera da sustentabilidade. Deverá ainda disponibilizar conversas com especialistas em sustentabilidade e/ou outros campos do saber. Todas os números possuem o Editorial, um espaço reservado para a apresentação das edições e comunicação com os editores.

PROCESSO DE AVALIAÇÃO PELOS PARES

A revista conta com um grupo de avaliadores especialistas no tema da sustentabilidade, doutores em suas áreas de atuação. São 211 revisores, oriundos de 67 instituições de ensino Brasileiras e 8 Instituições Internacionais. Os originais serão submetidos à avaliação e aprovação dos avaliadores (dupla e cega).
Os trabalhos são enviados para avaliação sem identificação de autoria. A avaliação consiste na emissão de pareceres, da seguinte forma:

- aprovado
- aprovado com modificações (a aprovação dependerá da realização das correções solicitadas)
- reprovado

PERIODICIDADE

Publicação quadrimestral com edições especiais. São publicadas três edições regulares ao ano. Conta ainda com pelo menos uma edição especial anual.

POLÍTICA DE ACESSO LIVRE

Esta revista oferece acesso livre imediato ao seu conteúdo, seguindo o princípio de que disponibilizar gratuitamente o conhecimento científico ao público proporciona maior democratização mundial do conhecimento.

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A contribuição deve ser original e inédita, e não estar sendo avaliada para publicação por outra revista; caso contrário, deve-se justificar em "Comentários ao editor".
O arquivo da submissão deve estar em formato Microsoft Word, OpenOffice ou RTF.
As URLs para as referências devem ser informadas nas referências.
O texto deve estar em espaço simples; usar uma fonte de 12 pontos; empregar itálico em vez de sublinhado (exceto em endereços URL); as figuras e tabelas devem estar inseridas no texto, não no final do documento na forma de anexos.
Enviar separadamente todas as figuras e imagens em boa resolução.
O texto segue os padrões de estilo e requisitos bibliográficos descritos em Diretrizes para Autores e na página http://mixsustentavel.paginas.ufsc.br/submissoes/.

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EDITORIAL

MIX SUSTENTÁVEL VOL. 10 N. 5 – EDIÇÃO REGULAR 2024

FINAL DE ANO

Esta é a última edição da Mix Sustentável em 2024. Finalizamos o ano com a notícia de que o sistema QUALIS/CAPES será extinto. As discussões sobre isso nem sequer começaram ainda. Independente das falhas do sistema QUALIS, algumas inclusive já comentadas em editoriais da Mix Sustentável, preocupamo-nos com o que virá em sua substituição.

Em geral as críticas da comunidade científica ao sistema QUALIS nunca foram direcionadas a sistemática do QUALIS em si, mas sim, a questão humana/operacional envolvida. Destacam-se três aspectos que desacreditaram o sistema: (1) o constante atraso na publicação dos quadriênios; (2) a presença de revistas claramente predatórias, na atribuição de QUALIS, por vezes em extratos elevados, (3) a presença de revistas que não atendem os critérios de números de publicações ou indexações, e outras que atendem, em extratos incompatíveis.

As falhas são decorrência da parte operacional humana atrelada ao processo, e não ao sistema QUALIS em si. Por exemplo, é inadmissível que nos dias atuais, com a capacidade tecnológica e com os recursos humanos disponíveis, tenhamos ao final do ano de 2024 referência ao quadriênio 2017-2020. Quantas novas revistas foram criadas nesse período? Quantas foram extintas? Em quantas delas os editores trabalharam na divulgação, na busca por parcerias, na expectativa de ampliar o escopo e o reconhecimento? Ora, todos nós sabemos que revistas com extratos baixos do QUALIS não atraem bons artigos, e que para que se tenha um bom extrato no QUALIS é preciso que se receba uma quantidade de artigos que seja suficiente para que se possa fazer uma boa seleção.

Como compor um grupo qualificado de revisores desta forma? Portanto este é um dos fatores mais graves do QUALIS; a demora demasiada na atualização dos extratos, ignorando o prejuízo causado a própria comunidade científica, que se vê desanimada a propor novas revistas, face as dificuldades encontradas. Penso que nesse sentido, poder-se-ia ter uma tabela de pontuação pública, para cada periódico, com uma classificação automatizada, onde fossem minimizados os fatores qualitativos, que poderiam ser agregados em um segundo momento.

A outra questão, talvez seja ainda mais grave. Nossos orientandos veem-se bombardeados por convites quase que diários de revistas predatórias que prometem, com uma taxa para cobrir "despesas editoriais", a publicação do artigo em até 30 dias. Alguns até mais ágeis. Qualquer um que já submeteu um artigo para uma revista séria sabe que o fluxo editorial fica, em média, em torno de 6 meses. Isso quando tudo acontece sem atrasos: os revisores não atrasam, os autores não atrasam para o envio da segunda versão, os revisores novamente não atrasam a conferência da segunda versão, a equipe editorial não atrasa no serviço gráfico, e por aí vai.

Bem, mas não cabe a nós, ao que parece, a decisão de extinguir ou não o sistema QUALIS. Nos cabe, como sempre, nos adaptarmos as constantes alterações e ver o que o futuro nos reserva.

Enquanto isso, temos em mãos uma nova edição, com os seguintes artigos:

O primeiro artigo aborda o assunto de metais pesados em solos, analisados na zona costeira do Nordeste brasileiro. Os pesquisadores (Universidade Federal Rural de Pernambuco e Universidade Federal de Viçosa) tiveram por objetivo estabelecer os VRQ para Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb e Zn nos solos da bacia do rio Jaboatão (PE).

Na sequência apresenta-se trabalho oriundo da Universidade de Pernambuco com participação da Universidade Federal do Rio de Janeiro, com o intuito de analisar a gestão de custos na indústria de cimento no Nordeste do Brasil.

O terceiro artigo também na área da engenharia civil, é proveniente a Universidade do Contestado, e analisa a influência das superfícies de pavimentação no conforto térmico.

Da Universidade Estadual do Centro-Oeste e Universidade Federal de Santa Maria vem o artigo intitulado "Efeito da idade dos equipamentos na geração de resíduos em serrarias do município de Irati-PR" que trata do problema com as empresas que geram quantidades grandes de resíduos, atrelados à falta de manutenção e uso de equipamentos obsoletos.

O quinto artigo analisa o desempenho de pisos vinílicos ao isolamento de ruído de impactos, e é proveniente da Universidade Federal de Santa Maria com contribuição da Universidade Federal de Pelotas.

Na sequência tem-se o artigo "Análise do desempenho de argamassas com fibras vegetais de Tucumã tratadas com Silano-Siloxano", proveniente da parceria entre pesquisadores de quatro IES: Instituto Federal de Rondônia, Universidade Tecnológica Federal do Paraná, Universidade de Brasília e Universidade Federal do Rio Grande do Sul.

O sétimo artigo é assinado por pesquisadora da Universidade Federal de Juiz de Fora, e foca no ensino da sustentabilidade através das hortas escolares.

Da parceria entre Unigranrio, Universidade do Estado do Rio de Janeiro e Universidade Federal do Rio de Janeiro vem o artigo número 8 da edição que estuda a evolução da Responsabilidade Corporativa e Social (CSR) e dos critérios Ambientais, Sociais e de Governança (ESG) nas redes sociais com o objetivo de compreender como a sociedade percebe as práticas organizacionais relacionadas a esses aspectos.

Com foco na tecnologia de ponta através da recuperação a laser de discos de freio para reduzir emissões de material particulado, o artigo 9 da edição é resultado da união de pesquisadores da Universidade de São Paulo, Universidade Federal de Lavras, Universidade do Vale do Paraíba e Instituto Tecnológico de Aeronáutica.

Também da área de engenharia civil, pesquisadores da Universidade Federal de Minas Gerais apresentam o artigo intitulado "Resíduos de concreto como agregado graúdo em matrizes cimentícias: revisão", que demonstrou ser viável a incorporação de agregados reciclados como substituição parcial dos agregados convencionais.

O décimo primeiro artigo desta edição, também assume como tema o concreto, vem da Universidade Estadual Paulista, com contribuição da Universidade do Oeste Paulista, sugere que a produção de blocos retangulares de concreto com substituição total de areia por ADF é uma alternativa mais sustentável, técnica e economicamente viável.

O artigo 12, com foco na arquitetura, apresenta a contribuição de pesquisadores da Universidade Federal do Rio Grande do Sul, e descreve como a Agricultura Urbana e Periurbana (AUP) está ligada a uma ampla agenda de sustentabilidade, sendo chave para um sistema alimentar robusto, resiliente e para cidades mais verdes.

Da Universidade Federal de Santa Maria e parcerias industriais chega o décimo terceiro artigo intitulado "Uso de agregado leve à base de resíduos de poliéster e laminado de PVC extrusados com poliestireno em matrizes cimentícias", em mais um estudo focado em resíduos.

O décimo quarto artigo é proveniente da Universidade do Estado do Pará, com contribuições da Universidade Federal Fluminense e objetivou explorar o contexto das diretrizes de projeto para Logística Reversa sob o conceito de DfRL (Design for Reverse Logistics).

Finalizando a edição, o artigo 15 é do Centro Universitário de Várzea, e aborda um dos principais problemas da atualidade: a mobilidade urbana. O estudo conclui que medidas de planejamento alinhadas à sustentabilidade têm impactos positivos no fluxo de tráfego, no bem-estar da população e no meio ambiente.

Também integram a edição dois resumos, de tese e de TCC. Desejamos a todos (as) uma excelente leitura, um excelente final de ano com o desejo de que 2025 seja um ciclo maravilhoso para todos.

Lisiane Ilha Librelotto e Paulo Cesar Machado Ferroli.

REFERENCE VALUES FOR HEAVY METALS IN SOILS OF A BASIN IN THE COASTAL ZONE OF NORTHEAST BRAZIL

VALORES DE REFERÊNCIA PARA METAIS PESADOS EM SOLOS DE UMA BACIA NA ZONA COSTEIRA DO NORDESTE DO BRASIL

VALORES DE REFERENCIA PARA METALES PESADOS EN SUELOS DE UNA CUENCA EN LA ZONA COSTERA DEL NORESTE DE BRASIL

MARCUS METRI CORRÊA, Dr. | UFRPE – Universidade Federal Rural de Pernambuco, Brasil
GILDERLAINE SOUZA DE LIMA, Msc. | UFRPE – Universidade Federal Rural de Pernambuco, Brasil
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ABSTRACT

The presence of heavy metals in the soil poses a threat to both ecosystems and human health. In order to assess the effects of human activities on soil contamination, the environmental monitoring authorities need reference parameters for these contaminants. These parameters, known as Quality Reference Values (QRVs), indicate the natural concentrations of heavy metals in soils unaffected by human interventions and should be established as essential guidelines. Although there are already studies on QRVs in Brazil, the lithological variability justifies the need for more detailed approaches. The objective of this study was to establish QRVs for Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in the soils of the Jaboatão River basin, state of Pernambuco, Brazil. The results revealed that the metals Cr, Cu, and Ni contained some undetected data. The QRV values (mg kg-1) were: 0.43 for Cd, 6.76 for Co, 5.41 for Mn, 21.23 for Pb, and 152.17 for Zn. The values for Co, Pb, and Zn exceeded the QRVs for Pernambuco, established by the State Environmental Agency (CPRH), but did not surpass the Prevention Values set by national legislation.

KEYWORDS

Geochemistry, soil pollution; trace elements.

RESUMO

A presença de metais pesados no solo representa uma ameaça tanto para os ecossistemas quanto para a saúde humana. A fim de avaliar os efeitos das atividades humanas na contaminação do solo, os órgãos responsáveis pelo monitoramento ambiental necessitam de parâmetros de referência para esses contaminantes. Estes parâmetros, conhecidos como Valores de Referência de Qualidade (VRQs), são indicativos das concentrações naturais de metais pesados em solos não afetados por intervenções humanas e devem ser estabelecidos como guias essenciais. Embora já existam estudos de VRQ no Brasil, a variabilidade litológica justifica a necessidade de abordagens mais detalhadas. O objetivo do presente trabalho foi estabelecer os VRQ para Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb e Zn nos solos da bacia do rio Jaboatão, estado de Pernambuco, Brasil. Os resultados permitiram verificar que os metais Cr, Cu e Ni contiveram parte dos dados não detectados. Os valores de VRQ (mg kg-1) foram: 0,43 para Cd, 6,76 para Co, 5,41 para Mn, 21,23 para Pb e 152,17 para Zn. Os valores de Co, Pb e Zn

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foram superiores aos VRQs de Pernambuco, estabelecidos pela Agência Estadual de Meio Ambiente (CPRH), porém não ultrapassaram os Valores de Prevenção estabelecidos pela legislação nacional.

PALAVRAS-CHAVE
Impactos ambientais; políticas públicas; geração de resíduos sólidos; Cariri.

RESUMEN
La presencia de metales pesados en el suelo plantea amenazas para los ecosistemas y la salud humana. Para evaluar el impacto de las actividades humanas en la contaminación del suelo, los organismos encargados del monitoreo ambiental requieren parámetros de referencia, conocidos como Valores de Referencia de Calidad (VRQ). Estos indican las concentraciones naturales de metales pesados en suelos no afectados por intervenciones humanas y deben establecerse como guías esenciales. A pesar de existir estudios de VRQ en Brasil, la variabilidad litológica justifica enfoques más detallados. Este trabajo buscó establecer los VRQ para Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb y Zn en los suelos de la cuenca del río Jaboatão, en Pernambuco, Brasil. Los resultados revelaron que los metales Cr, Cu y Ni contenían datos no detectados. Los VRQ (mg kg-1) fueron: 0,43 para Cd, 6,76 para Co, 5,41 para Mn, 21,23 para Pb y 152,17 para Zn. Aunque los valores de Co, Pb y Zn superaron los VRQ de Pernambuco establecidos por la Agencia Estatal de Medio Ambiente (CPRH), no sobrepasaron los Valores de Prevención de la legislación nacional.

1. INTRODUCTION

Among soil contaminants, trace elements stand out as they become hazardous to humans and biota when pollution levels are reached. These chemical elements are found in soils either naturally or anthropogenically. Their natural levels depend on the original material, pedogenetic processes, and soil development. Anthropogenic activities lead to an increase in the content of these elements, requiring knowledge of their natural concentrations for the prevention and monitoring of soil and water pollution. In environmental studies, natural concentrations of chemical elements are commonly referred to as "quality reference values" or "geochemical reference values" (Hernández-Crespo; Martín, 2015).

Various methods have been developed to determine Quality Reference Values. Generally, they are divided into direct, indirect, and integrated methods. Direct methods use samples from preserved areas to establish averages and medians of chemical element concentrations. On the other hand, indirect methods use a large number of samples, statistical tools, and spatial analysis to distinguish values related to anthropogenic contamination from Quality Reference Values. In this regard, the integrated method is most suitable, as samples are collected in preserved areas, and the results are subjected to statistical calculations (Galuszka; Migaszewski, 2011; Dung et al., 2013; Hernández-Crespo; Martín, 2015).

Several statistical techniques have been proposed. Generally, these techniques identify outliers in a studied dataset, which may result from contaminations (Matschullat et al., 2000; Reimann et al., 2005; Rothwell; Cooke, 2015). The most recommended techniques include "mean + 2 x Standard Deviation" (Redon et al., 2013), upper limit of Tukey's boxplot, inflection point of a cumulative frequency graph (Reimann et al., 2005; Mikkonen et al., 2017), "median + 2 x Absolute Median Deviation" (Reimann et al., 2005; Rothwell; Cooke, 2015; Mikkonen et al., 2017), 75th and 90th percentiles of the sample universe (Paye et al., 2010; Santos; Alleoni, 2013; Ander et al., 2013; Oliveira et al., 2014; Fernandes et al., 2018; Serafim et al., 2019).

In 2009, the National Environment Council (CONAMA) issued Resolution No. 420, requiring each state to establish its soil quality guideline values. The values indicated by the resolution are: Quality Reference Value (QRV), Prevention Value (PV), and Investigation Value (IV). Biondi et al. (2011), following CONAMA criteria, estimated the natural levels of some chemical elements for representative soils in Pernambuco. In 2014, the State Environmental Agency of Pernambuco (CPRH) issued Instruction No. 7, establishing QRV for Pernambuco.

Determining representative values facilitates monitoring and ensures stricter legislation. However, these values may present possible geochemical anomalies that interfere with the defined levels. Therefore, it is necessary to detail local realities, as various soil formation factors generate significant spatial variability (Cembranel et al., 2017).

The Jaboatão River watershed belongs to a region in the state of Pernambuco with high population density. Additionally, it faces industrial waste discharge into watercourses, lack of sanitation infrastructure, improper solid waste disposal, irregular settlements, deforestation, and the use of pesticides and chemical fertilizers driven by sugarcane cultivation. Given its increasing urbanization, it is urgent to determine local reference levels that can serve as a basis for assessing environmental impacts caused by economic and demographic growth.

In this context, the objective is to establish Quality Reference Values for the elements aluminum (Al), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) for the Jaboatão River watershed, based on the guidelines contained in CONAMA Resolution 420/2009.

2. MATERIAL AND METHODS

2.1 Study area

The Jaboatão River watershed is located between the coordinates 8º01' and 8º17' South and 34º54' and 35º18' West of Greenwich. It encompasses parts of six municipalities: Vitória de Santo Antão (Zona da Mata Sul), Moreno, São Lourenço da Mata, Jaboatão dos Guararapes, Recife, and Cabo de Santo Agostinho (Metropolitan Region) (Figure 1). It has a drainage area of 422 km^2, with the main watercourse extending over 75 km from its source in Vitória de Santo Antão to the Atlantic Ocean (CPRH, 2020; APAC, 2024).

The land use and occupation in the watershed are divided among urban areas, sugarcane cultivation, polyculture, Atlantic Forest areas, mangroves, and industrial occupation, encompassing various types of industries (chemical, food products, metallurgical, textile, beverages, paper, cardboard, plastic, electrical materials, sugarcane and alcohol production, clothing, footwear, mechanical, transportation equipment, pharmaceuticals, and veterinary products) (CPRH, 2020).

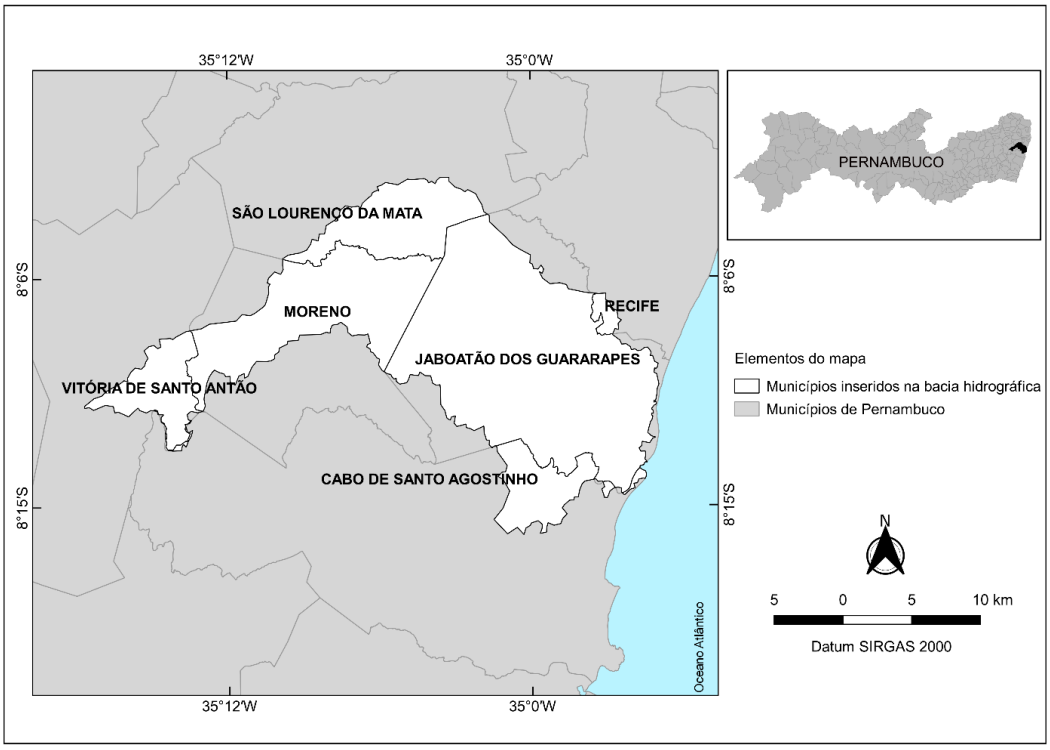

Figure 2: Location of the Jaboatão river watershed. Source: Authors, 2024.

2.2 Soil Sampling

For the study, sampling points were pre-defined and distributed throughout the Jaboatão River watershed, with the assistance of QGis® 3.10.6 and Google Earth Pro©, following criteria to be located in forested areas and away from civilization. Through visual analysis of the forest conservation status, prioritizing preserved or minimally anthropogenically influenced areas, 16 points were selected. Samples were collected at these points using a stainless steel Dutch auger. At each sampling point, single samples were collected, resulting in 32 samples—16 at the 0–0.20 m layer (surface) and 16 at the 0.20–0.40 m layer (subsurface), both in relation to the soil surface.

The geographic coordinates and altitude of the sampling points were georeferenced with the assistance of QGis® 3.10.6. The map of low and medium soil intensity recognition for the state of Pernambuco (Araújo Filho et al., 2000) served as a base to determine soil classes in the study area, and the geological diversity map of the state of Pernambuco (CPRM, 2014) was used as a reference for identifying the geological context of the region. The identification of sampling points according to municipalities, soil classes, geological context, and geographic coordinates is presented in Table 1.

2.3 Soil Analysis

The soil samples were air-dried, mechanically crumbled using a wooden roller, and sieved through a 2.0 mm mesh stainless steel sieve (ABNT 10) to obtain Air-Dried Fine Earth (ADFE).

The physical and chemical characterization analyses performed included: particle size distribution using the pipette method (EMBRAPA, 2017), hydrogenionic potential (pH) in soil-water suspension (1:2.5) (EMBRAPA, 2017), Total Organic Carbon (TOC) by wet oxidation with external heating, modified Walkley-Black method by Yeomans and Bremner (2008), and potential Cation Exchange Capacity (CEC) by the ammonium acetate and sodium acetate method (Freire et al., 2016).

2.4 Determination of Natural Contents

For the quantification of elements, the ADFE samples were ground in an agate mortar and sieved through a 0.053 mm mesh sieve (ABNT 230) to obtain a fine powder.

The extraction of trace and major elements was carried out following the method 3050B from the United States Environmental Protection Agency (USEPA, 1996a). This method is a pseudo-total digestion technique for most samples, as it involves a very strong acid digestion that will dissolve nearly all elements that can become

"environmentally available." The method does not extract elements bound in silicate structures, as they are generally not mobile in the environment.

The quantification of elements was performed using flame atomic absorption spectrometry. The accuracy of the analysis was assessed using certified reference material for metals, Trace Metals - Sandy Clay 1, CRM049 – 50 g Sigma-Aldrich.

Point	Municipality	Soil Class[1]	Geological Context[2]	Coordinates (S/W)	Altitude (m)
1	Vitória de Santo Antão	Yellow Ultisol	Subalkaline Granitic (Igneous)	8°11'56"/35°13'53"	281
2	Moreno	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°08'11"/35°12'35"	263
3	Moreno	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°07'56"/35°11'16"	189
4	Moreno	Yellow Ultisol	Subalkaline Granitic (Igneous)	8°09'07"/35°10'41"	227
5	Moreno	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°07'30"/35°10'20"	220
6	Moreno	Yellow Ultisol	Subalkaline Granitic (Igneous)	8°08'10"/35°08'30"	163
7	São Lourenço da Mata	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°05'14"/35°08'32"	150
8	Moreno	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°06'44"/35°06'59"	147
9	Moreno	Yellow Oxisol	Gneiss and Migmatite (Metamorphic)	8°08'32"/35°05'25"	112
10	Moreno	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°06'25"/35°04'38"	148
11	São Lourenço da Mata	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°02'22"/35°03'26"	101
12	Jaboatão dos Guararapes	Yellow Oxisol	Intensely Deformed Granitoid (Igneous/ Metamorphic)	8°10'59"/35°02'49"	96
13	Jaboatão dos Guararapes	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°05'20"/35°01'17"	88
14	Jaboatão dos Guararapes	Red-Yellow Ultisol	Gneiss and Migmatite (Metamorphic)	8°06'51"/34°59'41"	37
15	Jaboatão dos Guararapes	Red-Yellow Ultisol	Intensely Deformed Granitoid (Igneous/ Metamorphic)	8°09'32"/34°59'36"	16
16	Jaboatão dos Guararapes	Gleyic Gleisol	Clayey, Clayey-sand, and Sandy Sediments (Sedimentary)	8°13'15"/34°59'19"	13

Table 1: Identification of the 16 points sampled in the Jaboatão river basin.

(1) Araújo Filho et al., 2000; (2) CPRM, 2014

2.5 Quality Reference Values

To obtain the Quality Reference Values (QRV), the boxplot graphical representation was initially used to identify and remove anomalous values from the sample universe (CONAMA, 2009). Subsequently, the results of trace and major element concentrations were utilized to calculate the QRV for the Jaboatão River watershed according to statistical methods proposed by Redon et al. (2013), equation 1, Reimann et al. (2005) and Mikkonen et al. (2017), equation 2, Reimann et al. (2005), Rothwell and Cooke (2015), and Mikkonen et al. (2017), equation 3 for the upper inner limit of Tukey's boxplot and the 75th and 90th percentiles recommended by CONAMA (2009).

QRV=mean+2SD	(1)
QRV=median+2MAD	(2)
QRV=Q3+1,5Q3-Q1	(3)

where SD is the standard deviation, MAD is the median absolute deviation, and Q1 e Q3 are the first and third quartiles, respectively.

The obtained data were organized and subjected to descriptive analysis, normality hypothesis testing, analysis of variance (ANOVA), with means compared by Tukey's test at $p < 0,05$, as well as Pearson correlation analysis ($p < 0,1$), using the SISVAR software (Ferreira, 2011), and Microsoft Excel XLSTAT (version 2019.3.2) (Addinsoft, 2019). For multivariate analysis, factor analysis with factors extracted by principal components was used. The axes were rotated using the Varimax method. Factors with eigenvalues greater than 1.0 were chosen, and factor loadings greater than 0.6 were considered significant (Kaiser, 1960; Davis, 1986).

3. RESULTS AND DISCUSSION

3.1 Soil properties

The descriptive statistics of the chemical and physical properties for the two soil layers studied are presented in Table 2. Tukey's test at $p < 0.05$ showed statistical significance between the two layers for total organic carbon (TOC). On the other hand, the other analyzed parameters did not show statistical significance between the different layers.

The hydrogen potential (pH) of the samples ranged from 3.96 to 5.85 with an average value of 4.59 (Table 2); thus, the soils in the region are considered acidic. Soil pH has a significant effect on the dynamics of chemical elements in soils, as acidic conditions favor the solubilization and mobilization of cationic metals in the soil (Arias et al., 2005; Zeng et al., 2011; Almeida Júnior et al., 2016).

COT levels were higher in the surface and lower in the subsurface, ranging from 11.29 to 27.30 g kg-1 with an average of 17.75 on the surface, and 7.32 to 22.73 g kg-1 with an average of 13.85 in the subsurface (Table 2). A higher amount of organic carbon on the soil surface can contribute to the retention of chemical elements, as organic matter in soil samples actively participates in the immobilization of these elements in the soil (Tume et al., 2014). This behavior can be attributed to the generation of adsorption sites with a prevalence of negative charges that act, through ionic bonding, as a chelating agent in the soil solution (Garcia-Mina, 2006).

Cation exchange capacity (CEC) values varied from 2.58 to 13.57 cmolc kg-1, with an average of 5.50 cmolc kg-1 (Table 2). The potential for high CTC variation may be related to contributions from organic matter in tropical soils, in addition to minerals with high specific surface area (Eze et al., 2010).

The sand fraction ranged from 65.99 to 712.13 g kg-1, with an average of 533.46 g kg-1; the silt fraction ranged from 74.00 to 453.93 g kg-1, with an average of 128.97 g kg-1; and the clay, the most reactive soil fraction, varied from 146.00 to 419.90 g kg-1, with an average of 279.99 g kg-1 (Table 2). The texture classes of the analyzed soil samples were: loamy sand (59%), loamy clay (13%), loamy sand (9%), sandy loam (9%), clayey (6%), and clayey-silty (3%).

Variables	Layer[1]	Mean	Median	Minimum	Maximum	Standard Deviation
pH H2O	1	4.56	4.41	4.07	5.85	0.49
	2	4.63	4.62	3.96	5.04	0.28
	All	4.59	4.58	3.96	5.85	0.39
CEC ($cmol_c\ kg^{-1}$)	1	6.30	5.94	3.44	13.59	2.47
	2	4.69	4.31	2.58	12.16	2.10
	All	5.50	4.82	2.58	13.59	2.40
COT ($g\ kg^{-1}$)	1	19.75	20.77	11.29	27.30	4.48
	2	13.85	13.48	7.32	22.73	3.75
	All	16.80	16.41	7.32	27.30	5.05
Sand ($g\ kg^{-1}$)	1	521.64	558.24	65.99	712.13	151.01
	2	484.34	490.88	314.20	625.51	85.96
	All	502.99	533.46	65.99	712.13	122.35
Silt ($g\ kg^{-1}$)	1	154.99	125.98	77.99	453.93	98.95
	2	149.36	137.98	74.00	289.96	61.34
	All	152.17	128.97	74.00	453.93	81.03
Clay ($g\ kg^{-1}$)	1	259.10	253.98	146.00	405.94	62.07
	2	308.72	312.97	155.98	419.90	66.71
	All	283.91	279.99	146.00	419.90	68.21

Table 2: Chemical and physical properties of soil samples in the Jaboatão river basin.

(1) 1- surface (average of 16 samples); 2 – subsurface (average of 16 samples); All – mean of 32 samples (surface e subsurface).

3.2 Recovery of trace elements

The certified reference material used to verify that the extraction and quantification of elements occurred effectively has certified values based on the digestion method 3050B, 3051, or equivalent pseudo-total digestion methods.

The recovery rates of elements in the certified material ranged from 89 to 99% (Table 3), falling within the recommended range (USEPA, 1996b). Therefore, these results ensure the quality of the United States Environmental Protection Agency (USEPA) method 3050B for soil sample digestion, indicating the reliability of the results obtained in the analysis of trace and major elements.

Element	Certified Value[1]	Determined Value	Recovery
	mg kg-[1]		%
Al	10,300.00 (1,610.00)	9,194.67 (646.84)	89
Cd	87.90 (1.71)	87.13 (0.81)	99
Co	217.00 (4.77)	215.67 (0.82)	99
Cr	134.00 (2.26)	132.90 (0.51)	99
Cu	133.00 (2.52)	132.13 (0.29)	99
Fe	6,610.00 (253.00)	6,531.67 (10.27)	98
Mn	1,120.00 (36.80)	1,094.33 (4.64)	97
Ni	287.00 (5.71)	284.33 (1.25)	98
Pb	340.00 (7.24)	335.33 (2.49)	98
Zn	443.00 (7.92)	438.00 (2.16)	99

Table 3: Certified values [mean (standard deviation)], determined values [mean (standard deviation)] and percentage recovery of trace elements in certified material after submitting to USEPA method 3050B.

(1) Certified material values (Trace Metals - Sandy Clay 1, CRM049 – 50 g Sigma-Aldrich)

3.3 Natural levels of trace elements

Some elements showed high variations (Table 4) in their concentrations, such as Mn and Ni, which exhibited variations above 100%, due to different geological contexts for Mn and the low number of samples with detectable Ni levels. However, Al, Fe, Cd, Co, Pb, and Zn had variations lower than 65%.

Tukey's test did not show statistical significance between the concentrations of chemical elements for the two soil layers studied. Therefore, the averages of surface and subsurface samples were analyzed.

The average concentrations of elements followed the following decreasing order, in mg kg-1: Al > Fe > Zn > Mn > Pb > Cr > Co > Ni > Cu > Cd. Overall, the values were lower than those reported by Paye et al. (2010) in soils from Espírito Santo, except for Pb and Zn. The low values reflect the geological context of the Jaboatão River watershed, which is mainly composed of metamorphic rocks, predominantly gneisses, migmatites, quartzites, and granites (CPRM, 2014).

The average Al content was 16.27 g kg-1 (Table 4); the studied areas showed abundance in Al levels, as Al is dominant in the structure of secondary minerals, forming the majority of the clay fraction in weathered and acidic soils, similar to the soils in the region (Marques et al., 2004; Benedetti et al., 2011).

Fe presented a lower average concentration (3.89 g kg-1) (Table 4) than in studies conducted by Almeida Júnior et al. (2016) for soils in the state of Paraíba (14.31 g kg-1), Silva et al. (2015) for soils in the Ipojuca River watershed in Pernambuco (16.05 g kg-1), and Biondi et al. (2011) for soils in the Zona da Mata region of Pernambuco, with an average value of 21.42 g kg-1. However, they observed a wide variation in Fe levels, ranging from 0.70 g kg-1 to 94.50 g kg-1. In some locations with Yellow Argisol and Red Argisol, with sedimentary sandy and clay-sandy origin materials, as well as gneisses and migmatites, the levels are similar to those in the present study, and these authors attributed the large differences to the diversity of source materials.

Mn concentrations (Table 4) ranged from 4 to 407.10 mg kg-1 with an average value of 64.06 mg kg-1, where 88% of the samples had values below 200 mg kg-1, corroborating the results of Biondi et al. (2011) for soils in the state of Pernambuco. These authors attributed the low values to the weathering of the region's soils. However, the values were low when compared to studies in other states of Brazil, such as Espírito Santo with 131.69 mg kg-1 (Paye et al., 2010), Rio Grande do Norte with 3,300.00 mg kg-1 (Preston et al., 2014), and Pará with 100.40 mg kg-1 (Fernandes et al., 2018).

Element	Layer[1]	n[2]	Mean	Median	Min[3]	Max	Standard Deviation	Coeficient of Variation (%)
Al (g kg-1)	1	16	15.75	16.22	11.38	17.53	1.73	11
	2	16	16.79	17.13	11.52	19.29	1.96	12
	All	32	16.27	16.58	11.38	19.29	1.90	12
Fe (g kg-1)	1	16	3.84	3.91	2.98	4.10	0.29	7
	2	16	3.95	4.01	3.31	4.25	0.24	6
	All	32	3.89	3.98	2.98	4.25	0.27	7
Cd (mg kg-1)	1	16	0.31	0.26	0.02	0.71	0.19	61
	2	15	0.41	0.35	< LD	1.09	0.24	57
	All	31	0.36	0.35	< LD	1.09	0.22	60
Co (mg kg-1)	1	16	5.56	5.30	1.01	9.69	2.29	41
	2	16	5.89	6.21	1.61	11.10	2.28	39
	All	32	5.72	5.75	1.01	11.10	2.26	39
Cr (mg kg-1)	1	9	12.80	7.46	< DL	37.16	12.14	95
	2	9	21.41	17.46	< DL	45.81	14.98	70
	All	18	17.10	11.64	< DL	45.81	13.95	82
Cu (mg kg-1)	1	2	2.83	2.83	< DL	3.57	1.05	37
	2	2	3.78	3.78	< DL	5.63	2.62	69
	All	4	3.30	2.83	< DL	5.63	1.72	52
Mn (mg kg-1)	1	16	64.88	32.11	4.92	407.10	106.34	164
	2	16	63.25	30.19	4.00	353.57	103.07	163
	All	32	64.06	30.53	4.00	407.10	103.02	161
Ni (mg kg-1)	1	6	2.93	0.98	< LD	12.54	4.44	152
	2	7	3.89	1.24	< LD	14.20	5.42	139
	All	15	3.37	1.08	< LD	14.20	4.73	140

Table 4: Descriptive statistics of trace element contents of soils sampled in the Jaboatão river basin.

(1) 1 – surface; 2 – subsurface; All – average of all samples. (2) n – number of samples with content detected by the method. (3) < DL – less than the detection limit.

Element	Layer[1]	n[2]	Mean	Median	Min[3]	Max	Standard Deviation	Coeficient of Variation (%)
Pb (mg kg-[1])	1	16	19.11	19.69	8.61	27.07	5.56	29
	2	16	18.34	19.38	6.77	22.77	4.43	24
	All	32	18.73	19.69	6.77	27.07	4.96	26
Zn (mg kg-[1])	1	16	111.14	109.02	11.54	217.03	68.38	62
	2	16	120.46	129.50	12.15	238.83	77.57	64
	All	32	115.80	111.36	11.54	238.83	72.09	62

Table 4: Descriptive statistics of trace element contents of soils sampled in the Jaboatão river basin.

(1) 1 – surface; 2 – subsurface; All – average of all samples. (2) n – number of samples with content detected by the method. (3) < DL – less than the detection limit.

The Cd concentrations ranged from 0.02 mg kg-1 to 1.09 mg kg-1 (Table 4), with only one sample not detecting Cd. The average Cd content (0.36 mg kg-1) (Table 4) in soils of the Jaboatão River basin is very close to that determined by Fernandes et al. (2018) for soils in Pará (0.32 mg kg-1), but higher than those found by Santos and Alleoni (2013) for soils in Mato Grosso and Rondônia, where Cd levels were below the detection limit in all samples, as well as for São Paulo (CETESB, 2014), and Espírito Santo (Paye et al., 2010).

In six samples, Cd exceeded the Quality Reference Value (0.5 mg kg-1) defined by CPRH (2014) for Pernambuco. However, none exceeded the Prevention Value (1.3 mg kg-1) determined by CONAMA (2009). Values above the Quality Reference Values (QRV) may be associated with natural geochemical enrichment or factors such as topography and weathering intensity (Burak et al., 2010; Santos; Alleoni, 2013), as the levels found are within the literature-reported range for soils derived from igneous rocks of 0.1-0.3 mg kg-1, metamorphic rocks between 0.1-1.0 mg kg-1, and sedimentary rocks of 0.3-1.0 mg kg-1 (Alloway, 1990).

Co concentrations ranged from 1.01 to 11.10 mg kg-1 with an average of 5.72 mg kg-1 (Table 4). The average content was similar to that found by Almeida Júnior et al. (2016) for soils in Paraíba (5.97 mg kg-1) and lower than the content found by Paye et al. (2010) for soils in Espírito Santo (8.64 mg kg-1). Like Biondi et al. (2011), high Co values were observed for Gleisol. This author indicates that in the Zona da Mata region of Pernambuco, there is a tendency for Co to be maintained in soils located in floodplain environments, where leached elements from soils located at higher elevations are transferred and retained during the formation time. This phenomenon results in higher levels than in other soils in the region.

Approximately 78% of Co values are above the Quality Reference Value (QRV) determined by CPRH (2014), which corresponds to 4.00 mg kg-1. However, none exceeded the Prevention Value (PV) determined by CONAMA (2009), which corresponds to 25.00 mg kg-1. As the samples were collected in areas with minimal anthropogenic interference, quantifying higher values than the QRV determined by CPRH (2014) reinforces the need for determining the QRV for the Jaboatão River basin.

Cr concentrations (Table 4) varied from below the detection limit to 45.81 mg kg-1, with an average content of 17.10 mg kg-1. Cu presented concentrations ranging from below the detection limit to 5.63 mg kg-1, with an average value of 3.30 mg kg-1, and for Ni, values ranged from below the detection limit to 14.20 mg kg-1, with an average content of 3.37 mg kg-1. All three elements had average values lower than those found by Almeida Júnior et al. (2016) for soils in the state of Paraíba and also lower than those found by Silva et al. (2015) for soils in the Ipojuca River watershed in Pernambuco. The low values reflect the geological context of the Jaboatão River basin, where the majority is composed of metamorphic rocks and clay-sandy sediments, which are naturally poor in Cr, Cu, and Ni (CPRM, 2014; Araújo et al., 2018).

Pb values (Table 4) ranged from 6.77 to 27.07 mg kg-1, with an average of 18.73 mg kg-1. This value was higher than those of soils in Espírito Santo (8.79 mg kg-1) (Paye et al., 2010), Mato Grosso and Rondônia (8.10 mg kg-1) (Santos; Alleoni, 2013), São Paulo (10.10 mg kg-1) (Nogueira

et al., 2018), and Pará (3.69 mg kg-1) (Fernandes et al., 2018). However, it corroborates the values reported by Biondi et al. (2011) for soils in the Zona da Mata region of Pernambuco (16.85 mg kg-1) and Silva et al. (2015) for soils in the Ipojuca River basin in Pernambuco (19.48 mg kg-1).

Zn concentrations (Table 4) ranged from 11.54 to 238.83 mg kg-1, with an average of 115.80 mg kg-1. Most of the values found were much higher than those found in the study by Silva et al. (2015) for soils in the Ipojuca River basin, located in Pernambuco (45.41 mg kg-1). In the present study, the average value for soils derived from igneous rocks was 152.53 mg kg-1, and for soils derived from alluvial sediments, it was 12.95 mg kg-1. Oliveira e Costa (2004) also observed low Zn values for soils originating from gneiss and sediments and high values for soils derived from basalt.

Of the analyzed soil samples, about 84% had Pb values above the Quality Reference Value (QRV) (13.00 mg kg-1) determined by CPRH (2014), and about 81% of the analyzed soil samples exceeded the QRV (35.00 mg kg-1) determined by CPRH (2014) for Zn. However, all values were below the Prevention Value defined by CONAMA (2009) for Pb (72 mg kg-1) and Zn (300 mg kg-1), indicating that the evaluated soils do not pose risks to human health.

The highest Pb values were found in Oxisols, Ultisols, and Gleissol derived from Gneiss and Migmatites, Granitoids, and Alluvial Sediments. Kabata-Pendias and Pendias (2001) stated that soils derived from acidic rocks, granite, gneiss, and sandy and clayey sediments are materials that have high Pb levels. The most significant Zn values were found in Ultisols and Oxisols with a subalkaline granite and granitoid origin, indicating the possibility of this source material being rich in Zn (Kabata-Pendias; Pendias, 2001).

In addition to the source material, urban centers and local highway traffic may have influenced the concentrations of Pb and Zn. Studies conducted in São Paulo (Figueiredo et al., 2009), the Sydney watershed in Australia (Birch et al., 2011), and the Rio das Mortes watershed in Minas Gerais (Zuliani et al., 2017) have confirmed a close relationship between the distribution of Pb and Zn with urban centers characterized by high population density and vehicular emissions.

3.4 Quality reference values (QRV)

The concentrations of trace elements were used to determine the Quality Reference Value (QRV), with anomalous values previously removed through Boxplot, as recommended by CONAMA Resolution No. 420/2009. The elements Cr, Cu, and Ni did not exhibit a homogeneous distribution along the Jaboatão river basin, and in the majority of samples, they were not detected. Therefore, they were classified as less than the practicable limit of quantification (< LQP) (Table 5) and excluded from further procedures (CONAMA, 2009).

The "median + 2 x MAD," a method less sensitive to outliers, generated QRV very close to those determined by the 90th Percentile for most elements (Table 5). The 75th Percentile is the most conservative method; however, this technique tends to underestimate reference values, categorizing normal values as contamination, leading to the restriction or remediation of areas that are not actually contaminated in practice.

Among the analyzed methodologies, the upper limit of Tukey's boxplot and the "mean + 2 x SD" may have overestimated the QRV. On the other hand, the "median + 2 x MAD" showed values closer to the 90th Percentile (Table 5). Therefore, the 75th Percentile was adopted as the most suitable method for determining the QRV of the elements Al, Cd, Co, Fe, Mn, Pb, and Zn found in the soils of the Jaboatão river watershed.

Table 6 compares the QRV obtained for the Jaboatão river basin with other QRV established in Pernambuco. The values of Co, Pb, and Zn were higher than the QRV determined for the state of Pernambuco. However, none exceeded the prevention value determined by CONAMA (2009), Co (25.00 mg kg-1), Pb (72.00 mg kg-1), and Zn (300.00 mg kg-1), indicating that the evaluated soils do not pose potential risks to human health or the ecosystem of the region.

The values obtained in this study for Pb and Zn (Table 5) were higher than the QRV reported in other regions of Brazil: Espírito Santo (8.92 and 49.32 mg kg-1) (Paye et al., 2010), São Paulo (17.00 and 60.00 mg kg-1) (CETESB, 2015), Mato Grosso and Roraima (8.10 and 6.80 mg kg-1) (Santos; Alleoni, 2013), Rio Grande do Norte (16.18 and 42.44 mg kg-1) (Preston et al., 2014), Paraíba (14.62 and 33.65 mg kg-1) (Almeida Júnior et al., 2016), and Pará (6.40 and 21.00 mg kg-1) (Fernandes et al., 2018).

There are some similarities and clear differences between the concentrations in different regions of the state of Pernambuco. These differences emphasize the need to determine Quality Reference Value by regions, taking into account the geomorphological, pedological, and geological diversity of each region (Cembranel et al., 2017).

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Element	P75	P90	Median + 2 x MAD	Mean + 2 SD	Upper limit from Boxplot
Al (g kg-^{1})	17.33	18.27	18.44	18.62	18.83
Fe (g kg-^{1})	4.04	4.09	4.11	4.17	4.22
Cd (mg kg-^{1})	0.43	0.52	0.53	0.61	0.70
Co (mg kg-^{1})	6.76	7.95	8.54	9.23	10.49
Cr (mg kg-^{1})	<LQP	<LQP	<LQP	<LQP	<LQP
Cu (mg kg-^{1})	<LQP	<LQP	<LQP	<LQP	<LQP
Mn (mg kg-^{1})	35.41	40.90	46.68	51.82	60.22
Ni (mg kg-^{1})	<LQP	<LQP	<LQP	<LQP	<LQP
Pb (mg kg-^{1})	21.23	22.08	23.07	23.94	26.51
Zn (mg kg-^{1})	152.17	170.52	175.71	197.16	222.27

Table 5: Quality reference values for the soils of the Jaboatão river watershed, calculated through various statistical methods after the removal of anomalous values.
P75 - 75th Percentile; P90 - 90th Percentile; MAD - Median Absolute Deviation; SD - Standard Deviation; <LQP - less than the Limit of Quantification Practicable.

The "median + 2 x MAD," a method less sensitive to outliers, generated QRV very close to those determined by the 90th Percentile for most elements (Table 5). The 75th Percentile is the most conservative method; however, this technique tends to underestimate reference values, categorizing normal values as contamination, leading to the restriction or remediation of areas that are not actually contaminated in practice.

Among the analyzed methodologies, the upper limit of Tukey's boxplot and the "mean + 2 x SD" may have overestimated the QRV. On the other hand, the "median + 2 x MAD" showed values closer to the 90th Percentile (Table 5). Therefore, the 75th Percentile was adopted as the most suitable method for determining the QRV of the elements Al, Cd, Co, Fe, Mn, Pb, and Zn found in the soils of the Jaboatão river watershed.

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There are some similarities and clear differences between the concentrations in different regions of the state of Pernambuco. These differences emphasize the need to determine Quality Reference Value by regions, taking into account the geomorphological, pedological, and geological diversity of each region (Cembranel et al., 2017).

Element	Jaboatão river basin[1]	Pernambuco[2]	Ipojuca river basin[3]	Fernando de Noronha Island[4]
Al (g kg-^{1})	17.33	-	-	-
Fe (g kg-^{1})	4.04	-	13.02	-
Cd (mg kg-^{1})	0.43	0.50	0.08	-
Co (mg kg-^{1})	6.76	4.00	-	19.61
Cr (mg kg-^{1})	<LQP	35.00	15.00	266.13
Cu (mg kg-^{1})	<LQP	5.00	3.53	41.49
Mn (mg kg-^{1})	35.41	-	91.80	-
Ni (mg kg-^{1})	<LQP	9.00	3.30	58.75
Pb (mg kg-^{1})	21.23	13.00	13.12	-
Zn (mg kg-^{1})	152.17	35.00	30.12	117.58

Table 6: Quality Reference Values for Al, Fe, Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn for soils in the Jaboatão river basin, Pernambuco, Ipojuca river basin and Fernando de Noronha Island.
(1) This study; (2) CPRH (2014); (3) Silva et al. (2015); (4) Fabrício Neta et al. (2018).

3.5 Factor analysis

The set of 32 samples was used to perform Pearson correlation analysis. Significant and positive correlations (data not shown) were found among most of the variables analyzed. These correlations allowed the use of variables in the data matrix for the factor analysis.

Through principal component factor analysis, three factors were identified (Table 7). These factors account for 70.68% of the total variation in the data. The chosen factors had eigenvalues > 1 (Kaiser, 1960; Davis, 1986).

The first factor explains over 24% of the total variation and is composed of the elements Mn and Ni, which exhibited higher factor loadings. This suggests that they originate from the same source, as high correlations between trace elements are likely related to a common source material (Chandrasekaran et al., 2015).

The second factor explains nearly 25% of the total variance and includes Al, Fe, and Zn. Al and Fe are the two main constituents of the lithosphere, indicating a common source material.

According to Costa et al. (2002), tropical soils' mineralogy is mainly composed of kaolinite, iron oxides (hematite, goethite, and maghemite), aluminum oxides (gibbsite), and minor proportions of 2:1 type minerals (vermiculite). Adsorption of metallic ions can occur on iron and aluminum oxides and on the peripheries of silicate clays through the formation of covalent or electrostatic bonds with the functional groups on the oxide surface.

Element	Factor Axis[1]		
	Factor 1	Factor 2	Factor 3
Al	-0.120	**0.784**	0.211
Cd	-0.356	-0.129	**0.752**
Co	0.258	0.086	**0.825**
Cr	0.183	0.537	-0.148
Cu	0.498	0.350	-0.235
Fe	0.225	**0.887**	0.260
Mn	**0.904**	0.008	0.045
Ni	**0.938**	0.156	-0.098
Pb	-0.425	0.323	0.628
Zn	0.089	**0.717**	-0.571
Eigenvalues	3,143	2,317	1,609
Total Variance (%)	24,254	24,779	21,655
Cumulative Variance (%)	24,254	49,033	70,688

Table 7: Quality Reference Values for Al, Fe, Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn for soils in the Jaboatão river basin, Pernambuco, Ipojuca river basin and Fernando de Noronha Island.
Eixos fatoriais rotacionados pelo método Varimax

Even at low concentrations, Al and Fe oxides influence the adsorption of elements such as Zn (Alleoni et al., 2005). Both Fe and Zn may coexist in the soil source material and be released due to rock weathering (Sheng et al., 2012), explaining why these elements are in the same group.

Cd, Co, and Pb are represented by the third factor, explaining 22% of the total variation. This group includes some of the trace elements that pose significant environmental concerns, such as Pb and Cd, suggesting possible anthropogenic influence. Meanwhile, Co is more frequently associated with ores of Cu, Fe, Ni, and Pb, from which it is obtained as a byproduct (Preston et al., 2014).

4. CONCLUSIONS

The concentrations of Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were determined for 16 locations at two depths in the Jaboatão river watershed in Pernambuco. The abundance of elements in the Jaboatão river watershed followed the following descending order: Al, Fe, Zn, Mn, Pb, Cr, Co, Ni, Cu, and Cd. Chromium, copper, and nickel were not representative throughout the entire watershed. The calculation method deemed most appropriate for determining the Quality Reference Value (QRV) in the region was the 75th Percentile, with the following values (mg kg-1): Cd (0.43), Co (6.76), Mn (35.41), Pb (21.23), and Zn (152.17).

The QRV for the Jaboatão river watershed is lower than in other regions of Brazil, except for Co, Pb, and Zn. However, they did not exceed the Prevention Values established by CONAMA Resolution 420/2009, ensuring that the soils do not pose risks to human health and the ecosystems of the region. The principal component analysis, which grouped the metals Mn and Ni (Factor 1), Al, Fe, and Zn (Factor 2), and Cd, Co, and Pb (Factor 3), suggests the natural origin of these elements in the studied soils.

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DEVELOPMENT OF COST MANAGEMENT FOR THE CEMENT INDUSTRY IN NORTHEAST BRAZIL: A CASE STUDY

DESENVOLVIMENTO DA GESTÃO DE CUSTOS PARA A INDÚSTRIA DE CIMENTO NO NORDESTE DO BRASIL: UM ESTUDO DE CASO

DESARROLLO DE LA GESTIÓN DE COSTOS PARA LA INDUSTRIA DEL CEMENTO EN EL NORESTE DE BRASIL: UN ESTUDIO DE CASO

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ABSTRACT

The production of cement requires a suitable cost management tool to monitor overall expenses, calculate inventories, and improve control of activities that represent the flow of cement production. The aim of this study was to present a case study on the application of Activity Based Costing (ABC) in a cement plant located in northeastern Brazil. The methodology consisted of three main stages: characterization of the cement factory, diagnosis of the scenario before the implementation of ABC, and analysis of its practical application. The results allowed for the identification of how ABC facilitates decision-making, as it is a cost management tool for cost analysis that regulates the arbitrary allocation of indirect costs, thus allowing for the identification of non-value-added activities. The organization was divided into cost centers and cost generators, improving expense control. A total of 220 accounts were created to represent the areas and resources involved in cement production, as well as 145 instances of tasks. A detailed analysis of energy consumption in grinding allowed for the estimation of accurate costs for each type of cement. Although the total cost did not change, ABC allowed for a more in-depth analysis, increasing understanding of the cost system and the competitiveness and profitability of the company. This study provided support for an integrated view of the functioning of a cement industry with the application of ABC. Despite cultural barriers and the complexity of the method, the creation of cost centers and the identification of activities and cost generators enable active supervision of expenses.

KEYWORDS

Activity Based Costing; cement; cost management; cement industry.

RESUMO

A produção de cimento exige uma ferramenta de gestão de custos adequada para monitorar os gastos globais, calcular os estoques e principalmente melhorar o controle das atividades que representam o fluxo de produção de cimento. Este trabalho teve como objetivo apresentar um estudo de caso sobre a aplicação do Custeio Baseado em Atividades (ABC) em uma fábrica de cimento localizada no Nordeste brasileiro. A metodologia consistiu em três etapas principais: caracterização da fábrica de cimento, diagnóstico do cenário antes da implantação do ABC e análise da aplicação prática.

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Os achados permitiram identificar como o custeio baseado em atividades facilita a tomada de decisão, uma vez que é uma ferramenta de gestão para análise de custos que regula a alocação arbitrária de custos indiretos, permitindo a identificação de atividades que não agregaram valor ao produto. A organização foi dividida em centros de custos e geradores de custos, melhorando o controle dos gastos. Foram criadas 220 contas para representar as áreas e recursos envolvidos na produção de cimento e 145 instâncias de tarefas. A análise detalhada do consumo de energia na moagem permitiu estimar os custos precisos de cada tipo de cimento. Apesar de o custo total não ter sofrido alterações, o ABC possibilitou uma análise mais aprofundada, aumentando a compreensão do sistema de custos e a competitividade e rentabilidade da empresa. Este trabalho forneceu suporte para uma visão integrada sobre o funcionamento de uma indústria cimenteira com a aplicação do ABC. Apesar das barreiras culturais e da complexidade do método, a criação de centros de custos e a identificação de atividades e geradores de custos permitem uma supervisão ativa dos gastos.

PALAVRAS-CHAVE

Custeio baseado em atividades; cimento; gestão de custos; indústria de cimento.

RESUMEN

La producción de cemento exige una herramienta de gestión de costos adecuada para monitorear los gastos globales, calcular los inventarios y, principalmente, mejorar el control de las actividades que representan el flujo de producción de cemento. Este trabajo tuvo como objetivo presentar un estudio de caso sobre la aplicación del Costeo Basado en Actividades (ABC) en una fábrica de cemento ubicada en el noreste de Brasil. La metodología consistió en tres etapas principales: caracterización de la fábrica de cemento, diagnóstico del escenario antes de la implementación del ABC y análisis de la aplicación práctica. Los hallazgos permitieron identificar cómo el costeo basado en actividades facilita la toma de decisiones, ya que es una herramienta de gestión para el análisis de costos que regula la asignación arbitraria de costos indirectos, permitiendo la identificación de actividades que no agregan valor al producto. La organización se dividió en centros de costos y generadores de costos, mejorando el control de los gastos. Se crearon 220 cuentas para representar las áreas y recursos involucrados en la producción de cemento y 145 instancias de tareas. El análisis detallado del consumo de energía en la molienda permitió estimar los costos precisos de cada tipo de cemento. Aunque el costo total no sufrió alteraciones, el ABC permitió un análisis más profundo, aumentando la comprensión del sistema de costos y la competitividad y rentabilidad de la empresa. Este trabajo proporcionó apoyo para una visión integrada del funcionamiento de una industria cementera con la aplicación del ABC. A pesar de las barreras culturales y la complejidad del método, la creación de centros de costos y la identificación de actividades y generadores de costos permiten una supervisión activa de los gastos.

PALABRAS CLAVE

Costeo basado en actividades; cemento; gestión de costos; industria del cemento.

1. INTRODUCTION

Modern businesses frequently experience an increase in fixed expenses, typically due to the implementation of corporate automation. This consequently leads to higher costs for maintenance, depreciation, and necessary supplies. Additionally, there is a noticeable growth in the proportion of fixed expenses in indirect areas such as administration, human resources, and marketing. As a result of these rising costs and fixed expenses, their allocation using generic division criteria may result in inaccuracies when determining the costs of products and services (MARTINS, 2001; SABINO *et al.*, 2019; KNABBEN Jr. *et al.*, 2019).

The inception of Portland cement has catalyzed a profound revolution in the domain of construction, owing to its inherent hydraulic nature (i.e. the ability to cure in the presence of both air and water), malleability, exceptional durability under stress, and utilization of easily accessible natural materials (NWANKWO *et al.*, 2020; ABDUL-WAHAB *et al.*, 2021). Moreover, the resourcefulness of engineers, architects, and designers, combined with the precision of contemporary calculation methodologies, advanced the progress of cement innovations and, subsequently, concrete (LIMA, 2011; KHAN; McNALLY, 2023).

As a developing nation, Brazil necessitates a substantial infrastructure initiative (ALEIXO *et al.*, 2019). Cement is utilized as the primary base for the creation of dwellings, medical facilities, educational institutions, ports, airports, roads, highways, and hydroelectric facilities. This attribute highlights the significance of exercising careful regulation during its manufacturing and incorporation within the construction sector (CARVALHO, 2016; SHANKS *et al.*, 2019).

Since cement is a commodity, competition primarily arises through pricing and the quality of the final product (SNIC, 2013). Therefore, the implementation of a tool that enables better control of expenses and promotes the optimization of cement manufacturing processes, resulting in waste reduction, is critical for the survival of a company in this industry (MADLOOL *et al.*, 2011). As stated by Khoury (1997), unlike companies in the trade and service sectors, those in the industrial sector are greatly motivated and interested in adopting Activity Based Costing (ABC) due to intense competition and a wide range of products. Nevertheless, Azevedo *et al.* (2004) revealed that the utilization of ABC is limited in Brazilian companies, primarily due to the considerable investments required for data collection, the complexity of the cost allocation tool, and the need for personnel training.

According to Khoury (1997), most companies employ the Traditional Cost System (TCS), which generates auditable reports and adheres to Brazilian laws. Nonetheless, this method of cost calculation results in imprecise measurements for strategic decision-making due to the arbitrary distribution of indirect expenses.

The progress of information technology plays a significant role in the adoption of ABC in organizations (BJØRNENAK; MITCHELL, 2022). This is because ABC's fundamental principle is that activities consume resources and products consume activities, resulting in costs and expenses being initially categorized by activity. Furthermore, the concept of activity is more complex than that of a cost center or sector in an organization (ERASLAN; İÇ, 2020). Hence, from an operational perspective, the implementation of the ABC tool would be extremely challenging without the advancement of information technology (MARTINS, 2001).

Cokins (1996) stated that by closely monitoring activities and developing a deeper understanding of them, employees can come to recognize the significance of the cost driver - the primary factor that influences changes in costs. Put simply, this suggests that the increase in cost of one activity is directly correlated to the effort required by another supplier activity in meeting the demands of the customer activity.

Sabouri (2014) conducted a study on the viability of utilizing the ABC method in the cement industry. The study showed that the method was effective in reducing costs and implementing quality control systems. Sarwat and Godil (2017) examined the implementation of ABC in Pakistan's cement sector, emphasizing the impact of organizational variables and stressing the importance of managerial support and attitude in the adoption of this strategy. Nonetheless, their findings indicated that the size and structure of an organization did not have a significant correlation with the adoption of ABC. The authors suggested further investigation into the costs associated with implementation, level of support from management, satisfaction with the current costing system, and time expended.

In a study conducted by Robinson and Umo (2023), it was determined that there is a notable positive correlation between the ABC method and return on equity (ROE) among cement companies in Nigeria. The researchers suggested utilizing ABC due to its capacity to enhance profitability, highlighting it as a superior approach in comparison to alternative cost management strategies such as target costing, life cycle costing, and throughput accounting.

Oliveira *et al.* (2015) demonstrated the practicability of using the ABC method within the concrete production industry. They observed that the calculated cost showed a significant reduction of up to 75.6% when compared to the traditional approach. The researchers highly recommend the implementation of ABC due to its capacity to more accurately evaluate the profitability of products and enable the precise allocation of resources to more strategic and lucrative products. This, in turn, can enhance the effectiveness and efficiency of cost management.

Furthermore, research has linked the utilization of ABC to the sustainable growth of companies, specifically in the cement industry which is notorious for its significant carbon emissions (ROCHA *et al.*, 2022). Mashkoor *et al.* (2023) conducted a study examining the effects of ABC on sustainable development, demonstrating its ability to integrate environmental management with economic factors. Similarly, Yang and Chang (2018) discussed the application of ABC in the green sector, specifically in the recycling of blast furnace slag as a substitute for construction materials and cement. By implementing ABC, efficiency of operations improved, indirect costs decreased, and the company's competitiveness and profitability increased. Additionally, Akgün *et al.* (2023) assert that ABC can aid in reducing the environmental impact of industries associated with cement production.

In this respect, the objective of this research was to demonstrate a concrete example of implementing ABC in cement manufacturing, with the intention of improving the management of production costs. Nevertheless, prior to enacting ABC, it is essential to understand its theoretical principles.

2. ACTIVITY BASED COSTING

As indicated by Martins (2001) and Bertó and Beulke (2005), along with providing a comprehensive analysis of product costing, ABC also offers improved opportunities for identifying areas of inefficiency and serves as a means of cost management. Its purpose is to minimize the arbitrary allocation of indirect costs.

The expenditures categorized as indirect costs are not as readily apportioned to individual products, whereas direct costs can be directly assigned to the products (PINTO *et al.*, 2008). Figure 1 illustrates the steps of the methodology employed to conceptualize ABC and present the case study, with activities further subdivided.

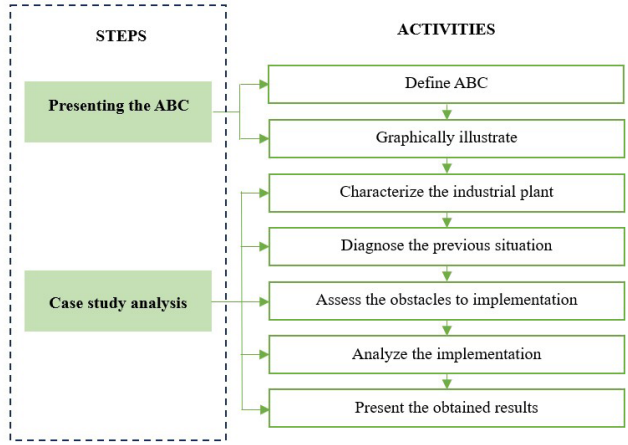

Figure 01: Flowchart outlining the methodology steps for developing the project
Source: Elaborated by the authors.

ABC is divided into resources, activities, and objects. Resources are the expenditures in their immature state, denoting the amounts disbursed that are readily observable. Instances of resources encompass electricity, wages, and inputs. Activities signify the outlay of resources essential to carry them out, while objects denote the commodities created by the company (MARTINS, 2001).

The cost drivers encompass the elements that ascertain the root cause of the cost (MARTINS, 2001). They illustrate how the activities will deplete the resources and how the objects will use the activities. Instances of drivers comprise the employee count, quantity of items ordered, amount of kWh consumed, and number of work hours.

The flowchart shown in Figure 2 displays the operation of the hierarchy of resources, actions, objects, and factors. Each resource, action, or object incurs or assigns its expenditures in a consecutive manner. To illustrate, the initial emphasis was on labor. The costs of each department or equipment (Human Resources - HR, General Maintenance, and Cement Mill) will be utilized by their corresponding activities. This constitutes the second emphasis. The third focus was on the principal service provider, specifically the HR activity. In exchange, the General Maintenance activity serves the cement grinding activity, which also necessitates electricity for its functioning (fourth focus). The fifth and ultimate emphasis was on the grinding of clinker and additions, specifically the production of cement. As each focus involved the transfer of costs, the total resources expended should be equal to the total cost of the objects.

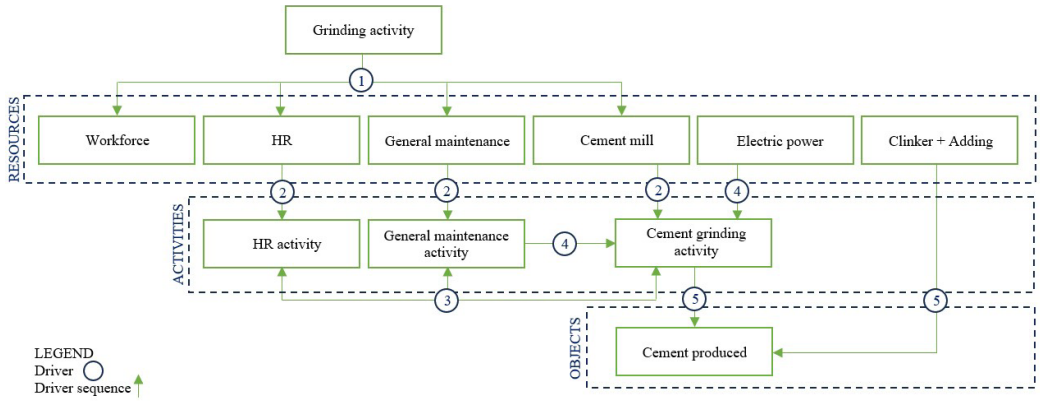

Figure 02: Flowchart outlining the methodology steps for developing the project

Source: Elaborated by the authors.

For example, in Figure 3, the human resources department distributes its expenses based on the number of employees in other departments. This is a logical approach, as in the studied cement plant, the workload of the HR department was directly proportional to the number of employees in various areas of the company. This includes tasks such as managing vacation requests, calculating labor taxes, and evaluating overtime and shift work. In numerical terms, if the HR department's expenses were US$10,000 and the total number of employees in other departments was 35 (20 in General Maintenance, 10 in Cement I Grinding, and 5 in Cement II Grinding), this would result in a contribution of US$5,714.29 for General Maintenance (20/35 x US$10,000), US$2,857.14 for Cement I Grinding (10/35 x US$10,000), and US$1,428.57 for Cement II Grinding (5/35 x US$10,000).

The maintenance process as a whole utilizes the number of hours that the drivers work on each piece of equipment. This indicates that each operation necessitates a suitable driver, depending on its specific role within the company.

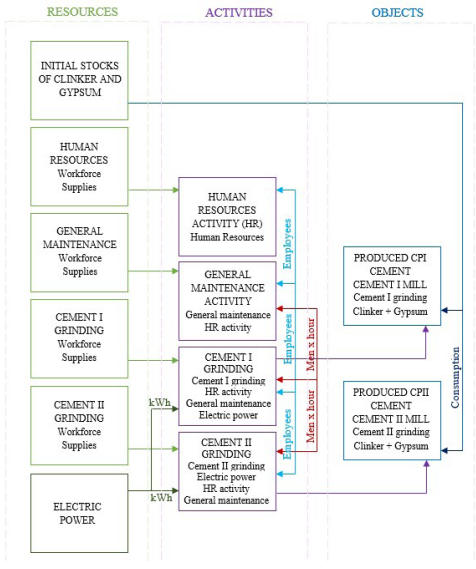

Figure 03: Flowchart of ABC

Source: Elaborated by the authors.

Every cost center, such as General Maintenance, Cement Mills, and HR, is designated as a resource in the cost chart template. As the distribution of resources and items is relatively simple, the primary difficulty for ABC is how to assign direct operations and, specifically, those that are indirectly connected to the production process.

Regarding the production activities, specifically Cement I and II Grinding, their targeting was based on intuition as each activity produced only one type of product. Therefore, the Cement I Grinding Activity directs 100% of its expenditures towards CP I cement, which is produced at the Cement I Mill. Similarly, Cement II Grinding is focused on producing CP II cement. It is important to note that when each of these production activities allocated their costs to the products, they also transferred a portion of their expenses that contributed to the overall cost. For example, when the Cement I Grinding activity allocated its full cost to CP I cement, it also included the costs of electricity, as well as the impact of HR and General Maintenance activities, as shown in Figure 4.

Figure 04: Flowchart of ABC

Source: Elaborated by the authors.

Another important factor to consider is that the motivation for performing maintenance activities is the number of hours dedicated by workers. In simpler terms, it is the result of the total hours worked by the employees assigned to a particular task. This driving force, much like the human resources aspect, is highly rational.

Each activity possesses an optimal driver, which is ascertained by its function within the company and the extent of demand from other departments.

3. METHODOLOGY

The methodology consisted of three stages: first, the characterization of the industrial plant to identify the unique aspects of the factory's production capacity; second, the diagnosis of the previous situation regarding cost management; and finally, the analysis of the practical implementation of ABC, assessing the obstacles that naturally arise when restructuring the organizational process and implementing management tools such as ABC.

According to Martins (2001) and Bertó and Beulke (2005), in addition to offering a comprehensive overview of product costing, providing improved means of identifying inefficiencies, and functioning as a means of cost management, ABC strives to minimize the arbitrary allocation of indirect expenses.

3.1 Characterization of the industrial plant

This paper discusses a case study of a cement industry with a daily clinker production capacity of 2,000 tons and an hourly cement production capacity of 140 tons. The plant, including its mining and cement sales areas, employed a total of 570 individuals.

The main energy-consuming process in the plant was the grinding of cement in two mills, which accounted for approximately 35% of the overall energy usage. Notably, these mills were not identical; one had a much higher production capacity and productivity. Despite this difference, both mills were responsible for producing the two types of cement sold by the company: CP II-Z 32 and CP II-F 32.

3.2 Assessment of the previous state of cost management

There existed a cost accounting system that operated through cost absorption. As stated by Moura (2005), this approach, in addition to adhering to tax regulations, places particular emphasis on the allocation of production expenditures overall, frequently employing capricious allotments for the assessment of inventory.

Only production-associated costs were apportioned to the cost of goods sold. Overhead expenditures, including those related to personnel, administration, and marketing, were not eligible for inclusion in the cost of goods sold for the purpose of income taxation.

In conclusion, the cost situation was strongly influenced by the tax regulations. The initial concept regarding the performance of a specific equipment became unclear within the previous framework for cost calculation. Table 1 demonstrates the presentation of the cost data. The underlying factors contributing to resource usage for each machine were not considered. Therefore, the cost of the produced cement was determined as an average of the two types. The expenses for each account were combined and ultimately divided by the total cement production.

3.3 Analysis of the practical implementation of ABC

Despite the perpetual necessity to strive for constant process enhancement, many organizations frequently face well-established obstacles when attempting to implement systems and methodologies that alter their current routines.

Cost contributions	Values in US$	%
Clinker	2,307,420.0	78.4
Electric power	208,251.0	7.1
Replacement materials	127,264.0	4.3
Crushed natural pozzolan	109,826.0	3.7
Crushed gypsite	77,570.0	2.6
Indirect manufacturing expenses	32,237.0	1.1
Third-party services	30,852.0	1.0
Crushed limestone	27,577.0	0.9
Direct workforce	30,268.0	0.7
Total (US$)	2,941,266.0	
Production (tons)	65,000.0	
US$/tons	45.25	
Administrative expenses	54,889.0	
Total expenses	2,996,155.0	

Table 1: Cost contributions of cement produced in one month
Source: Elaborated by the authors.

Several barriers, primarily of a cultural nature, were identified during the adoption of ABC. Some individuals perceived the new cost methodology, which required comprehensive data on organizational activities, as a form of surveillance rather than a tool for enhancing work management.

These hindrances have been taken apart and are consistently being overcome through earning the trust of individuals. It is essential to explicitly state that without the support of the general population, it would not be feasible to provide reliable information and assistance for decision-making by management.

In addition, the exchange of feedback is vital for earning the dedication of users and ensuring the effectiveness

of cost management. As stated by Cunha *et al.* (2005), the practice of giving and receiving feedback utilizes interpersonal relationships as a means of advancing the overall growth of the organization.

The implementation of ABC necessitates reconfiguring business processes to an appropriate level of specificity in order to avoid excessive length or brevity. All processes within the organization fundamentally involve utilizing resources, producing a product or service, and engaging customers (COKINS, 1996).

After initial meetings with department managers, the entire organization was mapped and divided into cost centers. These meetings also aimed to understand the tasks performed by each sector and illustrate their interdependence. As shown in Figure 5, the Human Resources department's main responsibilities were closely connected to the number of employees in other departments. In contrast, the workload of the Materials Management department was directly influenced by the demands of other sectors in the company.

It should be noted that an internal team was established to oversee cost management and enhance comprehension of the new costing methodology. Without the formation of this team, successful implementation may not have been feasible. As expressed by Senge (2002), team learning serves as a paradigm for learning within the organization, as the team's accomplishments can establish a precedent and standard for collective learning throughout the entire organization.

Figure 6 illustrates the flowchart outlining the stages of ABC implementation at the cement plant. Each phase depicted in Figure 6 has been assigned a numerical designation to facilitate understanding of the descriptions provided in Table 2.

After holding meetings with the managers of different departments in the company, the organization was partitioned into cost centers. This enabled the direct allocation of costs, including cash expenditures, material requisitions, personnel allocation, and third-party services. The number of cost centers established was based on the level of specificity required to efficiently monitor the specific expenses of each activity or process.

Once the cost centers were set up, it became imperative to develop cost drivers. These were responsible for determining the utilization of each resource, activity, or object.

The cost of relocating inputs within the factory and transporting materials from the mine to the plant by means of trucks incurred expenses that were unable to be allocated to the improvement of product quality. In contrast, the higher the expenses for transportation and

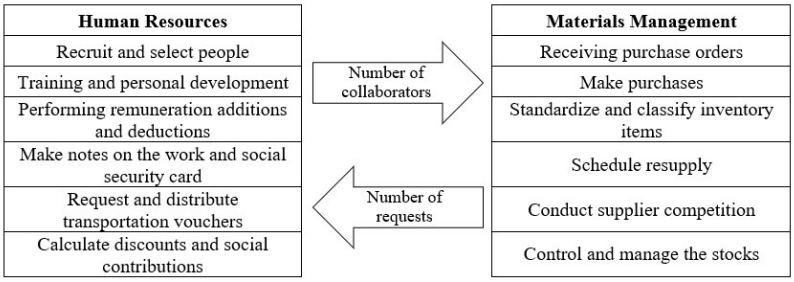

Figure 5: Interdependence among the various sectors of the company

Source: Elaborated by the authors.

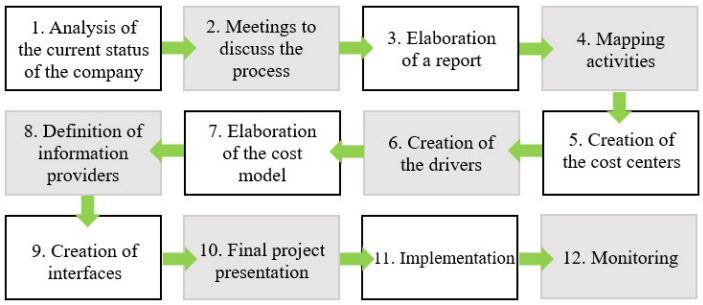

Figure 6: Flowchart outlining the implementation stages of ABC

Source: Elaborated by the authors.

#	Implementation Phases	Activity description
1	Analysis of the status of the company	Study the accounting reports, analyze the production bulletins, and check how the production controls are performed.
2	Meetings to discuss the process	Hold meetings with the managers of each area to discuss the processes performed by each sector, be it the production, production support, administrative, or commercial areas.
3	Elaboration of a report	Prepare a report with the diagnosis of the company and with the descriptions of the processes practiced by the areas or sectors of the company. In addition, it is important to inform the results expected with the implementation of ABC.
4	Mapping activities	List all the activities that will be costed.
5	Creation of the cost centers	Create a table with the cost centers that will be used to allocate the expenses of each sector of the company.
6	Creation of the drivers	Create a table with the drivers that will be used to identify how resources, activities and objects will be consumed
7	Elaboration of the cost model	Create the cost model in a specific program responsible for doing the cost calculation.
8	Definition of information providers	Define with the area managers those responsible for delivering the necessary data to feed the cost model.
9	Creation of interfaces	Define with the IT area the format of the data that will be delivered by the information providers, to feed the cost model.
10	Final project presentation	Present to the managers, manager, and director the result of the project, with the cost simulation with a monthly period and making the comparison with the previous situation of the company with reference to cost management.
11	Implementation	Set a date to start the monthly cost calculation. Define with the information providers the deadlines for sending data to feed the cost model.
12	Monitoring	Follow up on the monthly cost calculations.

Table 2: Description of the implementation stages of ABC
Source: Elaborated by the authors.

handling, the lower the profit, as these costs could not be passed on to the final price of the products without the risk of losing market share.

According to Kaplan (2010), it is possible to include the element of time in ABC in order to optimize the utilization of resources, such as personnel, machinery, technology, and physical space, and comply with the operating expense budget.

Hence, the expense incurred for the operations performed by the machinery responsible for the transportation of raw materials was computed based on their efficient utilization per unit of time. As an example, the budgeting for the process of extracting limestone, which relied on crawler tractors and excavators, was determined by the hourly unit cost of each equipment's availability. The allocated time for each equipment corresponded to the workload of the operators engaged in the limestone extraction task, not including maintenance hours.

4. RESULTS

The initial result was the division of the entire organization into cost centers and cost drivers, thereby increasing the ability to control expenses in each department of the company. Oliveira *et al.* (2015) also noted that the ABC method is suitable for companies in the concrete sector, as it enables a more precise calculation of the impact of each department and employee on the final cost of the product. This contributes to a more well-directed allocation of organizational resources, enhancing efficiency and effectiveness in cost management. For example, Figure 7

illustrates the contributions of activities and resources in the flour grinding process, which is responsible for producing the flour used in the clinker kiln.

Each step in the process of grinding flour assigned its costs based on a designated driver. For instance, the laboratory step distributed its expenses according to the quantity of tests and laboratory analyses performed during the monthly period.

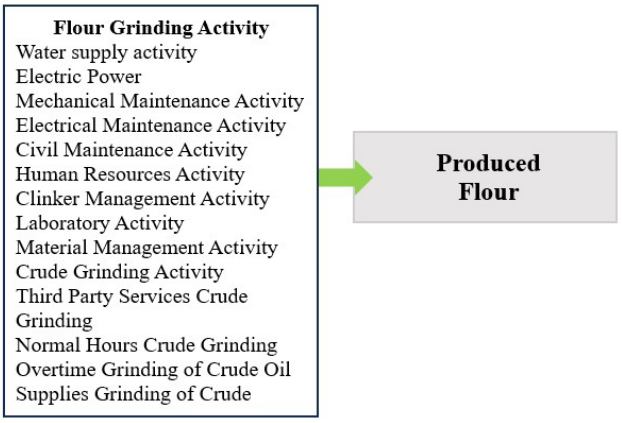

Figure 7: Contributions of the flour grinding activity
Source: Elaborated by the authors.

In order to obtain a thorough comprehension, 220 accounts were created to represent the areas and resources involved in the production of cement. In terms of tasks, 145 instances were produced, covering production, support for production, administrative, and commercial functions.

As a cost flow analysis tool, ABC not only delineated the company's operations but also allowed for the categorization of these activities based on their value aggregation using the criteria outlined in Figure 8. This instilled a culture focused on minimizing process losses, optimizing maintenance activities, and reducing unnecessary expenses associated with input movement. According to Yang and Chang (2018), the implementation of ABC enhanced the efficiency of activities and decreased indirect costs, ultimately bolstering the competitiveness and profitability of the company. Additionally, it facilitated the identification of distorted cost discrepancies and cross-subsidization among individual products, thereby improving production and marketing strategies and maximizing profitability.

Only the activities that resulted in the transformation of the product (LIKER, 2005) were classified as value-adding activities, as it is this transformation that generates the perception of value for both internal and external customers in the field of cement manufacturing. Table 3 outlines some

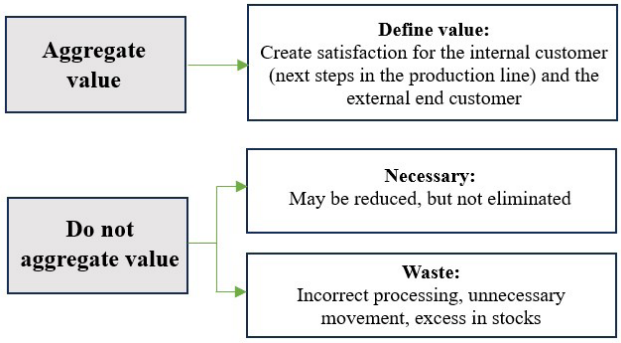

Figure 8: Criteria for aggregating value to the activities
Source: Elaborated by the authors.

of the key activities that contribute and do not contribute to the value of the cement manufacturing process.

The expenses incurred for the handling of inputs in the mill and mine were calculated. However, these costs were not allocated towards enhancing the product's features. Therefore, the handling activities did not add value to the product (LIKER, 2005). In this regard, Oliveira *et al.* (2015)

Activities that aggregate value	Activities that do not aggregate value
Limestone Extraction	Limestone stripping
Crushing	Fuel storage
Pre-homogenization	Fuel handling
Flour Grinding	Supply Handling
Clinkerization	Furnace heating
Cement Grinding	Maintenance
Bagging	Water supply

Table 3: Main activities that add and do not add value
Source: Elaborated by the authors.

also noted that the implementation of the ABC method allows for a better evaluation of the profitability of each product and informed decisions on the continuity or elimination of production lines. The ABC method enables the precise allocation of resources to the most profitable or strategic products.

It should be noted that the clinkerization process involves the consumption of fuel to produce thermal energy. However, this fuel is not incorporated into the final product as it is dissipated during the process. Therefore, it is considered a non-value-adding element.

Following the implementation of the ABC system, the integration between different areas of the plant significantly improved, as each area recognized its impact on the final product's cost. According to Kaplan (2009), the frequency of operational analysis meetings should be determined based on the company's operational cycle and the speed at which managers want to respond to sales

and operational data. As a result, these meetings became more frequent, allowing for discussions on preventive and corrective maintenance, production schedules, inventory levels, defects, and equipment downtime.

Figure 9 depicts the costs of cement production for each mill. This segregation of product costs enabled the computation of the individual product contribution margin, thus identifying the one that would yield the highest financial and economic gain for the company.

The cement grinding process was conducted with consideration for the energy consumption needed to produce each type of cement in each mill. This method resulted in a more precise estimation of the cost for each cement, as the maintenance tasks and replacement of plates and grinding bodies in the mills were a result of wear and tear caused by the reduction of material within the equipment. This reduction was solely achieved through the use of electricity, which is the main contributor to the cost of cement grinding. Furthermore, Sahoo and Kumar (2022) also point out that cement production requires a significant amount of energy and is responsible for greenhouse gas emissions. Therefore, it is imperative to enhance energy efficiency and reduce emissions, primarily in the grinding activities.

It is crucial to keep in mind that, regardless of the methodology used to calculate expenses, the total cost of US$ 2,996,155 remained unchanged. However, in the ABC methodology, the result was significantly more comprehensive and meticulous, as each activity began to impact the cost flow based on its actual usage. Therefore, the outcomes are related to greater benefits in terms of a better understanding of the actual cost system by identifying the main activities, demonstrating that the ABC method can be applied in the cement industry, as recommended by Robinson and Umo (2023) in Nigeria and Sarwat and Godil (2017) in Pakistan.

Table 4 illustrates that CP II-F cement, regardless of its production source, consumed a significantly higher level of electricity per metric ton of cement manufactured. This can be attributed to its higher clinker composition, which possesses a greater degree of grinding difficulty (ABCP, 2002). Therefore, this led to a higher cost of grinding for this cement in comparison to CP II-Z.

5. CONCLUSIONS

The implementation of Activity Based Costing (ABC) in a cement plant allowed for the categorization of

ACTIVITIES

Cement 1 Grinding Activity	US$ 292,994	50,000.00 t	US$ 5.86/t
Cement 1 Grinding Activity	US$ 111,774		US$ 2.23/t
HR Activity	US$ 1,005		US$ 0.02/t
Materials Activity	US$ 1,432		US$ 0.03/t
Electrical Maintenance Activity	US$ 7,307		US$ 0.15/t
Mechanical Maintenance Activity	US$ 6,589		US$ 0.13/t
Civil Maintenance Activity	US$ 3,601		US$ 0.07/t
Electric Power	US$ 161,317		US$ 3.23/t

Cement 2 Grinding Activity	US$ 133,520	15,000.00 t	US$ 8.90/t
Cement 2 Grinding Activity	US$ 66,640		US$ 4.44/t
HR Activity	US$ 1,005		US$ 0.07/t
Materials Activity	US$ 430		US$ 0.03/t
Electrical Maintenance Activity	US$ 6,189		US$ 0.41/t
Mechanical Maintenance Activity	US$ 8,721		US$ 0.58/t
Civil Maintenance Activity	US$ 3,601		US$ 0.24/t
Electric Power	US$ 46,934		US$ 3.13/t

ENERGY CONSUMPTION (kWh/t x produced tons)

OBJECTS

CP II-F MC1 Cement	US$ 558,417	12,000.00 t	US$ 46.53/t
Cement 1 Grinding activity	US$ 70,467		US$ 5.87/t
Supplies	US$ 487,950		US$ 40.66/t

CP II-Z MC1 Cement	US$ 1,790,290	40,000.00 t	US$ 44.76/t
Cement 1 Grinding activity	US$ 222,527		US$ 5.56/t
Supplies	US$ 1,567,762		US$ 39.19/t

CP II-F MC2 Cement	US$ 153,739	3,000.00 t	US$ 51.25/t
Cement 2 Grinding activity	US$ 31,752		US$ 10.58/t
Supplies	US$ 121,987		US$ 40.66/t

CP II-Z MC2 Cement	US$ 493,709	10,000.00 t	US$ 46.53/t
Cement 2 Grinding activity	US$ 101,768		US$ 10.18/t
Supplies	US$ 391,941		US$ 39.19/t
Total	US$ 2,996,155		

Figure 9: Cost contributions of the cement produced in one month

Source: Elaborated by the authors.

Cement 1 Mill	Specific consumption	Production	Power consumption
CP II-F Cement	44.0838 kWh/t	12,000.00 t	529,005.70 kWh
CP II-Z Cement	41.7636 kWh/t	40,000.00	1,670,544.30 kWh
		Total	2,199,550.00 kWh
Cement 2 Mill	**Specific consumption**	**Production**	**Power consumption**
CP II-F Cement	50.7277 kWh/t	3,000.00 t	152,183.23 kWh
CP II-Z Cement	48.7767 kWh/t	10,000.00 t	487,766.77 kWh
		Total	639,950.00 kWh

Table 04: Targeting the cement grinding activity (specific energy consumption (kWh/t) x cement produced tons)

Source: Elaborated by the authors

costs related to the core operations of the company, as well as those associated with intermediate and final products. Additionally, it facilitated the identification and classification of all auxiliary and inherent activities involved in the production of flour, clinker, and cement, based on their value contribution. Therefore, aside from determining the costs of the end products, ABC serves as a valuable management tool when paired with a thorough understanding of the company's production process.

The primary obstacle faced in implementing ABC in the company examined was the cultural barrier among most employees, resulting from the intricacy and complexity of the costing method. However, with the establishment of designated cost centers and the identification of activities and cost drivers, various departments within the company were able to closely and actively monitor their expenses, resulting in an overall reduction in costs for the cement company.

This study may prompt managers of companies, regardless of their industry, to consider the possibility of implementing ABC as a means of optimizing and overseeing expenses and operations.

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INFLUENCE OF PAVING SURFACES ON THERMAL COMFORT

INFLUÊNCIA DAS SUPERFÍCIES DE PAVIMENTAÇÃO NO CONFORTO TÉRMICO

LA INFLUENCIA DE LAS SUPERFICIES DE PAVIMENTACIÓN EN EL CONFORT TÉRMICO

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ABSTRACT
Constructive densification, increased asphalt paving, lack of vegetation, and climate change are factors contributing to the formation of heat islands in urban centers. This study aimed to investigate the characteristics of different pavement surfaces in the vicinity of the University of Contestado and their influence on thermal comfort. It is an applied research with a predominantly qualitative approach, a case study type, using a thermo-hygrometer for data collection at points distributed in the surroundings of the Concórdia and Mafra campi of the University of Contestado. The results show that surfaces covered with asphalt have the worst indices, with higher temperature and lower air humidity, while surfaces with vegetation have the best indices with lower temperature and higher air humidity. The study allows the conclusion that the presence of vegetation in the vicinity of the University can directly influence the reduction of heat island effects in urban areas, as it acts on the control of air temperature and humidity, as observed in both study environments.

KEYWORDS
Urban surfaces. Constructive densification. Microclimate control. Heat islands. Asphalt paving.

RESUMO
O adensamento construtivo, aumento da pavimentação asfáltica, ausência de vegetação e mudanças climáticas são fatores que contribuem para a formação das ilhas de calor nos centros urbanos. Este estudo teve como objetivo investigar as características das diferentes superfícies de pavimentação nos entornos da Universidade do Contestado e sua influência no conforto térmico. Se trata de uma pesquisa de natureza aplicada, com abordagem predominantemente qualitativa, do tipo estudo de caso, com uso de termo higrômetro para a coleta de dados em pontos distribuídos nas vizinhanças do campus de Concórdia e Mafra da Universidade do Contestado. Os resultados mostram que a superfície com cobertura asfáltica apresenta os piores índices, com maior temperatura e menor umidade no ar e as superfícies com vegetação apresenta os melhores índices com menor temperatura e maior umidade no ar. O estudo possibilita concluir que a presença de vegetação nos entornos da Universidade pode influenciar diretamente na redução dos efeitos das ilhas de calor em áreas urbanas, pois atua no controle da temperatura e umidade do ar, como observado em ambos os ambientes de estudo.

PALAVRAS-CHAVE
Adensamento construtivo. Controle do microclima. Ilhas de calor. Pavimentação asfáltica.

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RESUMEN

La densidad de construcción, el aumento de pavimentación asfáltica, la falta de vegetación y el cambio climático son factores que contribuyen a la formación de islas de calor en los centros urbanos. Este estudio tuvo como objetivo investigar las características de diferentes superficies de pavimento alrededor de la Universidad de Contestado y su influencia en el confort térmico. Se trata de una investigación de carácter aplicado, con enfoque predominantemente cualitativo, del tipo estudio de caso, utilizando un termohigrómetro para la recolección de datos en puntos distribuidos en las cercanías de los campus de Concordia y Mafra de la Universidad del Contestado. Los resultados muestran que la superficie con cobertura asfáltica presenta los peores índices, con mayor temperatura y menor humedad en el aire y las superficies con vegetación presentan los mejores índices con menor temperatura y mayor humedad en el aire. El estudio permite concluir que la presencia de vegetación alrededor de la Universidad puede influir directamente en la reducción de los efectos de las islas de calor en las zonas urbanas, ya que actúa controlando la temperatura y la humedad del aire, como se observa en ambos ambientes de estudio.

PALABRAS CLAVE

Superficies urbanas. Densificación constructiva. Control del microclima. Islas de calor. Pavimentación asfáltica.

1. INTRODUCTION

The increase in building density in Brazilian cities occurs without due attention to the effects on microclimates, which enhances the creation of thermally uncomfortable open spaces (MACHADO DOS SANTOS *et al.*, 2023). Climate change is causing environmental, social, and economic impacts due to extreme weather events, such as heavy rainfall and flooding (VASCONCELLOS *et al.*, 2023).

These and other events associated with climate change affect people's quality of life, especially in subtropical cities (SANTAMOURIS, 2020). As a solution, studies indicate the need to recognize the history, social and material relations, and trajectories that shape people's lives in any urban governance process aimed at combating climate change (CASTÁN BROTO, 2017).

The increase in temperatures in heat islands is more pronounced in areas with higher intensity of human occupation and less pronounced in areas covered by vegetation (KRÜGER; PEREIRA, N. H. G., 2020). Hence, the characteristics of the city serve as a barometer of urban climate, whereby its impermeabilization with paved areas and the reduction of green spaces lead to an increase in temperature levels and a decrease in air humidity, causing discomfort to its inhabitants (NERES; SILVA; PEREIRA, M. A. B., 2021).

Climate change can also be a significant factor when studying urban microclimates and their impacts on the quality of life of the population. Sustainable construction and the quality of surroundings can mitigate the effect of the urban heat island (ZIMMERMANN *et al.*, 2019). The characteristics of surfaces surrounding buildings can also impact urban microclimates. Trees are considered the best natural climate regulators, acting to balance the microclimate. Therefore, cities need to incorporate tree-planting programs into their projects (MARTINI; BIONDI; BATISTA, 2022; PINHEIRO; SOUZA, 2017; VASCONCELLOS *et al.*, 2023).

In the presented context, this study aims to investigate the characteristics of different paving surfaces in the surroundings of the University of Contestado (Concórdia and Mafra campi) and their influence on thermal comfort. To achieve this objective, an evaluation of temperature and humidity characteristics, important factors in urban microclimates, was conducted. The study presents the results of the evaluation of 10 points located on the Concórdia campus and 10 points located on the Mafra campus, using the same method and instruments, with data collection performed at a one-week interval between collections at each campus.

This study stands out by focusing on the specific characteristics of paved surfaces near the University of Contestado and their impact on thermal comfort. While many studies address heat islands broadly, this applied and qualitative research uses a case study to directly analyze how different types of pavement influence air temperature and humidity in specific urban areas. The novelty of the study lies in the detailed analysis of paved and vegetated surfaces around the University of Contestado, providing concrete data that highlight the importance of vegetation in controlling the urban microclimate, something that may not be as thoroughly addressed in other studies.

2. INTELLIGENT AND SUSTAINABLE

Smart cities should integrate cutting-edge technological solutions to tackle air quality issues, which can affect temperature and other microclimate factors. Cities can reduce their carbon footprint by measuring the reduction in emissions of pollutants resulting from technology use. Therefore, urban sustainability in smart cities can be impacted through the utilization of control Technologies (AHAD *et al.*, 2020). However, the use of technologies for smart cities can have both positive and negative impacts on urban microclimate, depending on how they are designed and implemented (MARTIN; EVANS; KARVONEN, 2018).

The impacts of climate change on urban microclimates can already be observed in various locations around the planet, often resulting in mortality related to socioeconomic and demographic factors, as well as specific health problems, especially in subtropical cities (SANTAMOURIS, 2020). In this circumstance, studies show that climate change can be an important factor to consider when studying urban microclimates, as well as their impacts on the quality of life of the population.

In San Francisco, California, measurements were taken at 26 points within a 250-meter radius, where it was observed that temperature and air humidity are important factors in urban microclimates and can significantly affect building energy usage and environmental comfort (HONG *et al.*, 2021).

In India, satellite data collection revealed critical heat zones in the summer in the central areas of two megacities (New Delhi and Kolkata), showing temperature variations between vegetated and built-up regions, with a difference of 8.76°C on one night (DUTTA; BASU; AGRAWAL, 2022). Based on the distribution of area, location, thermal

amplitude, and contribution to the formation of heat islands, sustainable planning strategies were developed for each local climatic zone.

In Brazil, a study analyzes the impact of building characteristics, such as building height, on thermal comfort and energy balance, after analyzing variables such as temperature, humidity, solar radiation, wind speed, and direction. The study concludes that in taller buildings, temperatures are higher, and wind speeds are lower in the surrounding area (CARFAN; GALVANI; NERY, 2012).

In the city of Bagé (RS), another study of urban microclimate shows that shading caused by the verticalization of buildings can favor thermal comfort in hot climates but tends to be unfavorable to the climate during winter periods due to shading in open spaces (MACHADO DOS SANTOS *et al*., 2023).

The studies cited demonstrate that sustainable construction practices can help mitigate the urban heat island effect, which is a phenomenon where urban areas experience higher temperatures than surrounding rural areas due to the absorption and retention of heat by buildings and other infrastructure (ZIMMERMANN *et al*., 2019). Furthermore, sustainable buildings can help promote more sustainable lifestyles and reduce the overall environmental impact of human activities.

Urban Heat Islands (UHI) is a microclimatic phenomenon affecting urban areas, causing temperature increases that amplify heat waves and reduce quality of life. A review of studies in 14 cities across 13 countries showed that specific urban characteristics present different challenges. The study suggests that maintaining and expanding urban green spaces can reduce the impacts of heat islands. (LEAL FILHO *et al*., 2021).

The presence of vegetation can directly influence urban heat islands and help reduce temperatures in urban areas. Studies on morphological classification reveal a relationship between local climatic zones and the resulting thermal field (KRÜGER; PEREIRA, 2020).

According to Martini, Biondi, and Batista (2022), trees are considered the best-existing climate regulators, acting naturally to stabilize the microclimate. They can help mitigate the effects of urban heat islands, heat stress, extreme precipitation, coastal flooding, soil erosion, air pollution, drought, and water scarcity, which are some of the global risks resulting from climate change concentrated in urban areas.

Regarding thermal performance, data collection in urban spaces is important for the calibration and validation of climatic models, which can be used to assess different urban scenarios and their microclimatic conditions (NOVAES; MONTEIRO, 2022).

3. MATERIALS AND METHODS

The present study was conducted during the course "Sustainable Technologies Applied to Engineering," offered by the Professional Master's Program in Sanitary and Environmental Civil Engineering (PMPECSA) in the first semester of 2023. It is an applied research, with a predominant qualitative approach, of the case study type. The case study entails a few objects with extensive and detailed knowledge, a task practically impossible through other considered designs, with results for the convergence or divergence of observations obtained from different procedures (GIL, 2002).

3.1 Study Area

The chosen location was the University of Contestado, at the Concórdia Campus (Figure 1, left), at the geographic coordinates (-27.217626311866873, -51.99542929565719), and at the Mafra Campus (Figure 01, right) at coordinates (-26.132242727948107, -49.80873483918057), in the state of Santa Catarina, Southern Brazil. In both locations, the terrain is relatively flat, with an average altitude of 690 m at the Concórdia campus and 815 m at the Mafra campus.

In Concórdia, throughout the year, the temperature ranged from 8°C to 32°C and rarely fell below 1°C or exceeded 37°C. In Mafra, the temperature ranged from 9°C to 28°C and rarely fell below 4°C or exceeded 31°C. In both locations, summers are hot and humid, and winters are cold and dry, with June and July being the coldest months (SPARK, [s.d.]).

3.2 Data Collection, Recording, and Analysis Method

Initially, 10 collection points were determined (Figure 01), using criteria such as surface characteristics (concrete, asphalt pavement, vegetation, soil), surroundings (presence of vegetation or buildings), and the distance between consecutive points, as in previous studies (GRIGOLETTI; LAZAROTTO; WOLLMANN, 2018; MARTINI; BIONDI; BATISTA, 2022), the developed method involved the use of geotagged photos, direct observation, and in-situ measurements of temperature and air humidity.

For each point, 10 measurements of temperature and relative air humidity were taken, with a 1-minute interval between each measurement. At each point, the equipment was allowed to stabilize in temperature and

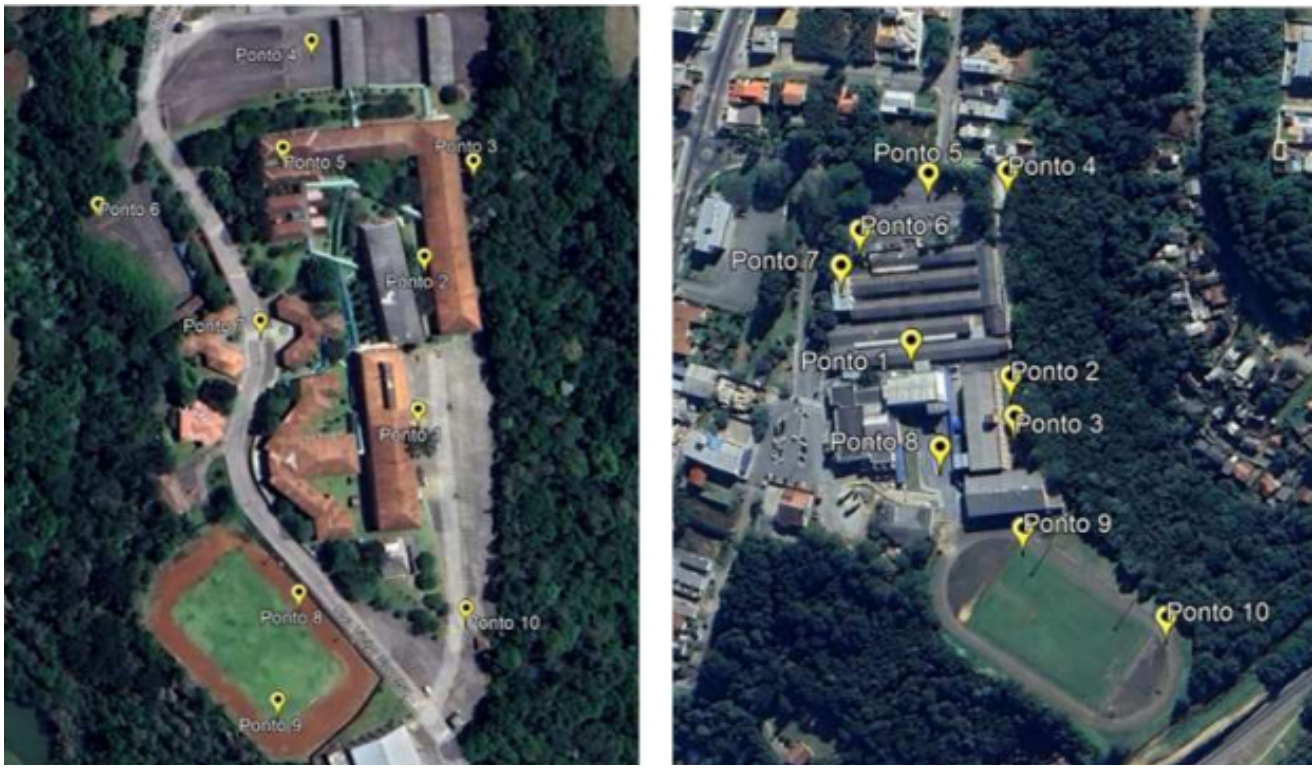

Figure 01: Data collection points location for Concordia campus (left) and Mafra (right).
Source: Adapted from Google Earth.

relative air humidity values, and simultaneously, geotagged photographic records were taken, along with notes regarding observations of the environment and its surroundings.

The observation (Figure 02) of the surroundings at the points was considered, as previous studies "demonstrate that increased building density limited to three-story buildings during the hottest period of the day (at 2:00 p.m.) minimally alters the microclimate in the analyzed block [...] (MACHADO DOS SANTOS *et al.*, 2023, p. 8). In addition to buildings, forests, ground cover, orientation, and street width influence microclimatic variables due to the amount of solar radiation received (MARTINI; BIONDI; BATISTA, 2022).

Data collection at the Mafra campus took place on July 1, 2023, from 2:00 p.m. to 5:00 p.m. And at the Concórdia campus, it was on July 7, 2023, at the same time, under sunny weather conditions. A term-hygrometer with a sensor installed on a tripod 25 cm from the surface was used as the data collection instrument. The data recording and analysis were conducted in spreadsheets using Microsoft Excel.

4. RESULTS AND DISCUSSIONS

Ten collections were conducted with a 1-minute interval

Figure 02: Characteristics and physical conditions of the studied points.
Source: Authors.

for each of the 10 points. The results indicate similarities in surface conditions when comparing the Mafra and Concórdia campi. The data show that there was solar incidence at most points, with surfaces including concrete, asphalt, and soil being considered.

The table below (Table 1) shows the characteristics of the surface and solar conditions of the collection environment. Data analysis reveals variations in temperature averages and relative air humidity indices at both the Mafra and Concórdia campi. At the Concórdia campus, the best indices (higher values for air humidity and lower values for air temperature) were at point 3 (68% and 23°C) and point 9 (60% and 24°C), both with surfaces covered by grass.

In a previous study (MARTINI; BIONDI, 2015), For all seasons, the statistics demonstrate the influence of vegetation on meteorological variables (temperature and air humidity) and on the thermal comfort index. Point 5, which has a surface covered with basalt gravel, also showed good results (57% and 24°C).

At the Mafra campus, the points with the best indices, higher relative air humidity, and lower temperature were points 1 (77% and 20°C), 4 (69% and 21°C), and 10 (76% and 21°C). The surface of points 1 and 4 is smooth concrete, located between the campus buildings, both with tree presence and solar incidence. The hypothesis is that the presence of buildings contributed to heat loss in the concrete, considering that low temperatures were recorded on previous dates.

Another factor that may have contributed was the presence of green areas near the evaluated site, as the literature emphasizes the importance of forests for environmental comfort (MARTINI; BIONDI; BATISTA, 2022). Therefore, these two points (points 1 and 4) in the summer period may be influenced differently (temperature gain and humidity loss). Point 10, with a gravel surface, near the sports field, with vegetation presence (grass) near the point.

At the Mafra campus (Figure 03), the point with the worst comfort condition was point 5 (54% and 28°C), with an asphalt surface and close to the masonry building. The

Campus	Point	Surface Characteristics	Solar Condition
Concordia	1	Smooth concrete floor	Without sun
	2	Concrete blocks (hexagonal)	With Sun
	3	With grass	Without sun
	4	Asphalt pavement	With Sun
	5	Gravel surface	Without sun
	6	Concrete blocks (hexagonal)	With Sun
	7	Concrete blocks (hexagonal)	With Sun
	8	Gravel surface	With Sun
	9	With grass	With Sun
	10	Concrete blocks (hexagonal)	Without sun
Mafra	1	Smooth concrete floor	With Sun
	2	Gravel surface	With and without sun
	3	Asphalt pavement	With Sun
	4	Smooth concrete floor	Without sun
	5	Asphalt pavement	With Sun
	6	Asphalt pavement	With Sun
	7	Asphalt pavement	With Sun
	8	Concrete blocks (interlocking)	With Sun
	9	With grass	With Sun
	10	Gravel surface	With Sun

Table 1: Characteristics and physical conditions of the studied points
Source: Authors.

initial and final collection points were close to green areas with tree presence, a factor that may have contributed to thermal comfort.

At the Concórdia campus, the worst air humidity and temperature indices observed were recorded at points 4 (45% and 30°C) and 7 (45% and 31°C), both with

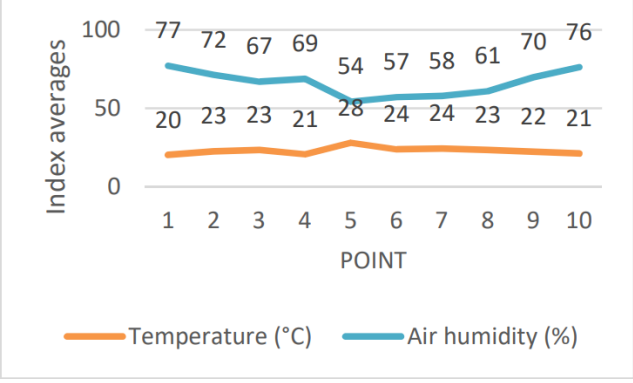

Figure 3: Mean temperature and humidity indices of the points at Mafra Campus.
Source: Authors.

asphalt and hexagonal concrete surface, exposed to solar incidence (Figure 04). Callejas, Durante, and Rosseti (2015) consider asphalt as "one of the main contributors to the formation of heat islands in cities" (p. 64). The results of the data collected in this study corroborate the assertion of these authors.

High levels of air humidity can exacerbate the perception of thermal discomfort in urban areas, affecting the body's ability to cool itself through the evaporation

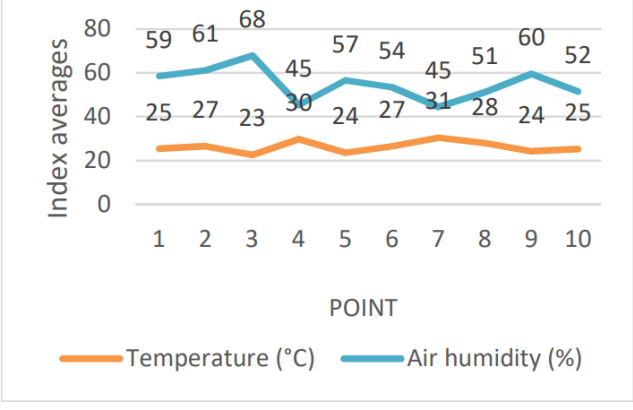

Figure 4: Mean temperature and humidity indices of the points at Concórdia Campus.
Source: Authors.

of sweat, leading to a higher perceived temperature and reduced thermal comfort. Likewise, higher temperatures can cause heat stress and discomfort among residents, especially during heat waves or prolonged periods of hot weather. Therefore, the combination of air temperature, humidity, wind speed, and radiation influence thermal comfort levels in urban environments. (ZHAO *et al.*, 2021).

The results of measurements carried out on different surfaces show the points where there is greater or lesser comfort when observing the humidity and air temperature levels.

The temperature data collection took place during July 2023, corresponding to the winter period in the study region. It was observed that the average temperatures recorded during this period ranged between 24°C and 31°C in Concórdia and 20°C to 28°C in Mafra, exceeding historical averages for the winter season. These elevated temperatures may have significant implications for understanding seasonal climate variations and for activities dependent on thermal conditions in this specific region.

In Oslo (Paris), temperatures in the hottest month are expected to increase by more than 5°C by 2050. Satellite measurements showed that on one of the hottest days in 2018, areas with paved buildings reached 39°C, while areas with vegetation maintained between 29 and 32 °C. The results indicate that the maintenance and restoration of tree cover reduces urban heat (VENTER; KROG; BARTON, 2020). This result observed in Oslo agrees with the results obtained in our study.

Understanding seasonal climate variations is crucial for assessing their impact on thermal comfort and energy demands, as thermal comfort directly influences heating and cooling needs. Understanding seasonal climate variations is crucial for assessing their impact on thermal comfort and energy demands, as thermal comfort directly influences heating and cooling needs, as evidenced by a study conducted on 505 residential buildings in six cities located in China's Hot Summer and Cold Winter zone (LIU *et al.*, 2017). However, these variations were not a relevant variable for this research.

5. CONCLUSION

The study aimed to assess the influence of surfaces on thermal comfort by evaluating temperature and relative air humidity indices at different points located in outdoor areas of the University of Contestado. The research, conducted in the course "Sustainable Technologies Applied to Engineering," was a case study at the Concórdia and Mafra campi. The analyzed surfaces included concrete pavement (smooth and in hexagonal blocks and interlocking pavers), asphalt-covered surface, grass, and soil and gravel surface.

The collected and analyzed data show that surfaces with vegetation and stone (gravel or pebble) were the ones that presented the best thermal comfort conditions.

The data also provide evidence of the importance of urban vegetation for good thermal comfort conditions. The presence of vegetation can directly influence the reduction of heat islands and temperature control in urban areas, as observed in both study environments on the Concórdia campus (figure 05) and the Mafra campus (Figure 06).

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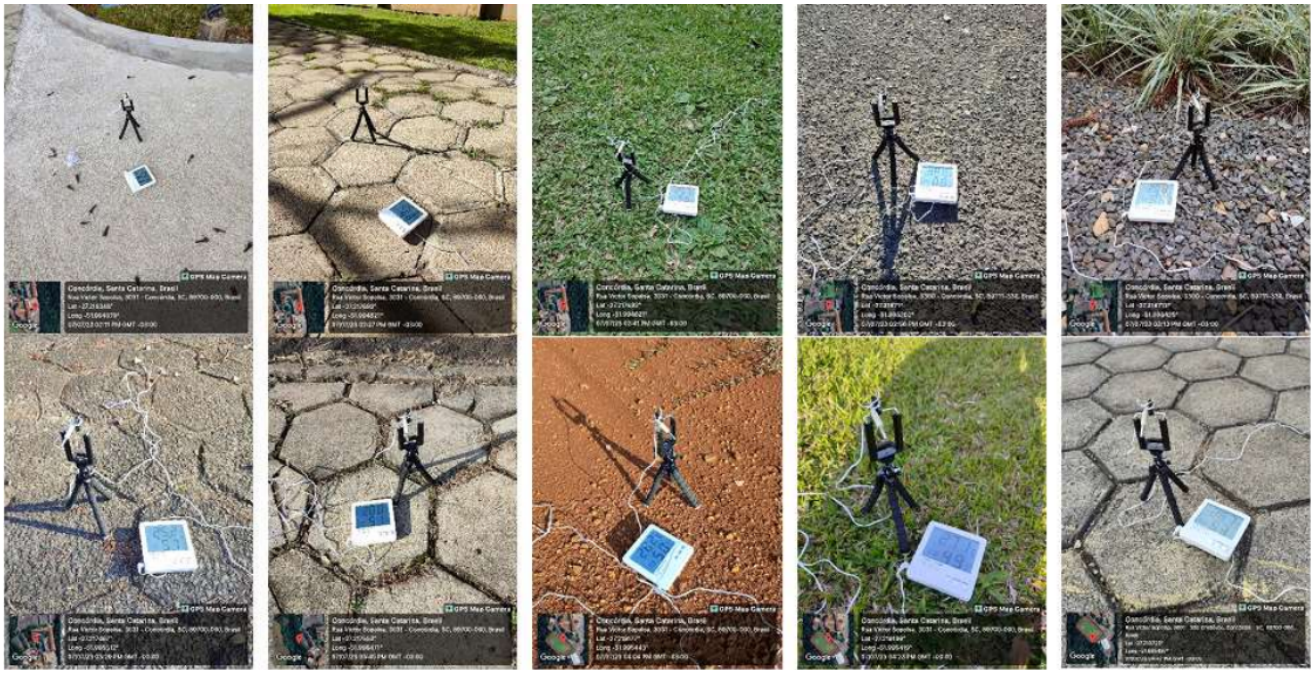

Figure 5: Characteristics of the surfaces analyzed on the Concórdia campus.
Source: Authors.

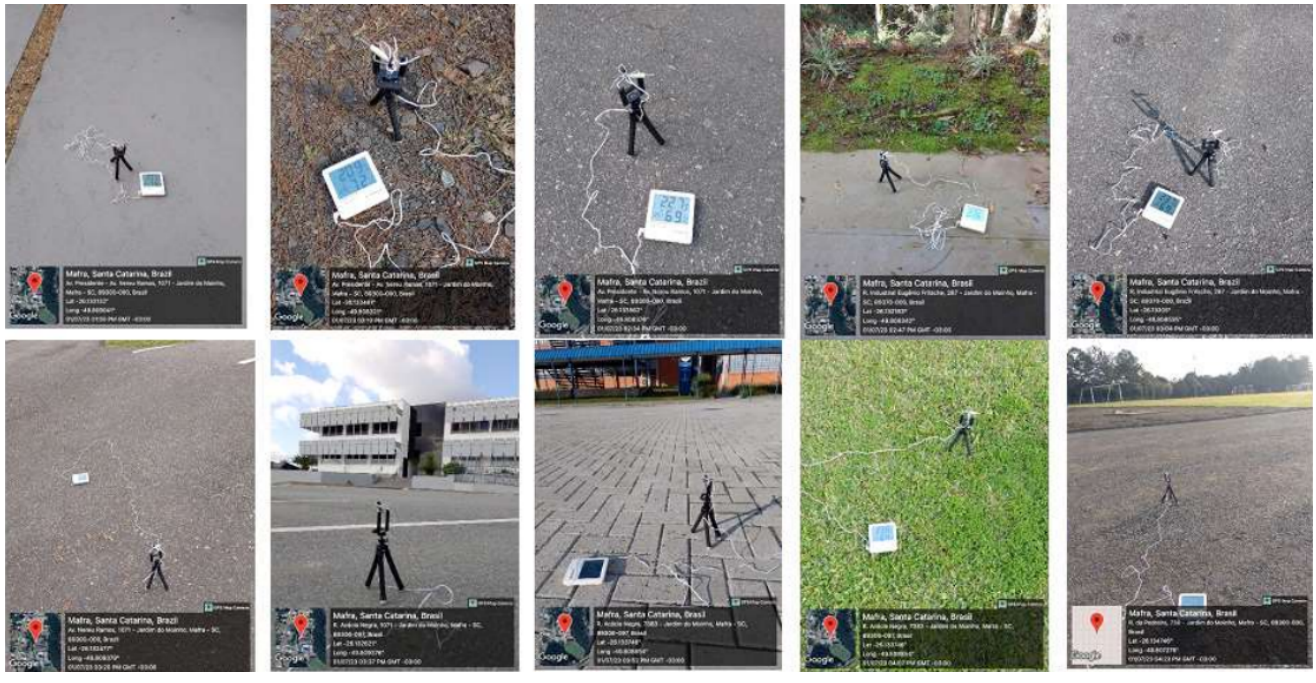

Figure 6: Characteristics of the surfaces analyzed on the Mafra campus.
Source: Authors.

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LC: conceptualization, investigation, methodology, validation, visualization and writing - original draft.

RJC: data curation, formal analysis, methodology and writing - original draft.

DCS: data curation, formal analysis, methodology and writing - original draft.

Conflict declaration:

EFFECT OF EQUIPMENT AGE ON RESIDUES GENERATION IN SAWMILL IN THE MUNICIPALITY OF IRATI-PR

EFEITO DA IDADE DOS EQUIPAMENTOS NA GERAÇÃO DE RESÍDUOS EM SERRARIAS DO MUNICÍPIO DE IRATI-PR

EFECTO DE LA EDAD DE LOS EQUIPOS EN LA GENERACIÓN DE RESIDUOS EN LAS SERRERÍAS DEL MUNICIPIO DE IRATI-PR

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ABSTRACT

The study aimed to describe the relationship between the age of equipment and the generation of residues in small wood processing industries in Irati-PR. Data were collected through a questionnaire, where 3 (three) sawmill industries were selected in order to collect data for their characterization. The companies approached were characterized as micro (2) and small companies (1), operating in the splitting and processing of wood. The species used as feedstock were from the Pinus sp., Eucalyptus sp. Genus and a small number of other species. Companies generate, on average, 175 m^3 of residues, with an average use of 43%. Residues generation was related to the age of the equipment, where the company with the oldest equipment had the highest amount. Companies do not manage waste, which is sold to third parties. Given this scenario, it was concluded that companies generate large amounts of residues, which, in this case, are linked to the lack of maintenance and use of obsolete equipment. The lack of correct disposal is attributed to the lack of incentive and information about the potential uses of waste and the possibility of generating extra income by companies.

KEYWORDS

Management; Wastage; Timber sector; Sawing; Feedstock.

RESUMO

O estudo teve por objetivo descrever a relação da idade dos equipamentos com a geração de resíduos em pequenas indústrias de processamento da madeira em Irati-PR. Os dados foram coletados por meio de um questionário, onde 3 (três) indústrias serrarias foram selecionadas, a fim de coletar os dados para sua caracterização. As empresas abordadas foram caracterizadas como micro (2) e pequenas empresas (1), atuando no desdobro e beneficiamento da madeira. As espécies utilizadas como matéria-prima foram dos gêneros Pinus sp., Eucalyptus sp. e uma pequena quantidade de outras espécies. As empresas geram, em média, 175 m^3 de resíduos, com aproveitamento médio de 43%. A geração de resíduos esteve relacionada com a idade dos equipamentos, onde a empresa com os equipamentos mais antigos, apresentou o maior montante. As empresas não realizam o gerenciamento dos resíduos, sendo estes vendidos para terceiros. Diante deste cenário, concluiu-se que as empresas geram quantidades grandes de resíduos, que, neste caso, estão atrelados à falta de manutenção e uso de equipamentos obsoletos. A falta de uma destinação correta é atribuída a falta de incentivo e informação sobre os potenciais usos dos resíduos e a possibilidade de geração de renda extra pelas empresas.

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PALAVRAS-CHAVE

Gerenciamento; Desperdícios; Setor madeireiro; Desdobro; Matéria-prima.

RESUMEN

El objetivo del estudio era describir la relación entre la antigüedad de los equipos y la generación de residuos en las pequeñas industrias de transformación de la madera de Irati-PR. Los datos se recogieron mediante un cuestionario. Se seleccionaron tres aserraderos con el fin de recoger datos para su caracterización. Las empresas contactadas se caracterizaban por ser microempresas (2) y pequeñas empresas (1), dedicadas al corte y transformación de la madera. Las especies utilizadas como materia prima eran Pinus sp., Eucalyptus sp. y un pequeño número de otras especies. Las empresas generan una media de 175 m³ de residuos, con una tasa media de utilización del 43%. La generación de residuos estaba relacionada con la antigüedad de los equipos, siendo la empresa con los equipos más antiguos la que presentaba la mayor cantidad. Las empresas no gestionan sus residuos, sino que los venden a terceros. Ante este panorama, se llegó a la conclusión de que las empresas generan grandes cantidades de residuos, que en este caso están relacionados con la falta de mantenimiento y el uso de equipos obsoletos. La falta de una eliminación adecuada se atribuye a la falta de incentivos e información sobre los usos potenciales de los residuos y la posibilidad de generar ingresos extra para las empresas.

PALABRAS CLAVE

Gerenciamento; Desperdícios; Setor madeireiro; Desdobro; Matéria-prima.

1. INTRODUCTION

Brazil is the second largest forested area in the world, with around 498 million hectares (58.5% of its territory), of which 98% is covered by native forests and 2% by planted forests (FAO, 2015; SFB, 2023). With the increase in population and the consequent demand for wood resources, the wood sector increases the processing of raw materials (IBÁ, 2020). The area of planted trees totaled 9.94 million hectares in 2022, with a growth of 0.3% compared to the previous year. The Eucalyptus genus covers 76% of the planted area in Brazil, being the most cultivated species (7.6 million ha). The genus Pinus spp., with 19% of the planted area (1.9 million ha) and around 5% of the total area, includes other species, such as the rubber tree (230 thousand ha), teak (76 thousand ha) and acacia (54 thousand ha) (IBÁ, 2023).

The processing of this feedstock leaves residue in the timber mills after its primary processing. An amount of around 63% is estimated for this sector (WZOREK *et al.* 2012; STOLARSKI *et al.* 2021). This is because the production of wood from the Pinus spp. and Eucalyptus spp. genus, presents, on average, yields between 25 and 63% (MONTEIRO *et al.* 2017; JUIZO *et al.* 2018; MÜLER *et al.* 2019), considered as low yield. In other words, sawmill waste can represent around 55% (by volume) of the feedstock processed (ANTWI-BOASIAKO *et al.* 2016), which depends on the characteristics of the wood (diameter, shape) and also the pattern of sawdust used (MURARA JÚNIOR *et al.* 2013; SALVADOR *et al.* 2020).

The wood processing industry is responsible for a large part of wood removal and imports and exports, providing products and by-products (SCHWARZBAUER *et al.* 2013). Sawn wood production has remained at around 8.0 million m^3 in recent years, with Brazil ranked 10th in the ranking of largest producers. The destination of sawn wood production reached 3.2 million m^3 for export in the year 2022 (FAO, 2021; ABIMCI, 2021; IBÁ, 2023). These can be classified as chips, shavings and dust. The main waste generated, according to the IBÁ report (2023), is bark, branches and leaves. In the case of sawn wood, the main residue with a representative amount is sawdust. The volume of waste generated is estimated at around 17 million/m^3/year (OLIVEIRA *et al.* 2017), and it is necessary to find ways to use this amount. These quantities, according to Garcia *et al.* (2012), for the most part, are not used in the industry where they were generated.

This is because, in the past, waste such as sawdust, wood particles and wood shavings were considered discarded. However, the primary processing industry depended on acquisitions from the paper and panel industry in order to avoid disposal costs (ZIPPUSCH *et al.* 2011). Given this, according to KRISTOFEL *et al.* (2016), the price of this waste remained low. With the demand for energy in the European market, the demand for these materials grew, consisting of the main production input. From this development, what was previously considered just disposal became a valuable raw material, used in different industrial processes (AUSTROPAPIER, 2022).

In addition to this, most sawmills are considered small (family, colonial), with little capital and have equipment in a precarious state of conservation, which reduces their income and, consequently, reducing their use. The lack of maintenance, inadequate maintenance (OLIVEIRA, 2016) and even the age of the equipment are linked to the final performance, therefore, the quality and conditions of the equipment are decisive. This is related to what is known as "non-value-adding work" or "additional work", which are activities that do not increase the value of the product, but provide proportional support for effective work, such as preparation and maintenance activities. equipment.

According to Camargo and Souza (2008), the correct maintenance of equipment helps the quality of workers, but also increases productivity and reduces the costs of industrial activity. Furthermore, according to Oliveira (2016), equipment maintenance can reduce costs, increase the company's profitability and preserve the environment by reducing waste. Waste does not add value to products, which consist of defective products, for example. Above all, they guarantee yield and quality of the raw material, since the lack of maintenance interferes with the productivity of sawmills, in addition to malfunctioning equipment (SILVA, 2001; SOARES, 2002). With the lack of maintenance of equipment and the high generation of waste, understanding the factors that contribute to their generation are relevant, where their identification will contribute to making improvements in the process.

The study aimed to evaluate the generation of waste in the sawmill industries depending on the age of the equipment used in wood processing, contributing to the research by Izekor and Osayimwen (2010), Mello *et al.* (2016), Ramos *et al.* (2018), Salvador *et al.* (2020), Moura *et al.* (2020), Spalenza *et al.* (2023), Dudziec *et al.* (2023), Fuhrmann *et al.* (2024) where they addressed, in general, the main destinations and use of waste generated in sawmills as raw material for other products, energy generation, where the factors involved in the process are not evaluated first hand.

Above all, the study presented a qualitative-quantitative approach, seeking to evaluate the reality of small and medium-sized sawmills. The methods used to describe this circumstance were through visits and application of questionnaires, in order to characterize their production systems, identify process variables and, finally, verify the generation of waste throughout the production process, seeking to identify factors linked to this generation.

2. MATERIAL AND METHODS

2.1 Selection of sawmill industries

For the purposes of this study, 3 primary wood processing sawmill industries were selected in the municipality of Irati, Central-West region of the State of Paraná (Figure 1).

Figure 1: Geographic location of the Municipality of Irati-PR.
Source: Google images.

2.2 Characterization of sawmill and its production process

For a better understanding of the production process and waste generation, the industries were classified according to their size, according to the criteria established by SEBRAE, described in Table 1.

Description	
Number of Employees	**Classification according to size**
Up to 19	micro Entreprise
Up to 99	Small
Up to 499	Medium
Above 500	Big

Table 1: Description of the size of the industries according to criteria established by SEBRAE.
Source: SEBRAE, 201, P. 17.

The industries selected in the study were not identified, being named as industry "A", "B" and "C", respectively. The characterization of the production process consisted of obtaining data relating to the feedstock used and quantity, origin and obtaining of the raw material, production line and consumer market and the operations of the industrial process and, finally, the generation of waste from of wood processing. Due to the high generation and the importance of correct waste disposal, a survey was carried out of the management practices for solid waste generated, in which this generation can be reduced with the correct maintenance of equipment, ensuring the best use of waste. natural resources, reducing environmental impacts.

2.3 Data collection

A diagnosis of waste generation was carried out in the selected sawmill industries in the municipality in question, in July 2019. A semi-structured questionnaire (research instrument) was prepared, containing questions about the production process. Through visits to the industries, data collection was carried out, with those responsible for the industries as listeners.

2.4 Data analysis

The data analysis was carried out by descriptive statistics, where realized the summation of each identified residue, obtaining the total volume and calculating the average amount generated.

3. RESULTS AND DISCUSSION

3.1 Characterization of industries

Among the 3 companies covered in the study, 2 are classified as micro-enterprises and 1 as a small company, according to criteria established by SEBRAE. The size of the company is important, as it is related to the amount of wood that is processed, being able to understand the production process. This understanding allows for the standardization of splitting, related to the characteristics of each species, which, according to Luz et al (2020), will contribute to the yield of sawn wood.

3.2 Characterization of the production process

The companies' production process varies from the primary splitting of the raw material to the final processing into sawn wood. The main species used by

the companies were the Pinus spp. and Eucalyptus spp. genus. Other species, however, in smaller quantities, were also found (Figure 2). The genus Pinus spp. is one of the most common and most important species for the economy (KRAKAU *et al.* 2013; KOZAKIEWICZ *et al.* 2020; ROSZYK *et al.* 2020). The use of eucalyptus in two of the three companies is also worth highlighting, as this species is widely used as a source of raw material for the paper and cellulose industries in Brazil (MIRANDA *et al.*, 2015).

The feedstock used in the sawmills production process is all obtained by third parties, none of them have their own plantations. The main production lines are fruit and vegetable boxes, boxes in general and sawn wood. In this

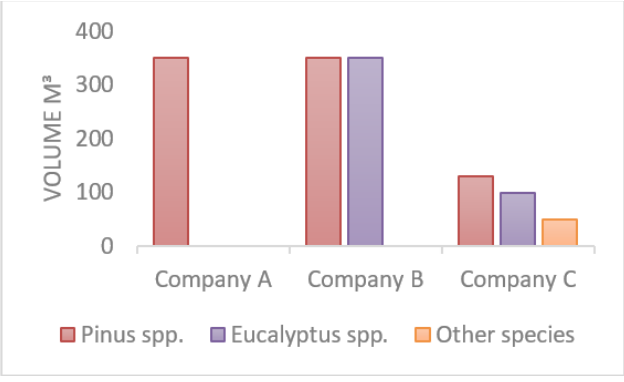

Figure 2: List of species by companies.

way, the time of use of the equipment and its ages were verified, shown in Figure 3.

It is noted that all the companies studied have equipment that has been used for more than 10 years. Regarding the maintenance of this equipment, those responsible said that maintenance is carried out, but not on a regular basis. Heinrich (2010), Nolasco and Uliana (2014) and Agra *et al.* (2021) verified factors related to the process that influence the productivity and yield of raw material splitting. Among them is the quality of the equipment used, as well as its respective maintenance. Therefore, the age of the equipment will influence the final performance and waste generation, especially if the equipment has not had its respective maintenance carried out. The lack of maintenance, as well as the use of obsolete equipment, influences productivity and yield throughout the processing of raw materials. The generation of waste would be avoided if adequate equipment and cutting methods were maintained (IZEKOR and OSAYIMWEN, 2010; CAMBERO *et al.* 2015; MELO *et al.* 2016). Low productivity, consequently, corresponds to high waste generation, which will therefore lead to greater waste and increased costs (RAMOS *et al.* 2016). However, solutions for this waste in the country are still incipient, although their potential as a feedstock and energy source is already known (SELLITTO, 2018). This is because they have potential for use in various sectors (BRYNGEMARK, 2019). Use as biofuel (ZETTERHOLM *et al.* 2020, BRYNGEMARK, 2019), gasification (AHLSTROM *et al.* 2017; PETTERSSON *et al.* 2015), biorefinery (ABDOU *et al.* 2021), clean energy generation (STOLARSKI *et al.* 2021) are some of the alternatives.

Table 2 indicates the generation of waste from each industry and correlates with the age of the equipment used in each of them.

The main waste generated is sawdust, wood shavings and wood shavings. Vasconcelos and Oliveira, 2020 observed that the main waste generated are peels, dust and chips. Companies generate, on average, 175 m^3 of waste, achieving an average utilization of 43%. Monteiro

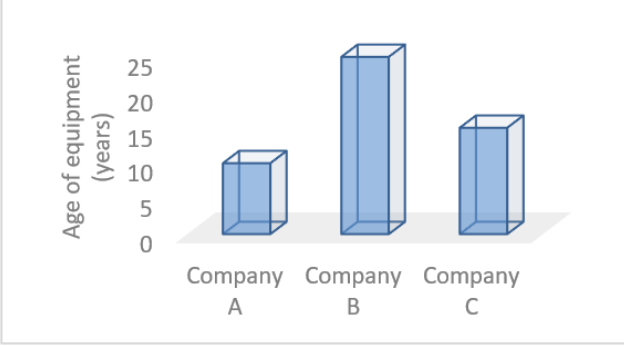

Figure 3: Age of equipment used by companies.

	Feedstock (m3)	Type of Residues	Amount generated (m^3)	Type of Process	Age of Equipment
Company A	350	Coastal	70	1º splitting	10 Years
		Sawdust	105	2º splitting	
		Overflows	18	sectioning	
		Σ	**193**		
Company B	700	Sawdust	100	2º splitting	25 Years
		Log	70	Other process	
		Overflows	20	sectioning	
		Wood shavings	15	finishing	
		Σ	**205**		
Company C	280	Coastal	65	1º splitting	15 Years
		Clippings	25	boards	
		Overflows	25	sectioning	
		Sawdust	11	splitting	
		Σ	**126**		

Table 2: Relationship between waste generation and the age of equipment used by companies.

et al (2013) found that the yield of sawn eucalyptus wood varies from 31.03% to 54.66%, with an average of 43.8%. According to some studies, yield varies between 25 and 63% for Pinus and Eucalyptus species (Monteiro *et al.* 2017; Juizo *et al.* 2018; Müler *et al.* 2019). In random splitting systems, the average yield of Pine logs of different diameters varies from 44.96% to 52.47% and the average is 49.01% (MANHIÇA, 2012). Olmos and Sponchiado (2022) found 49% of waste generated in sawmills.

As can be seen, there is a relationship between waste generation and the age of the equipment used in the sawmills' production process (Figure 4). It is noted that the company with the oldest equipment (25 years), which is still used in wood processing, presented the largest amount of waste generated, or wasted raw material, thus being related to the previously mentioned factors, such as lack of equipment maintenance and idleness. Therefore, one of the main tasks of companies must be the identification and elimination of waste that occurs during feedstock processing activities.

3.3 RESIDUES MANAGEMENT

The high amount of waste generated by sawmills throughout their production processes consequently increases

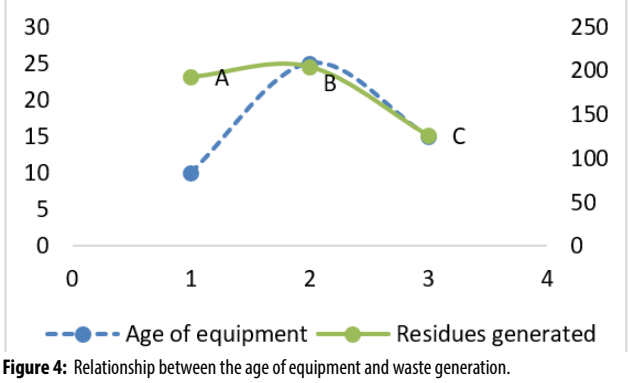

Figure 4: Relationship between the age of equipment and waste generation.

the amount stored without destination. The lack of waste disposal is an environmental liability that causes impacts at local and regional levels, where companies are located. The search for use represents an additional source of revenue for these industries (ZETTERHOLM *et al.* 2020), in addition to an adequate destination (RAMOS *et al.* 2017), as the part that generates the most concern is the final destination of these wastes (BAUER and SELLITTO, 2019). Losses in wood splitting processes range from 50 to 65% (MURARA JUNIOR *et al.* 2013) and require alternative uses and environmentally appropriate management (CERQUEIRA *et al.* 2012). Waste generation in the wood processing sector is high, with a lack of alternatives for use and final disposal, making the management of these materials a pertinent and important tool (NATALLI *et al.* 2023). Furthermore, inadequate waste disposal affects the environment as a whole, both aquatic and terrestrial (OWOYEMI *et al.* 2016; HAJAM *et al.* 2020).

The approach in the 3 sawmills brought information that corroborates the other studies, since all companies sell their waste to third parties and they will give it some destination. Only 1 company transforms its waste into wood chips and then sells it to third parties. The lack of incentives, such as public policies, income generation, cooperatives, specialization courses, information about new technologies, means that this waste, which has the potential for reuse on numerous fronts, such as fertilizer production and composting (SILVA *et al.* 2017), energy generation (CHARIS *et al.* 2019; SPALENZA *et al.* 2023), panel production (AKUTAGAWA *et al.* 2020; NATALLI *et al.* 2022), are discarded in such a way that their real value is not perceived as extra income generation.

According to Ochôa and Lhamby (2016), Vasconcelos and Oliveira (2020), the lack of adequate disposal for the waste generated is due to the lack of investment and appreciation, above all, the lack of information and technical knowledge regarding the potential uses of this material and the consequent generation of extra income from its sale. Furthermore, the use of older, unmaintained equipment corroborates this, highlighting the lack of information and knowledge on the part of operators.

4. CONCLUSIONS

The study aimed to evaluate the generation of waste in sawmill industries depending on the age of the equipment used in wood processing. From the results, the study concluded that the companies studied present a high generation of solid waste, presenting a yield of less than 50%. As they are micro and small companies, generally family-owned, investments are smaller. The results of this study demonstrated that the use of outdated equipment and lack of maintenance influence the processing and final yield of the raw material, and result in the high generation of waste.

This corroborates other studies that demonstrated high waste generation mainly due to the lack of cutting planning, characteristics of the raw material used, but also the list of equipment and their respective preventive and periodic maintenance, identifying that the lack these interfere with processing and final yield. The vast majority of sawmills, as they are small companies, lack long-term credit policies for equipment with greater technological capacity in production. The results demonstrate that the lack of equipment maintenance, inadequate maintenance, and the use of old equipment is a reality in these companies, affecting the productivity and profitability of these industries, increasing the generation of waste, due to waste.

Combined with this lack of incentive, especially information, the companies studied do not manage the solid waste generated, which is, in its entirety, sold to third parties, without a correct destination. Waste management would allow these companies to generate greater income. The scarcity of technologies, regulation, periodic and preventive maintenance, control systems, disassembly systems, inefficiency in use are also factors that affect yield and waste generation. These factors were not evaluated in the present study and make it limited. Therefore, new studies can be carried out to evaluate not only the age of the equipment, but also the operations and deployment systems, types of maintenance that are carried out and whether they are carried out.

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IMPACT NOISE INSULATION PERFORMANCE OF VINYL FLOOR WITH THE FLOATING FLOOR TECHNIQUE

DESEMPENHO DE ISOLAMENTO AO RUÍDO DE IMPACTO DE PISOS VINÍLICOS COM A TECNICA DE PISOS FLUTUANTES

DESEMPEÑO DE AISLAMIENTO AL RUIDO DE IMPACTO DE PISOS VINÍLICOS CON LA TÉCNICA DE PISOS FLOTANTES

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ABSTRACT

This study evaluated the acoustic performance of impact noise in prefabricated ribbed slabs with prestressed joists, using vinyl flooring as a covering and testing the efficiency of floating floors with different resilient materials. The tests were carried out by the Brazilian standards ABNT ISO 16283-2 and ISO 717-2 to determine the standard weighted impact sound pressure level (L'nT,w) in each composition tested to check that they met the minimum requirements of the Brazilian performance standard ABNT NBR 15.575-3. As a result, of the 13 vinyl flooring samples studied in the 4 cm subfloor system, only one did not satisfy the minimum requirements (82 dB). At the same time, eleven were classified at the minimum level, ranging from 67 to 80 dB, and one at the intermediate level (64 dB). Based on these results, six samples were selected for testing with the floating floor system solution using nine resilient materials. Most of the compositions showed intermediate performance levels, ranging from 62 to 56 dB, with 23 samples having a higher level (≤ 55 dB).

KEYWORDS

Impact noise; Acoustic performance; Sound insulation; Vinyl floors.

RESUMO

Este estudo avaliou o desempenho acústico em termos de ruído de impacto em lajes pré-fabricadas nervuradas com vigotas protendidas, utilizando pisos vinílicos como revestimento e, também, testando a eficiência de pisos flutuantes com diferentes materiais resilientes. Os ensaios foram realizados conforme as normas brasileiras ABNT ISO 16283-2 e ISO 717-2 para determinar o nível de pressão sonora de impacto padrão ponderado (L'nT,w) em cada composição testada, a fim de verificar se atendiam aos requisitos mínimos da norma brasileira de desempenho ABNT NBR 15.575-3. Como resultado, das 13 amostras de pisos vinílicos estudadas no sistema de piso com contrapiso de 4 cm, apenas uma não atendeu aos requisitos mínimos (82 dB). Ao mesmo tempo, onze foram classificadas no nível mínimo, variando de 67 a 80 dB, e uma no nível intermediário (64 dB). Com base nesses resultados, seis amostras foram selecionadas para testes com a solução de sistema de piso flutuante, utilizando nove materiais resilientes. A maioria das composições apresentou níveis intermediários de desempenho, variando entre 62 e 56 dB, com 23 amostras com um nível superior (≤ 55 dB).

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PALAVRAS-CHAVE

Ruído de impacto; Desempenho acústico; Isolamento sonoro; Revestimentos vinílicos.

RESUMEN

Este estudio evaluó el desempeño acústico en términos de ruido de impacto en losas prefabricadas nervadas con viguetas pretensadas, utilizando pisos vinílicos como revestimiento y, además, probando la eficiencia de pisos flotantes con diferentes materiales resilientes. Los ensayos se realizaron de acuerdo con las normas brasileñas ABNT ISO 16283-2 e ISO 717-2 para determinar el nivel de presión sonora de impacto estándar ponderado (L'nT,w) en cada composición probada, con el fin de verificar si cumplían con los requisitos mínimos de la norma brasileña de desempeño ABNT NBR 15.575-3. Como resultado, de las 13 muestras de pisos vinílicos estudiadas en el sistema de piso con contrapiso de 4 cm, solo una no cumplió con los requisitos mínimos (82 dB). Al mismo tiempo, once fueron clasificadas en el nivel mínimo, variando de 67 a 80 dB, y una en el nivel intermedio (64 dB). Con base en estos resultados, se seleccionaron seis muestras para pruebas con la solución del sistema de piso flotante, utilizando nueve materiales resilientes. La mayoría de las composiciones presentaron niveles intermedios de desempeño, variando entre 62 y 56 dB, con 23 muestras en un nivel superior (≤ 55 dB).

PALABRAS CLAVE

Ruido de impacto; Desempeño acústico; Aislamiento sonoro; Revestimientos vinílicos.

1. INTRODUCTION

With population growth and urban expansion in cities, verticalization has become an alternative to meet the demands of housing and commerce in city centers. In this way, NBR 15575: all parts has been one tool used to encourage better housing conditions by establishing minimum performance requirements for various factors, including acoustic performance.

The acoustic performance of the various systems that make up a home responds to the environmental issues they are exposed to, such as noise pollution, climate change, and the different demands of users. Since 2009, the World Health Organization (WHO) has defined noise pollution as the second largest source of pollution on the planet and a public health problem, as it can cause sleep disturbances, changes in blood pressure, and stress, among others.

Impact noise is caused by a mechanical vibration transmitted by the solid medium, that is, by the structural path; in this case, it can be transmitted by the internal and external vertical sealing systems, the roofing system, and the floor. The floor system, more specifically, is one of the boundaries between autonomous housing units, characterized by a minimal set of slabs and floor covering.

However, investigations into the acoustic performance of flooring systems are becoming increasingly complex as there are increasingly new materials and construction techniques used in civil construction. In this way, each material that makes up the floor system directly impacts the sound spectrum of impact noise insulation; therefore, insulation varies according to the floor covering, the subfloor's thickness, and the slab type adopted.

The characterization of the impact noise insulation performance of ceramic floors demonstrates that the rigidity of these coverings directly affects low frequencies, making it necessary to use resilient materials combined with the floating floor technique to mitigate sound transmission if the proposal is to achieve the higher levels recommended by NBR 15575-3. However, when the floor covering is laminated wood, there are possible compositions that achieve better performance without the floating floor technique, as these coverings have greater damping of low frequencies due to their surface density.

The choice of the slab system is also an essential factor, not only for structural reasons, as they will win, but also for acoustic performance. Slabs with a homogeneous composition (solid slabs) have greater mass, thus helping with insulation, compared to slabs with a heterogeneous composition (slabs filled with ceramic tiles, Styrofoam, etc.).

Vinyl floors, in turn, are a type of covering that is easy to install and maintain and are suitable for all types of use, even for hospital environments, due to their ease of replacing parts and cleaning . As for acoustic performance, vinyl blankets, even though they are not as rigid as other coverings, did not present sufficient sound attenuation in a sample with a reinforced concrete slab, having lower performance than laminate floors, for example. Some investigations demonstrate the toxicity capacity of this type of coating, mainly due to resins from petroleum, chemical additives, and organic compounds that can affect human health.

2. RESEARCH GOAL

This research evaluates the impact noise insulation performance of flooring systems composed of a prefabricated ribbed slab with ceramic tiles and prestressed joists, a 4-centimeter subfloor, and vinyl floor covering combined with the floating floor technique. Different materials are tested, such as expanded polyethylene blanket, expanded polypropylene, recycled rubber, glass wool, and polyester wool (PET).

3. METHODOLOGY

The Brazilian Standard ABNT NBR 15.575-1 (ABNT, 2021a) was a milestone in Brazilian civil construction, launched in 2013 and updated in 2021, establishing the minimum performance requirements for buildings. For acoustic performance, specifically in flooring systems and impact noise, the required performance criteria are divided into three categories: minimum (M), intermediate (I), and superior (S) (ABNT, 2021c). Furthermore, the measurement methodology is described by the ISO 16.283-2 standard. The values provided for in NBR 15.575-3 (ABNT, 2021c) were used to classify the performance of floor systems in terms of impact noise for cases of separation of autonomous housing units, as shown in Table 1.

Separation element	$L'_{nT,w}$ (dB)	Performance
The floor system of self-contained over-bedroom housing units	66 to 80	Minimum (M)
	56 to 65	Intermediate (I)
	≤ 55	Superior (S)
Flooring systems for areas for collective use over bedrooms in autonomous housing units	51 to 55	Minimum (M)
	46 to 50	Intermediate (I)
	≤45	Superior (S)

Table 1: Performance Criteria for Weighted Standard Impact Sound Pressure Level ($L'_{nT,w}$).
Source: (ABNT, 2021c)

3.1 Test location

The tests were carried out in (information suppressed for blind evaluation) a chamber built specifically for impact noise measurement tests. The set comprises two adjacent chambers overlapping and separated by a prefabricated ribbed slab composed of prestressed beams and ceramic tiles 13.5 cm thick. The walls are made of structural masonry made of 19 cm-thick concrete blocks, and the septa of the blocks were filled with 1:4 mortar (cement: sand). The walls have 3 cm of plaster on both sides, with a final thickness of 25 cm.

The chamber consists of an emission room, with an area of 14.33 m², and a reception room, with an area of 14.33 m² and a volume of 56.32 m³, vertically adjacent. Figure 1 illustrates the floor plan (A) and section (B).

The impact noise insulation measurements in floor systems were made to simulate the field situation, as the laboratory has conduits in the slab and walls and does not disconnect the building structures from the chambers.

3.2 Instruments of tests

The ISO 10140-3 and ISO 10140-3 Standards require that the minimum dimensions of the subfloor exceed 0.35 by 0.35 meters. Therefore, 1 × 1 meter plates were used. The subfloor slabs were produced with mortar, and the volumetric proportions of cement and sand were 1:4, reaching an average compressive strength of 20 MPa.

Table 2 describes the equipment used in the measurements. The manufacturer defines the sound level meter (sound pressure level meter) as class 1. Therefore, it is a meter for free fields (open areas) but has a correction for use in diffuse fields (closed environments), used for measurements in an environment such as the laboratory.

The calibrator used follows the CETAC-LCA-PC06 "sound pressure level meter calibration" and CETAC-LCA-PC-03 "sound pressure level meter calibration" procedures found in IEC 61672-3:2013 and IEC 60942:2017 for the calibration of the sound pressure level meter and sound level calibrator. The equipment was calibrated before use by an accredited institute. Figure 2 demonstrates the dodecahedral omnidirectional source (A), the standard impact machine (B), and the sound pressure level meter (sonometer) (C).

3.3 Measurements procedures

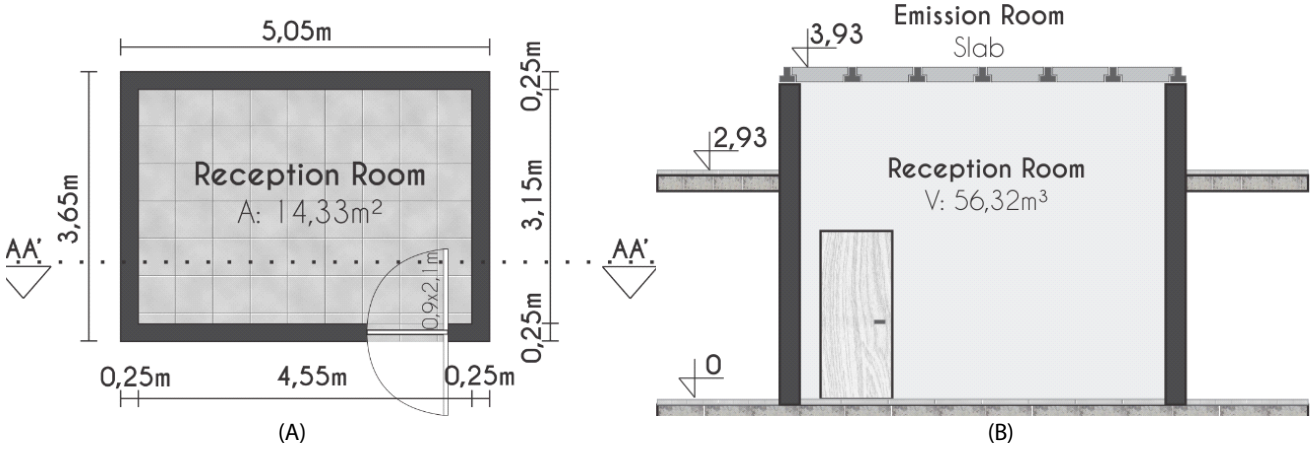


Figure 1: (A) Floor plan (B) Section AA
Source: Authors.

Equipment	Manucaturer	Model
Amplifier	01 dB	AMPLI 12
Sound level calibrator	01 dB	4230, class 1
Dodecahedral acoustic source	01 dB	OMNI 12
Standard Impact Machine	01 dB	CALPEST-one
Sound Pressure Level Meter	01 dB	Black Solo, class 1
Capacitive microphone	GRAS	MCE 212
Microphone preamplifier	Metravib	PRE 21 S
Termo-hygrobarometer	Instruterm	THB 100

Table 2: Instruments used in the tests.
Source: Authors.

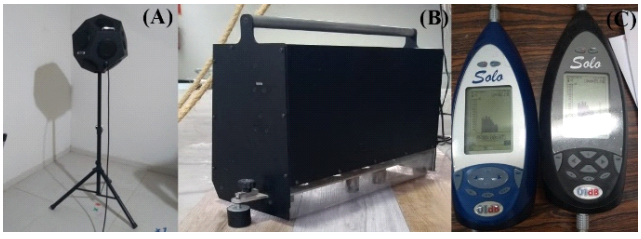


Figure 2: Instruments used in the tests.
Source: Authors.

NBR 15575-3 explains that tests to determine impact noise performance in flooring systems must follow the ISO 16283-2 standard . Which defines the measurement procedures to determine the standard impact level (L'_{nT}) and frequency bands in thirds of an octave, between 100 and 3150 Hertz (Hz), and the weighted standard impact level (L'_{nTw}) with data processing through ISO 717-2 . The standard ISO 16283-2 (ABNT, 2020b) determines four positions of the standard impact machine and fixed microphone in the reception room for tests in rooms with a volume of less than 20 m².

The standard ISO 16283-2 (ABNT, 2020b) defines reverberation time measurements, residual noise, and standardized impact sound pressure level as required. Therefore, the reverberation time was measured using the interrupted noise method described by NBR ISO 3382-2. Three microphone positions were used for measurements for each sound source position. Two measurements were made for each microphone position to determine the reverberation time, totaling 12 points. The microphone height used in the tests was 1.30 m, 1.90 m, and 2.3 m for the M1 and M6 microphones, M2 and M5, and M3 and M4, respectively. The distance between the microphone and the sound source used to measure the reverberation time is shown in Figure 3.

Figures 4 and 5 demonstrate the positioning of

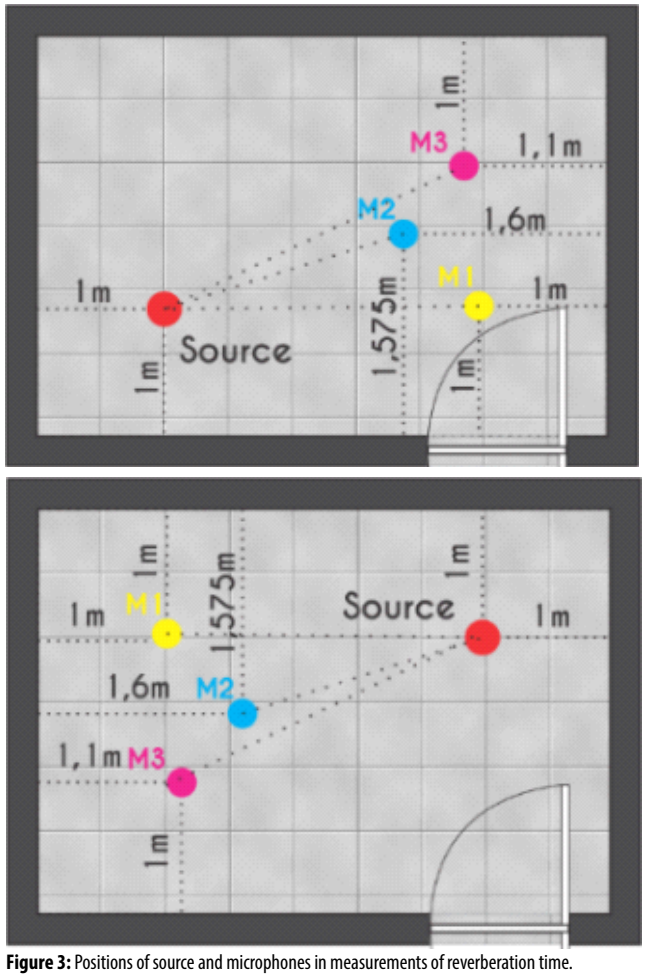


Figure 3: Positions of source and microphones in measurements of reverberation time.
Source: Authors.

the standard impact machine in the emission room (at 45º about the joists) and the fixed microphones in the reception room, respectively.

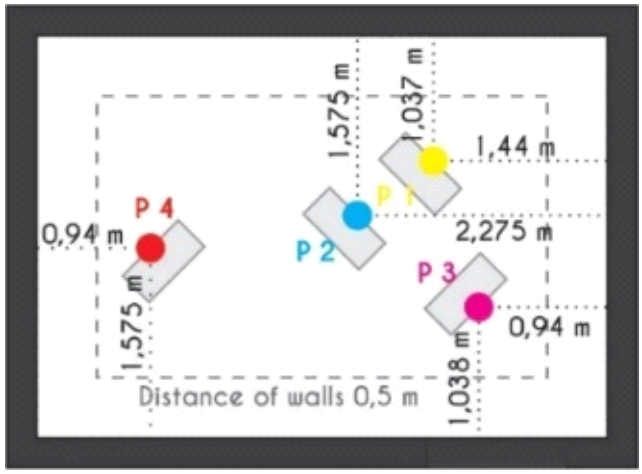


Figure 4: Position of standard impact machine.
Source: Authors.

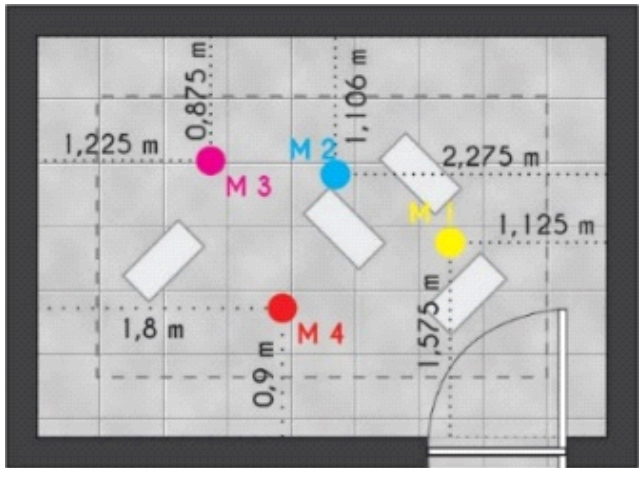


Figure 5: Position for fixed microphone.
Source: Authors.

3.4 Vinyl flooring test samples

Table 3 shows the test samples divided into four groups. Table 4 describes the characteristics of the floors used.

3.5 Tested resilient materials samples

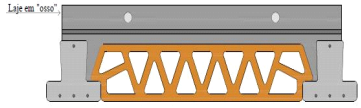
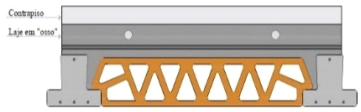
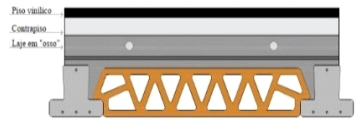
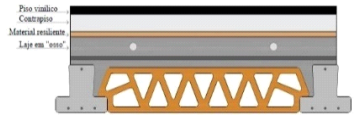
	Composition	Installation
A	Slab	
B	Slab + Subfloor (4 cm)	
C	Slab + subfloor (4 cm) + vynil floor	
D	Slab + resilien-te material + subfloor (4 cm) + vynil floor	

Table 3: Tested floor systems.
Source: Authors.

Vynill floor (VF)	Model	Thick-ness	Dimen-sion (m)	Density (kg/m$^{3)}$	Fire re-action (class)
1	Plate	5	0,5×0,5	1039	III A
2	Blanket	2,4	2×25	895,93	III A
3	Blanket	1,2	2×42	916,67	III A
4	Blanket	0,7	2×12	1314,29	III A
5	Ruler	4	0,2×1,22	1763	II A
6	Ruler	3	0,22×1,83	1833,33	II A
7	Ruler	2	0,192×1,23	1800	II A
8	Ruler	2	0,184×0,95	1880	II A
9	Ruler	4	0,20×1,22	1915	II A
10	Blanket	1,4	2×20	1300	II A
11	Blanket	1,6	2×25	1250	II A
12	Blanket	0,6	2×25	1774,69	III A
13	Blanket	1,8	2×25	1444,44	III A

Table 4: Definitions of vinyl floor coverings.
Source: Authors.

The resilient materials that were used for the tests will be presented below. It is worth mentioning that, in some cases, more than one material was considered for the same group, which could be from the same manufacturer with different thicknesses or from other manufacturers with the same thickness.

Glass wool consists of fibrous material from sodium and silica (glass and sand), covered with a waterproof film. It can be found in sheets or rolls. The glass wool used has the following characteristics: density of 60 kg/m^3, weight of 1.30 kg/m^2, and thickness of 15 mm.

Polyester wool (PET) is a fibrous material produced from recycled PET bottles with a waterproof film coating and is available in rolls. Three blankets of this material were tested, having the following characteristics: 5 mm, with a density of 20 kg/m^3; 8 mm, with a density of 30 kg/m^3; and 10 mm, with a density of 60 kg/m^3.

Expanded polypropylene (EPP) is a polypropylene resin combined with other elements to be expanded later. Its main characteristics are high resistance to impacts, chemicals, and lightness. The material is sold in rolls. Only a material with a thickness of 2 mm and a density of 42 kg/m^3 was tested.

Expanded polyethylene (EPE): This thermoplastic, made from ethylene, is chemically resistant and expands when subjected to the extrusion process, leaving it with a foamy characteristic. The material is sold in rolls. Three blankets were tested, presenting characteristics: 5 mm with a density of 20 kg/m^3, 5 mm with a density of 25 kg/m^3, and 10 mm with a density of 65 kg/m^3.

Recycled rubber: produced from recycled tire granules bonded with polyurethane. Only a 5 mm thick material with a 600 kg/m^3 density was tested.

4. RESULTS AND DISCUSSIONS

The results and discussion session will be presented in the following sequence: (i) two reference samples; (ii) thirteen samples of vinyl coverings; (iii) of the thirteen vinyl covering samples, six were selected for use in floating floor systems, highlighting the two best, the two intermediate and the two inferior samples;

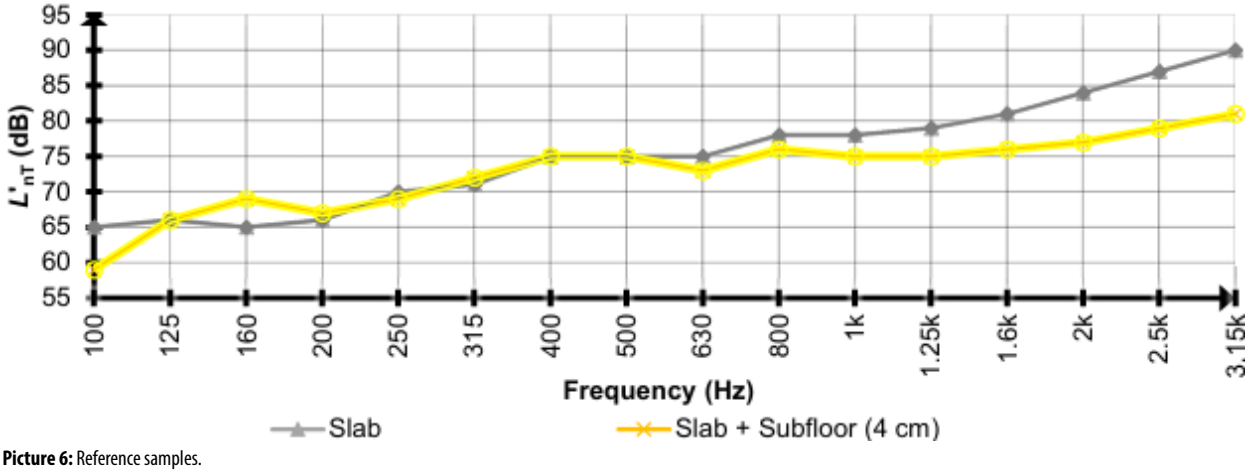
4.1 Reference samples

The slab sample corresponds to the raw structural system without a subfloor. Figure 6 shows the impact noise insulation graph in a bone slab, performance remains below 70 dB at low frequencies and has an isolation peak in the 160 Hz range. In the following ranges, the curve remains increasing, reaching close to 90 dB at high frequencies. The L'nT,w is 91 dB, well above the minimum 80 dB required by NBR 15.575-3 (ABNT, 2021c).

In the sample with a subfloor, it is possible to observe a behavior similar to the bone slab, remaining below 70 dB at low frequencies, with an isolation peak in the 100 Hz range, continuing to increase in the following bands, reaching close to 80 dB in the bands of high frequencies. The L'nT,w is 84 dB, above the minimum determined by the standard.

4.1.1 Vynil floor samples

Figure 7 shows the acoustic performance for impact noise insulation of the floor system consisting of slab, subfloor,



Picture 6: Reference samples.
Source: Authors.

and vinyl coverings.

Thirteen samples of different floor coverings are included, six of which stand out for the study's application of the floating floor technique.

In this study, only one sample of vinyl sheet was tested (VF 1–5 mm vinyl sheet). The curve increases up to 500 Hz, and the graph decreases from the frequency range of 630 Hz, with the best results occurring in the high-frequency bands. The L'nT,w is 67 dB, falling within the minimum level by NBR 15.575-3 (ABNT 2021c). When considering the reference curve (slab + subfloor), it can be seen that up to 630 Hz, the curves present similar values at almost all frequencies since, from this point onwards, the difference between the values increases. The reference curve is rising, and that of VF 1 is decreasing.

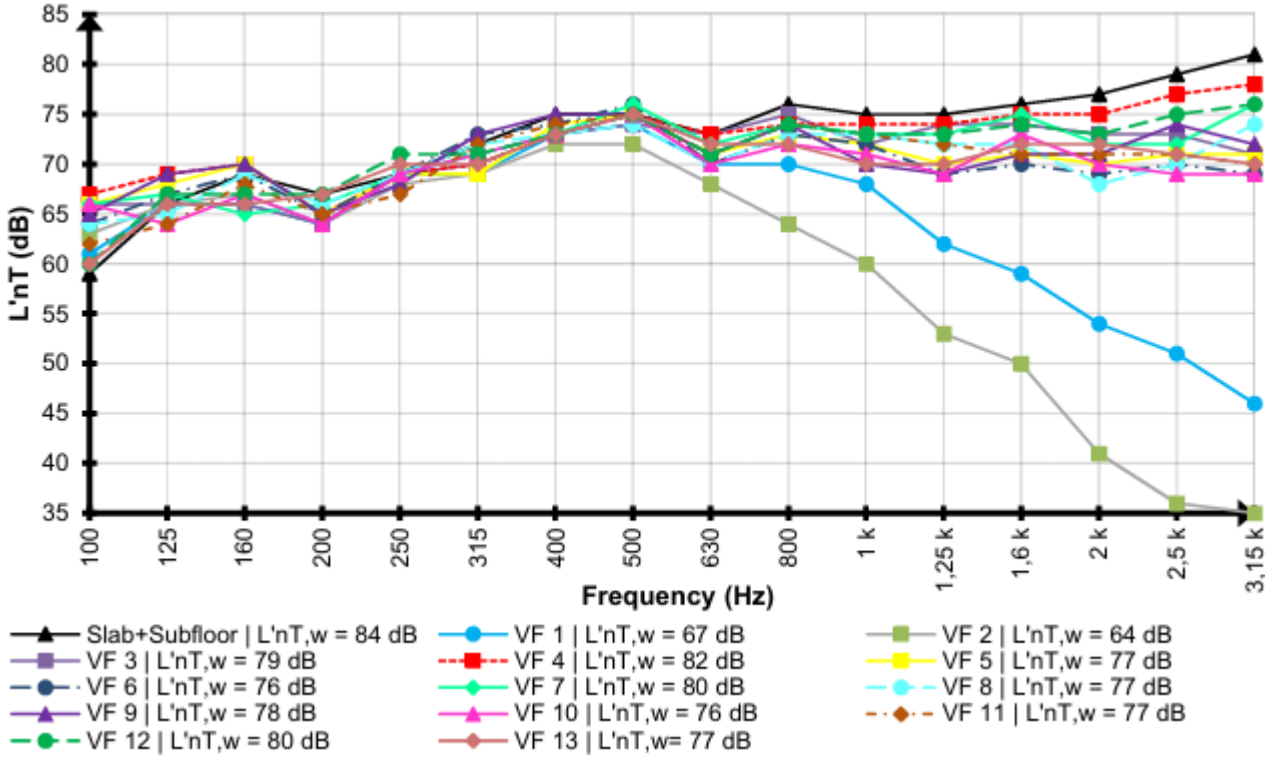
The vinyl plank samples show similar behavior at all frequencies. However, the reference curve increases from the 1 kHz frequency band onwards. From the floor samples, the curves are dispersed but present a significant difference at high frequencies, where the results are better.

When considering L'nT,w, all samples fall within the minimum level determined by the performance standard: VF 6 = 76 dB and the highest of VF 7 = 80 dB.

All vinyl blanket samples show similar behavior; however, the VF 2 curve sharply decreases from the 500 Hz frequency range onwards, with the most significant difference compared to the reference curve at high frequencies. In Figure 8, the L'nT,w results of the samples are compared to the performance levels indicated by NBR 15.575-3:2013 (ABNT, 2021c) to classify them according to the criteria that take into account the floor system, separating autonomous housing units.

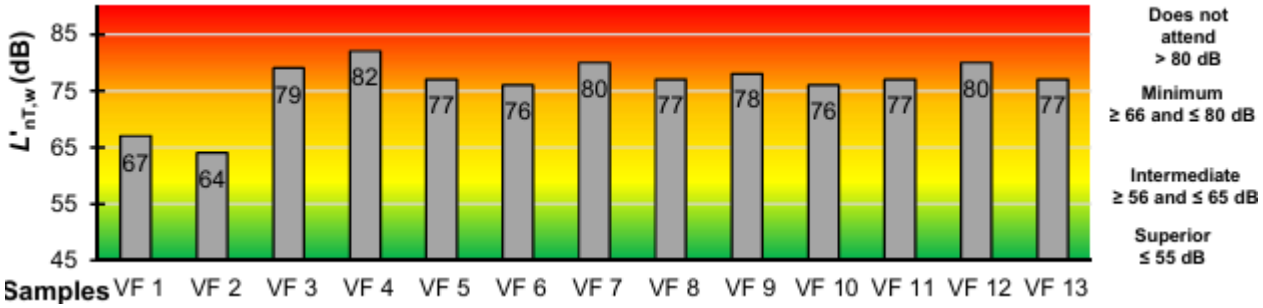
4.1.2 Floating floor samples

Six samples of vinyl flooring were meticulously chosen, with the two most promising results, VF 2 = 64 dB and



Picture 7: Performance of samples with Vynil floors

Source: Authors.



Picture 8: Classification of samples in the performance requirements of NBR 15575-3

Source: Authors.

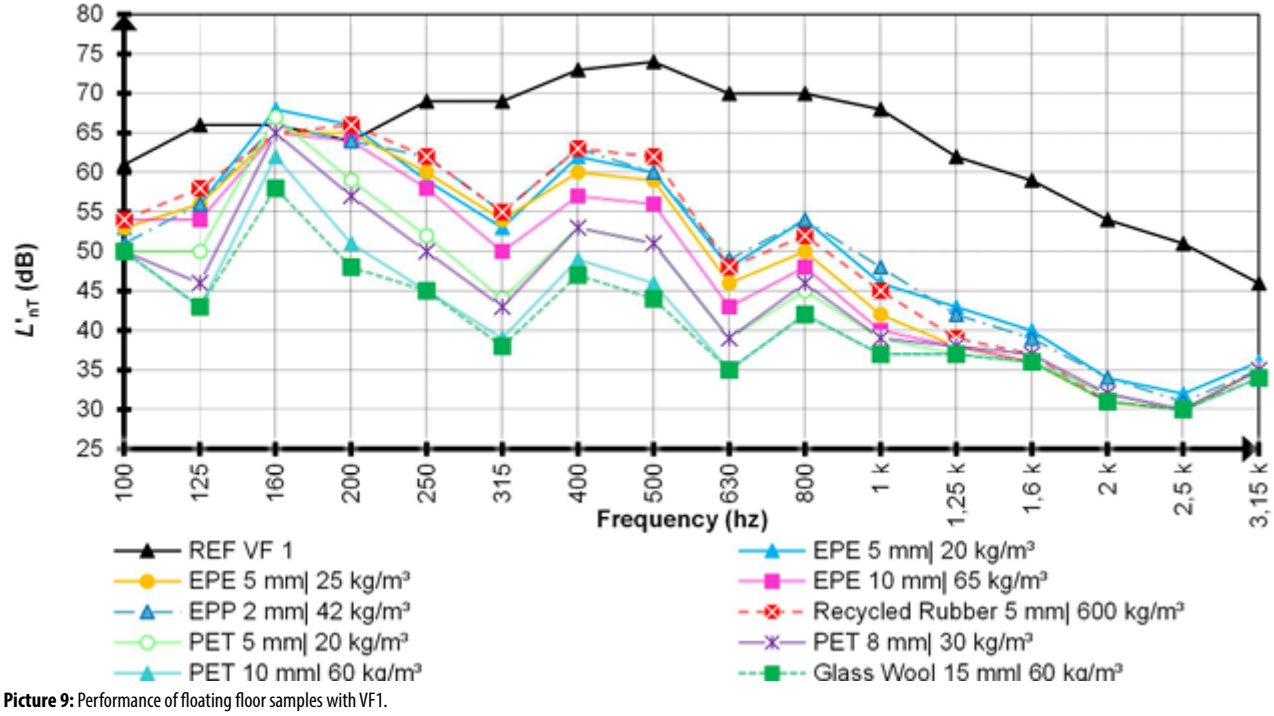
VF 1 = 67 dB, two intermediate results, VF 6 = 76 dB and VF 5 = 77 dB, and, finally, the two least favorable results, VF 7 = 80 dB and VF 4 = 82 dB. These results, as depicted in Figure 9, provide a comprehensive overview of the performance of the floating floor system, composed of the slab, resilient materials, subfloor, and 5 mm vinyl board (VF 1).

Three types of expanded polyethylene were tested: 5 mm with 20 kg/m³, 5 mm with 25 kg/m³, and 10 mm with 65 kg/m³ (EPE). The expanded polyethylene samples have curves with similar behavior, there is a loss of performance in the ranges of 160, 400 and 800 Hz, in addition, they present values above the reference curve at 160 Hz and 200 Hz.

From the loss of insulation at 800 Hz, the curves decrease and reach the best performance in the 2.5 kHz range, with 32 dB for the 5 mm sample and a density of 20 kg/m³ and 30 dB for the other 5 mm sample and the 10 mm sample. The L'nT,w of the 5 mm EPE sample with a density of 20 kg/m³ is 56 dB and is classified at the intermediate level of the performance standard. However, for a sample with the same thickness and density of 25 kg/m³, the L'nT,w is 55 dB and 53 dB for a sample with a thickness of 10 mm, both of which fall within the upper level of the standard.

A sample of expanded polypropylene was tested with a thickness of 2mm and a density of 42 kg/m³ (EPP). The L'nT,w of the EPP sample is 56 dB, with classification at the intermediate level by NBR 15.575-3 (ABNT, 2021c).

For the slab + polyester wool + subfloor (4 cm) + vinyl floor (5 mm) (PET) system, polyester wool was tested in three variations: 5 mm with 20 kg/m³, 8 mm with 30 kg/m³ and 10 mm with 60 kg/m³. The polyester fleece materials



Picture 9: Performance of floating floor samples with VF1.

Source: Authors.

demonstrated remarkably similar curves despite their different manufacturers, densities, and thicknesses. Notably, there was a more significant performance loss than the reference in the 160 Hz range, with a value of 67 dB, for the 5mm sample. However, the best performance of PET wool was observed in the high-frequency bands, reaching a peak of 30 dB in the 2.5 kHz band for all three blankets.

The 5 mm sample achieved a L'nT,w of 50 dB, while the intermediate 8 mm sample reached a L'nT,w of 49 dB, classifying it as the top level of the performance standard. The best performance was found by 10 mm PET wool, reaching a L'nT,w of 46 dB.

When considering the results obtained, together with the thicknesses and densities, it can be concluded that the sample with the smallest thickness (5 mm) and lowest density (20 kg/m^3) achieved the worst result. The sample with intermediate thickness (8 mm) and intermediate density (30 kg/m^3) obtained an intermediate result. Finally, the thicker blanket (10 mm) and higher density (60 kg/m^3) achieved the best outcome.

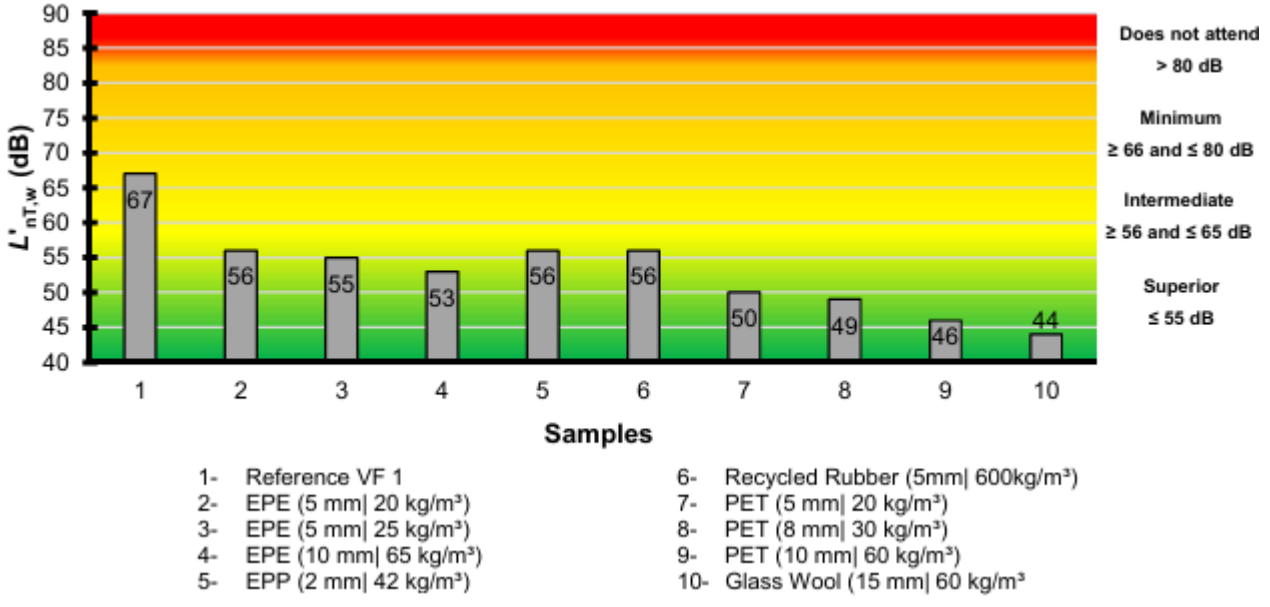
Thus, the best acoustic performance for the floating floor system with vinyl flooring 1 and polyester wool is related to the thickness and density of the resilient material; that is, they are directly proportional.

The acoustic performance for the system: slab + glass wool (15 mm and a density of 60 kg/m^3) + subfloor (4 cm) + vinyl covering (5 mm) obtained a L'nT,w of 44 dB, reaching the level higher than the performance standard, being the lowest value found among all the samples tested, with a difference of 23 dB about the reference sample. When observing the graph, it can be seen that the addition of resilient materials caused the curves of the floating floor system to show similar behavior, with the most significant insulation losses occurring in the 160 Hz range, with 5 mm of expanded polyethylene and 20 kg/m^3, the worst peak was reached (68 dB). The best performances occur in the 2.5 kHz range, with practically all samples being close to 30 dB.

The worst performances occur in the low and medium frequency bands. The best results happen in the high frequencies, where the curves stabilize. Glass wool typically performs best. Still, in this case, 10 mm polyester wool showed similar performance, with a better result than glass wool at low and medium frequencies and the same at high frequencies.

Figure 10 demonstrates the classification of samples according to the requirements of standard NBR 15575-3 (ABNT, 2021).

It can be seen that most of the materials are at the upper level (≤ 55 dB), and there are three samples at the intermediate level (≥ 56 and ≤ 65 dB). The 5mm expanded polyethylene blankets (density of 25 kg/m^3) and 10 mm are classified at the



Picture 10: Classification of floating floor samples + VF1 in the performance requirements of NBR 15575-3

Source: Authors.

top level, with L'nT,w 55 and 53 dB, respectively.

Therefore, the other 5 mm blanket (density of 20 kg/m^3) is placed in the middle and close to the upper one with a L'nT of 56 dB, with the expanded polypropylene and recycled rubber. Finally, the polyester wool and glass wool blankets are included in the upper level, with the 5 mm PET wool (L'nT,w = 50 dB), the 8 mm (L'nT,w 49 dB), and the 10 mm (L'nT,w = 46 dB), whereas the glass wool presented the lowest and best results of all with L'nT,w = 44 dB.

In this way, all resilient materials tested can be used in conjunction with the construction system of a prefabricated ribbed slab with prestressed joists and a 4 cm subfloor with a 5 mm vinyl board, falling within the requirements of NBR 15.575-3 (ABNT, 2021c) for the floor system, separating autonomous housing units.

Figure 11 demonstrates the impact noise insulation performance of the floating floor samples with the 2.4 mm thick vinyl blanket, which presented the best insulation result for the compositions without floating floors at 64 dB (VF 2).

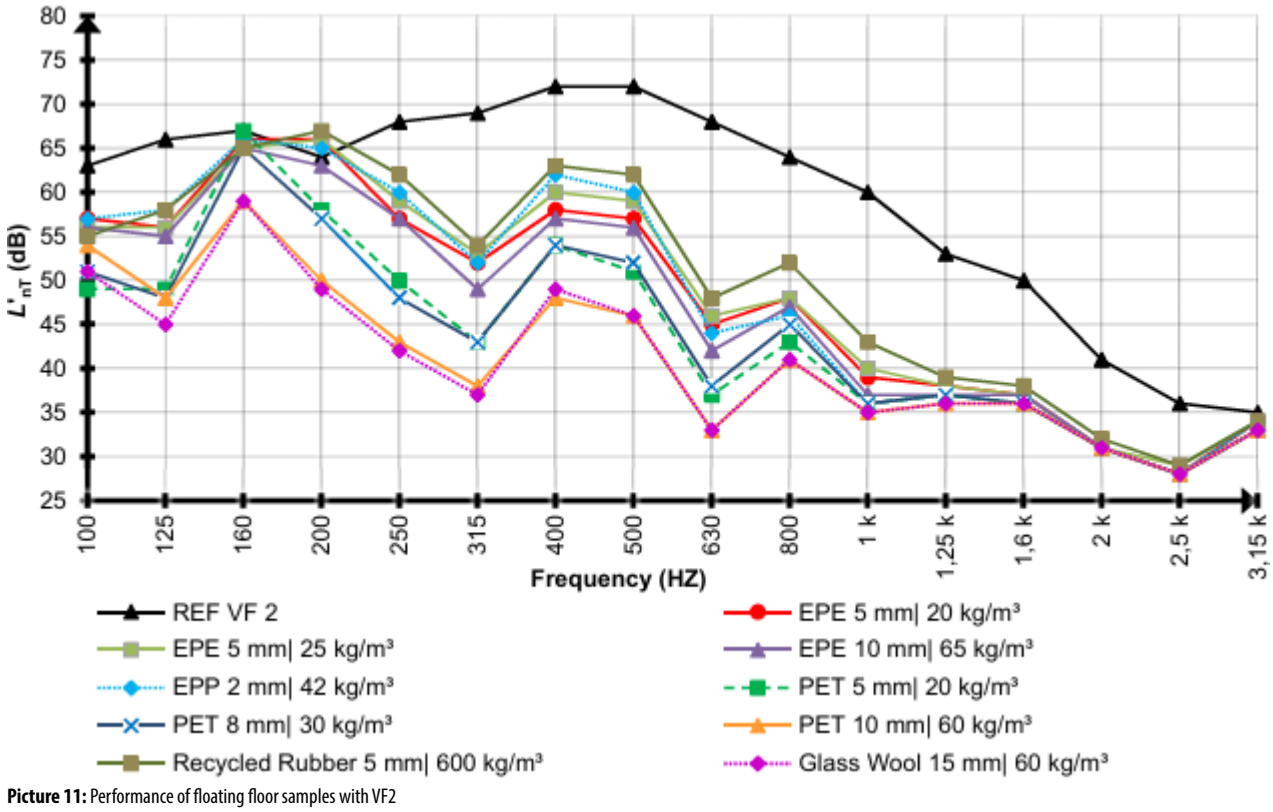
Three expanded polyethylene (EPE) samples were tested: 5 mm with 20 kg/m^3, 5 mm with 25 kg/m^3, and 10 mm with 65 kg/m^3. The curves of the expanding polyethylene samples have similar behavior, with a performance loss in the ranges of 200, 400, 800, and 3150 Hertz. In addition, they present values above the reference curve at 200 Hz for blankets with a thickness of 5 mm.

From 800 Hz onwards, the curves descend and reach their best performance at 2500 Hz. The L'nT,w of the two 5mm EPE samples is 54 dB; the 10 mm sample showed 53 dB of performance. The three samples are classified at the top level of the NBR 15.575-3 performance standard (ABNT, 2021c).

The composition slab + expanded polypropylene (2 mm) + subfloor (4 cm) and vinyl blanket (2.4 mm) present the L'nT,w of the expanding polypropylene is 55 dB, which is classified at the top level by the performance standard.

The performance curve of the expanded polypropylene (EPP) sample is similar to that of the expanded polyethylene (EPE) samples. It presents lower performance at low frequencies, with values above the reference curve at 200 Hz. Performance improves from the 1000 Hz frequency range onwards, reaching the best performance at 2500 Hz.

The recycled rubber sample's performance curve shows similar behavior to the previous ones, with a more significant insulation loss than the reference curve in the 200 Hz range. Furthermore, it presents performance loss points in the 400 and 800 Hz ranges. At 800 Hz, the curve



Picture 11: Performance of floating floor samples with VF2

Source: Authors.

shows decreasing behavior, with the best performance at 2.5 kHz. The L'nT,w of the recycled rubber sample is 56 dB, which is at the intermediate level.

The performance curves of PET blankets exhibit a consistent pattern, with insulation loss peaks at 160, 400, and 800 Hz. Notably, the most impressive performance is observed at high frequencies, with a peak of 28 dB in the 2500 Hz range. This key finding underscores the importance of high-frequency insulation performance.

The 5 and 8 mm thick samples both achieved a L'nT,w of 49 dB, ranking them at the top level of the performance standard. However, the 10 mm PET blanket stands out with a L'nT,w of 45 dB, one of the best results among all the tested flooring and resilient materials samples.

Moreover, the system slab + polyester wool (10 mm) + subfloor (4 cm) + vinyl floor (2.4 mm) ranks at the top level for this classification. It demonstrates its suitability for areas of collective use over autonomous units.

Adding glass wool to the floating floor system caused the performance curve to be below the reference curve. The most significant insulation loss is 59 dB in the 160 Hz frequency range. From this range onwards, the difference between the sample and reference curves increases, presenting a performance peak at 630 Hz. The most significant isolation gain occurs in the high-frequency bands.

The resilient materials samples showed curves with similar behavior. Most insulation weaknesses occur in the 160 Hz frequency range, with 5 mm polyester wool with a lower density (20 kg/m^3) achieving the worst result (67 dB). However, recycled rubber showed a loss of performance at 200 Hz. The best insulation performance occurs in the 2500 Hz range, with almost all samples reaching 28 dB.

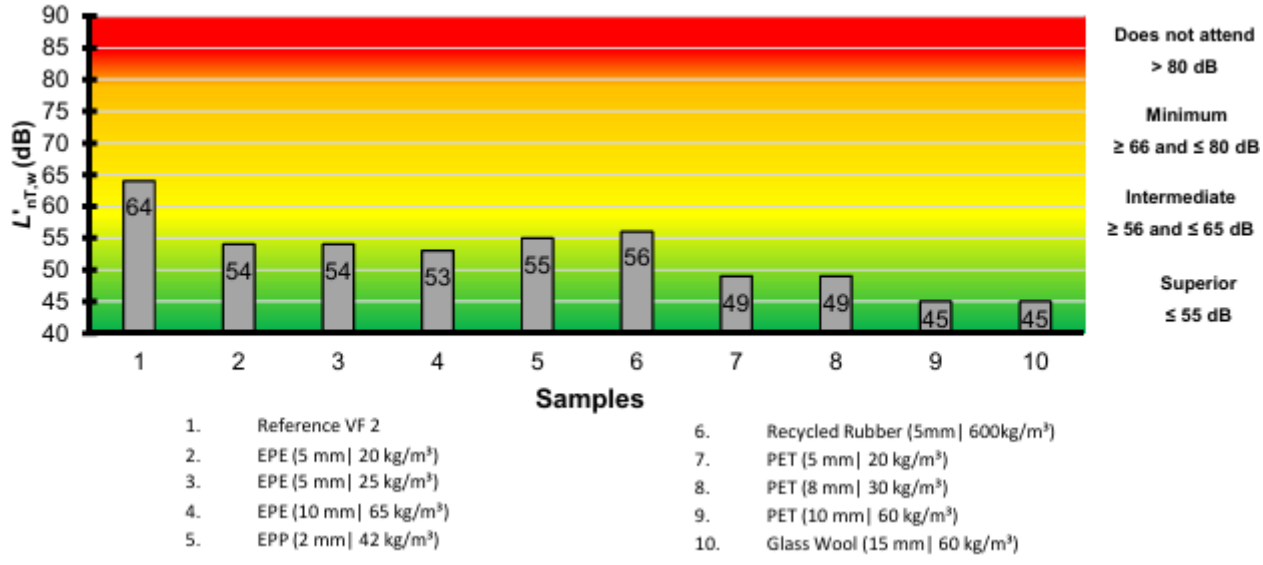
Furthermore, this system's best results are found in the high-frequency bands, where the curves stabilize. The worst performances occur in the low and medium-frequency bands.

Next, there are expanded polyethylene (EPE) blankets, which show similar behavior throughout the curve. However, the 10 mm blanket obtained better results than the other two samples, all of which were equal at high frequencies.

Glass wool and polyester wool samples fill the bottom with the chart, and glass wool typically performs best. Still, in this case, 10 mm polyester wool showed similar performance, with glass wool performing better at low frequencies and equal at medium and high frequencies. It is worth mentioning that the choice between glass wool (15 mm) and polyester wool (10 mm) depends on the cost/benefit and the possibility of using a thinner or thicker blanket. The other pet wools perform well, close to glass wool in the high-frequency bands.

Figure 12 shows the classification and comparison of the results in L'nT,w of the samples with the levels determined by NBR 15.5757-3 (ABNT, 2021) for the criterion that considers the floor system separating autonomous housing units.

It can be seen that the majority of resilient materials for the floating floor technique are found at the upper level (≤ 55 dB), and only one sample is at the intermediate level. In this way, all the materials studied can be used in



Picture 12: Classification of floating floor samples + VF2 in the performance requirements of NBR 15575-3

Source: Authors.

conjunction with the prefabricated ribbed slab system with prestressed joists and a 4cm subfloor with a 2.4mm vinyl blanket, falling within the requirements of the performance standard for the floor system separating autonomous housing units.

Figure 13 demonstrates the results obtained in the tests of the floating floor system tested with the vinyl blanket sample with a thickness of 0.70 mm (VF 4), which received the worst result of all samples tested, with L'nT,w of 82 dB.

With the change of floors, it is possible to see that the behavior of the curves with the EPE samples is similar to the others previously studied. However, the curves present linearity, varying between 50 and 70 dB, with peak performance loss in the frequency ranges of 200, 400, and 500 Hz, and at 200 Hz, the loss exceeds the reference curve of the vinyl coating. They present improved isolation in the 315, 630 and 1000 Hz bands, in addition, the best performances occur in the medium frequency bands, varying between 55 and 50 dB. The L'nT,w of the two samples with a thickness of 5 mm is 62 dB, while the L'nT,w of the 10 mm EPE is 61 dB.

The expanded polypropylene (EPP) blanket's performance curve shows insulation loss in the 200, 400, and 800 Hz ranges, with the 200 Hz range exceeding the reference curve. The best isolation occurs in the frequency ranges of 100, 315, 630, and 1000 Hz, after which the curve stabilizes below 55 dB. The sample has a L'nT,w of 62 dB.

The recycled rubber performance curve varies between 50 and 70 dB, presenting insulation loss in 200, 400, and 800 Hz ranges. At 200 Hz, the loss exceeds the reference curve by 2 dB. The best acoustic insulation behaviors occur in the ranges of 100, 315, and 630 Hz, and from 1250 Hz onwards, the curve decreases. The L'nT,w of the recycled rubber sample is 61 dB.

The expanded polypropylene (EPP) blanket's performance curve shows insulation loss in the 200, 400, and 800 Hz ranges, with the 200 Hz range exceeding the reference curve. The best isolation occurs in the frequency ranges of 100, 315, 630, and 1000 Hz, after which the curve stabilizes below 55 dB. The sample has a L'nT,w of 62 dB.

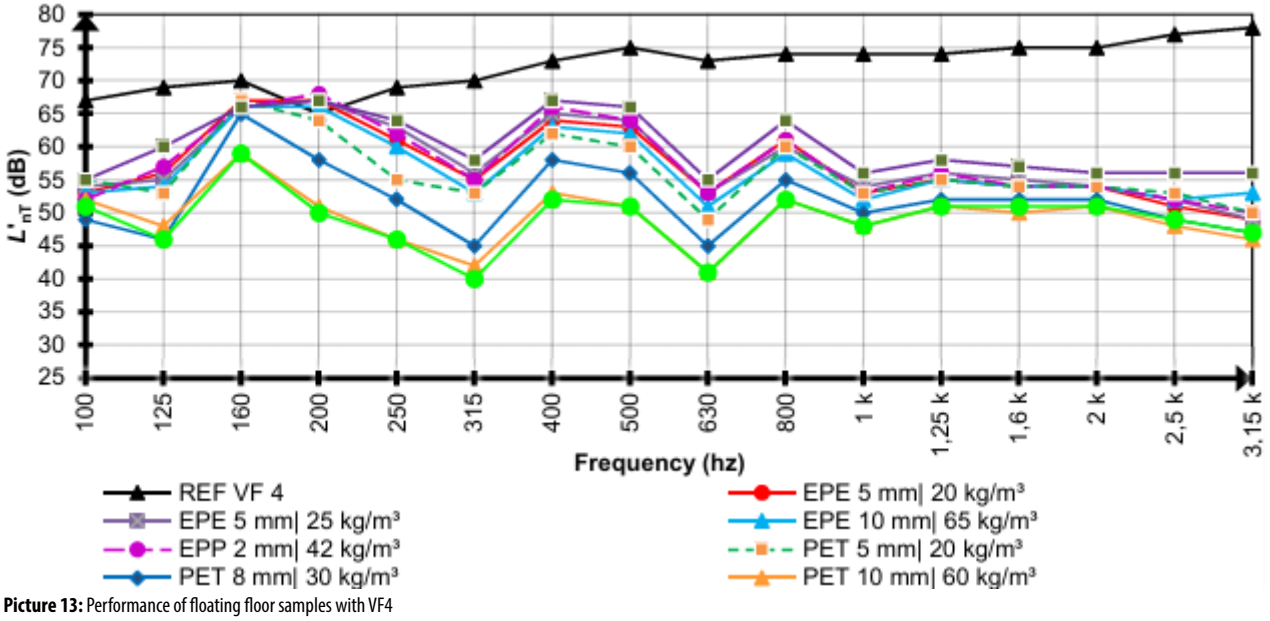
The recycled rubber performance curve varies between 50 and 70 dB, presenting insulation loss in 200, 400, and 800 Hz ranges. At 200 Hz, the loss exceeds the reference curve by 2 dB. The best acoustic insulation behaviors occur in 100, 315, and 630 Hz ranges, and the curve decreases from 1250 Hz onwards. The L'nT,w of the recycled rubber sample is 61 dB.

In all samples, PET wool has three performance losses in the 160, 400, and 800 Hz bands. The best performances are at 125, 315, and 630 Hz frequencies, reaching close to 40 dB.

The 5 mm polyester wool obtained a L'nT,w of 61 dB, the 8 mm blanket is 58 dB, and the 10 mm blanket is 56 dB, all classified at the intermediate level by the performance standard (ABNT, 2021).

The performance curve of this arrangement, with the addition of 15 mm glass wool, showed the most significant difference in the reference curve compared to the other samples studied. Furthermore, there was a considerable loss of performance in the 160 Hz range, reaching 59 dB. Now, the best L'nT occurs at frequencies of 315 and 630 Hz, close to 40 dB.

The sample has a L'nT,w of 56 dB, reaching the intermediate level of the performance standard. The



Picture 13: Performance of floating floor samples with VF4

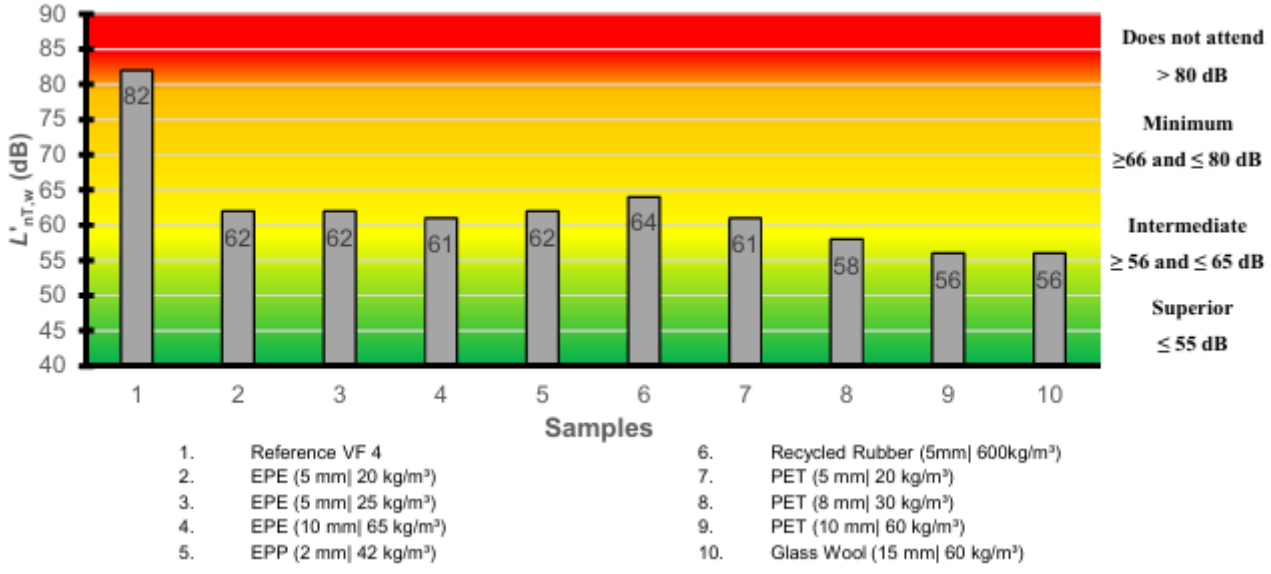
Source: Authors.

result is the same as that of pet wool, with a thickness of 10 mm and a difference of 26 dB in the reference sample.

Figure 14 demonstrates the classification of samples according to the requirements of the performance standard, NBR 15575 (ABNT, 2021c).

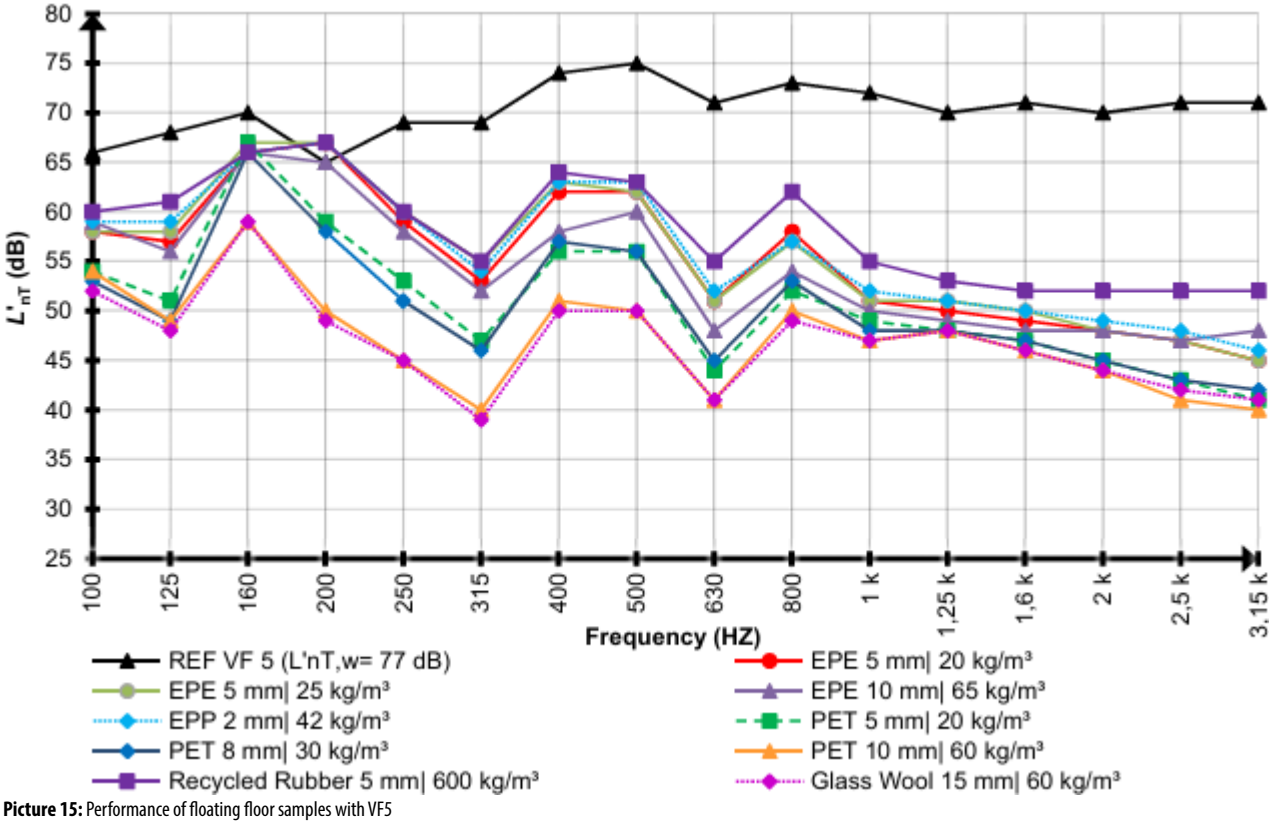
The results obtained in the tests of the floating floor system tested with the vinyl floor sample 5 with a thickness of 4 mm, which received the second-worst result (80 dB), are shown in Figure 15. Emphasizing that this floor is laid clicked, one piece fits into the other.

EPE blankets present insulation loss at 200, 500, and 800 Hz frequencies. At 200 Hz, the loss is more significant in 5 mm blankets and the same in 10 mm blankets, about the reference. The best isolation results occur in the 125,



Picture 14: Classification of floating floor samples + VF4 in the performance requirements of NBR 15575-3

Source: Authors.



Picture 15: Performance of floating floor samples with VF5

Source: Authors.

315, and 630 Hz bands.

Expanded polyethylene with a thickness of 5 mm and different densities showed very similar behaviors, having the same or very close values at various frequencies. According to the performance curve, they present better isolation at high frequencies. The L'nT,w of the 5 mm samples is 59 dB, while the 10 mm sample was 58 dB.

The EPP sample presents performance losses at 200, 400, and 500 Hz frequencies; at 200 Hz, the decrease is more significant than the reference curve. Now, the best isolation occurs in the 315 and 630 Hz bands. From 1000 Hz onwards, the curve decreases. The L'nT,w is 59 dB, being classified at the intermediate level by the performance standard (ABNT, 2021c).

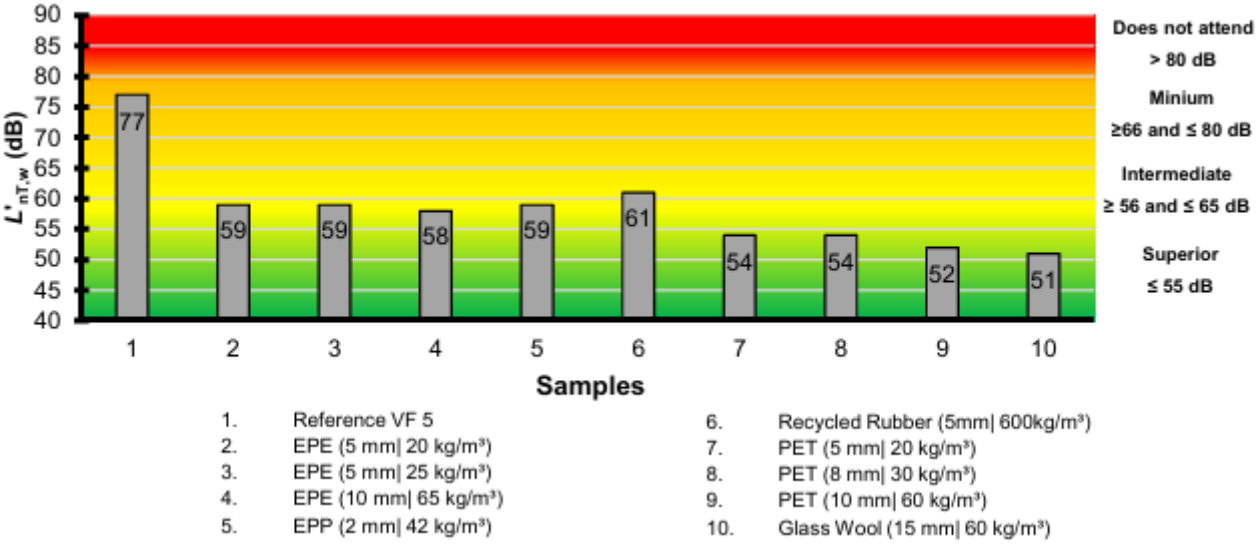
It presents a performance loss at 200, 400, and 800 Hz, with 200 Hz exceeding the reference curve. Now, the best isolation occurs at 315 and 630 Hz.

The pet wool samples show similar behavior, with the values of the curves of the 5 and 8-mm blankets coinciding at various points in the frequency bands. Now, the curve of the 10 mm sample stands out, presenting better results in practically its entire extension.

Performance losses occur at frequencies of 160, 400, and 800 Hz. Isolation peaks occur at frequencies of 125, 315, and 630 Hz. The curve decreases from 1000 Hz onwards.

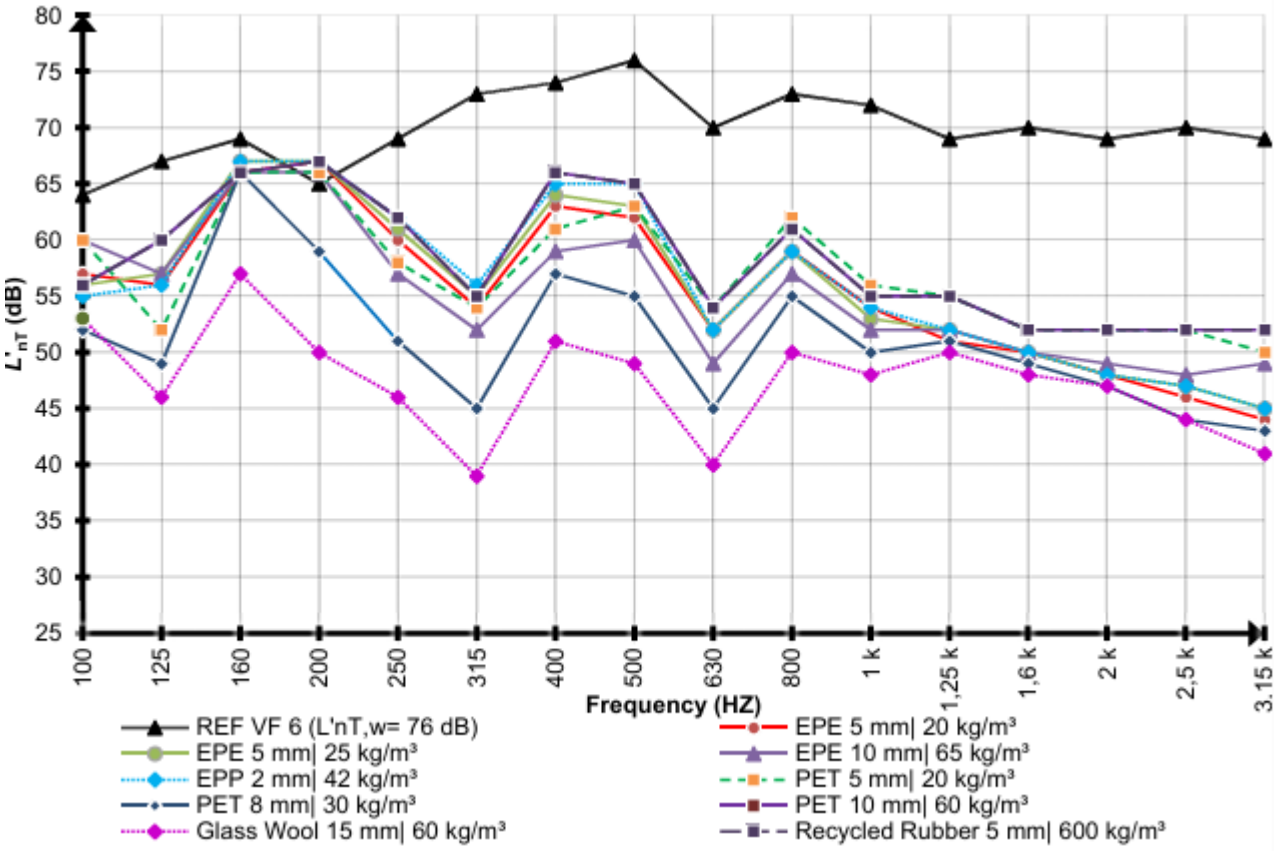
It can be seen that five samples of resilient materials are classified at the intermediate level (≥ 56 and ≤ 65 dB), and four samples are classified at the upper level (≤ 55 dB), as shown in Figure 16. In this way, it is possible to understand that This flooring system can be used to attenuate impact noise.

Figure 17 shows the results obtained in testing the floating floor system with a sample of vinyl covering (VF6), 3 mm thick, which obtained an intermediate result, with L'nT,w of 76 dB.



Picture 16: Classification of floating floor samples + VF5 in the performance requirements of NBR 15575-3

Source: Authors.



Picture 17: Performance of floating floor samples with VF6

Source: Authors.

Expanded polyethylene (EPE) curves have similar behavior. For the 5mm blankets, performance loss occurs at 200, 400, and 800 Hz, whereas for the 10 mm blanket, it occurs at 200, 500, and 800 Hz, and for all samples, the loss of insulation at 200 Hz exceeds the reference curve. Isolation gains occur at frequencies of 125, 315, and 630 Hz. Furthermore, from 1000 Hz onwards, the curves are decreasing, obtaining the lowest value at 3150 Hz. The L'nT,w of all samples is 59 dB.

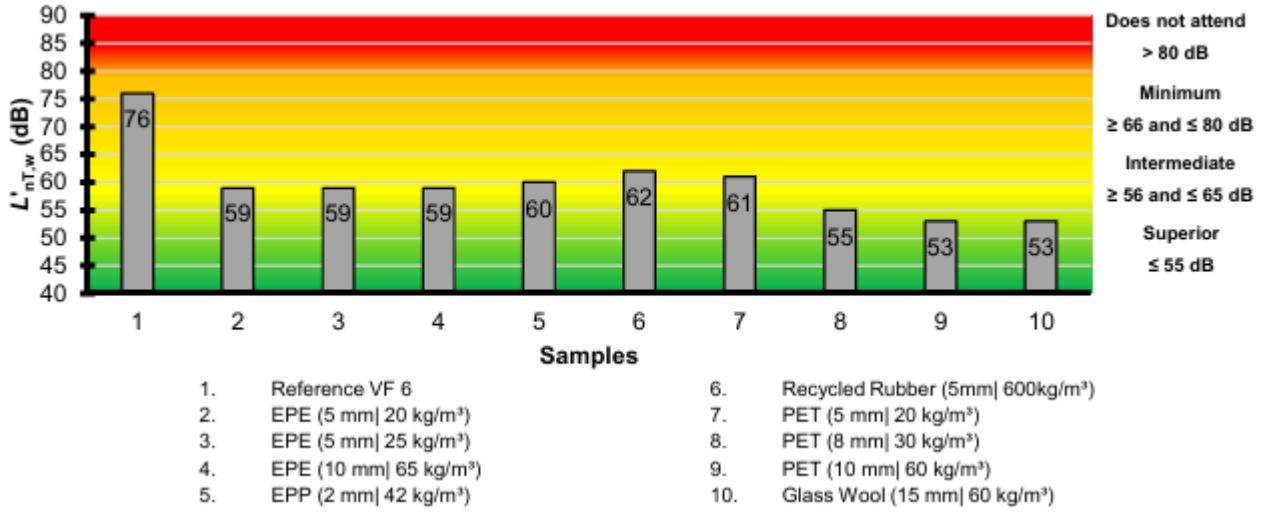
The curve shows a performance loss for the EPP sample at 160, 200, 400, 500, and 800 Hz frequencies. At 200 Hz, the loss is more significant than the reference curve. From 800 Hz onwards, the curve decreases with the best isolation results. The L'nT,w is 60 dB, classified at the intermediate level by the NBR 15575-3 performance standard (ABNT, 2021c).

The acoustic performance curve of recycled rubber varies between 50 and 70 dB, presenting insulation loss in the ranges of 200, 400, and 800 Hz, and at 200 Hz, the loss exceeds the reference curve by 2 dB. The best insulation values now occur at 100, 315, and 630 Hz frequencies. From 1600 Hz onwards, the curve stabilizes at 52 dB, the best results found. The L'nT,w of the recycled rubber sample is 62 dB, classifying it, according to NBR 15.575-3 (ABNT, 2021c), at the intermediate level.

For samples with polyester wool (PET), the performance loss is present in the curve of the 5 mm blanket in the bands 160, 200, 500, and 800 Hz. At 200 Hz, it exceeds the reference curve by 1 dB, and for the other two samples (8 mm and 10 mm), the losses are 160, 400, and 800 Hz. The best isolation values occur at 125, 315, 630, and 3150 Hz.

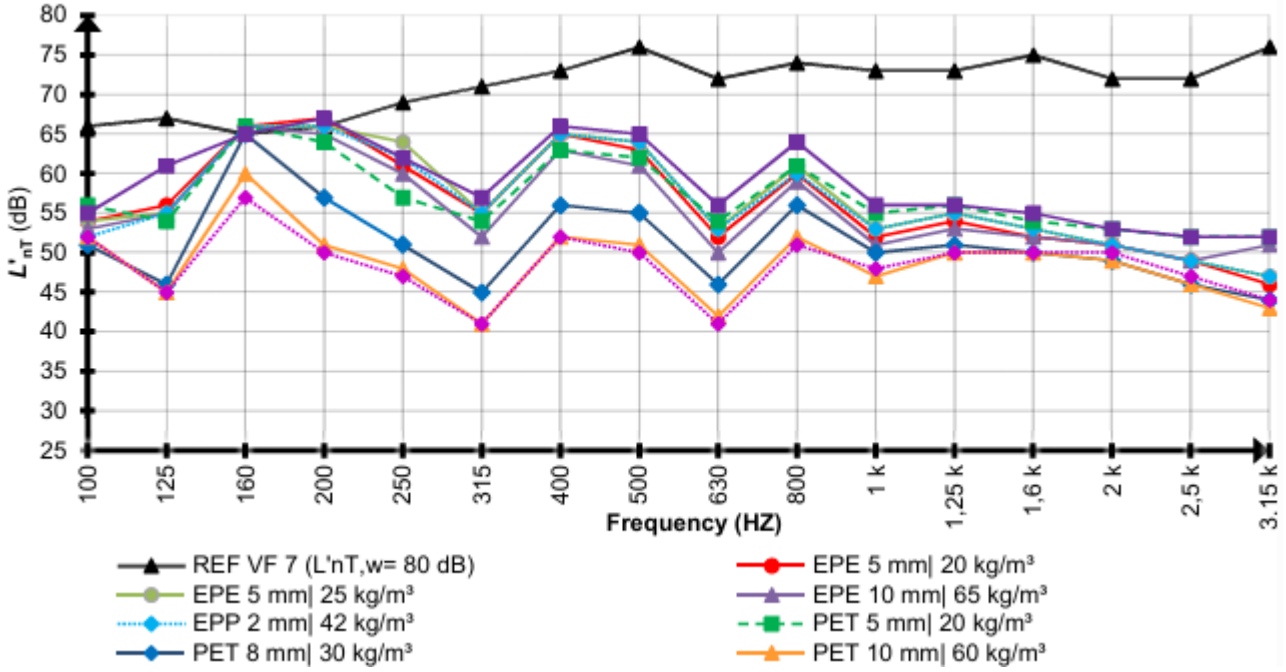
The 5 mm polyester wool obtained a L'nT,w of 61 dB, classifying it as the intermediate level. The 8 mm and 10 mm blankets are, respectively, 55 and 53 dB, classified at the top level by the NBR performance standard 15575-3 (ABNT, 2021c).

The curve of the floating floor system with glass wool showed the most significant difference in the reference curve. Performance losses occur at 100, 160, 400, 800, and 1250 Hz frequencies. The best isolation values occur in 125, 315, 630, and 3150 Hz bands. The L'nT,w is 53 dB, classified at the top level by the NBR 15575-3 performance standard (ABNT, 2021c). Figure 18 demonstrates the classification according to the NBR 15575-3 performance standard (ABNT, 2021c) for the tested samples, and Figure 19 shows the performance of the floating floor with the VF7 sample.



Picture 18: Classification of floating floor samples + VF6 in the performance requirements of NBR 15575-3

Source: Authors.



Picture 19: Performance of floating floor samples with VF7

Source: Authors.

EPE blankets show similar behavior, varying between 45 and 70 dB. At 160 and 200 Hz frequencies, the results obtained from expanded polyethylene blankets exceed the reference points. With this system implemented, the noise will be more significant at these frequencies than laying only the vinyl floor 7.

There is a gain in acoustic insulation at frequencies of 315, 630, 1000, and 3150 Hz. The samples present loss of insulation at different points: for the 10 mm blanket, the loss occurs in the 160 Hz range; for the 5 mm blanket with a density of 25 kg/m^3, the loss is constant in the 160 and 200 Hz bands and, for another 5 mm blanket with a density of 20 kg/m^3 the loss is at the frequency of 200 Hz.

The system with the expanded polypropylene (EPP) sample presents insulation loss at frequencies of 160, 200, 400, and 800 Hz, and in the first two bands, they exceed the points of the reference curve. Now, isolation gains occur in the bands of 100, 315, 630, and 1000 Hz, and from this frequency onwards, the curve decays until reaching 47 dB at the frequency of 3150 Hz. The L'nT,w is 61 dB, classified at the intermediate level according to the performance standard.

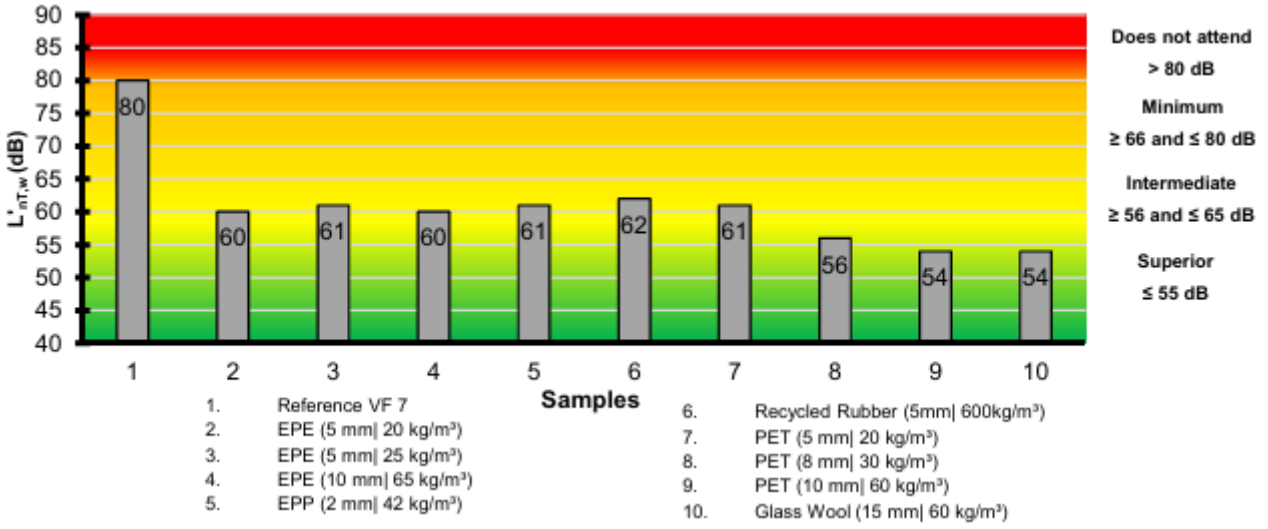
The performance curve of recycled rubber varies between 50 and 70 dB. Performance loss occurs at 200,

400, and 800 Hz; at 200 Hz, the loss is more significant than the reference curve point. Isolation gains occur in the ranges of 100, 315, and 630 Hz, and from 1000 Hz onwards, the curve decreases, obtaining the best isolation results.

The curves of the pet wool samples show similar behavior, making it possible to visualize and identify the blankets according to thickness and density, verifying that the curve with the best result is for the 10 mm sample. The loss of insulation occurs in the frequency ranges of 100, 160, 400, and 800 Hz; in addition, the 5mm blanket presents a more significant loss in the 160 Hz range than that of the reference curve and, at the same point, the 8mm sample mm got the same result.

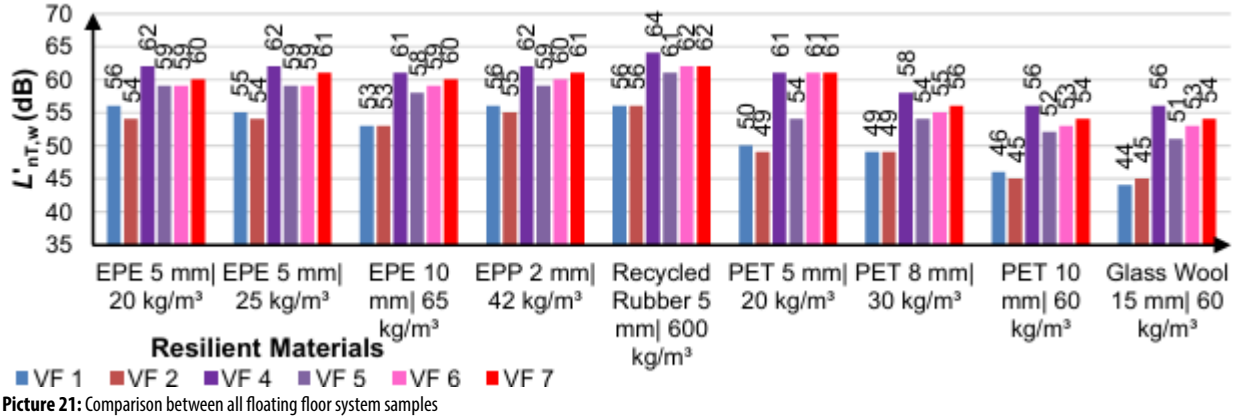
The glass wool sample curve obtained the most significant distance to the reference curve, varying from 41 to 57 dB. Performance loss occurs in frequency bands of 100, 160, 400, and 800 Hz. Isolation gains occur in 125, 315, 630, and 3150 Hz bands.

The results obtained (L'nT,w) in the samples of vinyl coverings tested in the floating floor system were compared with those of the respective resilient materials. Figure 20 shows the comparison with the requirements of NBR 15575 (ABNT, 2021c) and the Figure 21 shows this comparison, which was separated according to the group of resilient materials, presenting the column with the value obtained from that material in the six coatings tested.



Picture 20: Classification of floating floor samples + VF7 in the performance requirements of NBR 15575-3

Source: Authors.



Picture 21: Comparison between all floating floor system samples

Source: Authors.

5. CONCLUSIONS

Concerning the acoustic performance of the construction system of the ribbed prefabricated slab with prestressed joists and ceramic tiles, the bone slab obtained a L'nT,w of 91 dB, which is a very high value compared to other existing slabs. To this end, it was noted that the choice of construction typology directly influences the quality and performance of the building and the type of solution to the problem that will be specified and recommended. Adding the 4 cm subfloor improved performance by 7 dB, as the L'nT,w is 84 dB. That is, the increase in thickness improved the system's acoustic performance. However, it still does not meet the minimum required by the performance standard.

The result achieved by VF 2 (2.4 mm vinyl blanket) is due to the manufacturer considering the floor acoustic. Attenuating up to 19 dB, it attenuated more significantly at 20 dB. VF 1 (5 mm vinyl sheet) is also regarded as acoustic. With 15 dB isolation, however, it managed to attenuate 17 dB. This realization clarified that vinyl floors with acoustic treatment could attenuate impact noise as a simpler solution than installing a floating floor. However, the cost of applying each system should be considered, as vinyl flooring with this specification tends to have a higher value than others.

The results of the floating floor technique compared with the criteria determined by NBR 15.575-3 (ABNT, 2021c) for flooring systems separating autonomous housing units, with the chosen six vinyl flooring samples. The floors VF 1 (5 mm vinyl sheet) and VF 2 (2 mm vinyl sheet) obtained the best results in all samples of resilient materials tested. Of 18 samples, 14 were classified at the top level and the rest at the intermediate level but very close to the upper one with 56 dB. The worst results were found using recycled rubber blankets, the worst being 64 dB. However, all are classified as intermediate level.

To the worst result found in the simple system (slab + subfloor + vinyl floor) of VF 4 (0.70mm blanket) with L'nT,w = 82 dB, which did not reach the minimum level, the use of resilient materials attenuated 26 dB in glass wool and 10 mm PET wool, in addition, all samples fell into the intermediate level. In this way, all floating floor systems studied fit the requirements stipulated by NBR 15.575-3 (ABNT, 2021c) when considering the criteria for separating autonomous units at intermediate and higher levels.

As the study demonstrated, using vinyl flooring combined with the floating floor technique, a new construction method with limited research in the field, can achieve adequate acoustic performance levels for impact noise insulation, meeting established standards. Future perspectives in this area include exploring new resilient materials that could further enhance the efficiency of acoustic insulation systems and analyzing performance across different types of slabs and coverings. Additionally, further studies could consider the long-term durability of the materials used, and the environmental impact associated with the lifecycle of these floorings. These advancements could contribute to developing efficient and sustainable construction solutions, meeting the growing demands for acoustic comfort in urban environments.

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GM: resources, supervision, writing - review & editing, project administration and funding acquisition.

EHLS: formal analysis and writing - review & editing.

CTR: formal analysis and writing - review & editing.

GME: conceptualization, formal analysis, methodology, visualization, writing - original draft and writing - review & editing.

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ANALYSIS OF MORTAR PERFORMANCE WITH TUCUMÃ VEGETABLE FIBERS TREATED WITH SILANE-SILOXANE

ANÁLISE DO DESEMPENHO DE ARGAMASSAS COM FIBRAS VEGETAIS DE TUCUMÃ TRATADAS COM SILANO-SILOXANO

ANÁLISIS DEL COMPORTAMIENTO DE MORTEROS CON FIBRAS VEGETALES DE TUCUMÃ TRATADOS CON SILANO-SILOXANO

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ABSTRACT

Polypropylene fibers have been widely used in civil construction due to their good performance and low cost. However, plant fibers represent a viable alternative due to their favorable mechanical properties capable of mitigating construction anomalies, such as cracks, in addition to offering economic and sustainable characteristics. This study aimed to assess the incorporation of tucumã fibers, derived from a native plant in the Amazon region, as a substitute for polypropylene fibers in coating mortars. For this purpose, mortars with varying fiber content (0.5%, 1%, and 1.5% additions) were produced and treated with a silane-siloxane-based hydrophobic agent, as fibers are prone to degradation. Subsequently, tests were conducted in the fresh state, including consistency index, water retention, bulk density, and air content, as well as tests in the hardened state, such as flexural tensile strength, compressive strength, tensile adhesion, ductility analysis, and capillary water absorption. Regarding the results in the fresh state from the respective tests, the addition of tucumã fibers increased the consistency index and decreased bulk density and water retention. It was also observed that fiber addition reduced water absorption with increasing content, and the results from mechanical strength tests, namely flexural tensile and compressive strength, decreased. Moreover, both types of fibers exhibited positive results in terms of adhesion and ductility. Thus, this study demonstrated satisfactory outcomes for the use of tucumã fibers as a sustainable alternative to enhance the properties of coating mortars.

KEYWORDS

Plant fibers; Tucumã fibers; Coating mortars; Mechanical behavior; Sustainable construction.

RESUMO

As fibras de polipropileno têm sido amplamente utilizadas na construção civil devido ao seu bom desempenho e baixo custo. Porém, as fibras vegetais representam uma alternativa viável devido às suas propriedades mecânicas favoráveis capazes de atenuar anomalias construtivas, como fissuras, além de oferecerem características econômicas e sustentáveis. Este estudo teve como objetivo avaliar a incorporação de fibras de tucumã, derivadas de planta nativa da região amazônica, em substituição às fibras de polipropileno em argamassas de revestimento. Para tanto, foram produzidas argamassas com teores variados de fibras (0,5%, 1% e 1,5% de adições) e tratadas com agente hidrofóbico à base de silano-siloxano, pois as fibras são propensas à degradação. Posteriormente, foram realizados ensaios no estado fresco, incluindo

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índice de consistência, retenção de água, densidade aparente e teor de ar, bem como ensaios no estado endurecido, como resistência à tração por flexão, resistência à compressão, adesão à tração, análise de ductilidade e capilaridade. absorção de água. Em relação aos resultados no estado fresco dos respectivos testes, a adição de fibras de tucumã aumentou o índice de consistência e diminuiu a densidade aparente e a retenção de água. Observou-se também que a adição de fibras reduziu a absorção de água com o aumento do teor, e os resultados dos ensaios de resistência mecânica, nomeadamente resistência à tração à flexão e à compressão, diminuíram. Além disso, ambos os tipos de fibras apresentaram resultados positivos em termos de adesão e ductilidade. Assim, este estudo demonstrou resultados satisfatórios para a utilização de fibras de tucumã como alternativa sustentável para melhorar as propriedades de argamassas de revestimento.

PALAVRAS-CHAVE

Fibras vegetais; Fibras de tucumã; Argamassas de revestimento; Comportamento mecânico; Construção sustentável.

RESUMEN

Las fibras de polipropileno han sido ampliamente utilizadas en la construcción civil debido a su buen desempeño y bajo costo. Sin embargo, las fibras vegetales representan una alternativa viable por sus favorables propiedades mecánicas capaces de mitigar anomalías constructivas, como grietas, además de ofrecer características económicas y sustentables. Este estudio tuvo como objetivo evaluar la incorporación de fibras de tucumã, derivadas de una planta nativa de la región amazónica, como sustituto de fibras de polipropileno en morteros de revestimiento. Para ello, se produjeron morteros con diferente contenido de fibra (adiciones de 0,5%, 1% y 1,5%) y se trataron con un agente hidrófobo a base de silano-siloxano, ya que las fibras son propensas a degradarse. Posteriormente se realizaron pruebas en estado fresco, incluyendo índice de consistencia, retención de agua, densidad aparente y contenido de aire, así como pruebas en estado endurecido, como resistencia a la tracción a flexión, resistencia a la compresión, adhesión a la tracción, análisis de ductilidad y capilaridad. absorción de agua. Respecto a los resultados en estado fresco de las respectivas pruebas, la adición de fibras de tucumã aumentó el índice de consistencia y disminuyó la densidad aparente y la retención de agua. También se observó que la adición de fibra reducía la absorción de agua al aumentar el contenido, y los resultados de las pruebas de resistencia mecánica, es decir, la resistencia a la flexión, a la tracción y a la compresión, disminuían. Además, ambos tipos de fibras mostraron resultados positivos en términos de adhesión y ductilidad. Así, este estudio demostró resultados satisfactorios para el uso de fibras de tucumã como alternativa sustentable para mejorar las propiedades de los morteros de revestimiento.

PALABRAS CLAVE

Fibras vegetales; Fibras de tucumã; Morteros de revestimento; Comportamiento mecânico; Construcción sostenible.

1. INTRODUCTION

Cracking and delamination in coating mortars are prominent construction anomalies, particularly evident in sealing systems, given that stresses in the coating layer often arise from physical, mechanical, or cyclic efforts, such as temperature gradients. In an effort to prevent the occurrence of these pathological manifestations in coating mortars, researchers have sought solutions to minimize these construction anomalies. One alternative has been the use of fibers as reinforcement in the cementitious matrix (PEREIRA, 2011; MACIOSKI *et al.*, 2017; FONSECA, 2021).

Various types of fibers have been reported for diverse applications in cement matrices, including basalt fibers (KHANDELWAL; RHEE, 2020; IORIO *et al.*, 2021), glass fibers (YLMAZ *et al.*, 1991), carbon fibers (YANG *et al.*, 2022), graphene fibers (ZHANG *et al.*, 2021), plastic fibers (AHMED; MIHASHI, 2011), and natural fibers (do AMARAL *et al.*, 2022). Natural fibers such as flax (SAWSEN *et al.*, 2015), tucumã (FONSECA, 2021), and coconut (MARTINELLI *et al.*, 2023) emerge as competitive options compared to other types due to their sustainable and ecological characteristics.

Through the addition of polyester fibers to cementitious matrix mortars, Souza *et al.* (2019) analyzed the consistency and bulk density in the fresh state, as well as flexural tensile strength and bulk density in the hardened state. The results obtained through the consistency index revealed an inversely proportional decrease as the quantity of fibers increased. Furthermore, mortars with fibers demonstrated reduced weight both in the fresh and hardened states. The results also indicated a 28% increase in flexural tensile strength, contributing to the material's enhanced ductility.

In order to assess the influence of adding kraft paper fibers derived from recycled cement packaging on mortars, Pereira (2023) replaced aggregate volume at levels of 0.1%, 0.25%, 0.50%, and 1.00%. The analysis encompassed both the fresh and hardened states, evaluating the consumption of superplasticizer additive needed to achieve the specified workability, as well as flexural tensile strength, compressive strength, and water absorption through capillarity and immersion. It was observed that the required amount of additive to attain the specified workability increases with the fiber content. Additionally, the addition of fibers was found to enhance flexural tensile strength, although mortars without fiber additions exhibited better results in compression. Concerning water absorption, the introduction of fibers increased the void index.

Sandre *et al.* (2019) aimed to investigate whether the incorporation of bamboo fibers in mortars would enhance resistivity. They achieved this by adding 10%, 20%, and 30% of fibers to the composition. Through axial compression tests, they observed a decrease in strength; however, there was a noticeable shift in the cracking pattern. The addition of fibers led to a bonding effect between the mortar components, preventing the specimen from shattering.

Dias *et al.* (2021) incorporated sisal fibers into mortars to investigate their effects on physical and mechanical properties. The study involved tests for consistency index, water retention, capillary water absorption, dynamic modulus of elasticity, as well as axial compressive and diametral tensile strength. The authors observed that as the quantity of added fibers increased, the spreadability decreased. Regarding water retention, a higher fiber content resulted in increased water retention. Concerning mechanical strength, a decrease in compressive strength was noted, while tensile strength through diametral compression significantly increased. Water absorption did not show significant differences across different fiber proportions. Lastly, the modulus of elasticity was obtained, revealing a reduction with the incorporation of sisal fibers.

Fibers from the tucumã palm (Astrocaryum aculeatum) have emerged as a promising alternative to polymeric fibers. Native to the Amazon region and belonging to the Arecaceae family, this palm is known by various common names in northern Brazil, including tucumã, tucumã-do-amazonas, tucum-açu, tucum-do-mato, tucumã-arara, among others. Beyond its cultural diversity, the tucumã palm finds versatile applications, ranging from the utilization of its fruits to the extraction of fibers from its fronds (LIMA *et al.*, 1986). In Fonseca's study (2021), treatments applied to tucum fibers (Astrocaryum chambira Burret) yielded promising results in terms of compressive and tensile strength. The fibers underwent a hybridization treatment, resulting in a significant increase in strength from 67.2 MPa to 318.8 MPa.

The applicability of mortars with plant fibers exhibits both advantages and disadvantages. Among the advantages, it is generally noted that plant fibers possess low density, low cost, and flexibility. However, due to their hydrophilic nature, there is a compromise in the stability of the composite, along with significant variability in physical and mechanical properties (PEREIRA, 2011). Therefore, it becomes essential to carry out surface modification of natural fibers to enhance the interfacial bonding between the fiber and the

matrix, aiming to achieve improved performance in the resulting composites (FERRARA *et al.*, 2019).

Sepe *et al.* (2018) and Bollino *et al.* (2023) investigated the impact of chemical treatments on the mechanical behavior of hemp fabric-reinforced epoxy matrix composites. Test results reveal that silane treatment of hemp fibers enhances the tensile and flexural properties of the composites, proving more effective in preventing failure induced by water absorption. Theoretically, reducing the hydrophilic nature of the fiber to minimize its contraction and expansion in cementitious composites represents an effective strategy to enhance interfacial adhesion. Various fiber surface treatment methods have been explored to strengthen these matrices, including silane treatment (BILBA; ARSENE, 2008), hornification (CLARAMUNT *et al.*, 2010), and polymeric coating (FIDELIS *et al.*, 2016, 2019). These treatments have demonstrated positive impacts on fiber-matrix adhesion and the mechanical properties of cementitious composites.

In the presented context, tucumã fibers, renowned for their strength, hold potential to drive economic development and open avenues for research under various chemical treatments that modify their structure and enhance interfacial bonding between fiber and matrix. Therefore, this study aims to analyze the influence of adding silane-siloxane-treated tucumã fibers in coating mortars, with the goal of determining the optimal addition content that yields superior properties compared to the use of synthetic polypropylene microfibers.

2. MATERIALS AND METHODS

In the formulation of the mortars, Portland CP-V ARI cement served as the binder, accompanied by natural fine aggregate (fine river sand) featuring a characteristic maximum diameter of 1.18 mm and specific mass of 2.62 g/cm^3. Additionally, the mix incorporated synthetic polypropylene microfibers, natural fibers derived from tucumã straw, and a superplasticizing chemical additive (at a content of 0.2% relative to the mass of cement). Figure 1 provides visual representations of the tucumã fiber both before and after the beneficiation process.

(a)

(b)

Figure 1: Tucumã fibers: (a) Commercially available product, and (b) After preparation for testing
Source: Authors.

The tucumã fibers used were commercially obtained from an indigenous village located in Novo Airão, Amazonas. These fibers were provided in a collection of various straw lengths and thicknesses in their natural state. To be incorporated into the mortars, the fibers were manually cut to a size of 6 ± 1 mm, using rulers and scissors to standardize the sizes similarly to the polypropylene microfibers with a density of 0.93 g/cm^3, diameter of 18 µm, elongation of 80% and tensile strength of 300 MPa.

Three distinct percentages of natural fiber were proposed, namely 0.50%, 1.00%, and 1.50%, relative to the mass of the binder. These percentages were based on studies by Oliveira (2021).

To treat the tucumã plant fibers, a silane-siloxane-based water repellent was employed, with an addition of 0.3% relative to the fiber mass for a duration of 24 hours. This treatment is essential as the fibers may undergo degradation in a moist and alkaline environment, leading to increased water absorption and heterogeneity in the physical and mechanical properties of the natural fibers. Such variations can have a detrimental impact on their overall performance. Figure 2 illustrates the impact of silane-siloxane treatment on tucumã fibers via scanning electron microscopy (SEM). It is possible to see that the chemical admixture provided a protective layer on the fiber, thus reducing its porosity.

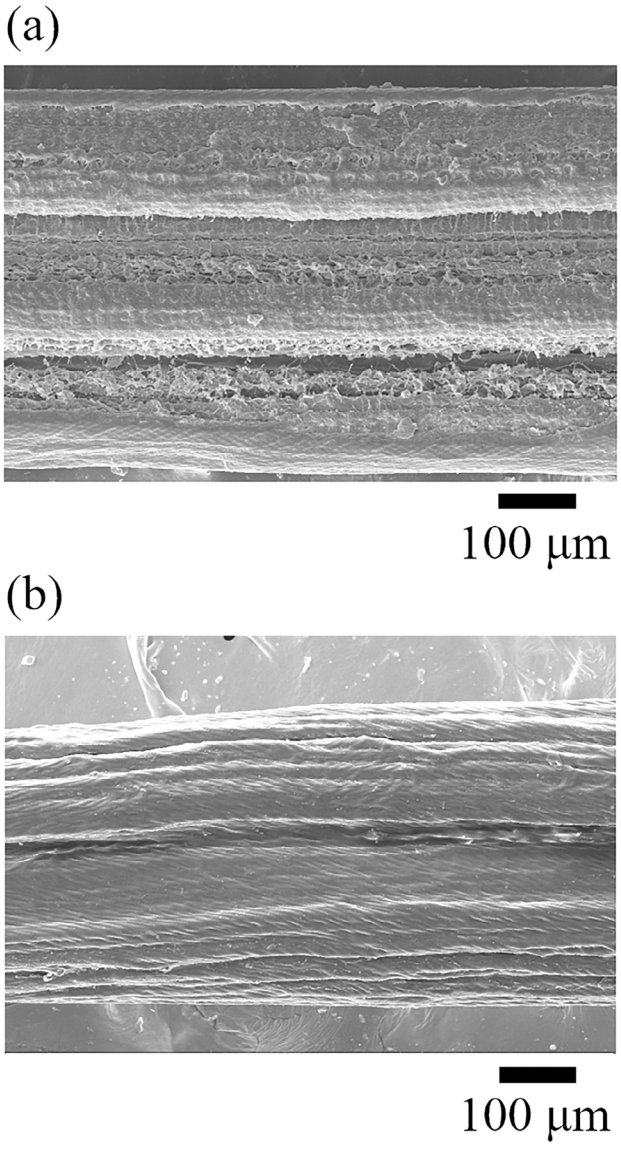

Figure 2: Tucumã fibers: (a) Natural fiber, and (b) Treated fiber.
Source: Authors.

The mortar mixing method adhered to the guidelines outlined in NBR 16541 (ABNT, 2016). The dosage ratio applied in this study was consistent with that used by Alberton (2022), maintaining a 1:5 ratio (cement:sand) by mass. The materials used to produce mortars remained in fixed quantities. 417 g of cement, 2083 g of fine aggregate, 0.83 g of plasticizing additive, and a water/binder ratio of 0.96 were used.

The mortar's consistency index was set at 270 ± 5 mm, given that the mortars with the spreading indicated by the standard proved to be inadequate, as the samples became dry and exhibited compromised workability.

Subsequently, tests were conducted in the fresh state, and specimens were produced. It is noteworthy that fresh state tests were performed immediately after sample production, followed by the molding of specimens. After a 24-hour period, the specimens were demolded and kept in an ambient cure at 25 ± 2ºC and a relative humidity of 85%.

The molding of the test specimens followed the procedures outlined in NBR 13279 (ABNT, 2005). The considered response variables encompassed properties in both the fresh and hardened states. In the fresh state, assessments included consistency index (ABNT NBR 13276, 2016; ASTM C305, 2020), water retention (ABNT NBR 13277, 1995), bulk density, and air content (ABNT NBR 13278, 2005; ASTM C185, 2020). After a curing period of 28 days for the specimens, evaluations in the hardened state involved flexural tensile strength and axial compressive strength (ABNT NBR 13279, 2005), bulk density (ABNT NBR 13278, 2005), tensile adhesion strength (ABNT NBR 15258, 2016), and capillary water absorption (ABNT NBR 15259, 2005; ASTM C1794, 2019). The plaster mixtures were prepared and applied to the substrates following the guidelines of NBR 7200 (ABNT, 1998). Only the mortars containing 1.0% of various fibers were tested for tensile adhesion strength.

It is important to note that in the tensile adhesion strength test, eighteen ceramic bricks (9x19x19cm) were employed for each mixture. The mortars were molded using EVA molds with circular sections and diameters of 50 mm on substrates that had previously been coated with plaster. The press utilized was an EMIC model, equipped with a 5kN load cell, operating at a speed of 0.08 mm/s.

3. ANALYSIS AND DISCUSSION OF RESULTS

The analysis of consistency indices revealed that, even when maintaining a constant water/cement ratio, mortars with fiber additions exhibited variations as the percentages of fibers increased, in comparison to the reference mortar. Results obtained with additions of 0.5% and 1.0% of polypropylene and tucumã fibers indicate an increase in the consistency index. Conversely, percentages of 1.5% for both fibers resulted in a decrease in workability, as shown in Figure 3.

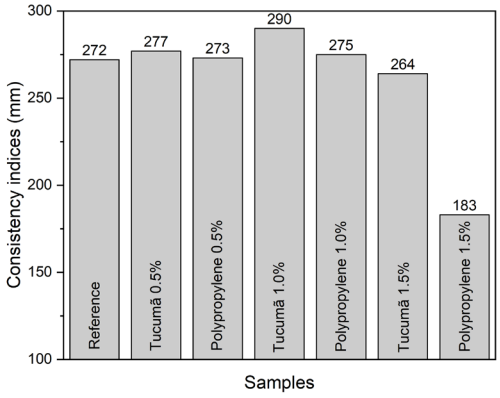

Figure 3: Consistency index of samples.
Source: Authors.

In the study conducted by Tiscoski (2016), a reduction in the consistency index was also observed as the content of polypropylene fibers increased. This resulted in an increase in the water/cement ratio necessary to maintain a constant index. Similarly, Alberton *et al.* (2023) investigated the influence of coconut fiber additions, resulting in a gradual decrease in the mean consistency as the percentage of fiber addition increased. The study by Centofante and Dagostini (2014) also indicated a decrease in the consistency index of mortars with fiber additions. Notably, mixtures containing additions of polypropylene fibers showed a reduction in the workability of mortars compared to those without fiber additions. These workability reductions can be attributed to fiber clustering and difficulty in proper dispersion during mortar preparation.

Regarding the increase in indices caused by tucumã fiber additions up to 1.0%, one of the possible influencing factors may be related to fiber treatment. This is evidenced in the studies of Oliveira (2001), Macioski *et al.* (2017) and Alberton *et al.* (2023), where untreated fibers negatively impacted mortar workability. Therefore, a plausible hypothesis is that the use of the water repellent may have contributed to the increase in indices, as this product has water-repelling properties on treated surfaces, as described by Costa (2014).

Figure 4 presents the results obtained for bulk density, where it can be observed that mortars with additions of both fibers exhibited a decrease in mass compared to the reference mortar, making them lighter.

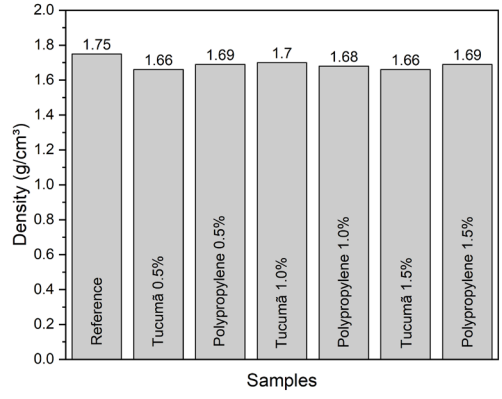

Figure 4: Bulk density of samples.
Source: Authors.

According to Carasek (2010), mortars with bulk density ranging from 2.30 to 1.40 g/cm³ are classified as normal mortars. Therefore, all mortars produced in this study fall within this classification. The reduction in bulk density when adding polypropylene fibers is a consistent finding in previous studies, such as that of Centofante and Dagostini (2014). Additionally, similar results regarding bulk density were obtained when using natural fibers like curauá, sisal, and coconut, as observed in the studies by Alberton (2022) and Nascimento *et al.* (2023).

The air content in mortars is directly related to bulk density. Therefore, as the bulk density decreases, the incorporated air content increases, as illustrated in Figure 5.

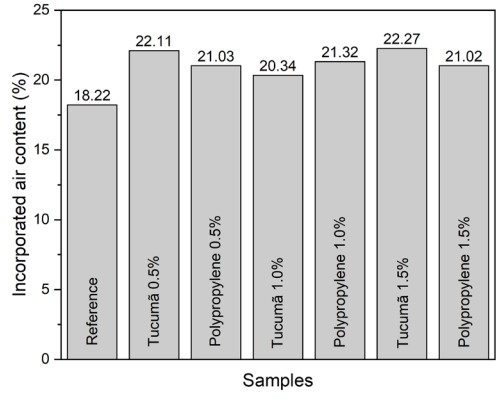

Figure 5: Incorporated air content of samples.
Source: Authors.

The mortars with fiber additions have a significant impact that influences an increase in the incorporated air in the samples. It is observed that the mortar with tucumã fiber additions up to 1.0% showed a reduction in the air content, as it obtained a higher apparent density for the same sample. This behavior is consistent with the results obtained by Alberton (2022), who used natural coconut fibers, and Nascimento *et al.* (2023), who used natural curauá and sisal fibers, as well as microfibers of polypropylene.

Regarding water retention, it was observed that all mortars (Figure 6), except those using 1.5% polypropylene fibers, exhibited approximate values of 94%. This finding aligns with the study by Nascimento *et al.* (2023), which also reported no significant differences in water retention with the addition of fibers. According to the Centre Scientifique Et Technique Du Batiment (CSTB, 1993), water retention for external coatings should fall within the range of 80% to 90%. However, for atmospheric conditions characterized by hot or windy climates, mortars should ideally have values between 91% and 100%. ASTM C270:12a (2012) stipulates that values should not be lower than 75%. Consequently, all mortars presented in this study demonstrated a retention exceeding 90%. This implies that mortars containing fibers maintain their workability for a longer duration when subjected to conditions causing water loss during mixing. A similar observation was made in Pczieczek's (2017) study, which analyzed the properties of coating mortars using fly ash and waste from non-recyclable tire rubber.

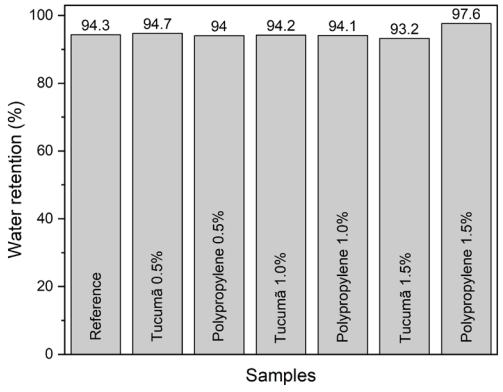

Figure 6: Water retention of samples.
Source: Authors.

Figure 7 provides the values of average and individual tensile strengths, along with the standard deviation for each tested formulation.

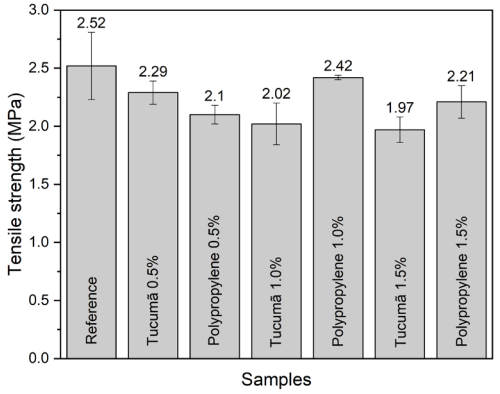

Figure 7: Summary of tensile strength results for samples.
Source: Authors.

It is observed that specimens with fiber additions exhibit a decrease in flexural tensile strength compared to the reference mortar. These results contradict the findings of Pereira *et al.* (2023), where the authors noted a significant enhancement in flexural tensile strength properties with the addition of polypropylene fibers, both in conventional and industrial mortars, when compared to the reference mix.

Fonseca (2021) found that the flexural tensile strength of composites with the addition of both treated and untreated tucum fibers increased compared to the reference sample. Furthermore, it was observed that hybridization treatment, particularly with the addition of 4.5% tucum fibers, significantly improved the mechanical performance in flexural tensile strength. This enhancement also resulted in an increase in direct tensile strength in the fiber, rising from 67.2 MPa to 318.81 MPa.

The results of the axial compression strength tests for the mortars are detailed in Figure 8.

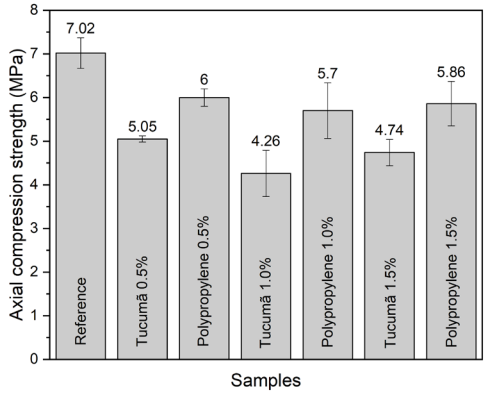

Figure 8: Summary of axial compression strength results for samples.
Source: Authors.

The obtained results indicate that the addition of fibers reduces the compressive strength of mortars compared to the reference mortar. Mortars with tucumã fibers, when

compared to those containing polypropylene fibers, showed an average reduction of approximately 1.3% across all analyzed addition levels for this property. It is noteworthy that mortars with the addition of 0.5% of both fibers exhibited superior results compared to other addition levels.

The decrease in compressive strength was also observed in the studies of Alberton (2022), and Nascimento *et al.* (2023). They found that additions of coconut fibers, curauá fibers, sisal fibers, and microfibers of polypropylene, respectively, resulted in a reduction compared to the reference mortar. In Fonseca's study (2021), tucum fibers, both treated and untreated, also exhibited a reduction in compressive strength when compared to the reference mortar, consistent with the findings presented in this study for tucumã fibers.

With the results of tensile and axial compressive strength, the relationship between the parameters of flexural tensile strength and axial compressive strength was determined. This relationship allows for obtaining the ductility values of the mortars. The tested mortars exhibited an average range of 0.35 to 0.47% in the ratios (Rf/Rc) of the strengths of the tested samples. It is observed that the addition of fibers to coating mortars can significantly enhance their ductility, as evidenced in the study by Maia *et al.* (2018).

Furthermore, samples with additions of tucumã fibers exhibited higher ductility values compared to both polypropylene and reference mortars. Therefore, the incorporation of vegetable fibers enhances the structure of the composites, providing them with improved ductility and post-cracking energy absorption (FONSECA, 2021). Additionally, Johnston (1992) argues that the addition of fibers in a cementitious matrix tends to enhance the ductility and toughness of a naturally brittle matrix.

Figure 9 presents the results obtained in the tensile bond strength test of the mortars.

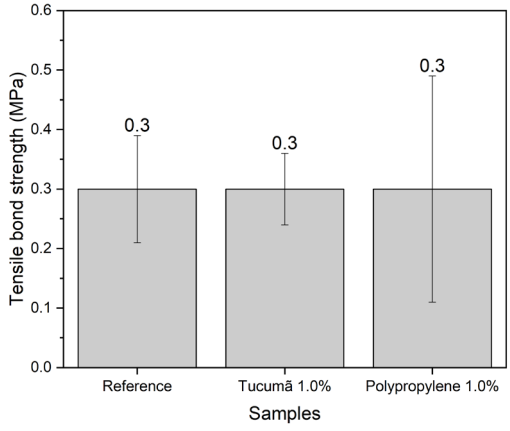

Figure 9: Tensile bond strength of samples.

Source: Authors.

From the obtained data, it was observed that all tested samples had an average of 0.30 MPa, thereby meeting the criteria established by the NBR 13749 standard (ABNT, 2005). Additionally, mortars produced with the addition of polypropylene fibers exhibited high coefficients of variation (58%) and standard deviations (0.19), whereas mortars with tucumã fiber additions showed the lowest standard deviations (0.06) and coefficient of variation (20%).

Silva *et al.* (2023) observed that the adhesion of tucumã fibers, when treated with silane-siloxane, yielded satisfactory results. These findings emphasize the positive influence of these treated fibers on this mechanical property. The increase in adhesion with the addition of polypropylene fibers, compared to the reference sample, was also observed in the study by Tiscoski (2016). However, the values found by this author were below the specified standard, possibly due to the direct application on the substrate, which may have influenced the results.

Concerning the failure mode, a visual inspection of the fractured specimens was conducted, identifying only four types of failure modes (Figure 10) in the tests performed for a plastering system and a set of layers (adhesive, tile, and mortar). The results of the failure modes are presented in Table 1.

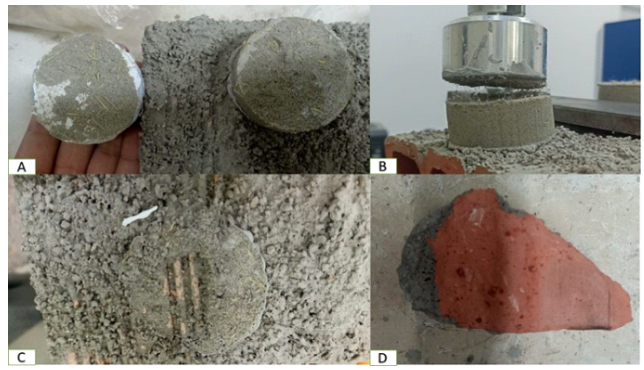

Figure 10: Visual appearance of fractured specimens.

Source: Authors.

Sample Type	Reference	Tucumã 1%	Polypropylene 1%
	Number of Samples		
Chapisco	1	6	
Mortar/ Adhesive	2		2
Adhesive		6	
Adhesive/ Tile	2		
Substrate			4
Note: The table represents the number of specimens for each type of failure mode observed in the tests			

Table 1: Summary of failure mode characteristics of specimens.

Source: Authors.

The specimens of the reference mortar showed failures at the adhesive/tile interface. In these cases, NBR 13755 (ABNT, 2017) suggests disregarding these obtained values as they indicate imperfections in the tile bonding. For the samples that failed in the plaster, adhesive, and mortar/adhesive interfaces, the standard indicates that the test values are superior to those obtained. As shown in Table 5, it was found that 50% of the mortars produced with tucumã fibers failed at the upper face of the adhesive mortar, demonstrating that the adhesion at the substrate interface has values exceeding 0.30 MPa.

On the other hand, the samples of mortars with additions of polypropylene fibers, for the most part, failed at the substrates. In contrast to the study by Tiscoski (2016), which examined 48 specimens, including reference mortar samples and mortar samples with additions of polypropylene fibers, it was observed that only two samples failed at the substrate, two at the mortar/adhesive interface, and the remaining 44 samples failed at the substrate/mortar interface.

The results of the capillary water absorption tests are illustrated in Figure 11.

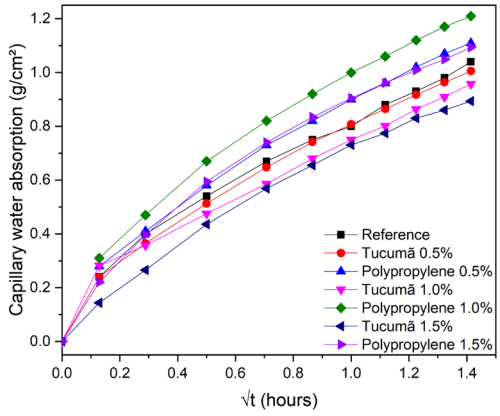

Figure 11: Results of capillary water absorption tests.
Source: Authors.

According to the data, it is evident that the addition of tucumã fibers reduces water absorption as the additions increase progressively, compared to both the reference and polypropylene mortars. Therefore, mortars with tucumã fiber additions exhibited a lower rate of absorption over the test period. Thus, these mortars demonstrated better performance in terms of impermeability.

The percentage reduction in water absorption in mortars with tucumã fibers can be explained by Fonseca (2021), who found that treating fibers with silanes, commonly used as water repellents, can alter the morphology of the fibers, causing swelling and increased porosity, resulting in reduced water absorption by the fibers. In the same referenced study, the author observed lower results for tucum fibers with treatments using baking and hot water, while treatments with NaOH and hybridization resulted in higher water absorption. Additionally, untreated fibers exhibited water absorption values higher than those of the reference mortar.

The polypropylene fibers exhibited higher water absorption values when compared to both the reference and tucumã mortars. However, Centofante and Dagostini (2014) observed a reduction in water absorption values with the addition of polypropylene fibers. They explained that polypropylene fibers are effective in reducing porosity, consequently making the mortar more impermeable. The difference in findings may be attributed to variations in experimental conditions, mix proportions, or fiber characteristics between different studies.

Cavalheiro *et al.* (2023) observed that mortars with additions of treated coconut fibers did not show a significant difference when compared to the reference mortar. On the other hand, the mortar with the addition of untreated fibers resulted in lower water absorption for this property. This highlights the impact of fiber treatment on water absorption properties, with untreated fibers potentially exhibiting improved performance in certain cases.

4. CONCLUSIONS

In conclusion, the investigation into the fresh and hardened states of mortars with tucumã and polypropylene fiber additions has provided valuable insights into their properties and performance. The following key findings and implications can be drawn from this research:

- The consistency indices of mortars with fiber additions exhibited variations compared to the reference mortar. While 0.5% and 1.0% additions of both polypropylene and tucumã fibers increased the consistency index, 1.5% additions resulted in a decrease in workability.
- The reduction in bulk density was observed in mortars with fiber additions, making them lighter. This aligns with previous studies on the influence of natural and synthetic fibers on mortar density.
- All mortars, except those with 1.5% polypropylene fibers, demonstrated approximately 94% water retention. This exceeds the recommended range for external coatings, suggesting that fiber-containing mortars maintain workability for an extended period.

- Compressive strength of mortars decreased with fiber additions, indicating a trade-off between flexibility (ductility) and compressive strength. Notably, 0.5% additions of both fibers showed superior results.
- The relationship between flexural tensile strength and compressive strength ratios revealed that mortars with fiber additions exhibited improved ductility. Tucumã fibers contributed to higher ductility values compared to polypropylene and reference mortars.
- Mortars with fiber additions exhibited an average tensile bond strength of 0.30 MPa, meeting standards. Tucumã fibers, especially when treated, positively influenced adhesion, while polypropylene fibers exhibited higher variability.
- Tucumã fiber-containing mortars predominantly failed at the upper face of the adhesive mortar, indicating superior adhesion at the substrate interface. Polypropylene fiber-containing mortars mainly failed at the substrate, in contrast to previous studies.
- Tucumã fibers reduced water absorption with increasing additions, outperforming polypropylene fibers. Fiber treatment with silanes played a crucial role in decreasing water absorption, highlighting the importance of fiber treatment.

These findings collectively underscore the complex interplay between different fibers and their impact on various mortar properties. The study contributes valuable data to the ongoing discourse on fiber-reinforced mortars, emphasizing the need for a nuanced understanding of the trade-offs between different performance parameters. Further research could delve into optimizing fiber proportions for specific applications and exploring additional treatment methods to enhance overall mortar performance.

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TEACHING SUSTAINABILITY: THE PEDAGOGICAL FUNCTIONS OF SCHOOL GARDENS

ENSINO DA SUSTENTABILIDADE: AS FUNÇÕES PEDAGÓGICAS DAS HORTAS ESCOLARES

ENSEÑANZA DE LA SOSTENIBILIDAD: LAS FUNCIONES PEDAGÓGICAS DE LOS HUERTOS ESCOLARES

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ABSTRACT

This paper explores the role of school gardens as pedagogical tools, focusing on their potential beyond mere food provision. In visited schools, gardens are not intended to meet dietary needs due to limited cultivation space relative to student populations. However, they offer opportunities for diverse educational activities, including agroecology and environmental education, contingent upon educators' willingness to integrate them into various disciplines. Despite logistical challenges, such as resource acquisition and interdisciplinary integration, gardens contribute to promoting healthy eating habits among students, staff, and faculty. Effective garden management remains crucial, with individual teachers often assuming responsibility. Additionally, the paper explores design's innovative potential in conceptualizing gardens not just as ornamental spaces but as catalysts for therapeutic, social, and knowledge-building experiences. A proposed framework guides practical application and outcome evaluation, emphasizing considerations like activity meaning, experiential nature, social interaction facilitation, knowledge generation, and aesthetic appeal. Ultimately, by addressing these aspects, educators can develop projects that resonate emotionally and culturally, yielding enduring and meaningful outcomes.

KEYWORDS

School gardens; Sustainability; Education; Design; Cultivation.

RESUMO

Este artigo explora o papel das hortas escolares como ferramentas pedagógicas, com foco em seu potencial além da simples provisão de alimentos. Nas escolas visitadas, as hortas não têm o objetivo de suprir necessidades alimentares devido ao espaço limitado de cultivo em relação ao número de alunos. No entanto, elas oferecem oportunidades para diversas atividades educativas, incluindo agroecologia e educação ambiental, dependendo da disposição dos educadores em integrá-las a várias disciplinas. Apesar dos desafios logísticos, como aquisição de recursos e integração interdisciplinar, as hortas contribuem para a promoção de hábitos alimentares saudáveis entre alunos, funcionários e professores. A gestão eficaz das hortas é essencial, sendo que, muitas vezes, professores individuais assumem essa responsabilidade. Além disso, o artigo explora o potencial inovador do design ao conceber hortas não apenas como espaços ornamentais, mas como catalisadores para experiências terapêuticas, sociais e de construção de conhecimento. Um modelo proposto orienta a aplicação prática e a avaliação dos resultados, enfatizando considerações como o significado das atividades, a natureza experiencial, a facilitação da interação social, a geração de conhecimento e o apelo estético. Em última análise, ao abordar esses aspectos, os educadores podem desenvolver projetos que ressoem emocional e culturalmente, gerando resultados duradouros e significativos.

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PALAVRAS-CHAVE

Hortas escolares; Sustentabilidade; Educação; Design; Cultivo.

RESUMEN

Este artículo explora el papel de los huertos escolares como herramientas pedagógicas, centrándose en su potencial más allá de la mera provisión de alimentos. En las escuelas visitadas, los huertos no están destinados a satisfacer las necesidades dietéticas debido al espacio limitado para el cultivo en relación con las poblaciones estudiantiles. Sin embargo, ofrecen oportunidades para diversas actividades educativas, incluida la agro-ecología y la educación ambiental, siempre y cuando los educadores estén dispuestos a integrarlos en diversas disciplinas. A pesar de los desafíos logísticos, como la adquisición de recursos y la integración interdisciplinaria, los huertos contribuyen a promover hábitos alimenticios saludables entre estudiantes, personal docente y administrativo. La gestión efectiva de los huertos sigue siendo crucial, con frecuencia, los maestros individualmente asumen la responsabilidad. Además, el artículo explora el potencial innovador del diseño al concebir los huertos no solo como espacios ornamentales, sino como catalizadores de experiencias terapéuticas, sociales y de generación de conocimiento. Un marco propuesto guía la aplicación práctica y la evaluación de resultados, enfatizando consideraciones como el significado de la actividad, la naturaleza experiencial, la facilitación de la interacción social, la generación de conocimiento y el atractivo estético. En última instancia, al abordar estos aspectos, los educadores pueden desarrollar proyectos que resuenen emocional y culturalmente, produciendo resultados perdurables y significativos.

PALABRAS CLAVE

Huertos escolares; Sostenibilidad; Educación; Diseño; Cultivo.

1. INTRODUCTION

In the global pursuit of sustainability and healthy living, educational environments play a crucial role in shaping future generations. School gardens have emerged as an important tool in this context, promoting not only environmental awareness but also healthy eating habits among students.

Design, as an interdisciplinary activity within a complex contemporary scenario, manifests itself in various ways. This multiplicity is also evident in activities related to plant cultivation. The relevance of design lies precisely in its capacity to connect and create bridges within a context of spatialization and fragmentation of knowledge (Cardoso, 2012). When considering the relationship between design project actions and the interface with the plant kingdom, a multitude of possible interactions can be envisioned.

In this research, the perspective of design is used in conjunction with environmental education to address the use of school gardens. A school garden, in a simplified and objective definition, functions to intervene in the food culture of students and all involved actors, enabling them to replicate their new knowledge of healthy and environmentally sustainable nutrition within their family environment (Lima; Conde Sobrinho; Silva Junior, 2015).

However, the implementation of a garden in a school environment presents several challenges for institutions. It requires various resources and often does not meet the nutritional demands of the school community. This article aims to investigate the balance between the difficulties of managing a garden and the justifications for the solutions implemented in three different scenarios.

2. METHODOLOGY

The overarching goal of this research is to understand the complex process of plant cultivation through the lens of design, using it as a framework to analyze strategies for promoting this activity. To achieve this, theoretical foundations from design, environmental education, and ethnobotany are explored to propose models for the creation, management, and evaluation of cultivation systems.

The first stage of the study involves documenting and analyzing field visits to school gardens to identify and assess the potential of cultivation as a pedagogical tool. Following this, a comparative analysis examines the educational functions of school gardens, providing a critical perspective on the roles designers can play in this setting. This analysis integrates design with other disciplines to uncover potential synergies between various sectors that can enhance creative activities.

The identified concepts are organized to culminate in design guidelines aimed at elucidating the subjective aspects of plant cultivation, facilitating their application in projects related to cultivation activities.

3. SCHOOL GARDENS

Recognizing the importance of personal development, we chose to visit daycare centers and schools with gardens to understand their pedagogical functions.

Three visits were conducted at schools utilizing gardens. The first visit was to a private school offering both elementary and secondary education. In a contrasting setting, a rural public state school providing elementary and secondary education was visited. Finally, the third visit was to a public university with its own garden.

3.1 Saci International School

Recognizing the significance of personal development, we visited the Saci International School, a private institution in Juiz de Fora/MG, offering preschool and elementary education along with optional bilingual (English) extracurricular activities. The school's pedagogical approach follows the Montessori method, aiming to facilitate the holistic development of individuals through principles of freedom, activity, and independence, with an emphasis on knowledge transmission (Lancillotti, 2010).

The Saci International School features a garden located in its outdoor area, partially situated on land borrowed from a neighboring club (Picture 1). Presently, the school collaborates with a couple of farmers from the MOGICO group (Monte de Gente Interessada em Cultivo Orgânico), a collective comprising consumers, producers, and technicians from Juiz de Fora and the surrounding region, who assist with garden maintenance weekly and conduct pedagogical activities with students.

Within this garden and orchard space, activities encompassing Science and Practical Life are conducted,

Picture 1: Saci International School garden
Source: the author, 2018.

including composting, harvesting food for school meals, and culinary classes. Students actively participate in planting, harvesting, research, experimentation, and tasting activities (Saci, 2019).

According to the school's principal, although the garden doesn't fully meet the demands of the cafeteria meals, students occasionally assist with harvesting vegetables for inclusion in meals. Nonetheless, the promotion of healthy eating habits is encouraged, echoing observations made by Cunha (2015, p. 128), who highlighted "awareness of the benefits of ecological cultivation of food for self-consumption and the cultivation activities undertaken by some students at home" in her report.

The school garden serves as a multifunctional educational tool for various subjects and preschool activities. For younger children (up to approximately 3 years old), it serves as an area for exploration and discovery of colors and textures. Guided activities are introduced gradually as children progress, tailored to each teacher's preferences. While participation is optional, there is significant interest among the teaching staff across various disciplines and themes. Thus, the school garden serves as a living laboratory that enriches the learning process (Cunha, 2015).

Both the principal and the collaborating farmers agree that while the garden has the potential to introduce healthy foods into students' diets, family involvement is crucial for sustaining healthy habits. Additionally, beyond nutritional benefits, the garden's educational activities promote cooperation and agroecology among students (Lima, Conde Sobrinho, Silva Junior, 2015).

Under the influence of the MOGICO proposal, the garden features a variety of Non-Conventional Food Plants (PANC), such as "peixinho" (*Stachys byzantina*) and purple lettuce (*Lactuca canadensis*), along with the cultivation of native maize species.

Aligned with the Montessori approach, which encourages self-directed learning, plants are integrated into the indoor classroom environment as well (Picture 2) to stimulate curiosity and foster a sense of responsibility among students.

This integration of plants into the learning

Picture 2: Plant inside the classroom at Saci International School
Source: the author, 2018.

environment aligns with Maria Montessori's philosophy, which emphasizes self-directed education and learning through exploration (Lancillotti, 2010).

3.2 Tiago Delgado State School

The visit to Tiago Delgado State School was guided by the institution's vice principal. Situated in the rural village of Manejo, within Lima Duarte/MG, this public school provides education ranging from elementary to high school levels, as well as adult education.

In contrast to Saci International School, Tiago Delgado State School boasts a more extensive garden area (Picture 3), which, although still not fully meeting the cafeteria's needs, provides herbs and vegetables to students' meals more regularly.

It's noteworthy that state schools in Minas Gerais benefit from manuals offering menu suggestions tailored to each educational stage. These menus integrate basic food groups with nutritional guidelines, taking into account the dietary and agricultural customs of the state (Minas Gerais, 2014).

Additionally, the suggested menu ingredients provided by SEE/MG (Minas Gerais State Department of

Education) are accompanied by a seasonal harvest table, indicating the availability of each food item throughout

Picture 3: Tiago Delgado State School garden
Source: the author, 2018.

the year. Such documentation aids in planning garden cultivation to support the cafeteria.

According to the vice principal, extracurricular activities are available to certain classes, and the topics covered during these non-formal hours are often chosen with input from the students themselves. Thus, in response to their initiative, there was a demand for environmental education, leading to the utilization of the garden space.

In this framework, students play a significant role in decision-making regarding the garden, including the selection of plants and their active involvement in cultivation activities. Lima, Conde Sobrinho, and Lima Junior (2015) underscore that "the establishment of a school garden should, above all, engage students, educators, and partners in the process. Such endeavors embody the principles of cooperativism and agroecology, fostering educational and productive balance."

Beyond disciplinary activities, where teachers from any subject can use the space for instruction, students also utilize their free time in the garden, collaborating to brainstorm and implement improvements. They are even permitted to eventually harvest vegetables for family consumption.

As a public school primarily serving low-income children and youth, all garden improvements, along with other school enhancements, are achieved without public funding. Instead, they rely on group mobilization and non-monetary resources. Neighboring producers donate materials, and students and teachers collaborate in mutual aid efforts, among other strategies to achieve objectives without financial reliance. This approach reflects some of the current challenges in design, emphasizing its role as a facilitator of interpersonal relationships rather than transactions of ownership (Secomandi, 2014).

When Bonsiepe (2011) posed the question, "how can we reclaim a concept of democracy not dominated by the economy and restore its credibility?" he interrogated a present landscape dominated by market forces shaping social and economic interactions. Gradually, communities are recognizing the value of collective action as essential assets, equating in significance to tangible resources. "As crucial as the values of utility and exchange highlighted in product acquisition are the values of esteem, linked to emotional factors and satisfaction" (Pinto, 2017, p. 395).

A community mobilizing and crafting its own narrative using alternative resources (beyond mere currency) for implementation can serve as one viable response to Bonsiepe's inquiry.

3.3 Education School

The Education School (FACED) at the Federal University of Juiz de Fora (UFJF) features an open, grassy area at the back of its structure. With the aim of making the space more productive, one of the institution's professors took on the task of setting up a garden in this area (Picture 4). However, what is noticeable is that visually, it is not immediately apparent that it is a garden; there are no signs or well-defined beds as in the two schools mentioned earlier. It is only upon approaching the plants, which occupy the peripheral area rather than the center, that one realizes they are edible plants.

There is no leadership or individuals with specific obligations regarding garden care, as the initial idea is to leave the space open so that anyone can freely take the initiative to engage with it. FACED staff, students, and professors are the ones who usually take care of some stage of cultivation. It is worth noting that "anyone can

Picture 4: Education School - UFJF
Source: the author, 2018.

cultivate a garden, as long as they have reserved time for it" (Melo, 2019, p. 120).

At times, professors and participants in the college's activities teach classes or hold meetings in this area, as was the case with the course "Pedagogical Potentials of Agroecological School Gardens," promoted by members of the Environmental Education Study Group (GEA), which in 2018, held part of its activities in the garden.

In the university setting, students are adults, and campus dining is optional. Therefore, the garden here does not need to instruct the student body on good dietary or even environmental practices, as it is not the main focus of FACED's courses. Participation arises from individuals' desire to be in that space and engage in cultivation activities, largely without any obligation.

Professors may often wonder about their level of involvement in guiding a project or activity, but in the university, student autonomy is a fundamental aspect of their learning. One can envision a more active participation where certain issues are imposed, such as the working method, for example, or the delegation of tasks to specific members. However, in addition to teaching a project, it is important to teach about the responsibilities of decision-making. Therefore, the less decisive the teacher's role, the greater the freedom and autonomy of the group of students to express themselves, learn, and decide thoughtfully. And perhaps decision-making, knowing how to choose, define, is one of the main lessons in a career.

4. THE GARDEN AS A DIDACTIC OBJECT

The gardens observed in the visited schools do not mandate compulsory usage by any teacher/professor, nor do they directly contribute to meeting the dietary needs of students or staff in any of the scenarios presented. So, why do schools invest in maintaining a garden? Wouldn't this allocation of resources seem excessive for an uncertain outcome?

Considering that none of the schools have institutionalized the use of the garden, it may appear as though this effort could be misdirected. However, in contemporary discourse, concepts like environmental responsibility and social inclusion are prominent and often emphasized within educational frameworks (Cardoso, 2012). Hence, integrating cultivation activities into the curriculum appears to offer a practical means of engaging students in environmental education.

In 1978, Tanner drew a comparison between conservation education and environmental education, suggesting that the former focused solely on nature, without incorporating the human environment, while the latter actively involved human-environmental dynamics to foster discussions on political, cultural, and socio-economic issues related to environmental themes (Layrargues, 2000).

Aligned with the principles of environmental education as outlined by Tanner, advocating for the presence of a garden within a school environment without mandating its use at specific points in the curriculum grants educators the flexibility to integrate it as they see fit within their pedagogical approach. This adaptability underscores that the emphasis should not solely be on determining the optimal form and timing for teaching environmental concepts within a particular discipline but rather on embedding environmental consciousness into the institutional ethos, irrespective of the subject being taught.

The challenges faced by environmental educators underscore that presenting information in a linear format, such as through pamphlets extolling the benefits of plant cultivation or natural food consumption, is unlikely to catalyze behavioral changes. Thus, the essence of the proposal lies in devising alternative methods that encourage individuals to reflect on their habits within their immediate environments.

In essence, it encompasses more than merely imparting ecological knowledge; it fosters a sense of civic responsibility (Layrargues, 2000). Ultimately, environmental education encompasses a diverse range of knowledge, necessitating a departure from didactic methods towards engagement with the conflicts and complexities inherent in the environments that both transmit and receive knowledge.

The presence of a garden in educational institutions facilitates various activities that support educators in achieving diverse educational objectives. Literature offers insights into a spectrum of outcomes resulting from garden-based initiatives, including combating student apathy and disengagement (Souza; Carvalho; Souza, 2018), promoting dietary awareness and healthier eating habits (Santos *et al.*, 2014), soil conservation efforts (Melo, 2019), fostering social values, and reducing violence (Oliveira; Cintrão, 2004), as well as advancing environmental sustainability (Paula; Benedetti, 2018). With its multidimensional nature, a garden serves as a versatile platform for teaching a range of subjects, spanning geography, history, sociology, biology, and chemistry, while also addressing cross-cutting themes

such as agroecology and pesticide usage (Cunha, 2015), among numerous other possibilities, each tailored to the unique needs and preferences of individual educators.

5. CAN DESIGN BE A TOOL FOR ENVIRONMENTAL EDUCATION?

Despite the discourse surrounding formal environmental education dating back to the 1977 Tbilisi conference (Layrargues, 2000), educators across various disciplines continue to grapple with the challenge of fostering critical engagement with the subject matter, rather than relying on preconceived notions derived from antiquated theories. Addressing a pervasive state of environmental unawareness extends beyond the confines of elementary and secondary education to encompass stakeholders such as policymakers, decision-makers, and administrators (Fernandes *et al.*, 2018).

The creation of platforms for community deliberation and critique has emerged not only as an integral component of environmental education but also within the realm of social design. Indeed, ongoing debates question whether design initiatives should transcend the conventional paradigm of perpetuating dependency on products and brands to instead facilitate the development of liberating solutions that empower marginalized communities (Bonsiepe, 2011).

While conventional design practice historically centered on the development of interventions aimed at ameliorating the conditions of socially marginalized groups, a paradigm shift is evident. Embracing the concept of infrastructuring, designers are now envisioned as more than mere problem-solvers; rather, they play a pivotal role in discerning the political dimensions inherent within the design process.

Adopting an infrastructuring approach entails transitioning from a directive stance to one that prioritizes the facilitation of inclusive and participatory spaces conducive to the expression of diverse viewpoints on societal issues. Through this lens, designers are positioned to orchestrate collaborative efforts among disparate stakeholders to navigate and address the multifaceted challenges that emerge (Del Gaudio, 2017).

Contemporary scholarship underscores that, instead of merely developing didactic products, fostering environments conducive to open discourse holds greater promise for effective educational outcomes reflective of real-world complexities. While physical artifacts may serve instrumental roles in pedagogical contexts, their potential for engendering sustained dialogue remains limited. Recognizing the dynamic nature of discourse vis-à-vis the static attributes of material artifacts prompts a critical inquiry: How can design practices be harnessed to cultivate spaces conducive to nuanced and evolving debates?

6. DESIGN AS A PROJECT, NOT A PRODUCT

While a didactic object, a common project type in design and education, may not be the most necessary or relevant development in the presented context, it is worth considering that a designer's involvement in cultivation activities should take into account subjective factors, such as user experience.

The term User Experience (UX) is an area of design study that deals with planning the effects felt by a user as a result of interaction with the context a usage of a system, a device, or a product, including the influence of usability, utility, and motor impact during interaction and the memory retained after the interaction (Hartson; Pyla, 2012).

Engagement with a garden can be crafted to provide an impactful experience for its users (students, teachers, staff, etc.). The garden itself already holds the potential to impact user experience. It is an ecosystem with a diversity of living beings and evolving elements in an open setting subject to weather changes. Thus, even if there are repeated activities of the same theme, each one will offer a unique experience.

Therefore, for learning, a designer may not necessarily need to create tools for handling plants or special clothing, for instance. While the use of an object may bring an interesting experience the first time it is used, the elements of surprise and interest may diminish with repetition. The use of the garden may present a series of complicating factors regardless of the activity: presence of insects, days of intense sun or rain, plants that grow, sprout, or die. Each visit or activity will offer a unique experience. Thus, a designer would act as a facilitator rather than a developer in this environment.

In addition to practical considerations, emotions are also generated. Regarding emotional design, it is said that our connection is not with objects per se, but with the relationship, the meanings, and feelings they represent (Norman, 2004). When speaking of cultivation, one speaks above all of relationships, as cultivation is defined by interaction with other living beings (the plants in this case) that will behave and react in specific ways according to the caregiver's behavior. In today's disposable society, where

product use may last only a few seconds before disposal, the interaction with plants tends to be more enduring. Considering shorter-lived crops like lettuce, which can be harvested in about 2 months, to trees that can last decades (or more), one understands why the bond with plants can be so strong for those who cultivate them.

A garden also presents socializing potential that permeates any stage of cultivation activities, especially those involving food plants, such as vegetable gardens and orchards. This point is relevant precisely because it contrasts with the current lifestyle profile in urban areas. Cities constrain their residents, who increasingly close themselves off in smaller circles of socialization.

In a school context, interaction with the garden is usually guided by educators, suggesting that memories will be created not only of the plants but also of the interpersonal contacts that cultivation activities generate. The school garden promotes interaction among children and with the environment, allowing them to understand themselves as part of nature, reinforcing values of solidarity, collectivity, and respect (Nunes, 2019).

This necessary interaction with the plant environment can be explained by the principle of biophilia, which suggests that human dependence on nature extends beyond issues of material and physical sustainability to encompass aesthetic, intellectual, cognitive, spiritual, and satisfaction needs.

Lidwell *et al.* (2010) suggest that environments with natural images reduce stress and increase concentration. The author proposes that in constructing environments, aspects of biophilia should be considered but notes the positive outcomes when applied to those engaged in learning, healing, and concentration activities.

The principle of biophilia may be one of the justifications for the use of the garden yielding a variety of positive results as a learning environment. According to Kellert (1993), the human need for an aesthetic experience of nature has suggested an apparent mismatch with artificial environments.

7. CONCLUSIONS

The gardens observed in the visited schools do not primarily aim to fulfill the dietary requirements of students, teachers, or staff within the institutions. The discrepancy between the number of students per institution and the available cultivation area, coupled with the demand for various resources, underscores this challenge, which persists even in the rural school setting.

Therefore, the garden serves as a pedagogical tool, extending beyond its role in dietary matters to encompass a range of educational objectives. It can be effectively utilized to teach agroecological practices, environmental education, or other educational methodologies, provided educators embrace this multifaceted approach. However, its implementation poses multifaceted challenges, including spatial constraints, personnel requirements, and the need for resources such as water, seedlings, fertilizer, and tools. Moreover, integrating the garden into disciplines unrelated to the natural sciences presents additional pedagogical complexities.

In a study examining school gardens in Juiz de Fora/MG, Araújo *et al.* (2017) critique the prevailing didactic and pedagogical use of these green spaces, arguing that the environmental issues addressed in these institutions fail to foster a critical discourse among students regarding environmental justice and food sovereignty.

Furthermore, effective garden management emerges as a crucial consideration. While many teachers use the garden for disciplinary activities, the responsibility for its establishment, care, and maintenance typically falls upon individuals rather than being shared collectively.

Despite its indirect role in food provision, the garden serves as a valuable tool for promoting healthy eating habits among students, faculty, and staff, thereby warranting recognition and support within educational contexts.

The role of design in incorporating plant-based elements into projects is not novel. However, the innovative aspect of the present proposal lies in reimagining the cultivation activity as a catalyst for therapeutic, social, and knowledge-building experiences, alongside its aesthetic contributions to the environment.

In conclusion, the paper presents a framework for guiding practical applications and evaluating outcomes in projects involving cultivation (Table 1).

This framework emphasizes considerations such as the intrinsic meaning of the activity, the nature of the experience it engenders, its potential for facilitating social interaction, the knowledge it generates, and its aesthetic dimensions. By addressing these aspects, educators can develop projects that resonate with users on emotional and cultural levels,

Areas and project questions	
Experience/ emotion/ meaning	1. What feelings are involved in this context? 2. Do plants have representations that relate to people, places or situations experienced?
Socialization	1. Does it promote interaction between people? 2. Does it create groups with a common interest? 3. Does it generate ocial value? 4. Does it promote the sharing of knowledge and experiences?
Biophilia / aesthetics	1. Does it insert plants into new environments? 2. Is the cultivation activity consistent with the activities carried out in the environment in which it operates? 3. Is the visuality coherent with the environment?
Knowledge	1. Does it introduce new knowledge about cutivation into people's lives? Does it generate autonomy? 2. If so, is it done in a manner consistent with the activities involved in cultivation? 3. Does it involve reflection? Is knowledge subject to discussion?

Table 01: Relevant factors for the development of human/plant interfaces.

yielding enduring and meaningful outcomes.

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THE EVOLUTION OF THE CSR AND ESG DEBATE ON TWITTER: AN OVERVIEW FROM THE USER PERSPECTIVE

EVOLUÇÃO DO DEBATE RSC E ESG NO TWITTER: UM PANORAMA NA PERSPECTIVA DO USUÁRIO

EVOLUCIÓN DEL DEBATE RSC Y ESG EN TWITTER: UN PANORAMA DESDE LA PERSPECTIVA DEL USUARIO

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ABSTRACT
This study analyzes the evolution of Corporate and Social Responsibility (CSR) and Environmental, Social, and Governance (ESG) in social media (Twitter) from 2007 - 2022. The research aims to understand how society perceives organizational practices related to these aspects. Twitter provides an authentic environment for capturing user perceptions. The methodology included collecting Tweets using Python and analyzing them in English, Spanish, and Portuguese with RStudio. The study's main findings highlight significant contributions and concerns within the CSR and ESG debates. CSR's popularity declined from 2010 to 2019, while ESG emerged during and after the pandemic. Word analysis revealed the impact of specific hashtags: RSC in Spanish, #CSR in English, and #ESG in Portuguese. Society's increasing concerns concern environmental issues for combating global warming and ensuring a better quality of life; however, the social aspect of ESG, represented by the letter "S," did not garner the same attention as environmental and governance.

KEYWORDS
ESG, RSC; Social Media; Twitter.

RESUMO
Este estudo analisa a evolução da Responsabilidade Corporativa e Social (CSR) e dos critérios Ambientais, Sociais e de Governança (ESG) nas redes sociais (Twitter) de 2007 a 2022. A pesquisa tem como objetivo compreender como a sociedade percebe as práticas organizacionais relacionadas a esses aspectos. O Twitter oferece um ambiente autêntico para capturar as percepções dos usuários. A metodologia incluiu a coleta de Tweets usando Python e a análise deles em inglês, espanhol e português com o RStudio. As principais descobertas do estudo destacam contribuições significativas e preocupações dentro dos debates sobre CSR e ESG. A popularidade da CSR diminuiu de 2010 a 2019, enquanto o ESG surgiu durante e após a pandemia. A análise de palavras revelou o impacto de hashtags específicas: RSC em espanhol, #CSR em inglês e #ESG em português. As crescentes preocupações da sociedade envolvem questões ambientais para combater o aquecimento global e garantir uma melhor qualidade de vida; no entanto, o aspecto social do ESG, representado pela letra "S", não recebeu a mesma atenção que os aspectos ambientais e de governança.

PALAVRAS-CHAVE
ESG, RSC; Mídias Sociais; Twitter.

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RESUMEN

Este estudio analiza la evolución de la Responsabilidad Social Corporativa (RSC) y de los criterios Ambientales, Sociales y de Gobernanza (ESG) en las redes sociales (Twitter) desde 2007 hasta 2022. La investigación tiene como objetivo comprender cómo la sociedad percibe las prácticas organizacionales relacionadas con estos aspectos. Twitter ofrece un entorno auténtico para capturar las percepciones de los usuarios. La metodología incluyó la recopilación de tweets utilizando Python y su análisis en inglés, español y portugués con RStudio. Los principales hallazgos del estudio destacan contribuciones significativas y preocupaciones dentro de los debates sobre RSC y ESG. La popularidad de la RSC disminuyó de 2010 a 2019, mientras que el ESG surgió durante y después de la pandemia. El análisis de palabras reveló el impacto de hashtags específicos: RSC en español, #CSR en inglés y #ESG en portugués. Las crecientes preocupaciones de la sociedad incluyen temas ambientales para combatir el calentamiento global y asegurar una mejor calidad de vida; sin embargo, el aspecto social del ESG, representado por la letra 'S', no ha recibido la misma atención que los aspectos ambientales y de gobernanza.

PALABRAS CLAVE

ESG, RSC; Medios Sociales; Twitter.

1. INTRODUCTION

According to Nascimento (2021), in recent decades, there have been several discussions on Environmental, Social, and Corporate issues due to the critical role that small, medium, and large organizations play in society. In this context, it is essential to consider the "user perspective," which refers to how individuals and stakeholders perceive and are impacted by these organizational practices. As highlighted by Lacombe (2015), many organizations focus on producing goods or providing services not solely for profit but also for the positive impact they can have on society as a whole.

Teodósio (2018) conceptualizes CSR (Corporate Social Responsibility) as the obligations of entrepreneurs and managers to pursue policies and decision-making that align with societal values, thereby exerting significant influence on people's lives, addressing economic and social imbalances, and assuming specific responsibilities towards society.

ESG (Environmental, Social, and Governance) assesses the extent to which an organization contributes positively to society, going beyond mere profit maximization to encompass practices that benefit the environment, society, and the organization in a sustainable manner (Cruz, 2021).

Cruz (2021) found that companies adhering to robust ESG practices aim to minimize environmental impacts. This focus extends to better care for society, respecting differences, promoting diversity, equality, and social inclusion. These practices are crucial in the present time, emphasizing transparency and accountability in organizational policies and actions.

According to Gomides (2009), the need for transparency in political decisions and societal involvement in decision-making processes, known as governance, is evident. Governance emerged from the World Bank's reflections, which deepened the understanding of creating more efficient states.

From the study presented, it is noted that CSR and ESG, as identified through literature review, have become increasingly complementary over time. This evolution reflects updates in thinking, technology, corporate practices, and the everyday needs of corporations seeking to sustain themselves and gain a competitive advantage (Gomides, 2009).

This work aims to investigate how the debate between CSR and ESG has evolved on Twitter from its inception to 2022, particularly focusing on societal perceptions of these topics. The study is confined to analyzing the evolution of thought from CSR to ESG, addressing updates in information and organizational practices. Data collection was performed on social media (Twitter) through extraction using Python and analysis with R software, focusing on public perception in three languages: Portuguese, Spanish, and English.

This study is significant as it provides insights into societal perceptions of Social and Corporate Responsibility and the emerging ESG theme. It aims to evaluate whether companies are acting ethically and transparently, beyond mere profit motives, and to understand the practical applications of these techniques. By examining their impact on working conditions, employability, sustainable development, and economic growth, this study contributes to the discourse on responsible corporate practices.

2. THEORETICAL FRAMEWORK

2.1 Analyzing the Origins of CSR and ESG

Contemporary studies focused on Social and Corporate Responsibility were significant after the evolution suffered in industrial society. All the scientific studies originated since that time, collecting diverse thinkers and researchers such as Henri Fayol, Frederick Taylor, Adam Smith, and Max Weber, among others, and theories such as Scientific Management, Classical Theory, and Human Relations Theory, among others, as pointed out by Porter (2004).

According to Tenório *et al.* (2011), the first theoretical studies developed after the post-industrial period emerged in 1950, but only after 1970 that the works gained prominence. However, in this context, they developed a study to propose the term "public responsibility" because they understand that social responsibility is a function of the management of organizations in the context of public life, showing the difficulty of identifying and defining the limits between what is public and what is private in the business field.

In the 1980s, the concept of Social Responsibility underwent a makeover when faced with the argument of globalization, covering itself with rules that favored the market. It invoked liberal ideology and mentions that the market regulates and supervises business activities, preventing abuses and actions by organizations that harm the operating environment (Tenório *et al.*, 2011).

In this way, according to Finatto (2022), from the 1980s onwards, companies globally began to act not only thinking about the profit obtained or to be obtained but

also to adopt social and environmental actions that would bring benefits not only the organization's image but as a more significant achievement perceived in the long term applied directly to society.

Rubim (2021) also reports that in the late 1990s, the United Nations (UN) prepared the Global Compact, with several issues involving ethics and morals within the business scope (taking more significant proportions on the subject). This document recommends that business people consider several applications of rules and actions involving principles on human rights, labor, and environmental issues. In this way, this document was a precursor to the object of Social Responsibility.

Another widely used term, Triple Bottom Line, is considered a self-sustaining theme, as Elkington (2018) mentioned. This concept, also known as the Sustainability Tripod, was developed by the British sociologist John Elkington in 1994, establishing that environmental and social performances should be implanted in the financial statements of companies, making an analytical comparison of their benefits, considering the ecological dimensions, social and economic system, explored. Three pillars form the basis of this method: People, Planet, and Profit - the 3 Ps of sustainability.

The term ESG (Environmental, Social, and Governance), as evidenced by Cruz (2021), has been widely used to refer to companies that adopt this model as a strategy or nominate themselves for investment funds. According to Barney (2017), new acting methods have become essential competitive strategies for an organization's health. The role of process innovation in more mature sectors, whether or not within a specific niche, is of great value for business growth. Thus, assessing a company's external environment and analyzing the threats and opportunities that organizations face must begin with assessing the general environment in which it operates and, in this context, which may impact all strategic choices.

ESG is a subject that has been introduced previously. This sensitivity has existed for decades. The big news is the translation and application involving the three words that comprise this acronym. Corporate environments have come to treat this issue as one of the most important lately, mainly due to the global objective of wanting to make the world a better place. This acronym has become synonymous with sustainability, becoming a strategic issue among organizations (Cruz, 2021).

However, how did the term ESG come about? According to Pacto Global (2022), the term was first seen in 2004 in the Global Compact in the United Nations (UN), in reports to implement the idea in organizations regarding the adoption of principles in areas of human rights, work, environment, and anti-corruption, with more transparencies and ethics, in partnership with the World Bank, called "Who Cares Wins" (in free translation, "Win who cares"). At that time, the then UN Secretary-General Kofi Annan encouraged and attacked the 50 presidents of critical financial institutions on how to act and integrate social, environmental, and governance factors in the capital market.

According to Belinky (2021), it is critical to highlight the difference between ESG and CSR, verifying the main inequalities between these concepts, proposing criteria that address their applications in organizations, and even considering their similarities when the theme involves socio-environmental responsibility, reputation, and credibility, considering the so-called SDGs (Sustainable Development Goals), a term used by the UN.

Loureiro (2021) identifies in his studies that sustainable development is a need for the world to make better use of raw materials over the years. Concern about climate issues has become something essential and recurrent in recent times, causing investors to demonstrate reasons for implementing actions for this purpose aimed at better use, as occurs with the replanting of forests carried out by loggers after the extraction of trees.

According to Moche (2021), all that investment based on ESG brings the importance of organizations to social and governmental responsibility and the results of the impacts of their actions on society, reducing risks related to financial disasters caused by environmental and political crises. In addition, there is the other extreme aimed at investors, who rely on ESG for decision-making, conducting their business on critical assumptions such as: 1) Climate change; 2) Toxic components; 3) Sustainability Reports; 4) Attracting and retaining talent; 5) People development; 6) Quality of life improvements; 7) Incentive to volunteer work; 8) Promotion of code of conduct; 9) Commitment to value creation; 10) Guarantee of efficient risk actions.

2.2 A Discussion About the Evolution of Concepts

In his studies, Carvalho (2018) confirms that corporate governance originated from debates stemming from the Classical Agency Theory. In this theory, the owner assigned actions to an administrator who made decisions about the companies he worked for and undertook various tasks contributing to the ultimate business objectives. Over the years, these activities have undergone improvements that,

influenced by technology, have adapted to various business activities worldwide, such as the advent of the Internet, cell phone applications, websites, and payment methods.

Tkatch (2021) identifies that since its emergence in 1950, the concept of Social and Corporate Responsibility has evolved along with several other theories that permeate those related to business administration. Since then, the academy has discussed topics, practices, and tools that enable companies to act fairer toward society.

Tachizawa (2019) also identifies some main strategies normally applicable to organizations over time, such as reducing energy use; reduction of water use, with recovery or recycling of water; reduction in the use of raw materials; change in storage, transport and handling procedures; selectivity of environmentally correct suppliers; social, cultural and educational projects. These implementations vary according to the performance and activity of each organization as they develop different policies to meet these needs.

Still, according to studies by Tkatch (2021), CSR has its first literary record in the book Social Responsibility of Business Men by Bowen (1953). In this work, the author assumed that, in the figure of an entrepreneur, the organization's responsibility goes beyond its corporation, treating CSR as the business people's obligation to pursue policies and take decisions and actions in favor of society's objectives and values.

In this way, Bowen comes to be considered the father of corporate social responsibility by many researchers. The historical analysis imposed still presents the expansion of the concept when it gains new contours, expanding the area's vision. Keith Davis contributes by introducing voluntariness to this theme, stating that men's decisions go beyond direct economic and technical interests (Davis, 1973).

In 1963, the ideas of justice, citizenship, and ethics began to be discussed more in the corporate environment, causing Joseph W. McGuire to bring the concept of corporate social responsibility to the fore. It reinforces the idea that organizations are part of a whole that makes up society and, thus, have a responsibility to everyone (Carroll, 2010).

Since the 1970s, several productions of concepts and discussions on this theme have developed. Carroll (2010) also includes in this relation the treatment of philanthropy and relations with the community, noting that companies view the public's perspective of interest as a matter of concern. The Economic Development Committee discussed highlighted subjects in 1971, particularly the Social Responsibilities of Business Corporations, stating that three prominent circles explain all production:

- • First circle: as being more internal, focused on the efficient execution of the economic function, production of goods, quality, jobs, and growth;
- • Second circle: the economic function with sensitive knowledge of changes in values, prioritizing society;
- • Third circle: more external, dealing with the responsibility of companies, assuming the involvement of activities to improve the social environment.

In the 1980s, according to Carroll (2010), other themes emerged from those discussed in the 1970s: corporate social responsiveness, social and public responsibility policies, business ethics, and the theory of stakeholders.

Loureiro (2021), when dealing with the subject of this theory, highlights the word's etymology as something fundamental. The term "stakeholder" refers to individuals or organizations with economic value, regardless of whether they assume responsibility for a specific value that will undergo distribution following the resolution of a particular event. With this, stakeholder theory describes which agents serve as stakeholders of a given company or institution. It proposes methods that administrators should use to follow through with appropriate actions to comply with the interests of these agents.

Thus, the company must convert the invested amount into inputs and use them to produce products that have the potential to be sold in the market, generating a financial return. Following this line, the theory proposes a strategy that aligns the economic view of resources with the economic view of the market, incorporating a sociological and political view of society.

Nevertheless, Jones (1980) makes one of the main contributions in this last period, treating social responsibility as a process rather than a set of organizational results. CSR becomes the theory discussed and debated by the academy on this theme, practiced by the institutions in the corporate day-to-day, highlighting the managerial criteria in decision-making.

Soon, there is a strong and growing environmental concern. In 1987, in the Brundtland Report, coordinated by the then Prime Minister of Norway, Gro Harlem Brundtland, the World Commission on Environment and Development disseminated the idea of sustainable development. In this CSR environment, the report entitled Our Future highlights the importance of the present need without compromising

future generations (Comum, 1991).

Following this historical panorama, Wood (1991) revisits essential concepts such as legality, public responsibility (where companies face penalties for their social and environmental impacts), and managerial criteria (where decision-making is grounded in moral criteria).

In his studies, Tkatch (2021) analyzes that globalization is responsible for this phenomenon's rapid growth. He relates the increase in purchasing power of small private, transactional, and multinational groups with income concentration and significant social exclusion. Thus, from the perspective of the public impacted by the organizations, there is an expansion on a global scale because of the need for socially responsible action.

In 2010, in Brazil, for example, ISO 26000 for social responsibility was created, involving 450 specialists from 99 countries, contributing to a set of criteria that led to a consensus on how companies should act to be socially responsible, setting guidelines common goals, guiding all organizations towards this purpose (Marques, 2020).

Loureiro (2021) further aligns with his studies that companies began to feel pressure from their partners to be more concerned with stakeholders. For example, on the stock exchanges, it is perceived that decisions have little impact on those involved or interested parties. It shows that the price ratio of a share after a significant event affects both the environment and the company's internal issues or other sensitive points in society.

As a result, the author, as mentioned earlier, points out that there is a more excellent perception of the social and environmental impact, with the need for investments by companies aligned with the theme. Soon after, the ESG agenda began to gain momentum. There is a concern with valuing companies, the well-being of stakeholders, and total social interest.

Still, considering the premises set forth by Loureiro (2021), one can mention the inclusion of socio-environmental issues in companies' portfolios and the focus on the outcomes achieved in decision-making. This focus aims to prevent environmental and social harm, as seen in organizational accidents resulting from neglecting necessary reviews, treatments, and actions to address potential errors that might arise.

2.3 The Color Washing Phenomena: Green, Rainbow, Brown, and Whitewashing

Greenwashing, also referred to as "greenwashing," is a term that has gained significant traction in recent years. It serves as a cosmetic alteration undertaken by companies aiming to conceal their true intentions regarding the organization's stance on socio-environmental responsibility as perceived by society.

The “sold” image of the company as value and economic growth and concern for the environment is that it practices socio-environmental solutions, but this is not exactly what happens, as verified by experts (Tachizawa, 2019). This debate began in the 1990s in the United States due to the circulation of expressions such as "sustainable," "eco-friendly," "environmentally correct," and "green" associated with products and services that many times were not related to the good practices, which can be something very superficial and without real impact on the environment (Cruz, 2021).

Therefore, the Federal Trade Commission (FTC) guides were created in the United States with green marketing "Green Guides" requirements to contain these frauds. In Brazil, there is no regulation similar to the American one; however, companies are subject to the Consumer Protection Code, particularly the articles dealing with misleading advertising (Rotman *et al.*, 2021).

Currently, instances have come to light where corporations employ self-generated reports founded on fictitious data to cultivate a favorable image in front of the market, society, and their respective stakeholders, thereby enhancing their perceived value. Companies engage in this practice within standalone ESG reports needing consistent social and environmental records. The great popularity of ESG has made organizations look for more accessible means, disguising true corporate interests, neglecting activities, and using social responsibility as a marketing gimmick, as seen by Sampaio (2021).

Asserting that a product is "green" without substantiating its environmental claims, intending to attract investors and customers, and often displaying this information on packaging or in service promotion, even when knowingly false, results in actual harm and non-compliance with legal standards. Such actions violate transparency and truthfulness norms related to information, and they also create unfair competition in the market against organizations that genuinely engage in proper activities. Hence, consumers ultimately experience deception, as Sampaio (2021) indicates. In this way, companies that perform greenwashing, for the most part, aim to bring greater profitability in a smaller space-time without significant expenses.

Today, greenwashing has been considered one of the most destructive practices practiced in the market, as it harms, by deceiving, consumers and investors, including society as a whole. Society has been very concerned with issues related to the social and environmental environment, and many have avoided directing their resources to companies that do not comply with ESG practices (Nascimento, 2021).

In this way, Nascimento (2021) still perceives that the failure to seek loyal and legal practices violates the professional ethics of private law, harming the entire financial market, as it causes long-term losses that are difficult to reverse when identified. It is worth emphasizing the government's importance in creating punishment methods through fines for companies that do not adequately follow the regulations in force on this subject. Through punishments, companies will bring the desired results. However, it is also perceived that the more regulation, the greater the strategies to circumvent the law, with less effectiveness.

Therefore, when common sense aligns with cultivating an ethical intent grounded in awareness of sound legal practices, the outcomes yield advantages for the community. Voluntary endeavors foster a moral consciousness that transforms social conduct alongside generating favorable financial outcomes (Sampaio, 2021). According to Cruz (2021), the best governance practices added to corporate ethics and good socio-environmental actions, with responsibility and transparency, become essential for economic and strategic health in business, with excellent chances of being perpetuated in time.

Rainbow washing, or Pinkwashing, is a movement practiced by many companies in order to minimize diversity related to gender choices, helping, in a way, LGBTQIA+ communities, UN (2023). According to the UN (2023), the sustainable development goals in Brazil (SDGs) have become a global call to eradicate several issues, and one of them would be to equalize the issue of gender equality in society, not only in companies but also in society community, as highlighted in the 2030 Agenda.

Whenever the month of June arrives, many companies change their logos, adding the colors of the rainbow to raise this flag. However, does it work positively for the LGBTQIA+ community? This trend is often seen as superficial, making it difficult to understand the actual situation of those involved in this issue, as Rodríquez and Pernias (2023) described.

In the case of Brownwashing, it applies to all those black, brown, indigenous, and non-ethnic groups. Like the other cases mentioned above, these are actions of companies in which, in a disguised way, they try to implement practices to give strength to this group of people with the support of society. Nevertheless, they must act correctly with these people in the organization's day-to-day, not equalizing salaries or promoting those who deserve it, UN (2023).

In the case of whitewashing, after a particular tragedy, a particular organization tries to disguise what happened through another action. For example, a fire where people are injured, and after that, the company donates supplies to orphanages, advertising as a "good deed," without paying due compensation to the accident victims (Rodríquez, 2023).

Thus, it is clear that many organizations try to make up a situation through so-called color washing, trying to promote actions to gain popularity with society and thus gain market share. It harms the market and invalidates the real intention of the CSR and ESG movements, which aim to develop work that will benefit society, organizations, and the world's future (Da Silva, 2020).

We will not delve into these subjects further to ensure we stay focused on the debate between CSR and ESG. However, the importance of and the vast field available for research and study to address and comprehend the challenges within this realm is evident. In this manner, companies and society should discuss how to address the issues related to these matters in the coming years.

2.4 The Influence of Social Media on the Corporate Governance Environment

According to Pereira (2021), communication is a natural characteristic of human beings, being well intermediated by the media that provide new forms of expression, which can be through sounds, texts, and images. Another way of characterizing the word “media” is all the support a physical medium can provide, whether through VHS tapes, CDs, DVDs, or other means of propagation such as radio, television, and newspaper. Therefore, regarding its nature, through printed, electronic, and digital media.

In other words, according to Perassi (2019), media is every mediator system that relates man or technology to create, store, and exchange information among all those involved and interested. Thus, it is clear that the advancement of technology has also made information better disseminated at all times and that relationships between people and organizations have become closer, bringing ideas and opinions about different events closer together, as seen by Mahon (2021).

Nose (2018) points out that social media are another tool in the continuous process of communication between the whole society, considering organizations and people, diversifying opinions, and disseminating information, which may or may not shape a group or community, in addition to being a source of research and studies.

Still following this line of reasoning, Fermann (2021) stresses in his studies that communication is a basic need that accompanies human beings from birth. Communication involves the development of various strategies to express feelings, opinions, desires, and needs. Social media, in the digital-technological field, such as using the Internet on computers and smartphones, have become an excellent tool for this and are currently paramount.

Given the above, De Lima (2021) also verifies the impact of social media on the population with the continuous use of social media. The population's need to communicate is continuous, causing impulses and people's dependence on these tools. Information disclosed by celebrities, organizations, and digital influencers becomes debates and models of thought and emotions when well discriminated, trained, with regulated sources, resolving doubts and offering the exchange of criticism subject to corrections when well highlighted. Even so, social media can become a realm in individuals' lives requiring interpersonal relationships and physical interactions, potentially leading to societal psychological issues.

Nose (2018) also defines that social media influences companies and their attitudes in negotiations, dissemination of information, and day-to-day internal and external activities because of the image they want to pass on to the population. This influence is perceived daily as a thermometer of society's opinions concerning various subjects and themes, being able to verify the reflection and result of its actions almost immediately, without the need to implement more elaborate field research, avoiding the waste of time when it comes to something more superficial or immediate. Such influence is also present in many organizations that must create, review, and program new means of communication with their stakeholders to develop decision-making forms that must consider how individuals access information.

Another point to consider is the so-called "mass media" from newspapers, magazines, cinema, and television. Today, applications also use these tools to spread information, making mass communication through podcasts, posters on social media, and Twitter, among others, as Nose (2018) exposed.

Companies widely use Twitter to disseminate and retransmit articles related to specific topics mentioned or published in other media, for example, on the Internet. As exposed by the company Twitter (2022) on its website, a great way to promote it would be through visual aids. With good images as part of the organizational campaign, more people can be attracted and thus publicize a brand, opinion, and various information, giving "up" in a particular event.

According to the Brazilian Institute of Corporate Governance, IBGC (2022), the basic principles of corporate governance permeate all practices of the 'Code of Best Practices of Corporate Governance' and its better adaptation and implementation to organizations' policies. Therefore, it is essential to remember that these practices include Transparency, Equity, Accountability, and Corporate Responsibility.

When using tools such as Twitter, it is clear that there is a need to correlate the information provided with the good practices of good corporate governance indicated by the IBCG, maintaining reliable data and pre-established information disclosure policies, preventing partners and investors from being penalized for misinformation, also preventing them from being disclosed prematurely, preserving what is said to be confidential, in order to prevent asymmetries and leakage of relevant or privileged information that affect organizations or any strategic action of companies, as adopted by the Code of Best Corporate Governance Practices at IBGC (2015).

For Fermann (2021), it is possible to perceive that Information and Communication Technologies (ICT) have increasingly gained space in the proliferation of content due to the ease of access by the population. It generates value and develops new practices, norms, and rules regarding governance.

With the current need for a better world, with education, health, and safety programs that add value not only to companies but to society as a whole, organizations have developed various advertising and marketing actions to meet this need in the present with a long-term vision (Mahon, 2021). This continuity reflects the organization and the need for a more dignified society, with more apparent objectives in its activities, transparency, and equity in the business, without leaving aside social and environmental issues.

3. METHODOLOGY

The research aimed to analyze the evolution of the debate on CSR and ESG on Twitter. We employed a descriptive,

quantitative, and qualitative approach to achieve this objective. In the qualitative approach, the most common and popular opinions and characteristics concerning the subject studied will be verified based on engagement rates of the most used words in the general context practiced on Twitter. Based on this, we will quantitatively investigate the aspects observed earlier.

In order to achieve the results, as there is no defined target audience, it was decided to use social media for data collection. The choice was made due to the great popularity and availability of concrete and current opinions, in addition to the transparent and immediate observance that one can have and, according to Soares and Recuero (2017), because it is a place of construction of public opinion.

For the research, we chose Twitter since it is possible with this social media to collect information in a more accessible way, considering that it circulates information more openly due to the simultaneity of its publications, according to Soares and Recuero (2017), society can express what they are thinking, with the exchange of information through small texts, contributing to the debate of various topics.

In addition, according to Marques (2020), Twitter is a platform that allows the publication of short but relevant content with easy access to current trends by associating different types of content with published and disseminated hashtags. Twitter also allows circulation in addition to Tweets, reposts by Retweets actively, and execution of mentions through the '@,' making the platform increasingly democratic and public. In this social media, the character limit is 280 per Tweet. Its contents are usually objective and focused on specific subjects, facilitating search queries or reuse on different platforms where users want to make the same publication.

To extract the information from the Tweets, an API Web Crawler developed in Python was used to collect the initial research data. After that, we made data processing using R programming to refine the information. According to Moraes (2019), a Web Crawler is an application developed to automatically extract data and access information from internet pages through copies found on the visited pages. It is widely used by search engines such as Google.

For this study, in the Web Crawler, we intended to base on a more advanced and refined search on Twitter in the three main languages (Portuguese, English, and Spanish) to verify the presence of this theme around the world for identification and extraction of Tweets that contained the words CSR, RSC (the same as CSR, but in Portuguese and Spanish) and ESG, in addition to those that presented contexts similar to the theme between the period of creation of Twitter until 2022. year for calculating two indices: (1) Popularity = Number of likes ÷ Tweets and (2) Virality = Number of Retweets ÷ Tweets, demonstrating public interest in the subject. After verifying and calculating the evolution of this engagement over the period studied, we understand the fluctuations of publications made, thus aiming to identify the increase or decrease in the relevance of the subject studied.

In the next point, we developed a treatment of the content collected through the API Web Crawler with Phyton, treated by the 'R' programming, thus eliminating the unnecessary part of the search for a more qualitative approach, listing the most relevant words. Example: connecting words, or those in the same context as others already identified, enabling the identification of the main terms most present. For this purpose, we will determine a sparseness index of 99%, which implies cutting the words appearing in less than 1% of the Tweets.

The sparseness index, or scarcity index, is used to eliminate words or objects that appear less frequently, and in this case, in the collected publications, being discarded from the analysis because it is considered of low impact, in addition to being considered meaningless for the study (called stop words), being present in sentences only to give meaning or contextual value.

In this way, we unfolded the results, identifying which terms became more present within the searched period and classifying their words according to their similarities. With the segregation of the identified words through quantitative analysis, with qualitative understanding, it is intended to understand how individuals perceive subjects such as CSR and ESG employed by organizations and their reflections in society in Portuguese, English, and Spanish.

4. RESULTS AND DISCUSSIONS

4.1 Engagement Index (Popularity x Virality x Number of Tweets)

The intention is to demonstrate a general overview of the evolution of the debate in this first analysis. The themes followed the North American trend for all the languages. The following sections will evaluate the particularities of the Spanish and Portuguese languages.

In Table 1, it is possible to observe that searches with the "hashtag" for the term CSR had a more significant impact in terms of popularity and Virality, as they began to draw more attention earlier than the word without

the "hashtag" that is, since 2010 it has presented a more accentuated growth of both indices (popularity of 0.147 and Virality of 0.051 with 19,599 Tweets). For the search without the "hashtag," it is observed that 2018 initially presents a more accentuated growth of both indices (popularity of 0.055, Virality of 0.312, and 64,631 Tweets), with more Tweets compared to 2017.

Around 2010, some factors contributed to awakening the interest of social media in CSR. Some relevant facts include, for example: growing concern with socio-environmental issues like the United Nations Conference on Climate Change - COP15 - in 2009, growth of the environmentalist movement "Fridays for Future" led by activist Greta Thunberg with growth at the end of 2009; increase in public awareness with the documentary "An Inconvenient Truth" starring former Vice President of the United States Al Gore, released in 2006, continued to influence public opinion and generate discussions on the subject; corporate scandals and lack of trust in business (BP and the Gulf of Mexico oil spill in April 2010; Toyota and vehicle recall in 2010; Goldman Sachs and the Abacus case in 2010; Hewlett-Packard and the espionage case also in 2010); among others.

In Table 2, the ESG repeated the pattern seen in the CSR of more significant popularity for the search term with the "hashtag." For both cases involving ESG, the year 2015 can be perceived as being the most accentuated growth of both indexes, both for ESG (popularity of 0.545, Virality of 0.818, and an increase in the number of published Tweets of 22% compared to 2014) and #ESG (popularity of 1,326, Virality of 1,246, with a significant increase in the number of published Tweets of 41.88% compared to 2014).

Around 2015, some factors contributed to awakening the interest of social media in ESG. Some relevant facts include, for example: increased awareness of social and environmental issues (Paris Agreement in December

Search by CSR			
Year	Popularity	Virality	Nº Tweets
2007	0	0,033	30
2008	0	0,044	410
2009	0,017	0,077	9.171
2010	0,147	0,051	19.599
2011	0,183	0,041	24.345
2012	0,252	0,062	29.956
2013	0,306	0,213	29.436
2014	0,421	0,399	31.912
2015	0,525	0,602	37.375
2016	0,491	0,847	37.934
2017	0,697	1,433	32.314
2018	1,118	2,818	39.027
2019	1,388	4,428	34.608
2020	4,718	1,342	33.139
2021	5,704	1,593	24.401
Total	1,265	1,228	383.657

Search by #CSR			
Year	Popularity	Virality	Nº Tweets
2007	0	0	0
2008	0,057	0	53
2009	0,088	0,021	14.559
2010	0,055	0,312	64.631
2011	0,079	0,406	104.699
2012	0,082	0,406	159.113
2013	0,233	0,486	158.845
2014	0,53	0,597	159.318
2015	0,723	0,731	163.768
2016	1,149	0,98	142.468
2017	1,624	0,894	129.549
2018	2,283	1,017	115.396
2019	2,986	1,044	93.273
2020	3,111	1,001	66.791
2021	4,244	1,213	170
Total	1,127	0,715	1.422.633

Table 1: Corporate Social Responsibility Engagement Index in English.
Note: Popularity = Likes/Tweets; Virality = Retweets/Tweets. Source: Developed by the Authors.

Search by ESG			
Year	Popularity	Virality	Nº Tweets
2009	0	0	12
2010	0,054	0,071	56
2011	0	0,333	45
2012	0,05	0,363	80
2013	0,15	0,271	133
2014	0,239	0,427	117
2015	0,545	0,818	143
2016	1,057	1,166	175
2017	3,952	3,195	231
2018	5,51	2,106	822
2019	3,106	1,204	1.147
2020	3,586	1,186	1.554
2021	5,655	2,029	2.756
Total	4,192	1,614	7.271

Search by #ESG			
Year	Popularity	Virality	Nº Tweets
2009	0,018	0,012	164
2010	0,06	0,226	1.572
2011	0,04	0,204	6.120
2012	0,084	0,328	13.030
2013	0,238	0,547	15.880
2014	0,56	1,013	14.950
2015	1,326	1,246	21.212
2016	1,282	1,166	31.397
2017	1,484	1,281	40.922
2018	2,129	1,056	50.370
2019	2,452	0,947	66.185
2020	2,875	1,035	101.918
2021	4,448	1,325	184.019
Total	2,782	1,114	547.739

Table 2: ESG Engagement Index (Environmental, Social, and Governance) in English.
Note: Popularity = Likes/Tweets; Virality = Retweets/Tweets. Source: Developed by the Authors.

2015; Black Lives Matter Movement in 2016; Sustainable Development Goals (SDGs) in 2015); corporate scandals and lack of transparency (Volkswagen scandal in September 2015, Wells Fargo scandal in 2016 and even Petrobras scandal that reached its peak in 2016); just as the rise of younger generations, such as millennials and Generation Z, has brought a new mindset regarding corporate social and environmental responsibility.

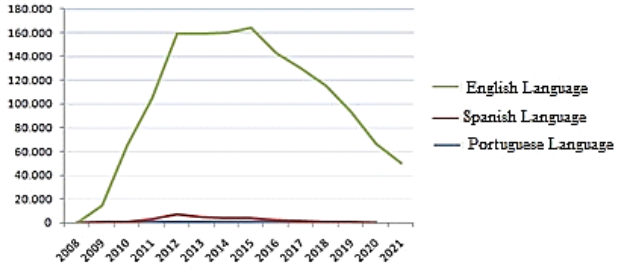
Comparing Tables 1 and 2, it is still possible to note that the decline in popularity of the RSC in 2019 follows the gain in popularity of the ESG, which begins a significant climb in 2020 and 2021. We believe that some factors may have contributed to this issue, such as: the perception of change in terminology and expansion of scope (the term ESG may have been considered more current and comprehensive compared to CSR by individuals); increased attention to sustainable investing, i.e., investors began to consider ESG factors when making investment decisions, as well as with the creation of the significant ESG funds in 2019 (such as BlackRock's Global Impact Fund, J.P. Morgan's Global ESG Enhanced Index Fund, Vanguard's ESG U.S. Stock ETF and State Street Global Advisors' ESG Dividend ETF); global social impact events (Global Climate Strike in 2019; and UN Climate Action Summit in 2019); as well as a growing trend of publications of sustainable reports on exchanges (in Brazil, for example, it was observed in Carvalho *et al.* 2023).

4.2 Analysis of the Words that Appeared Most Often in Collected Tweets

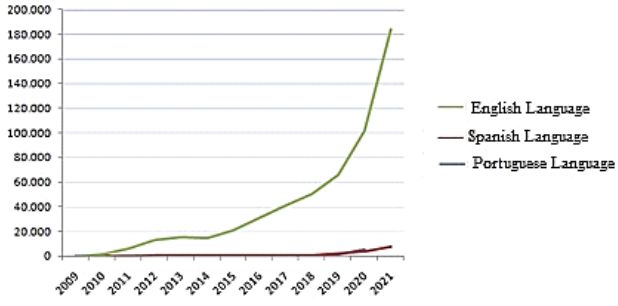
When we analyzed the collected words individually, we noted that, in the general total during the period, in Portuguese, the term #ESG appeared with a general percentage of 58.20%; in Spanish, the RSC appeared at 58.78%; and in English, the #CSR with 50.14 %.

It is also interesting to check the history of total Tweets in the three languages surveyed considering the themes #CSR and #ESG (the most popular ones with the use of "hashtags") shown in graphs 1 and 2 (which reflect the information presented in tables 1 and 2).

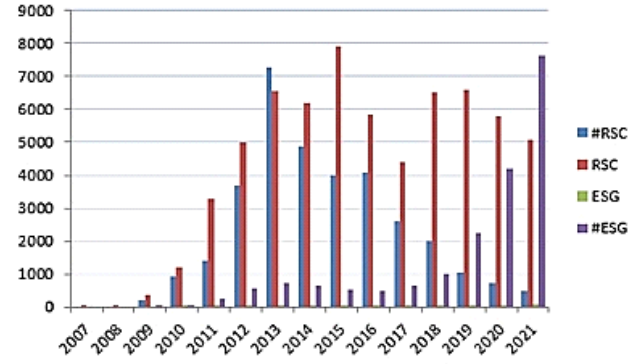
By further exploring the number of Tweets in Portuguese, Graph 3 shows greater prominence of #ESG compared to the other words, mainly from 2020, considerably in 2021. We noted that Brazil, even before the pandemic period, did not highlight issues involving ESG issues. This interest is considered essential within the population, with a focus on well-being, healthy living,



Graph 1: #CSR - Number of Tweets.
Source: Developed by the Authors.



Graph 2: #ESG - Nº Tweets.
Source: Developed by the Authors.

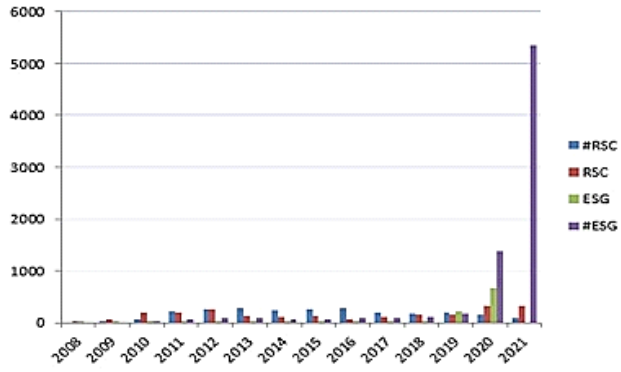


Graph 4: Nº Tweets (Spanish).
Source: Developed by the Authors.

and ethical interpersonal relationships being prioritized. Additionally, there is an emphasis on the necessity of environmental care to ensure the coexistence and perpetuity of society within nature.

Concerning the number of Tweets in the Spanish language, Graph 4, we observed that the RSC theme had a greater prominence. While #RSC Retweets decreased with time, there was an increase in ESG popularity, similar to what we observed in the previous case seen in Graph 3.

Finally, in the English language, it was noticed in Graph 5 that the #CSR theme had a greater prominence,

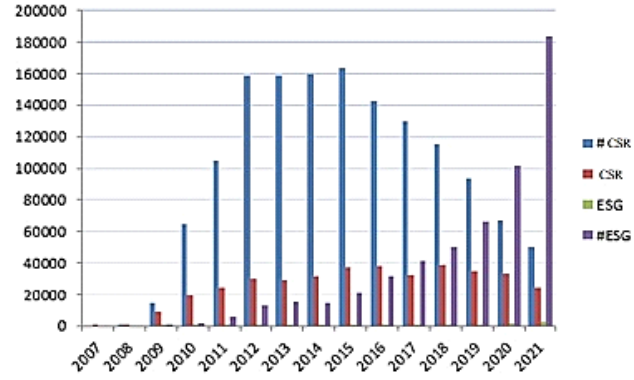


Graph 3: Nº Tweets (Portuguese).
Source: Developed by the Authors.

showing a continuous decline since 2015 when the #ESG was introduced and beginning to gain strength to surpass it over the years analysis periods.

Regarding the formation of word clouds, the research identified that over time, it gained greater sympathy with the theme involving subjects such as environmental responsibility and corporate governance by society, incorporating in each person the interest in actions involving ESG, as seen in Figure 1.

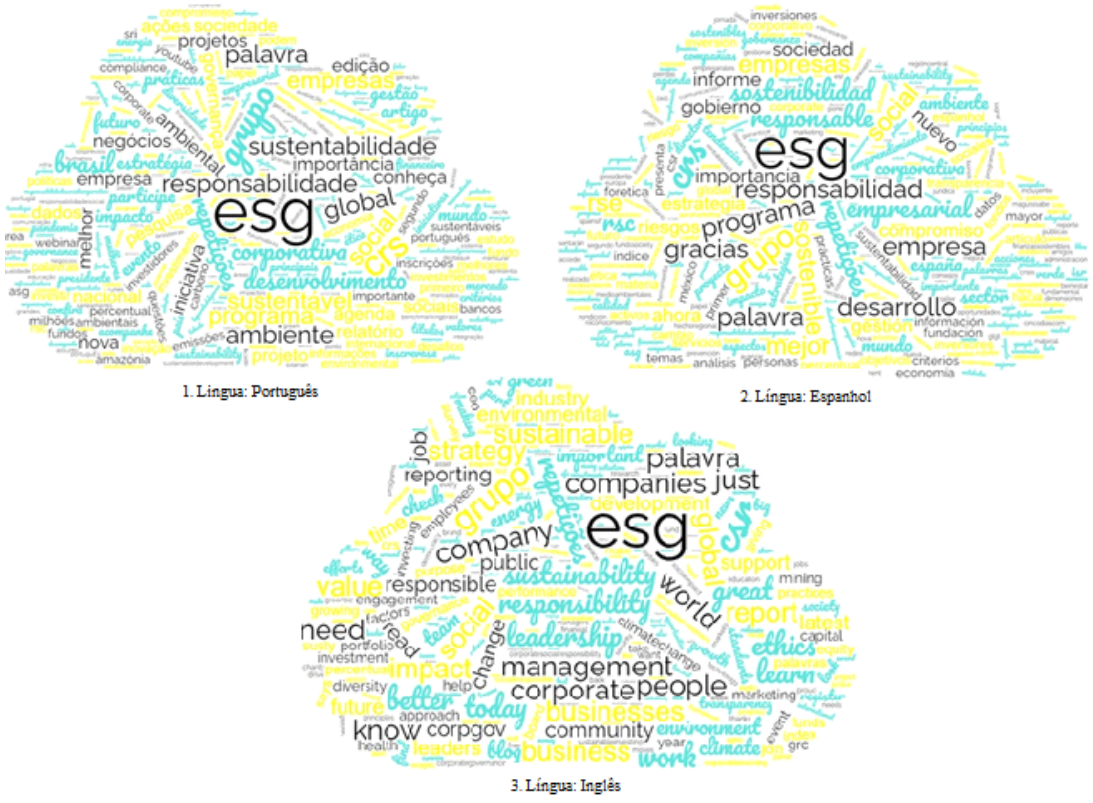
The analysis of the word clouds presented in Figure 1



Graph 5: Nº Tweets (English).
Source: Developed by the Authors.

of the study highlights a growing interest in well-being, health, environment, governance, and ESG, indicating an increasing public concern with these issues. However, a more in-depth analysis reveals a notable absence of the social aspect, represented by the letter "S" in ESG, which does not appear with the same prominence as the other concepts. This gap warrants a more detailed investigation to understand the possible reasons behind this absence and its implications for understanding and communicating ESG and CSR topics.

To better explore this issue, it is essential to deepen the qualitative analysis of the emerging word clouds by examining the context in which the words appear and the frequency with which they are used compared to others. For example, "health" and "well-being" could be explored to determine whether they are predominantly mentioned in positive contexts, such as health promotion campaigns,



1. Língua: Português 2. Língua: Espanhol 3. Língua: Inglês

Figure 1: Word Clouds in the three languages.
Source: Developed by the Authors.

or in negative contexts, such as criticisms of inadequate healthcare infrastructure. This contextual analysis could provide insights into public perception of these topics and their relevance in current discussions.

Similarly, terms associated with corporate governance and ESG can be investigated to determine if their usage is predominant in institutional discourse or appears in community and individual discussions. This analysis could reveal whether there is a broader interest in governance and sustainability topics or if these themes are restricted to business and academic circles. Furthermore, a network analysis of the word clouds could help understand how different themes are interrelated, highlighting possible emerging subtopics that need to be discussed in depth. For example, if there is a strong association between terms like "environment" and "governance," this may indicate that sustainability debates frequently include discussions about responsible governance practices.

Another aspect that deserves attention is the discussion about greenwashing and similar processes introduced in the article. Greenwashing refers to deceptive practices where organizations promote themselves as environmentally responsible without adopting sustainable practices. The analysis of the word clouds could be expanded to investigate whether there are mentions of terms related to greenwashing and, if so, how these terms relate to the rest of the discussions on ESG. If these terms do not appear in the word clouds, this might suggest a lack of awareness or public debate, an important observation that would merit further discussion.

It is crucial to consider several possible hypotheses to address the gap identified in the representation of the social aspect in ESG discussions. One hypothesis is that the absence of terms related to the "S" in ESG may reflect lower visibility of this aspect in public and social media discussions. This may result from a lack of awareness or a lower priority given to social issues on the public agenda. Another hypothesis is that social problems, although equally important, are more complex and multifaceted, making them more challenging to address meaningfully and engage the public in productive discussions. The lack of engagement with social issues may also reflect a more individualistic perspective or a lack of consensus on which social problems should be prioritized.

To better understand the need for more attention to the social aspect and its implications, it would be necessary to conduct additional investigations and qualitative analyses of social media interactions. Analyzing posts, comments, and debates that use terms

related to ESG topics could offer a richer and more detailed understanding of how the public perceives and discusses these concepts. A qualitative analysis of these interactions could reveal, for instance, whether discussions about "health" are predominantly positive or critical or how discussions on "governance" vary among different stakeholder groups.

5. CONCLUSIONS

The research aimed to analyze the evolution of the debate between CSR and ESG on Twitter from the user's perspective since its creation until 2022 to understand how society perceives this theme.

The results showed that society's perception of the debate between CSR and ESG is very present in the public's daily discussions, showing a growing concern about the Environment, Society, and Governance, dealing with issues relevant to various daily problems, both in companies and in the community worldwide, when checking the three main languages such as Portuguese, English, and Spanish.

Thus, a substantial question was raised in the perception of the need, through reflection, that it is necessary to change thoughts, with the possibility of changing old practiced activities, adapting and improving them to result in a better world. This study contributes to exploring this discussion in the Brazilian and global context, offering evidence about the expectations generated by public opinion on the subject in social media, where Twitter users generate comments spontaneously and sincerely.

After collecting data, it was possible to verify certain aspects regarding engagement – Popularity x Virality x Number of Tweets – in the three languages studied, where the rise of CSR in this media environment we noted in 2010, with the subsequent emergence of ESG in From 2015 to mid-2019, it was possible to perceive the decline in popularity of CSR to the detriment of the growth of ESG, as previously pointed out, one of the explanations may be the issue of originality and the perception by the user that ESG is a broader concept than the previous one.

For the terms identified for the research and the number of different users, we have the following: for the researched theme CSR in Portuguese, 1,580 different users were traced, while in Spanish, 30,824, and in English, a total of 176,594.

Regarding the theme CSR with hashtag #CSR, 1,149 users were verified in Portuguese, 5,737 in Spanish (both with the respective equivalent RSC), and 156,824 in English. For ESG, data were collected from 609 different users for Portuguese, 216 for Spanish, and 5,131 for English. For the term #ESG, we saw 1,670 users for Portuguese, 3,235 for Spanish, and 56,263 for English.

In this way, it is clear that the most significant contributions and concerns regarding the debate between CSR and ESG take place in the English language, leveraging achievements not only on the part of society but also actions by companies to resolve issues seen as “worrying” ” in the social, environmental and governmental spheres, in order to transform the future of everyone involved for the better, which may be an internal or external factor to the organization, which will influence not only the perpetuity of any business but also reflected in the health of future generations.

Thus, we have shown that in the last decade, there was a remarkable evolution in the debate on this theme, CSR and ESG, discussed in society, where initially there was a more significant concern with the social responsibility of each one within each organization, it evolved to encompass the responsibility of individuals towards others, extending beyond the realm of business, but also in their respective communities experienced daily, outside the organization, having better empathy, highlighting various subjects such as religion, sexuality, well-being, race, politics, and the mutual respect sought by each.

Regarding sustainability issues, Belinsky (2021) shows that more assertive metrics and forms of measuring ESG in organizations would be needed. In this way, it would be possible to perceive how these practices bring value to companies, modifying cultures and actions and resulting in better applications. Thus, verify if the ESG is sustainable and to what extent this happens, highlighting the different types of activities in an institution.

Concerning governance, we found that the debate evolved into organizations' concerns about financial transparency and professional ethics, highlighting actions such as audits (internal and external), due diligence, and accountability that brought greater security to shareholders, managers, and others. Stakeholders.

As a suggestion for future research, we recommended thinking of a study developed with the analysis of the opinion of researchers and professionals in the area by verifying the collection of data obtained with the perception of public opinion on this theme to align the

interests of the institutions, public and private, with society, resolving and dealing with issues such as the care to be taken with the environment, with society and with the management of companies, to ensure organizations' perpetuity without neglecting fundamental issues that require careful and attentive treatment, while taking into account norms, regulations, and ethical considerations within each aspect under discussion.

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SUSTAINABLE TECHNOLOGY: LASER CLADDING OF BRAKE DISCS REDUCING ITS PARTICULAT MATTER EMISSIONS

TECNOLOGIA SUSTENTÁVEL: RECUPERAÇÃO A LASER DE DISCOS DE FREIO PARA REDUZIR SUAS EMISSÕES DE MATERIAL PARTICULADO

TECNOLOGÍA SOSTENIBLE: RECUBRIMIENTO LÁSER DE DISCOS DE FRENO PARA REDUCIR SUS EMISIONES DE MATERIAL PARTICULADO

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ABSTRACT

The emission of 2.5μm particulate matter (PM2.5) from braking systems poses a significant health hazard. The wear of brake discs contributes to this issue. However, it can be mitigated. In this paper, a brake disk was Nickel laser cladded. Resulting in an improvement of more than 5 times of coefficient of friction and wear resistance. Likewise, under the deduced mathematical model, this improvement brings an estimative of annual reductions of 230,000 metric tons of PM2.5 not emitted; and more than 400,000 deaths, resulting from these emissions, avoided.

KEYWORDS

Sustainability, brake disk, Laser cladding, Matter emissions, PM2.5

RESUMO

A emissão de material particulado de 2,5 μm (PM2,5) dos sistemas de freio representa um risco significativo à saúde. O desgaste dos discos de freio contribui para esse problema. No entanto, ele pode ser atenuado. Neste trabalho, um disco de freio foi revestido com níquel; utilizando laser. O resultado foi uma melhoria de mais de 5 vezes no coeficiente de atrito e na resistência ao desgaste. Da mesma forma, de acordo com o modelo matemático deduzido, essa melhoria traz uma estimativa de redução anual de 230.000 toneladas métricas de PM2,5 não emitidas; e mais de 400.000 mortes, resultantes dessas emissões, evitadas.

PALAVRAS-CHAVE

Sustentabilidade, discos de freio, deposição à laser, Material particulado, MP2,5

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RESUMEN

La emisión de material particulado de 2,5 µm (PM2,5) de los sistemas de frenos representa un riesgo significativo para la salud. El desgaste de los discos de freno contribuye a este problema. Sin embargo, puede ser atenuado. En este trabajo, un disco de freno fue recubierto con níquel mediante el uso de láser. El resultado fue una mejora de más de 5 veces en el coeficiente de fricción y en la resistencia al desgaste. De la misma manera, según el modelo matemático deducido, esta mejora implica una estimación de reducción anual de 230.000 toneladas métricas de PM2,5 no emitidas, y más de 400.000 muertes evitadas como resultado de estas emisiones.

PALABRAS CLAVE

Sostenibilidad, discos de freno, deposición con láser, material particulado, PM2,5

1. INTRODUCTION

In Brazil and around the world, there has been aggressive urban expansion in the last five decades; expanding land transport (SILVEIRA, 2013). However, this expansion has contributed to the increase in air pollution; and consequently, causing serious damage to health (LARKIN *et al*., 2017; WHO, 2022).

According to research by King's College, although a large portion of atmospheric emissions: gases and particulate matter (PM) originate from mopeds, more than 20% of PM are produced by braking. With the friction between disc and pad releasing fine metallic particles that remain in suspension for long periods. Observing in this way, a problem that goes unnoticed (FUSSEL *et al*., 2022; SELLEY *et al*., 2020).

In this context, researchers have highlighted the importance of utilizing high-technology processes to improve the properties of tools and parts. Increasing its useful life and performance; in view of the working conditions that impose high wear and tear (CALLISTER Jr. and RETHWISCH, 2014). These processes include coating techniques using lasers. In which, a beam of electromagnetic waves (OEM) provides sufficient energy to produce fusion between base metal and coating (VILAR, 1999). As a result, studies indicate that the surface; such as automotive brake discs; could be improved to the point of reducing PM emissions; increasing its useful life and reducing its disposal (SAURABH *et al*., 2023). In which, high-speed laser application techniques (EHLA) prove to be efficient, and feasible in mass production industrial chains (RETTIG *et al*., 2020; OLOFSSON *et al*., 2020). On this topic, recent studies show viable processes for processing brake discs. The results of which are satisfactory in light of the final quality (ARIAS-GONZÁLEZ *et al*., 2016). However, there is still a significant opportunity for research, as these processes exhibit a wide diversity, presenting advantages and disadvantages depending on the typology of the experiment set-up and the use or not of high-speed laser application techniques (ARIAS-GONZÁLEZ *et al*., 2016; SHI *et al*., 2021; TONOLINI *et al*., 2021; SAURABH *et al*., 2023). In this sense, this article presents a new proposal for laser coating of automotive brake discs. Considering EHLA techniques and a rotation system; whose results were analyzed regarding aspects of materials engineering. In a complementary way, the objective was to implement a mathematical model, estimating the reduction in PM depending on the results.

2. CONTEXT

This Chapter will address socio-environmental issues due to the increasing generation of particles smaller than 2.5 microns; or PM2.5 from automotive braking. Next, technological processes for laser coatings will be discussed; which bring technological solutions to the research problem. Finally, the context of the proposed coating technique will be presented.

2.1. Socioenvironmental issue of PM2.5

According to Tiseo (2023), there has been an annual increase in emissions in the last 10 years; culminating in more than 37 billion metric tons emitted in 2022. Of these, according to the latest report from the World Health Organization (2022), 76% are greenhouse gases (CO2, NOX, CH4 and vapors) and the remainder composed by PM2.5. In other words, a solid so fine that it behaves like a gaseous effluent, remaining in suspension for weeks (MENDONÇA *et al*., 2019).

In this way, PM2.5 are transported for kilometers, spreading carcinogenic propensities such as heavy metals that accumulate in the lungs and adipose tissues (MENDONÇA *et al*., 2019; SELLEY *et al*., 2020). Therefore, despite representing 24% of emissions, they are responsible for more than 4 million deaths per year worldwide, as shown in Figure 01. In this sense, it is common to point to mopeds powered by fossil fuels as the biggest emitters of PM2.5; and in fact, these are still the main responsible (SELLEY *et al*., 2020). However, studies show that a significant 20% of the total PM2.5 comes from the braking process of land vehicles; in which the friction between disc and pad releases millions of metric tons per year, or 1 kg/year per disc (FUSSEL *et al*., 2022; SELLEY *et al*., 2020; BONICCI, 2022). Therefore, brake discs are responsible for almost 1 million deaths.

Thus, braking systems are a little-known problem in the context of transport (SELLEY *et al*., 2020). Tonolini *et al*. (2021) explain that the materials/base of these systems present a good cost-benefit ratio.

Imbued with operability within security criteria; due to good resistance to tension/corrosion and easy workability

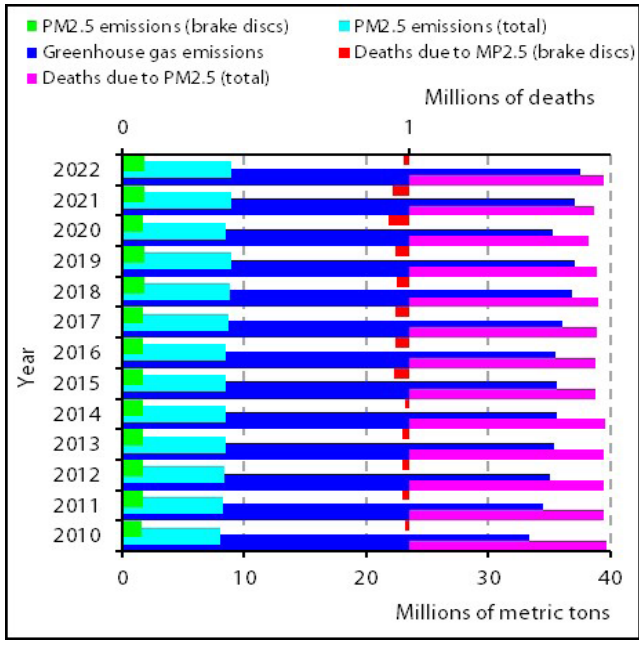


Figure 01: Worldwide evolution of greenhouse gas emissions, PM2.5, and PM2.5-related deaths (brakes and total).

Source: Adapted from Tiseo (2023); WHO (2022); Selley et al. (2020) e Southerland et al. (2022);

in casting. Furthermore, Djafri *et al*. (2014) conclude that the porous structure of gray iron (the most used material) provides wear resistance that guarantees coverage over the factory's useful life; which consequently promotes PM2.5 dispersion.

2.2. Laser coating technologies

Callister Jr. and Rethwisch (2014) explain that processing techniques can improve the surface properties of metallic structures, such as tools and parts; highlighting wear resistance and friction coefficient. Thus, starting materials; or substrates; previously fragile and susceptible to wear, they become more resilient due to the structural improvement used on the surface.

In this context, Vilar (1999) highlights the role of laser surface treatments; in which a focused OEM beam reaches temperatures higher than metal melting. Enabling the anchoring of more resistant materials; through metallurgical connections; under the substrate of interest. In contrast, Keist and Palmer (2016) explain that the concentrated OEM is designed with two possibilities of characteristic morphological profiles: Gaussian and Top-Hat; as detailed in Figure 02[A]. In which, Gaussian profiles transfer twice the power in 30% of their profile region. Top-hat beams, on the other hand, provide uniform energy, in theory, throughout the entire trapezoidal cross-section, state Hamburg and Mitra (2012). However, as noted by Tenbrock *et al*. (2020), in many cases there is a central region of diffuse energy, similar to Gaussian profiles; containing peaks with a width smaller than the beam; as also highlighted by Figure 02[A]. Where there is a high energy density, which can produce small cavities in the substrate; depending on the coating method.

Among laser cladding methods, Sommer *et al*. (2021) list directed energy deposition (DED) systems and EHLA extreme speed laser application. According to Li *et al*. (2019), both systems operate with simultaneous laser emission and powder coating injection; in DED the powder is sprayed directly onto the surface of the substrate, while in EHLA, it is injected directly into the focal region of the beam, as illustrated in Figure 2[B]. With this, explain Yong *et al*. (2023), in DED only 20% of the laser energy is transferred to the powder, while in EHLA, this energy is in the order of 60-80%. Increasing the efficiency of EHLA processes, due to its "commitment to transparency", that is, the OEM beam "sees" the substrate without major obstruction. Therefore, the injection of the powder into the focal region promotes its fusion before reaching the molten substrate, as shown in Figure 02[C]. Consequently, the system transfers sufficient energy to provide a satisfactory metallurgical bond between coating and substrate, add Svetlizky *et al*. (2022).

2.3. Brake disc coating

The application of such processes, such as sustainable technology in brake discs, could significantly contribute to

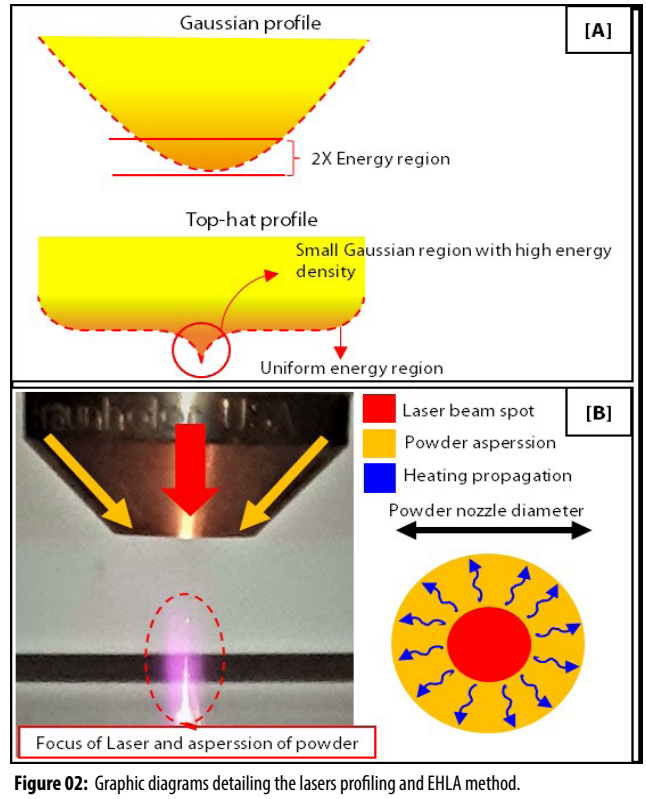


Figure 02: Graphic diagrams detailing the lasers profiling and EHLA method.

Source: Adapted from Homburg and Mitra (2012) and Li et al. (2021);

the reduction of PM2.5 due to braking, point out Dyer *et al*. (2024). In fact, as highlighted by Olofsson *et al*. (2020), in addition to reducing PM2.5 emissions, the coating extends the useful life of the disc, impacting the disposal cycle. To this end, the processing parameters must be adjusted depending on the method (DED or EHLA) and beam profile (Gaussian or Top-hat), reinforce Tonolini *et al*. (2021). Considering that the porous nature of gray iron (disc material) can lead to the occurrence of cavities due to vaporization of the surface (ablation) or the occurrence of cracks, due to the effect of expansion, as shown in the micrographs in Figure 3[A] (DYER *et al*., 2024). Likewise, the deposition process must prioritize the uniformity of the coating, depending on the geometry of the disc, highlight Arias-González *et al*. (2016). Noting that each coating line (or "track") must follow the circular design of the surface and be positioned over the neighboring line, with at least 50% of overlay in relation to the width of each track (or "W"); as illustrated by Figure 3[B]. With a powder coating made up of a material that provides improved wear resistance, with good anchoring in the gray iron and with a cost/benefit ratio compatible with the production cost of the disc, add Shi *et al*. (2021).

In this horizon, Olofsson *et al*. (2020) report the advantages of using a system for rotating the disc during laser deposition. Providing satisfactory uniformity of the coating (Figure 4[A]). Rettig *et al*., (2020) add that using

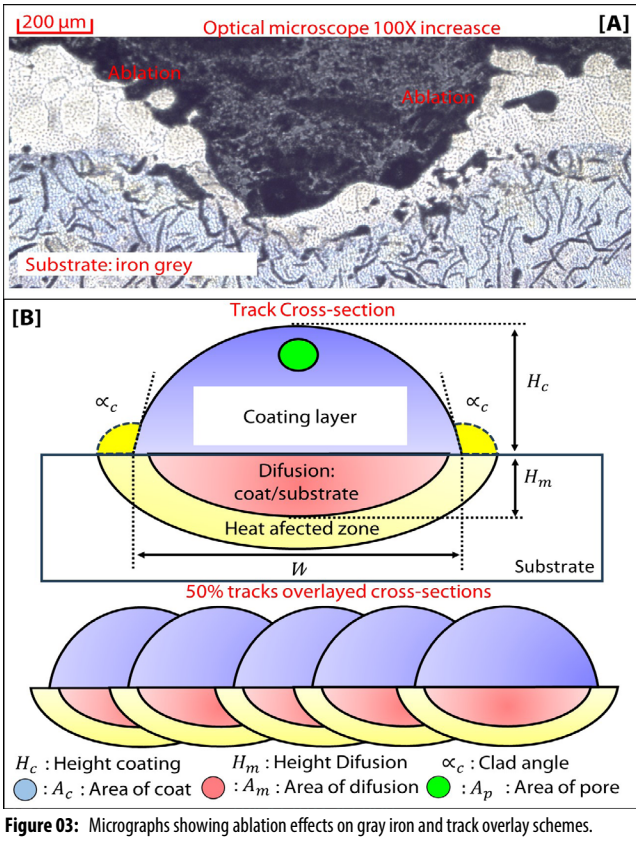


Figure 03: Micrographs showing ablation effects on gray iron and track overlay schemes.

Source: Adapted from: Dyer et al. (2023); Arias-González et al. (2016) e Santos (2017);

EHLA, with the disc in motion, not only improves the anchoring of the coating, but also reduces processing time (Figure 4[B]); something important from the point of view of application in industrial chains. Hirata *et al*. (2023) in turn, complete that such processes operated by a robotic arm, which carries the laser system and positions the beam through a programming routine, provides precise and efficient execution; reducing adverse effects, such as excessive energy concentrations from Top-hat profiles (ablation and cracks), by the response in real time of the equipment during execution. As a coating, on the other hand, Shi *et al*. (2021) Arias-González *et al*. (2016) highlight the use of Nickel-based alloys; presenting good anchorage in gray iron. Obtaining wear resistance about 1.5 times greater than gray iron. Based on this retrospective analysis, the present study aimed to propose the utilization of technology for sustainable purposes in coating of brake discs. To this end, a method will be proposed consisting of a laser coating system, with disk rotation. In which the emission system is handled by a robotic arm and performs deposition by the EHLA method. At the same time, a mathematical model will be proposed to estimate the reduction in PM2.5 emissions worldwide. Based on increased wear resistance of the disc surface. To this end, results from the microstructural characterization of the material will also be presented, such as wear, friction coefficient, roughness, optical microscopy (OM) and electron microscopy (SEM/EDS).

3. MATERIALS AND METHODS

To implement technological processes in the service of

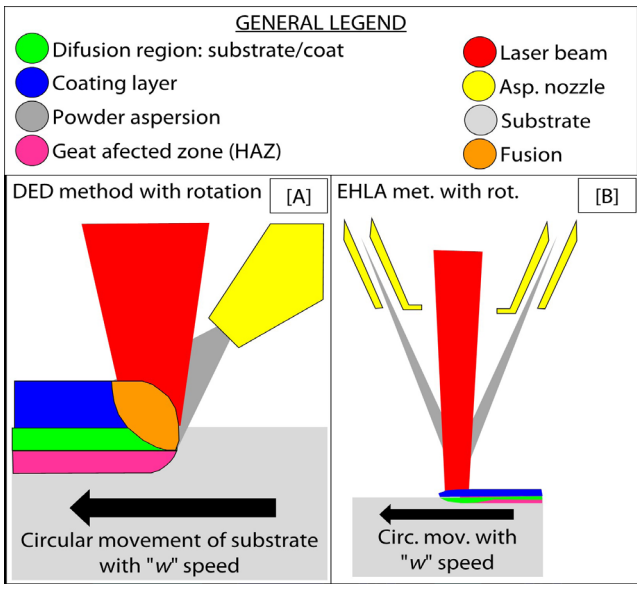


Figure 04: DED and EHLA schemes with disk rotation.

Source: Adapted from: Dyer et al. (2024); Arias-González et al. (2016) e Santos (2017);

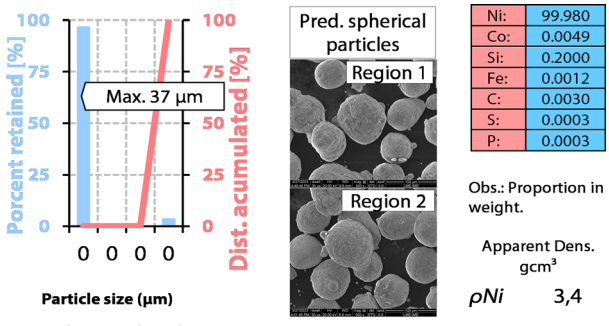
sustainability, materials, methods and modeling were used. In this experimental development, nickel was laser deposited onto a brake disc. The specimen was evaluated according its mechanical and elemental properties. Likewise, a mathematical model was deduced in order to quantify the PM2.5 not unemitted and deaths avoided resulting of this improvement.

3.1 Materials/Equipment

3.1.1 Coating and substrate

As a coating, a commercial Nickel powder (P/M Ni XF Master-Melt PLUS) was used; whose granulometric, morphological and elementary properties (EDS) are presented in Figure 05.

According to Figure 05, Ni powder was considered compliant, according to Shi *et al.* (2021). With particles of a homogeneous size of a maximum of 37μm, spherical and little contaminated. As a substrate, were used 2 automotive brake discs (S1 and S2) of specification: "Bd2064" refurbished. With Figure 06 showing discs deposition regions; along with the elementary composition (EDS) of the discs.



Ni:	99.980
Co:	0.0049
Si:	0.2000
Fe:	0.0012
C:	0.0030
S:	0.0003
P:	0.0003

Obs.: Proportion in weight.

Apparent Dens. gcm³

ρNi 3,4

Particle size distribution | SEM: 500 X | Composition

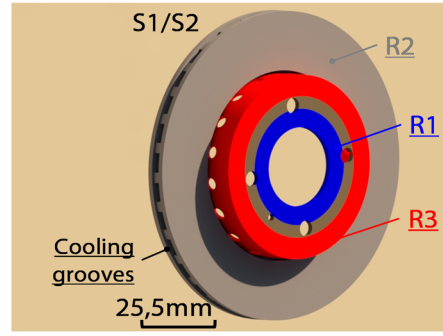
Figure 05: Characteristics of powder coating.
Source: Adapted from: Dyer et al. (2024); Arias-González et al. (2016) e Santos (2017);

According to Rettig *et al.*, (2020), the discs compositions matches that typically found in commercial brake discs; whose design is the most used in passenger vehicles. Therefore, to develop this new coating technique, two experimental setups were realized in order to: 1-Control of parameters and conditions; 2-Coating application and analysis.

3.1.2 Equipment set-up

These set-ups are presented in Figures 07, which also describes the equipment used.

As shown in Figure 07, the coatings were produced by



Fe:	70.300
O:	14.000
C:	13.300
Si:	1.7000
Mn:	0.4000
S:	0.2000
P:	0.1000

Obs.: Proportion in weight.

Apparent Dens. gcm³

ρFe 7,9

Deposition regions, according disc geometry | Composition

Figure 06: Substrate characteristics.
Source: authors (2024).

a powder aspersing system; composed of Argon cylinders and a powder feeder (AT-1210 Thermach); Ytterbium fiber laser and head-stock (IPG YLR-1500). Where the laser has λ = 1.07μm and maximum power "*P*" of 1500W; which may be variable at a given efficiency "*E*" (%). The head-stock has a Top-Hat optics beam, with an incidence diameter "b_d" of 6mm. Being "operated" by a Yaskawa GP25 robot; with a payload of 25kg and precision of 100μm, using routines in Phyton language through the RoboDk interface.

According above explanation; this paper aimed to demonstrate a new coating method; by laser cladding; for brake discs in order to reduce PM2.5 emissions.

This system is also equipped with an STC-HD203DV camera; recording (at 10X magnification) the action of the laser. The aspersion system, on the other hand, transports the powder to the focal region of the laser, i.e., like a ELHA method at a certain flow "*st*" of gas (l/min) at a rate "μ" (g /min); depending on the "*Tx*" rotation (RPM) of the perforated disc (100μm in diameter) internal to the feeder, as explained in Figure 08. Where the powder released from the holes in *Tx* falls into the st stream and is aspersed at the μ rate. However, an empirical relationship must be established between [*Tx*, s_t and μ], as will be explained later. At the same time, it is provided a gas supply (without powder); à certain flow "s_g" under the substrate, acting as a surface protective gas.

For the set-up, S1 and 2 were fixed by a lathe plate (Emco) under a reduction gearbox (National 439), moved by means of pulleys (15 to 48mm) driven by a stepper motor (Steping motor); ensuring a 40X reduction in initial rotation. The operation was carried out by an Arduino

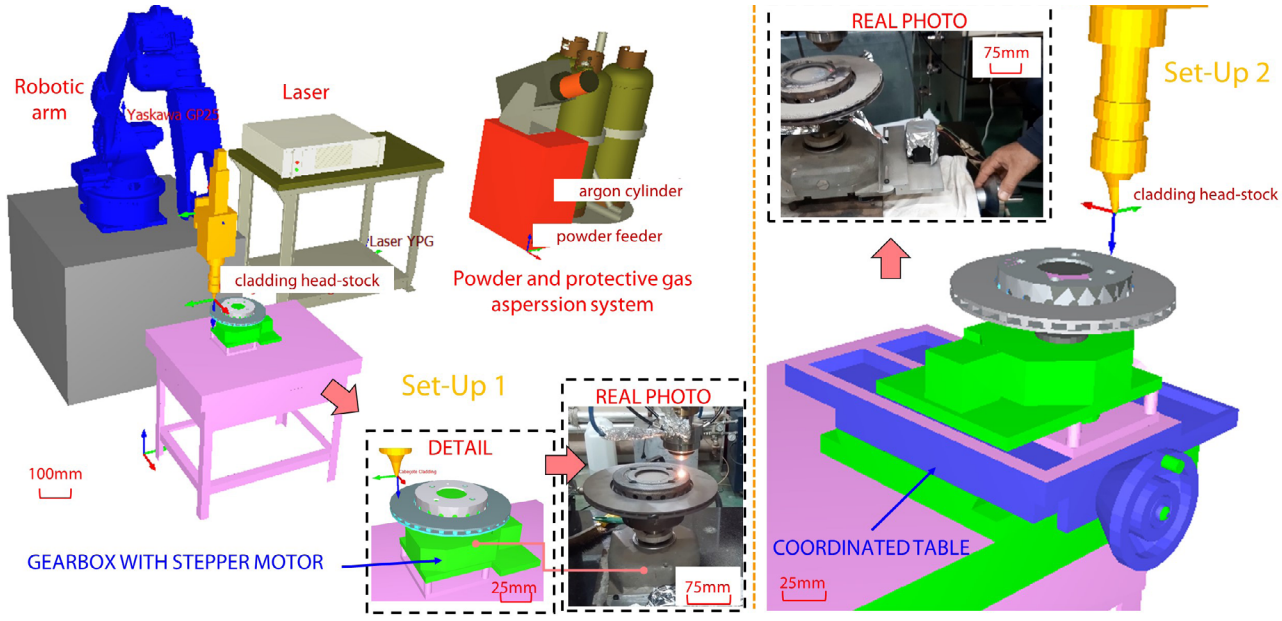


Figure 07: Experimental setups.
Source: authors (2024).

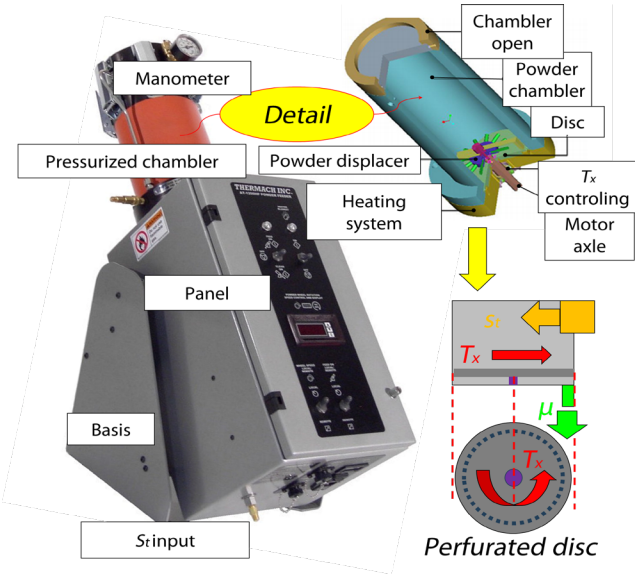


Figure 08: Powder feeder operating diagram.
Source: authors (2024);

system, using G-code (Universal G-code) routines to control the number of turns and angular speeds "ω" (RPM). In set-up 1, this system was mounted on a fixed bench. In set-up 2, this system was placed on a Mr-25 coordinate table.

In the analysis stage, the samples were extracted using diamond discs. Built in Bakelite, with a Buehler insert. Sanded and polished using an Aropol 2V polisher. Analyzed by microscopes: MO - Zeiss and Dino-Lite; and SEM/EDS - Tecsan Vega. Wear and friction were evaluated using Anton Paar TRB^3 and CETR tribometers and Contour X-500 profilometer. To assess roughness, a Taylor Hobson; whose reading was aided by an A-RH Line Tool table to support samples. As well as an FM-700 for Vickers micro hardness (MHV).

3.2 Methods

3.2.1 Initial Stage: Control/conditions

Initially, for experimental, the relationship between *Tx*, st and μ was established; empirically; performing collections, varying st and *Tx*; for a period of time "*t*". Weighing the empty "P_V" and full "P_C" vessel, obtaining the net weight of the powder "P_I" per minute, as a function of st and *Tx*, as shown in the graph of Figure 09; demonstrating the governance of *Tx* over μ.

For the coating, firstly, using S1 in set-up 1, control of tangential speed parameters "v_s" (mm/s) was obtained as a function of the G-code and ω command. In addition to boundary conditions to limit adverse effects on the disc, depending on: *E*, μ and focal length "d_f": which refers to the distance from the head-stock to the substrate. Where, this first step is more detailed in previous work (DYER *et al.*, 2024). To this end, tracks were deposited in S1 with *W* 6mm as concentric circles (R1) and arcs (R2) from within outward with orthogonal movement of the arm. At *E* = 70-75% (or 10501125W), μ = 4g/min and st = sg =15l/min. With the G-code command "*F*" varying from 20-300 (RPM), corresponding to the stepper motor rotation (in RPM) which is equivalent to a ω 40X lower. And thus, control of the rotation system was obtained, as well as an optimal range of 9-11mm/s for v_s; allowing the formation of

a metallurgical bond between the gray iron and the Ni powder. Then, still in S1, linear tracks were deposited in R3 with the disk stopped to determine boundary conditions. Observing material removal with $E > 75\%$ due to energy accumulation and ablations with df < 24mm due to the small Gaussian region of the Top-Hat profile. However, E < 70% and $d_f >> 24$mm did not anchor Ni. With the definition and control of: F, ω, v_s, E and d_f . In S2; with set-up 1; tracks were deposited in arcs (R2) with v_s = 3-6mm/s, E = 7075% and μ = 4-5.7g/min; observing, through the STC-HD203DV, adverse effects of thermal propagation, depending on the varying thickness of the cooling grooves. Likewise, the variation in the morphology of the molten metal pool as a function of μ was evaluated using the camera. Concluding that the coating for analysis would be carried out in R1, with μ = 4g/min presenting the most homogeneous pool.

3.2.2. Final Stage: application/analysis

Therefore, S2 was positioned in set-up 2 where circular, concentric tracks were deposited, with W = 600μm, from the inside to the outside on R1 with an "O_v" overlap of 50% for the "*n*" tracks on the entire R1 surface. For this purpose, the arm was kept static; at a d_f = 24mm from S2;

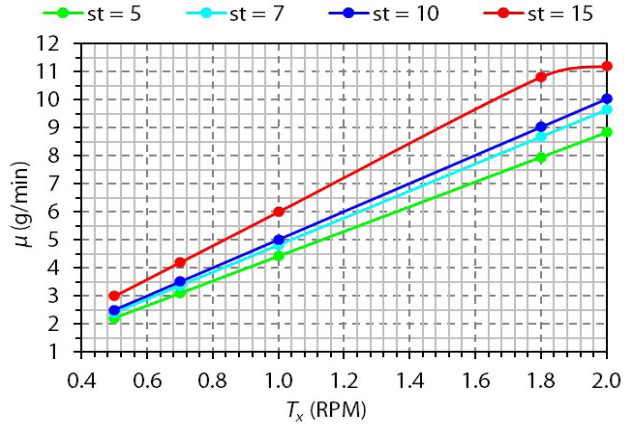


Figure 09: Correlation graph of st, Tx e μ.
Source: authors (2024);

varying "d_y" by 300μm by MR-25. Thus, improving coating accuracy. Where the deposition parameters are presented in Table 01. With Figure 10 illustrating this procedure.

Parameters					
variables	**unit**	**value**	**variab.**	**unit**	**value**
E	%	70,00	F	RPM	850
T_x	RPM	0,70	sg	l/min	15
st	l/min	15,00	ω	RPM	21
μ	g/min	4,00	df	mm	24
v_s	mm/s	11,00	n	-	30
O_v	%	50,00	d_y	μm	300
W	μm	600			

According to Figure 10, the precise movement of MR-25 made it possible a dense and wellconsolidated coating. Which when superficially sanded (Figure 09[B]) revealed a massive and homogeneous surface. Next, both worked surface and cross sections were extracted. After embedding and metallographic preparation, cross section was analyzed by MO (100X magnification). With this, was calculated the dilution "*D*" and coating angle α_c; as Figure's 03 shown; according to Goodarzi's *et al.* (2015) Eqs. 1 and 2. Likewise, this section was SEM analyzed (500X magnification) and EDS mapping.

Table 1: Laser cladding application parameters.

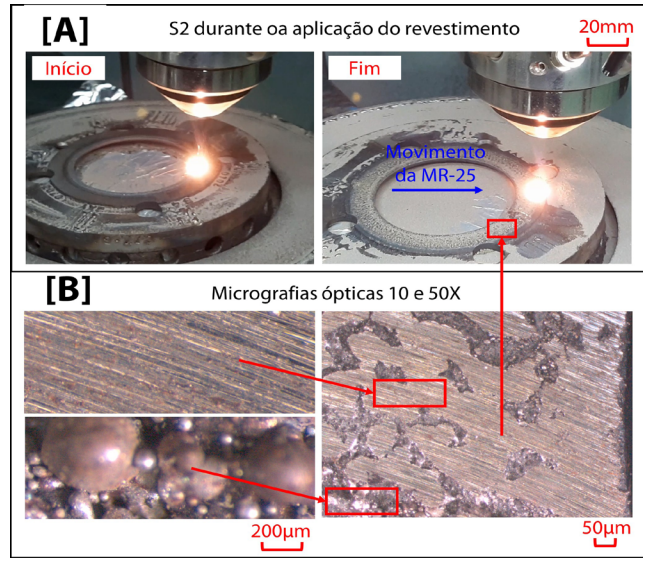


Figure 10: Photographs of the laser deposition process.
Source: authors (2024);

In addition, MHV (100gf, 10s) were also obtained from the sections. In parallel, for surfaces were obtained the friction coefficient "θ" (T^{-1}). In addition, were obtained the following results: wear coefficient "*K*" (T^{-1}) and wear rate "*k*" ($mm^3/N.m$).

$$D = A_m[A_c - A_p + A_m]^{-1} \quad (1)$$

$$\propto_c = 180 - 2\tan^{-1}([2H_c][W]^{-1}) \quad (2)$$

Where, "k_1"and "K_1" were taken on for surface without coating and "k_2" and "K_2" for surface with coating. To this end, the Table 02 conditions were considered for wear "$K_{[1}$

$_{and\ 2]}$" and "$k_{[1\ and\ 2]}$" results calculation.

Likewise, for the roughness test, the "*RA*" value was obtained using parameters also in Table 02. Although, θ and *RA* were obtained directly from equipment output. For $K_{[1\ and\ 2]}$ and $k_{[1\ and\ 2]}$, in the other hand, were used the equations: Eqs 3 and 4 (REYE, 1860; HOLM *et al*., 1958; SILVA, 2014).

Where "N_r" is the normal load, "HV_m" is the MHV of the softest material (N/mm²) and "l_x" (mm) the total distance covered in the test. For roughness test, the needle moves a distance "d_{es}" (mm) with speed "vr_u" (mm/s), as illustrated in Figure 11; which also highlights other variables

$$K = \frac{(V_e+V_a)}{l_x.N_r} \quad (3)$$

$$k = \frac{(V_e+V_a)HV_m}{l_x.N_r} \quad (4)$$

from these trials.

Noting that lx is the sum of the total distance traveled by the sphere on the sample surface; with "*Ax*" outward/return amplitude. In addition, "$M1_a$" is the initial mass of the sample. Furthermore, "ρ_e", "HV_e" and "$M1_e$" are the corresponding density, hardness and initial mass of the sphere (respectively). For CETR, an A_x of 10mm was measured for 9.6min at 200mm/s. For TRB³, however, an *Ax* of 2mm was used, traveled back and forth in 400 cycles at 4mm/s.

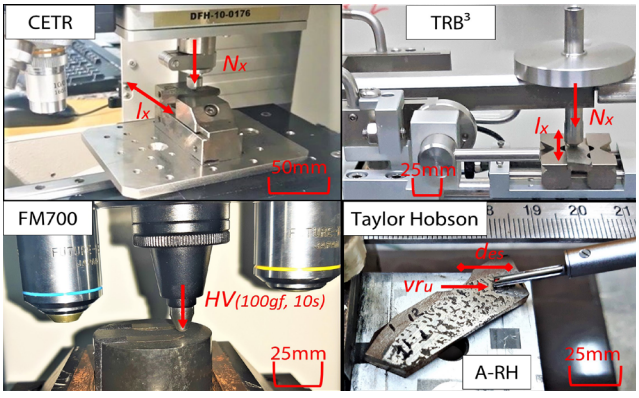


Figure 11: Surface analyses photographs with test conditions.
Source: authors (2024);

3.2.3 Mathematical Modelling

The mathematical model deducing stage, was carried out using a structuration based on "methodological routes", according to Dyer *et al*. (2023).

Material Properties					
With coating			**Without Coating**		
var.	un.	valor	var.	un.	valor
ρNi	g/mm³	0,0034	ρFe	g/mm³	0,0079
$M1_a$	g/mm³	12,827	$M1_a$	g	12,827
Wear test - conditions for CETR equipment: radius sphere re = 1,5mm, made by 304 steel					
ρ_e	g/mm³	0,0080	l_x	mm	8400
$M1_e$	g	0,2562	N_r	N	5,0
Wear test - conditions for TRB³ equipment: radius sphere re = 2,5mm, made by 440C steel					
HV_e	g/mm³	0,0077	l_x	mm	800
$M1_e$	g	0,4083	N_r	N	2,0
Roughness test: conditions for Taylor Hobson equipment					

Table 2: Surface analyzes conditions, by equipment.

Firstly, the actors involved were listed. And then, using a methodological route, algebraic variables of interest were named. Finally, boundary conditions were defined. Considering as input variables: emissions, deaths and reduction in brake disc wear, according to data and Eqs. 3 and 4. According to Bianchi *et al*. (2023), between production and disposal, land transport is used between the stages of the life cycle of brake discs, such The Figure's 12 flowchart shown. Where, the actors were identified:

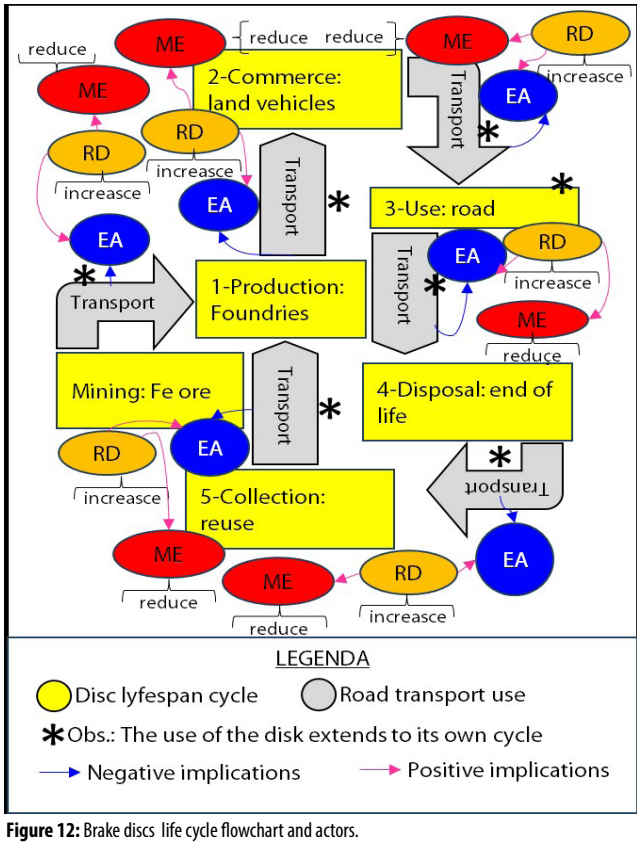


Figure 12: Brake discs life cycle flowchart and actors.
Source: authors (2024);

atmospheric emissions (*EA*), deaths due to PM2.5 emissions (*ME*) and positive implications due to wear resistance (*RD*) throughout the cycle.

After listing the actors, functions were structured (Eq. 5) to estimate the reduction in PM2.5 emissions from brake discs (R2.5) and reduction in deaths (*RM*) due to the RD increase factor. Considering that EA covers all pollutants, according to literature. Likewise, the *ME* indices include all deaths (in cases per 100 thousand inhabitants) due to PM2.5 emissions. With this, these indices were broken down, obtaining variables of interest: PM2.5 emissions from brake discs (*ED*) and deaths from PM2.5 (*M2.5*), through the methodological route in Figure 13.

From this understanding, were obtained Eq. 6 e 7 for *ED* and *M2,5*; observing the correction factor annual population, in millions of habitants [10^{-12}].

Next, *RD* was implemented. To this end, unlike EA and ME, this was calculated based on: *k* and *K* (Eq. 3 and 4). According to Figure 14 methodological route; using Eqs. 8

$$R2{,}5 = [ED] - [ED][RD]$$
$$RM = [M2{,}5] - [M2{,}5][RD] \quad (5)$$

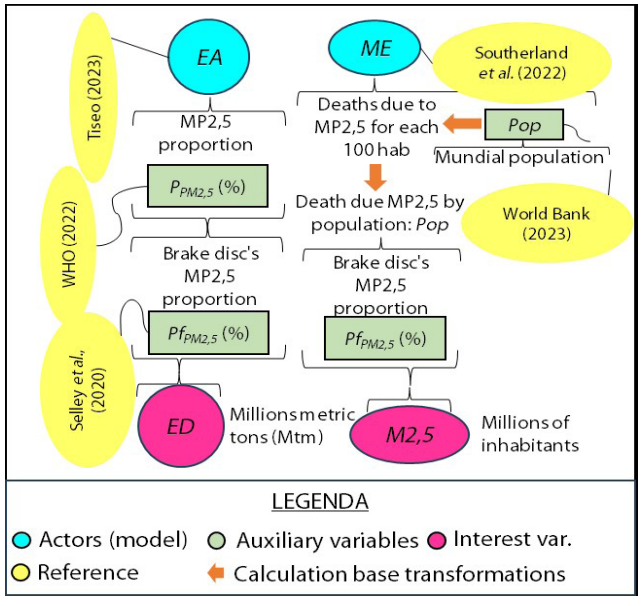


Figure 13: Methodological route for obtaining ED and M2.5.
Source: authors (2024);

and 9 relative and average difference.

With a_1 and a_2 corresponding to: k_1, k_2, K_1, K_2. Now E_1 and E_2 to the terms K and k respectively. Therefore, at the

$$ED = [EA][P_{PM2,5}][Pf_{PM2,5}] \quad (6)$$

end of the route, *RD* is dimensionless (Eq. 10), and can act as an absolute proportion factor in Eq. 5.

Replacing *RD* (Eq. 10) and Eqs. 6 and 7 in Eq. 5, the Eq. 11 model was obtained to estimate reduction in emissions

$$Erro\ relativo = [a_1 - a_2][a_1]^{-1} \quad (8)$$

$$Média = [E_1 + E_2][2]^{-1} \quad (9)$$

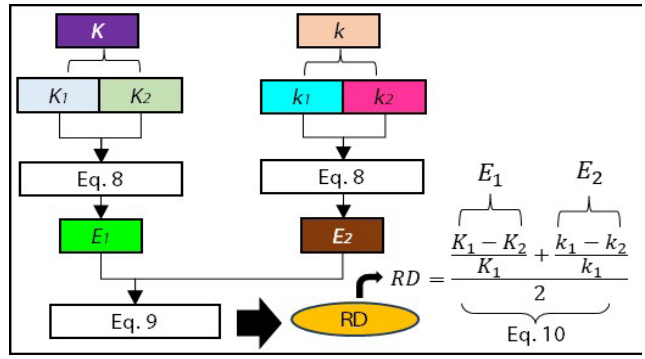


Figure 14: Methodological route for obtaining RD.
Source: authors (2024).

and deaths from PM2.5 by brake discs.

Finally, the boundary conditions were deduced in order to establish maximum and minimum *R2.5* and *RM*. To this end, the "*REM*" ratio in Mtm per %/100 thousand deaths (Eq. 12) was established based on the series of Tiseo (2023) and Southerland *et al*. (2022)

Obtaining minimum (*REMa*), average (*REMb*) and maximum (*REMc*) annual *REM*. Then the terms were normalized, as shown in Figure 15. To obtain the range: maximum and minimum *R2.5* and *RM*.

$$\begin{cases} R2{,}5 = [EA][P_{PM2,5}][Pf_{PM2,5}](1 - RD) \\ RM = [ME][Pop][Pf_{PM2,5}][10^{-12}](1 - RD) \end{cases} \quad (11)$$

3.3 results

3.4 Cross Section Analysis

$$REM = [EA][ME]^{-1} \quad (12)$$

The coating layer, composed of multiple tracks, presented microstructure (by MO analysis 50X magnification) with a morphology considered to be of good execution, according to the criteria of Pellizzari *et al*. (2022) for *D* =

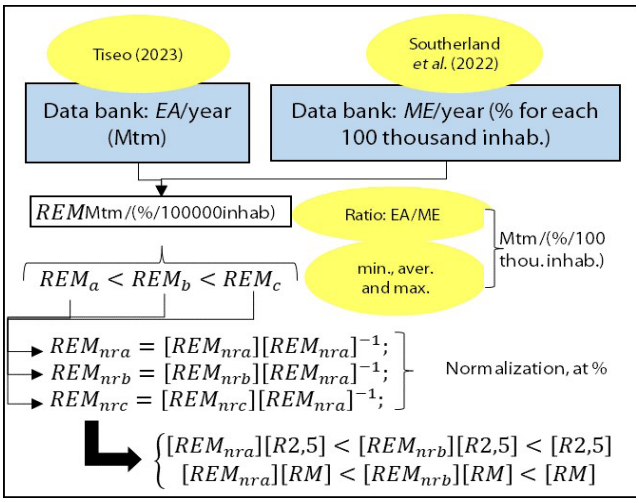


Figure 15: Methodological route for boundary conditions.

Source: authors (2024).

7.5-18.4% and $\alpha_c > 162.3°$, as shown in the micrographs in Figure 16[A]. In this sense, despite the presence of cracks, macro pores and irregularities, mainly in the initial tracks, dense and well-anchored regions were observed (by SEM, 100X magnification) in the substrate. Characterized by the presence of dendritic structures typical of the occurrence of metallurgical bonding (CALLISTER Jr. and RETHWISCH, 2014), as shown in the micrographs in Figure 15[B]; with relative differences: $A_c/[A_p]$ and $A_c/[A_c(\text{expected})]$ within acceptable limits.

Furthermore, the EDS analysis, including total area mapping and specific areas, demonstrated the presence of a mixture of substrate and coating elements in the diffusion region. This confirms the metallurgical bonding, as Figure 17 shown.

The analysis presents accentuated concentrations of Ni and O in the coating region, with a mixture between Ni and Fe in the diffusion region and absence of Ni in the substrate. Proving the metallurgical bond between coating and substrate. The MHV test, in turn, obtained similar results between Ni hardness and gray iron (FC); as shown in Figure 18. Where the two materials have similar hardness and in accordance with the literature (CALLISTER Jr. e RETHWISCH, 2014).

However, Figure 18 shows an increase in hardness in the diffusion zone, characterized by the formation of a metallic alloy between Iron and Nickel. Thus, presenting yet another indication of the formation of a metallurgical bond between substrate and coating.

3.5 Surface Analysis

The roughness index "RA" demonstrated that the surface with surface sanding of the coating presented surface characteristics similar to the uncoated disc. Pointed out that the proposal would adapt easily; only with a simple surface treatment; to a conventional braking system, as

Figure 16: Morphology of the coated section by MO and SEM.

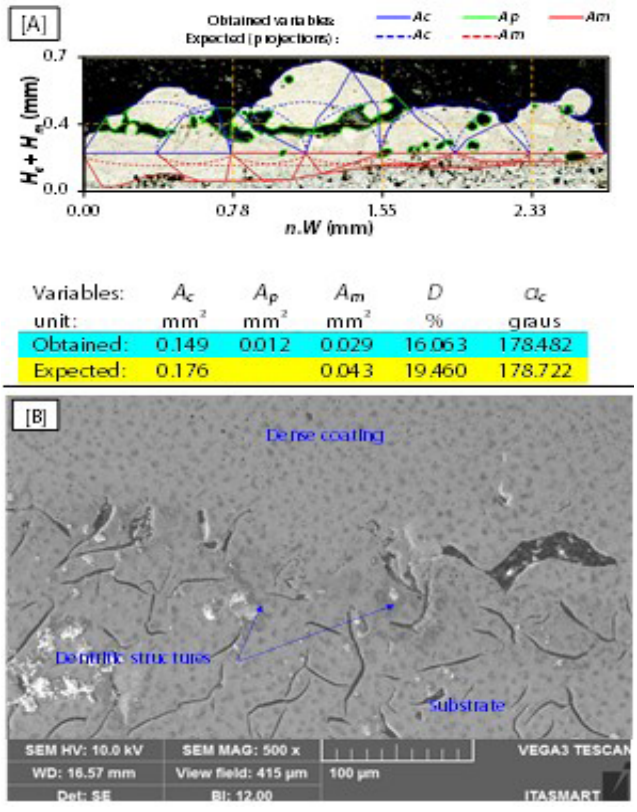
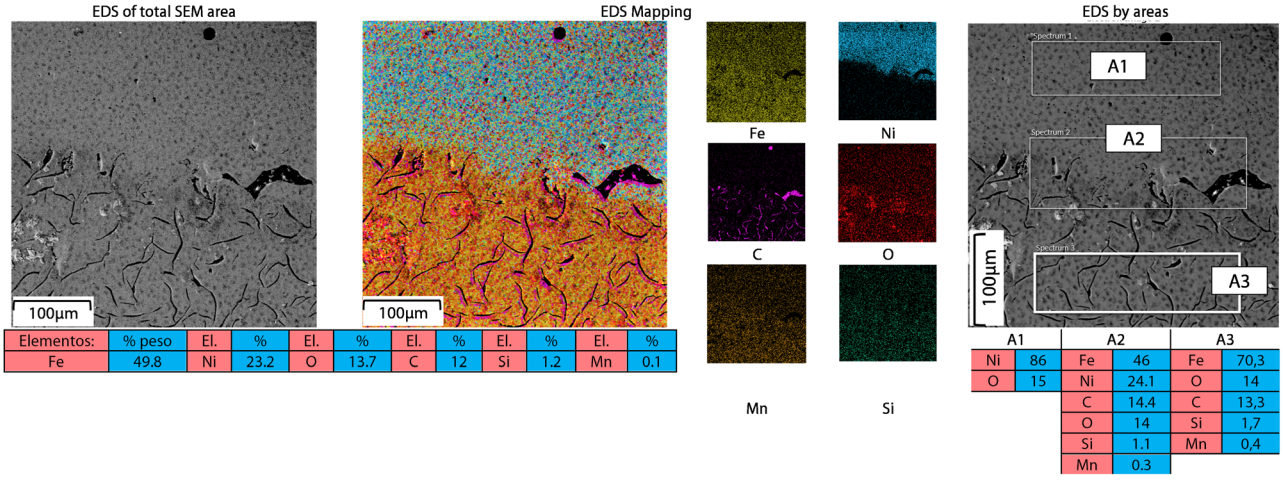


Figure 16: Morphology of the coated section by MO and SEM.

Source: authors (2024).



Elementos:	% peso	El.	%	El.	%	El.	%	El.	%	El.	%
Fe	49.8	Ni	23.2	O	13.7	C	12	Si	1.2	Mn	0.1

A1		A2		A3	
Ni	86	Fe	46	Fe	70,3
O	15	Ni	24.1	O	14
		C	14.4	C	13,3
		O	14	Si	1,7
		Si	1.1	Mn	0,4
		Mn	0.3		

Figure 17: EDS of total SEM area, mapping and elemental compositions by areas.
Source: authors (2024).

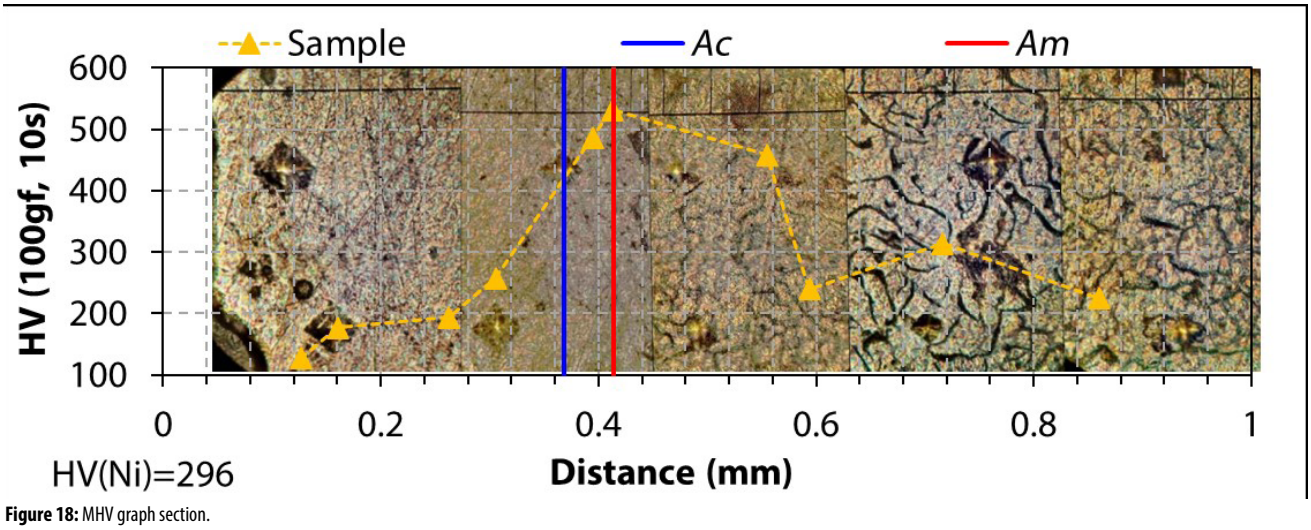


Figure 18: MHV graph section.
Source: authors (2024).

shown in Figure 19.

Therefore, within an industrial context, the coated discs would only be machined superficially; obtaining the necessary adaptation to the braking system with pad/disc pair. Thus, observing the of industrial application feasibility; with a low economic impact. In addition, the θ coefficients shown a reduction 5 times between coated/uncoated surfaces, as Figure 20 shown. Noting that the alternation of parameters and equipment didn't impact a θ variation. Where, in Figure 20[A], the micrographs (50X magnification) from the Dino-Lite microscope showed darker regions in the uncoated sample; indicating a greater loss of mass. Figure 20[B] (Zeiss, 100X), in the other hand, did not provide much information; due to low visual perception due to the occurrence of macro pores. However, the Countour X-500 confirmed deeper grooves on without coating surfacing (Figure 21[A]) in view of the coated surface (Figure 21[B]).

Therefore, Va was obtained by multiplying the cross-sectional area of the groove "Asa" (mm^2); according to Figure 21[C]; and *Ax*. For Ve, however, "he" was initially calculated by Eq. 13 (cap area) from the groove area "Ase", (mm^2), (Figure 21[D]); being substituted in Eq. 14 (shell volume) to obtain Ve.

With Va and Ve, k and K were calculated for both equipment; despite Figure 21 showing only CETR images (superior visual quality); as shown in Figure 22, comparing to literature. Where, k and K are superior without coating. Concluding that the disc's Ni coating improved its wear resistance by 3-5 times. Note that there were no major variations in results between equipment; such as to obtain θ. However, this gain was almost half that obtained by Tonolini *et al*. (2021); which carried out a similar study. Indicating that there is room for improvement in the

technique.

3.6 Application in the model

The variables: K and k (equipment means), EA and ME (historical series) and Pop (population database) were applied in Eq. 11; estimating annual R2.5 and RM. With annual maximums, averages and minimums being defined (boundary conditions) as Figure 23 graph shown. In

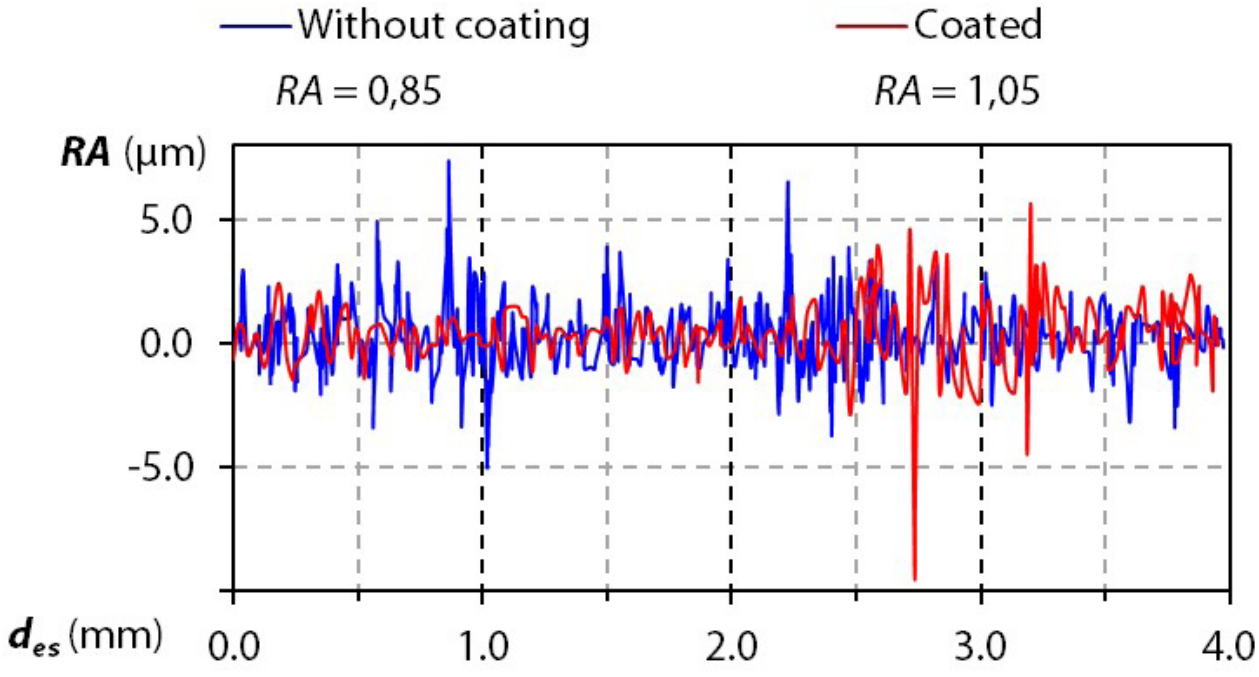


Figure 19: Graph of the roughness test.
Source: authors (2024).

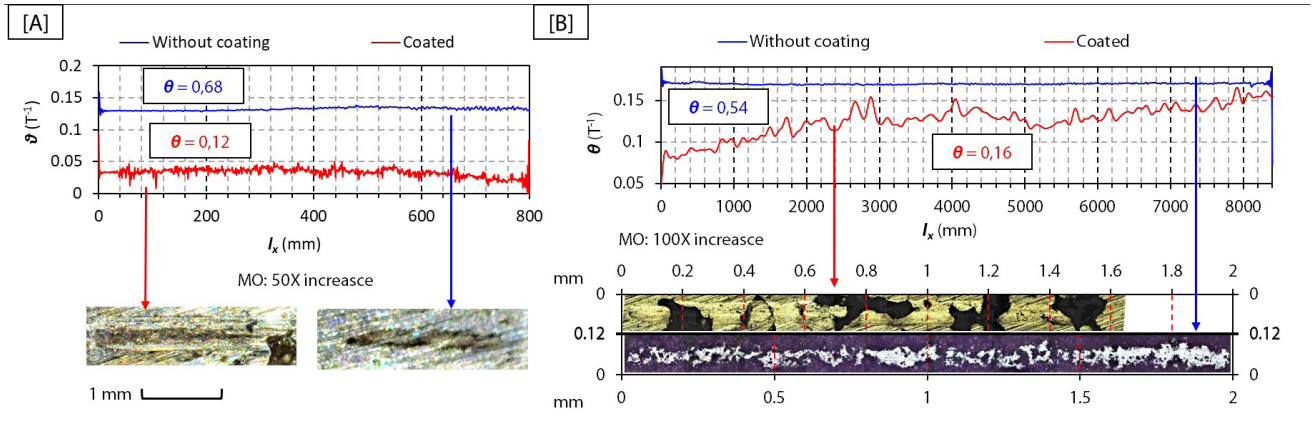


Figure 20: Wear test results for coefficient of friction.
Source: authors (2024).

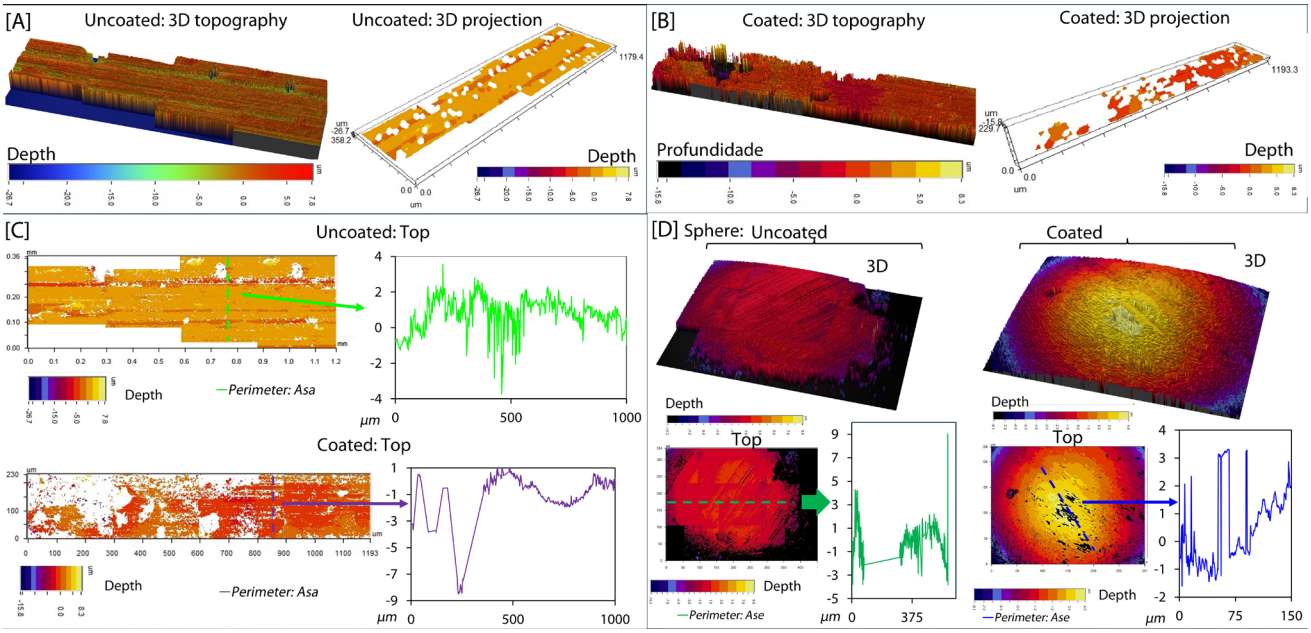


Figure 21: Results of the profilometry test on the CETR equipment.

Source: authors (2024).

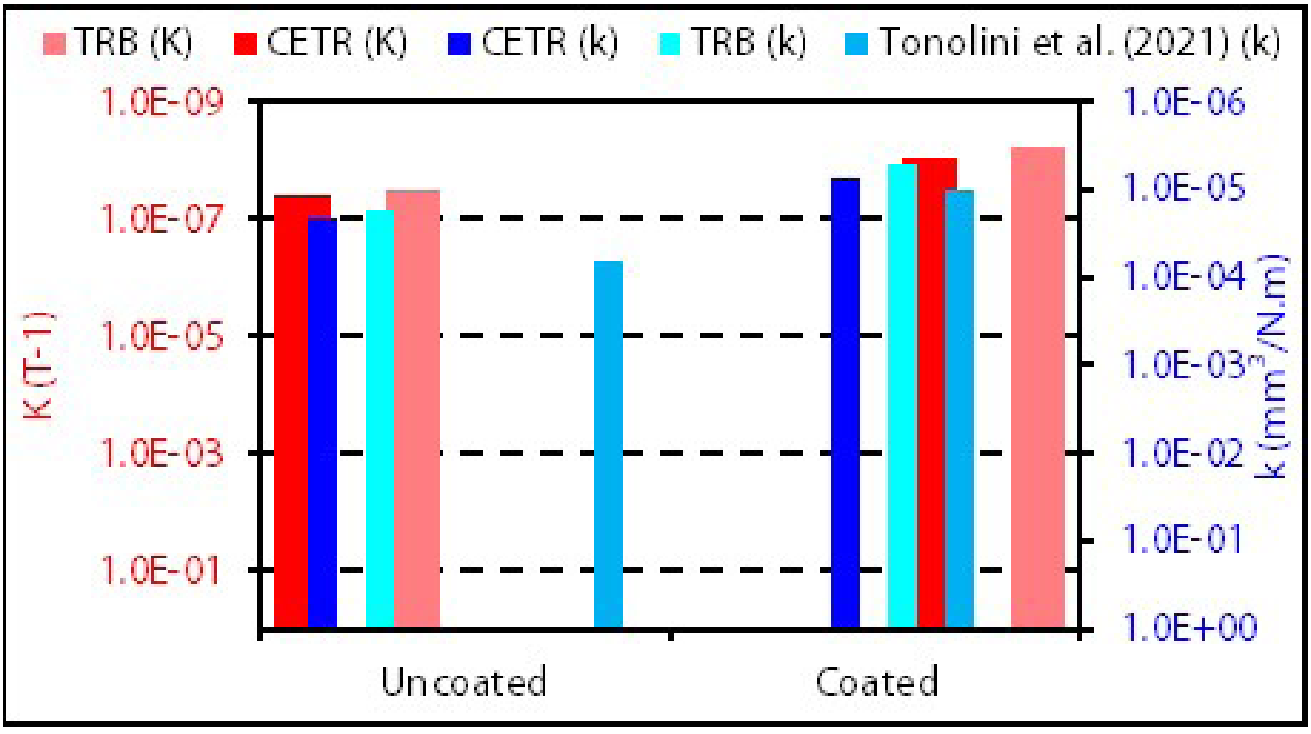


Figure 22: Bar graph with k and K results.

Source: authors (2024).

addition, Table 03 shown these variables.

Model Variables			
var.	unit	value	reference
PPM2,5	%	24,0	WHO (2022)

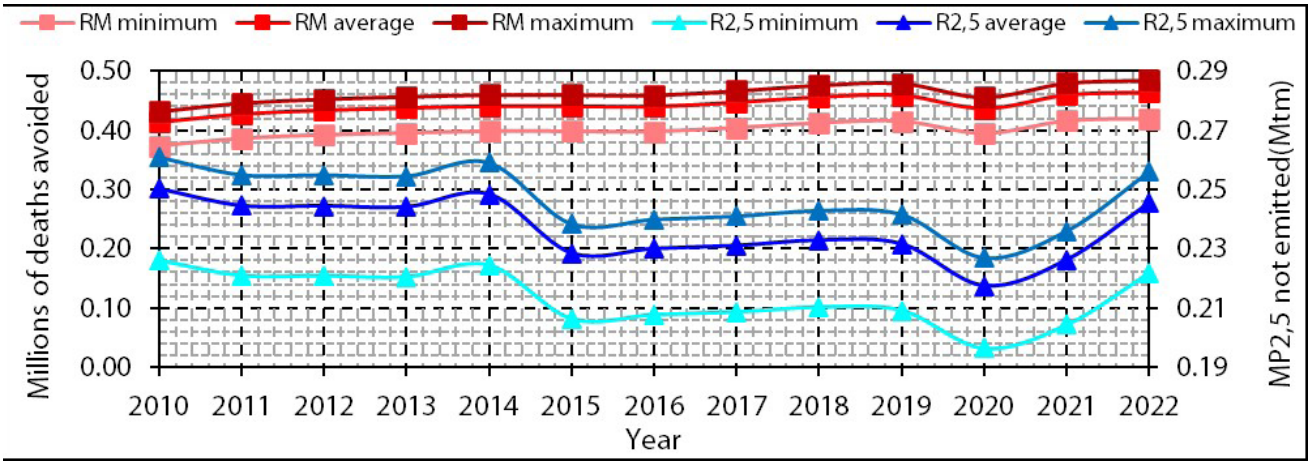


Figure 22: Graph of the benefits obtained with brake disk coating in terms of non-emissions and reduced fatalities.
Source: authors (2024).

Model Variables			
PfPM2,5	%	20,0	Selley *et al.* (2020)
K_1	T^{-1}	$3{,}5.10^{-8}$	Average value between CETR and TRB equipment
K_2	T^{-1}	$7{,}6.10^{-9}$	
k_1	$mm^3/N.m$	$2{,}0.10^{-5}$	
k_2	$mm^3/N.m$	$6{,}4.10^{-6}$	

Table 3: Variables applied in Eq. 11 for R2.5 and RM.
Source: authors (2024).

According these results, was observed a reduction of *PM2.5* emission. With this, a significant reduction of deaths was estimated. Thus, highlighting the role of technology in the service of sustainability. In this case, a laser surface treatment process; using Nickel as a coating is capable of preventing the dispersion of 230 thousand metric tons of *PM2.5*, per year on average. Impacting the reduction of more than 400 thousand deaths worldwide; due to respiratory complications.

Obviously, the impact of this processing could not be observed instantly; since the harmful health effects caused by *PM2.5* occur cumulatively. Likewise, the dispersion of this material occurs over the years. However, given such impressive numbers, it can be concluded that improving the wear resistance of automotive brake discs generates positive repercussions in terms of sustainability and population health.

4. CONCLUSION

In conclusion, based on the research problem presented and the proposed mitigation procedures, grounded in relevant literature, it can be affirmed that the objectives of this study were achieved.

Structurally, significant improvements were observed in the brake disc; whose coating morphology remained within the criteria of Pellizzari *et al.* (2022) and similar to the D and α_c parameters observed by Arias-González *et al.* (2016). Regarding mechanical properties, the coefficient of friction stands out, which was almost 5 times lower than uncoated disc and better than other studies: $\theta = 0.43$ (SHI *et al.*, 2021) and $\theta = 0.3$ (TONOLINI *et al.*, 2021).

In the hardness test, on the other hand, despite no improvements occurring; leaving behind other results such as: HV(0.5) = 1060 (TONOLINI *et al.*, 2021); there was additional proof of satisfactory anchoring; as observed by Shi *et al.* (2021) and Arias-González *et al.* (2016). In this case, with similar maximum values: HV(0,3) = 350 and HV(100, 10) = 600, respectively. Where the diffusion region also presented a peak of HV(0,3) = 400 and HV(100, 10) = 600. Proving the occurrence of metallurgical bonding.

Furthermore, an enhancement in the wear resistance of the coated surface was observed, potentially leading to reductions in PM2.5 emissions and associated fatalities, as predicted by the mathematical model implemented in this study. However, compared to other studies, the technique can still be improved in future scopes. Of these improvements, observations noted during the execution of the coatings stand out, such as the implementation of an automated system to reduce errors and improve the uniformity of the tracks Likewise, there is a lack of real-time control of E to reduce imperfections in the coating such as cracks, macro pores and flaws.

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ACCO: formal analysis and writing - review & editing.

CHS: formal analysis and writing - review & edition.

MMS: resources, supervision and writing - review & editing.

GV: project administration, funding acquisition, resources, writing - review & editing, conceptualization and supervision.

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CONCRETE WASTE AS COARSE AGGREGATE IN CEMENTITIOUS MATRICES: REVIEW

RESÍDUOS DE CONCRETO COMO AGREGADO GRAÚDO EM MATRIZES CIMENTÍCIAS: REVISÃO

RESIDUOS DE HORMIGÓN COMO ÁRIDO GRUESO EN MATRICES CEMENTANTES:REVISIÓN

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ABSTRACT

The aggregates present in concrete composition are non-renewable resources obtained through multiple mining or extraction innovations, which cause significant damage to nature. At the same time, the increasing generation of concrete waste is a worrisome reality. Most construction and demolition waste is quimically inert and non-hazardous, however it represents a problem when it is disposed of, since landfills have their useful life shortened due to the large volume of this type of disposal. Therefore, this article's objective is to survey the caracteristics of concrete waste and the properties of concretes produced using this type of residue as coarse aggregate. A systematic literature review is carried out and the feasibility of applying hardened concrete waste as recycled aggregate in cement matrices is discussed. It is observed that composites with recycled aggregates present similar characteristics to conventional concrete, being within usable ranges based on normative references, such as the properties of compressive strength, water absorption, density and modulus of elasticity. Therefore, it is viable to incorporate recycled aggregates as partial replacement for conventional aggregates.

KEYWORDS

Recycled concrete; Concrete waste; Coarse aggregate; Cementitious matrices.

RESUMO

Os agregados presentes na composição do concreto são recursos não renováveis obtidos através de múltiplas inovações de mineração ou extração, que causam danos significativos à natureza. Ao mesmo tempo, a crescente geração de resíduos de concreto é uma realidade preocupante. A maioria dos resíduos de construção e demolição é quimicamente inerte e não perigosa; no entanto, representa um problema quando é descartada, pois os aterros sanitários têm sua vida útil reduzida devido ao grande volume desse tipo de descarte. Portanto, o objetivo deste artigo é analisar as características dos resíduos de concreto e as propriedades dos concretos produzidos utilizando esse tipo de resíduo como agregado graúdo. Realiza-se uma revisão sistemática da literatura e discute-se a viabilidade de aplicar resíduos de concreto endurecido como agregado reciclado em matrizes cimentícias. Observa-se que os compósitos com agregados reciclados apresentam características semelhantes ao concreto convencional, estando dentro de faixas utilizáveis com base em referências normativas, como as propriedades de resistência à compressão, absorção de água, densidade e módulo de elasticidade. Portanto, é viável incorporar agregados reciclados como substituição parcial dos agregados convencionais.

PALAVRAS-CHAVE

Concreto reciclado, resíduos de concreto, agregado graúdo e matrizes cimentícias.

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RESUMEN

Los agregados presentes en la composición del hormigón son recursos no renovables obtenidos a través de múltiples innovaciones de minería o extracción, que causan daños significativos a la naturaleza. Al mismo tiempo, la creciente generación de residuos de hormigón es una realidad preocupante. La mayoría de los residuos de construcción y demolición son químicamente inertes y no peligrosos; sin embargo, representan un problema cuando se disponen, ya que los vertederos ven acortada su vida útil debido al gran volumen de este tipo de desechos. Por lo tanto, el objetivo de este artículo es analizar las características de los residuos de hormigón y las propiedades de los hormigones producidos utilizando este tipo de residuo como árido grueso. Se realiza una revisión sistemática de la literatura y se discute la viabilidad de aplicar residuos de hormigón endurecido como agregado reciclado en matrices cementantes. Se observa que los compuestos con agregados reciclados presentan características similares al hormigón convencional, estando dentro de los rangos utilizables según las referencias normativas, como las propiedades de resistencia a la compresión, absorción de agua, densidad y módulo de elasticidad. Por lo tanto, es viable incorporar agregados reciclados como reemplazo parcial de los agregados convencionales.

PALABRAS CLAVE

Hormigón reciclado, residuos de hormigón, árido grueso, matrices cementantes.

1. INTRODUCTION

Concrete is one of the most used materials in the world. The aggregates most commonly presente in its composition, namely sand and crushed stone, are non-renewable resources obtained through multiple stages of mining or extration.

To satisfy the growing global demand for these aggregates, 50 billion tons of natural river sand and gravel are extracted every year (CHANDRU; BAHURUDEEN; SENTHILKUMAR, 2023). Recent research points to a possible shortage of these materials if the same extraction rate continues to be followed (MAKUL *et al.*, 2021; ESTOKOVÁ; FABIÁNOVÁ; ONDOVÁ, 2022). In Brazil, the demand for natural aggregates in 2023 was 654 million tons, of which 272 million tons were crushed stone (ANEPAC, 2024). According to Araújo (2011), the production of crushed stone causes catastrophic effects on the environment, such as air and water pollution, noise and visual pollution, in addition to the accumulation of solid waste.

Allied to the utilization of concrete, there is the production of ever-increasing amounts of construction and demolition waste. The inadequate management of this waste can cause serious environmental problems (ZHANG *et al.*, 2023). Worldwide, construction and demolition activities contribute to the production of ten billion tons of waste each year and this production is constantly growing (KABIRIFAR *et al.*, 2021; WANG *et al.*, 2019). Most construction and demolition waste is inert and non-hazardous, but may contain substances harmful to the environment such as asbestos, organic pollutants and heavy metal (TRIVEDI *et al.*, 2023).

Due to the leaching of heavy metals, these residues become prone to soil and water pollution (ZHENG *et al.*, 2017). Furthermore, the civil construction waste represents a disposal problem, due to which sanitary landfills have their useful life shortened, due to the large volume of landfilled waste or the inadequate occupation of useful land that is converted into waste disposal (DEVI *et al.*, 2023).

Among the various types of construction and demolition waste, hardened concrete is presente in large quantities. However, concrete waste, particularly that from demolition, is a highly heterogeneous material and tends to absorb large amounts of water. The aggregates present in the concrete are also difficult to use, as the hydrated cement that surrounds the surface of the aggregates compromises the adhesion of the new mixture constituents (NEDELJKOVI *et al.*, 2021). Instability under compression forces (TANTA *et al.*, 2022) limits the use of recycled concrete in the manufacture of new concrete for structural use (TRAN; DANG; HO, 2022). On the other hand, recent studies point to the feasibility of using recycled concrete, reducing the environmental impact caused by construction waste (BALDANIA; BHOGAYATA, 2023).

With a focus on sustainable development, the search for other sources of concrete aggregates is crucial and the recycling of concrete waste presents itself as a promising alternative. Reusing this waste means reducing the need to extract new materials, which could represent a reduction in the consumption of natural aggregates by 60% (BRAVO *et al.*, 2015).

Furthermore, when compared to natural aggregates, recycled aggregates emit 28% less carbon dioxide due to the lower energy incorporated in their production and transportation process (TAM *et al.*, 2018). Thus, the incorporation of construction and demolition waste to replace natural aggregates represents the promotion of more sustainable and responsible development, as it contributes to reducing the ecological footprint caused by the construction sector.

For this paper, a bibliographical review was carried out, with the selection of studies that addressed the feasibility of applying waste composed of hardened concrete, as coarse aggregate in the production of recycled concrete. By tabulating the collected data, the main properties of the resulting concretes were analysed and discussed.

2. METHODOLOGY

For the paper production, a bibliographic research methodology was employed. The "Periódicos Capes", "Google Scholar", "Scopus", "Science Direct" and "Web of Science" databases were used, in addition to academic institutional repositories. The terms "concrete", "hardened", "crushed", "waste", "construction", "reuse", "recycled", "eco-friendly" were used as keywords for the research, limiting the selection to those studies published in the past ten years.

In order to refine the searches, the boolean logical operators "AND", "OR" and "NOT" were used, with the aim of combining search terms or expressions, as well as a proximity operator (double quotes) to search for compound terms, since this operator determines the maximum distance between terms or expressions in a document, making the search more objective. Twenty articles about the use of recycled concrete aggregate as substitute for conventional aggregate in concretes were selected.

Although the waste was classified as "hardened concrete waste" by the selected authors, it is important to highlight that according to NBR 9935, recycled concrete

aggregates (RCA) are those obtained through the recycling of concrete in a fresh or hardened state, whose coarse fraction (> 4.75 mm) is made up of at least 90% of fragments composed of Portland cement, by mass. Mixed recycled aggregates (MRA) are those whose coarse fraction (> 4.75 mm) consists of a maximum of 90% of fragments composed of Portland cement, by mass (ABNT, 2011).

Among the selected studies, 15 publications refer to normal concrete, 2 to pavement materials, 2 to structural concrete and 1 to self-compacting concrete. In all cases, natural coarse aggregates was replaced through the manufacture of recycled coarse aggregates from concrete waste.

Once the research and selection of the various sources of information were carried out, the collected data was tabulated and subsequently presented in the form of graphs for data analysis. Consequently, discussions and conclusive comments were made.

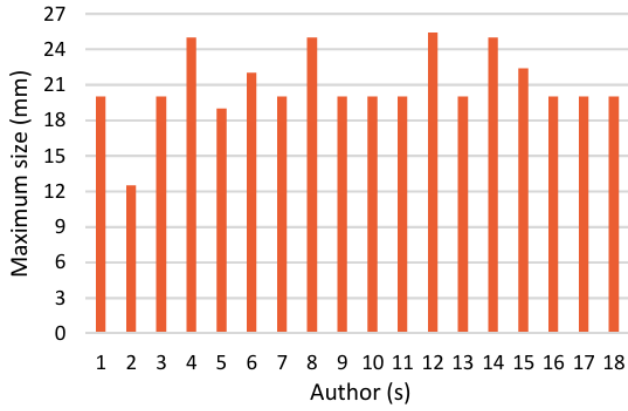
3. RESULTS AND DISCUSSION

The results and discussions regarding the physical properties of the recycled aggregates are presented, namely: maximum size, density and water absorption rate. Durability and mechanical resistance indexes of the concretes produced with these aggregates are also presented, namely: water absorption rate, compressive strength, flexural tensile strength, diametrical compression tensile strength and modulus of elasticity.

3.1. Concrete waste

Figure 01 shows the maximum size of the recycled coarse aggregate used by different authors in the production of concrete. There is a The results for the water absorption rate of recycled aggregates (Figure 03) showed great variability between the selected studies, with the minimum, maximum and average values equal to 2.76% (SURYA, *et al,* 2013), 7.35% (GHORBEL; WARDEH, 2017) and 4.21% respectively.

The high water absorption rate (Figure 2) presented by this type of aggregate is well above the limit values defined by NBR 15844 (ABNT, 2015) and C615 (ASTM, 2023) for granitic rocks (<0.4%) and by ASTM-C568 (ASTM, 2022) for high-density limestone rocks (≤ 0.3%). In regard to the size of the aggregates, there is a variation from 12.5 mm to 25 mm, with the maximum size of 20 mm being the most

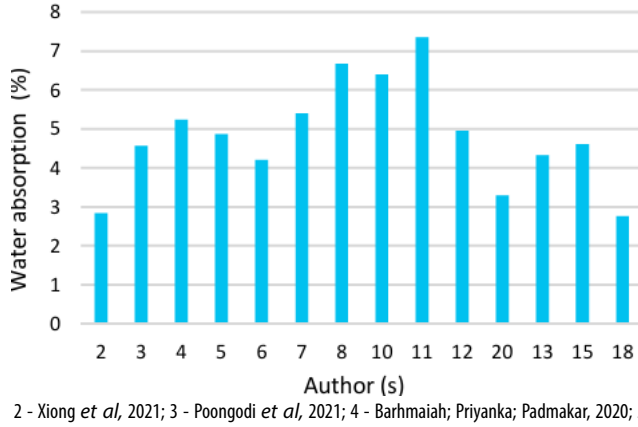


1 - Harish; Ramana; Gnaneswar, 2021; 2 - Xiong *et al,* 2021; 3 - Poongodi *et al,* 2021; 4 - Barhmaiah; Priyanka; Padmakar, 2020; 5 - Mohammed Ali; Zidan; Ahmed, 2020; 6 - Pacheco *et al,* 2019; 7 - Adessina *et al,* 2019; 8 - Ghorbani *et al,* 2019; 9 - Wang *et al,* 2019; 10 - Thomas; Thaickavil; Wilson, 2018; 11 - Ghorbel; Wardeh, 2017; 12 - Hamad; Dawi, 2017; 13 - Gupta; Khaudhair; Ahuja, 2016; 14 - Abdel-Hay, 2015; 15 - Soares *et al,* 2014; 16 - Orie; Orojo, 2014; 17 - Vyas; Patel; Bhatt, 2013; 18 - Surya; Kanta; Lakshmy, 2013.

Figure 01: Recycled aggregate's maximum size
Source: Authors (2023).

used among the authors of the selected studies. This results are within the dimensional range (4.75 mm to 75 mm) defined by NBR 7211 (ABNT, 2022) for coarse aggregates.

The bulk density (Figure 3) of the recycled coarse aggregate ranged from 2,240 kg/m^3 (GHORBEL; WARDEH, 2017) to 2,740 kg/m^3(VYAS *et al,* 2013). Among the results, the average density was 2,501 kg/m. For purposes of comparing the nature of the material, the reference given by NBR 15844 (ABNT, 2015) establishes that the density for granitic rocks must be greater than 2,550 kg/m^3. By C568 (ASTM, 2022), the density



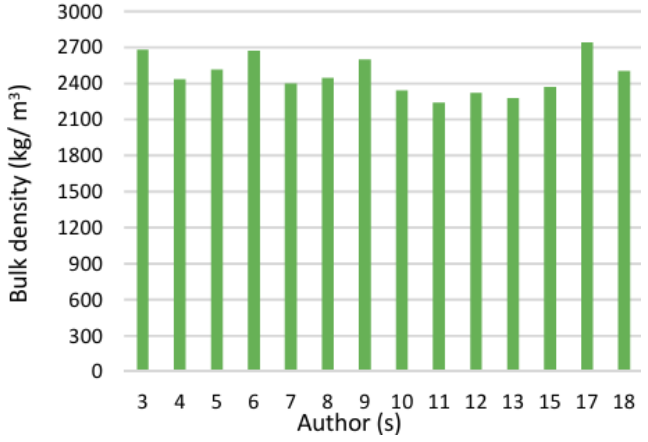
2 - Xiong *et al,* 2021; 3 - Poongodi *et al,* 2021; 4 - Barhmaiah; Priyanka; Padmakar, 2020; 5 - Mohammed Ali; Zidan; Ahmed, 2020; 6 - Pacheco *et al,* 2019; 7 - Adessina *et al,* 2019; 8 - Ghorbani *et al,* 2019; 10 - Thomas; Thaickavil; Wilson, 2018; 11 - Ghorbel; Wardeh, 2017; 12 - Hamad; Dawi, 2017; 13 - Gupta; Khaudhair; Ahuja, 2016; 15 - Soares *et al,* 2014; 18 - Surya; Kanta; Lakshmy, 2013; 20 - Fraile-Garcia *et al,* 2017.

Figure 02: Recycled aggregate's water absorption ratio
Source: Authors (2023).

must be greater than 2,560 kg/m^3 for high density limestone rocks. This range is close to the values found for the density of the recycled aggregate (Figure 02).

3.2. Physical properties

For the dosage of concrete mixtures, the water/cement ratio was kept constant in the majority of studies (Figure 04). Among the authors, the rate varied from 0.26 (MOHAMMED ALI, *et al,* 2020) to 0.61 (POONGODI *et al,* 2021). It is noteworthy that, according to the authors, to reach the value of 0.26, a superplasticizing additive was used, at a constant rate of 2% in all mixtures tested.



3 - Poongodi *et al,* 2021; 4 - Barhmaiah; Priyanka; Padmakar, 2020; 5 - Mohammed Ali; Zidan; Ahmed, 2020; 6 - Pacheco *et al,* 2019; 7 - Adessina *et al,* 2019; 8 - Ghorbani *et al,* 2019; 9 - Wang *et al,* 2019; 10 - Thomas; Thaickavil; Wilson, 2018; 11 - Ghorbel; Wardeh, 2017; 12 - Hamad; Dawi, 2017; 13 - Gupta; Khaudhair; Ahuja, 2016; 15 - Soares *et al,* 2014; 17 - Vyas; Patel; Bhatt, 2013; 18 - Surya; Kanta; Lakshmy, 2013.

Figure 03: Recycled aggregate's bulk density

Source: Authors (2023).

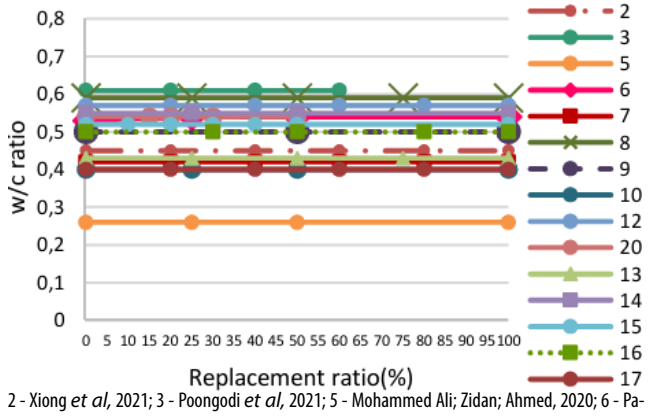
In GHORBEL & WARDEH (2017) however, cement consumption varied depending on the replacement ratio of natural coarse aggregate by recycled coarse aggregate. According to the authors, in order for the w/c ratio to be kept constant, it was necessary to vary the quantities of cement, since the high rate of water absorption by the recycled aggregate created the need for additional water to be incorporated into the mixtures.

The amount of cement used in the studies varied from 294 kg/m³ to 479 kg/m³, with the average value (384 kg/m³) being higher than the minimum cement consumption determined by NBR 12655 (ABNT, 2022), for concrete subjected to Class I aggressiveness (260 kg/m³).

It is observed an increase in water demand as the proportion of recycled aggregate increases. Nevertheless, the values for the w/c ratio, presented by different authors, were lower than the maximum value determined by NBR 12655 (ABNT, 2022) for concrete in Class I aggressive environments (≤0.65). In four studies, the value of the w/c ratio was below the maximum normative value for concrete in aggressive Class IV environments (≤0.45).

Figure 05 shows the rate of variation in slump for concretes produced with recycled aggregates and those produced with natural aggregates. Among the eleven studies in which this property was presented, the highlight is the decrease of up to 57% in the slump values obtained by Abdel-Hay (2015), in which no superplasticizing additive was used in the mixtures.

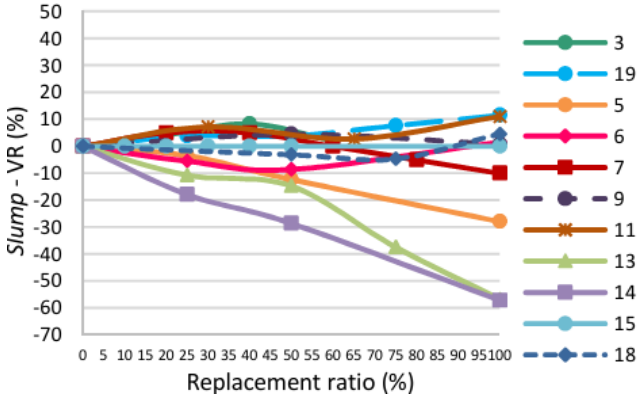
In Gupta *et al.* (2016), the superplasticizer additive content was kept constant for all concrete mixtures, which according to the authors explains the progressive drop in slump test values. This fact is related to the increase in the replacement content of aggregates, which leads to an increase in the amount of old, more porous mortar, adhered to the recycled aggregate. This results in a



2 - Xiong *et al,* 2021; 3 - Poongodi *et al,* 2021; 5 - Mohammed Ali; Zidan; Ahmed, 2020; 6 - Pacheco *et al,* 2019; 7 - Adessina *et al,* 2019; 8 - Ghorbani *et al,* 2019; 9 - Wang *et al,* 2019; 10 - Thomas; Thaickavil; Wilson, 2018; 12 - Hamad; Dawi, 2017; 13 - Gupta; Khaudhair; Ahuja, 2016; 14 - Abdel-Hay, 2015; 15 - Soares *et al,* 2014; 16 - Orie; Orojo, 2014; 17 - Vyas; Patel; Bhatt, 2013;

Figure 04: Recycled aggregate's bulk density

Source: Authors (2023).



3 - Poongodi *et al,* 2021; 5 - Mohammed Ali; Zidan; Ahmed, 2020; 6 - Pacheco *et al,* 2019; 7 - Adessina *et al,* 2019; 9 - Wang *et al,* 2019; 11 - Ghorbel; Wardeh, 2017; 13 - Gupta; Khaudhair; Ahuja, 2016; 14 - Abdel-Hay, 2015; 15 - Soares *et al,* 2014; 18 - Surya; Kanta; Lakshmy, 2013;19 - Panda; Imran; Samal, 2021.

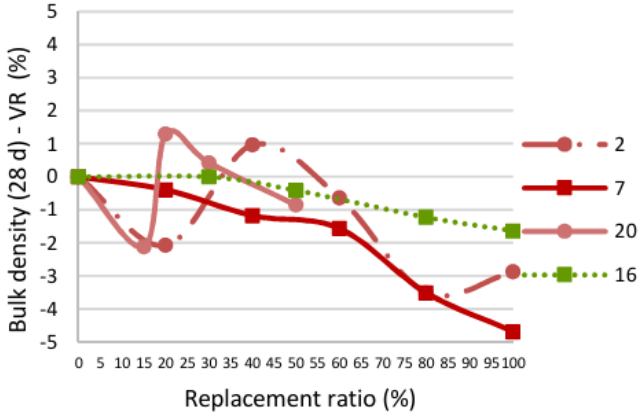
Figure 05: Variation in the slump flow values among mixtures.

Source: Authors (2023).

decrease of free water and, consequently, of the workability of the mortar mixtures. The variations occur because there is a greater wetting area in the aggregates, which require more water than conventional ones, impacting the workability and plasticity acquired by the mixture.

The rates of variation in the bulk density of concretes produced with different proportions of recycled coarse aggregate, after 28 days, are shown in Figure 06.

In general, a slight drop in density values is observed according to the replacement ratio of aggregates. In this context, an optimal substitution level is observed, with variations of ± 2.0%, around 20% substitution. This fact is related to the porous mortar adhered to the recycled aggregate which influence the connection between the constituents by increasing the porosity in the aggregate-



2 - Xiong *et al,* 2021; 7 - Adessina *et al,* 2019; 8 - Ghorbani *et al,* 2019; 16 - Orie; Orojo, 2014; 20 - Fraile-Garcia *et al,* 2017.

Figure 06: Variation in the slump flow values among mixtures.

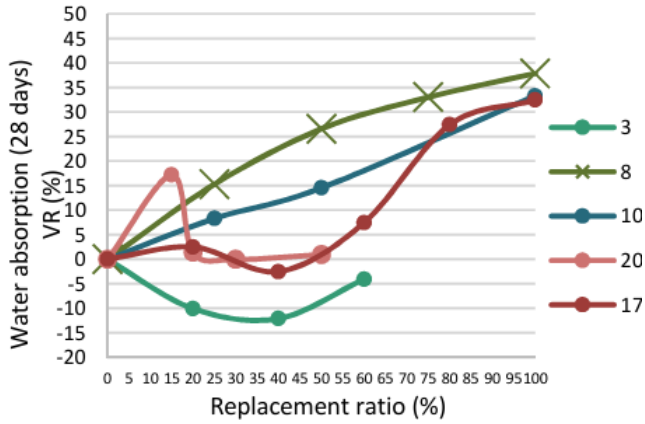
Source: Authors (2023).

-paste transition zone. The concretes produced with total replacement of natural coarse aggregates showed the highest rates of decrease in density values (up to 5%), in relation to the reference concretes.

3.3. Durability and mechanical properties

Figure 07 shows the rates of change in water absorption of concretes produced with recycled aggregates, after 28 days, compared to conventional concretes.

There is a tendency for water absorption to increase (up to 38%) with the total replacement of coarse aggregates. The results presented by Poongodi *et al.* (2021) are an exception. According to the authors, the drop in water absorption is due to the filler effect caused by the addition of fly ash to the mixtures, as well as the pozzolanic reactions facilitated by the addition of silica fume, both capable of promoting the densification of cement matrices and, consequently, a decrease in water absorption rates.



3 - Poongodi *et al,* 2021; 8 - Ghorbani *et al,* 2019; 10 - Thomas; Thaickavil; Wilson, 2018; 17 - Vyas; Patel; Bhatt, 2013; 20 - Fraile-Garcia *et al,* 2017.

Figure 07: Variation in the water absorption ratio among mixtures

Source: Authors (2023).

However, in general, increasing the replacement content of aggregates leads to greater water absorption.

It is noteworthy that, in four studies, water absorption values are below the maximum value (≤10%) determined by NBR 6136 (ABNT, 2016) for Class B or C concrete, with or without structural function, produced with natural aggregates.

It is observed that this is a property directly related to the physical properties that lead to durability indicators, since it is possible to evaluate the behavior trends of concrete with the addition of recycled aggregates against water, a potentially aggressive agent.

After 28 days, the porosity of the concretes with recycled aggregates increased by 28%, 44% and 52% for coarse aggregate replacement levels equal to 30%, 65% and 100%, respectively (GHORBEL; WARDEH, 2017). Similarly, the sorptivity of the recycled concretes, resulted in increases of 193%, 286% and 406% for replacement levels equal to 60%, 80% and 100% (VYAS *et al.*, 2013).

The compressive strength of concretes at 28 days are shown in Figure 08. Despite the great variability among the results, a downward trend in resistance values can be seen from low levels of replacement (10%) of natural coarse aggregates with recycled aggregate.

For 100% replacement content, Gupta *et al.* (2016) resulted in a decrease in compressive strength of up to 46%. According to the authors, it is important to highlight that, in a normal dosage, when replacing aggregates, the masses of recycled and natural coarse aggregates are considered equivalent. For this purpose, the old mortar adhered to the recycled aggregate is considered an integral part of it. However, it is known that the strength of the adhered mortar is lower than the strength of the aggregate which,

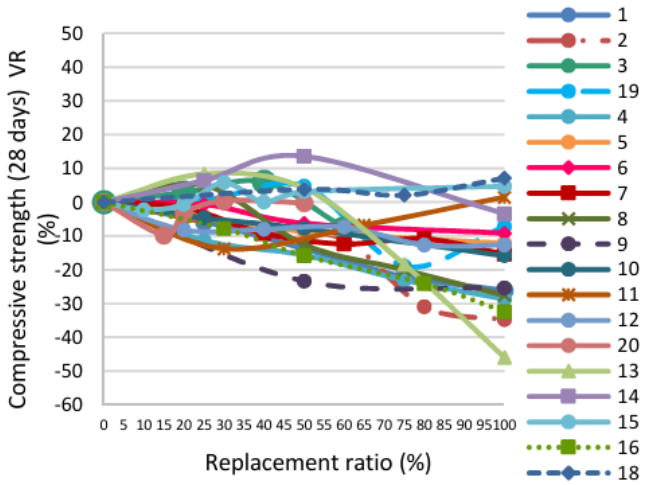


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Figure 08: Variation in compressive strength among mixtures

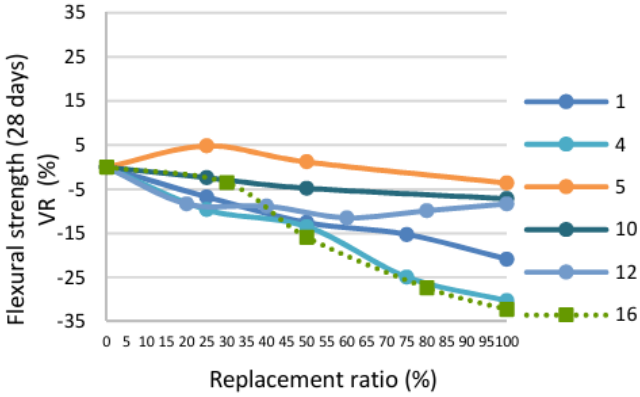
Source: Authors (2023).

in part, could explain the drop in the strength values obtained in the tests. Furthermore, there is an increase in the transition zone between aggregates and mortar residues, which are identified as areas of great fragility. For this work, a constant water/cement factor was used, in addition to a superplasticizing additive, also at a constant fraction. Even so, in all studies, recycled concrete exhibited compressive strength greater than the minimum value (20 MPa) determined by NBR 8953 (ABNT, 2015).

The rates of variation in flexural strength are, shown in Figure 09, which analyzes the evolution of this property depending on the reference. In all studies presented, the flexural strength, tested at 28 days, also decreased after replacing 50% of natural coarse aggregate by recycled aggregate. The biggest drop (32%) was shown by concrete produced with total replacement of natural coarse aggregate (ORIE, OROJO, 2014).

This fact may be related to changes in the packaging of the mixture particles and changes in water absorption generated by recycled aggregates, in addition to areas of weakness at the interface between aggregates and old mortars, as well as with the final mortars molded in the study.

The rates of variation in tensile strength, obtained through the diametrical compression test, also showed a downward trend in ten of the twelve studies presented in Figure 10. For the majority of these studies, the largest



1 - Harish; Ramana; Gnaneswar, 2021; 4 - Barhmaiah; Priyanka; Padmakar, 2020; 5 - Mohammed Ali; Zidan; Ahmed, 2020; 10 - Thomas; Thaickavil; Wilson, 2018; 12 - Hamad; Dawi, 2017; 16 - Orie; Orojo, 2014.

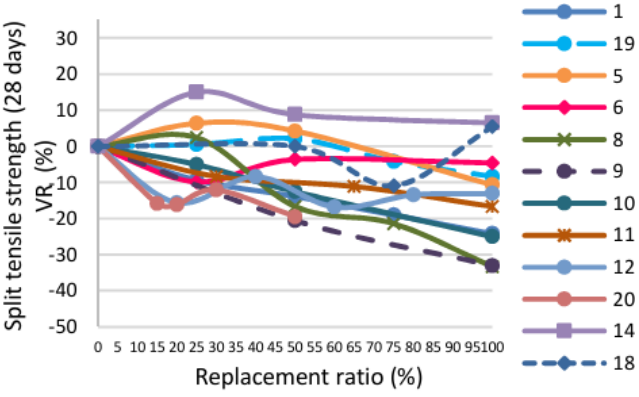
Figure 09: Variation in flexural strength among mixtures

Source: Authors (2023).

drops (33%) correspond to the concretes produced with complete replacement of natural coarse aggregate with recycled ones.

According to Surya *et al.* (2013), whose results showed an increase in tensile strength for the content of 100% replacement of natural coarse aggregate, the rough texture of the recycled aggregate and the absorption capacity of the mortar adhered to it, may have provided better adhesion and interlocking between mortar and recycled coarse aggregate, improving tensile strength.

Tested in eight studies, the modulus of elasticity (Figure 11) also showed a drop at the lowest levels of replacement



1 - Harish; Ramana; Gnaneswar, 2021; 5 - Mohammed Ali; Zidan; Ahmed, 2020; 6 - Pacheco *et al,* 2019; 8 - Ghorbani *et al,* 2019; 9 - Wang *et al,* 2019; 10 - Thomas; Thaickavil; Wilson, 2018; 11 - Ghorbel; Wardeh, 2017; 12 - Hamad; Dawi, 2017; 14 - Abdel-Hay, 2015; 18 - Surya; Kanta; Lakshmy, 2013; 19 - Panda; Imran; Samal, 2021; 20 - Fraile-Garcia *et al,* 2017.

Figure 10: Variation in the split tensile strenght among mixtures

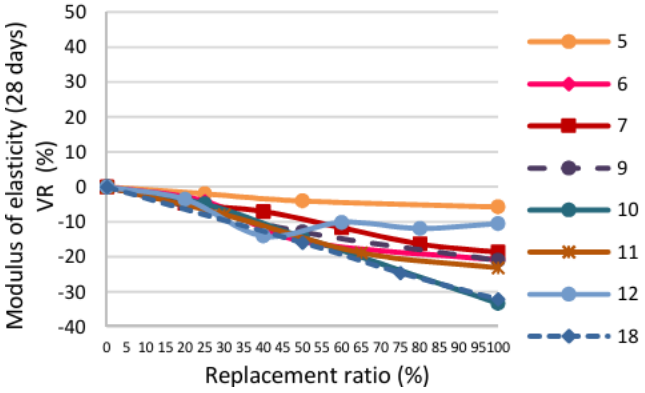
Source: Authors (2023).

of natural aggregate with recycled aggregate (20%).

It is observed that the biggest drops (32% and 33%), related to the complete replacement of coarse aggregate, were recorded by Surya *et al.* (2013) and by Thomas *et al.* (2018), respectively

This characteristic can be explained by the lower modulus of elasticity of recycled aggregates, which leads to greater deformation of mixtures with recycled aggregates (SURYA *et al.*, 2013).

4. FINAL CONSIDERATIONS



5 - Mohammed Ali; Zidan; Ahmed, 2020; 6 - Pacheco *et al,* 2019; 7 - Adessina *et al,* 2019; 9 - Wang *et al,* 2019; 10 - Thomas; Thaickavil; Wilson, 2018; 11 - Ghorbel; Wardeh, 2017; 12 - Hamad; Dawi, 2017; 18 - Surya; Kanta; Lakshmy, 2013.

Figure 11: Variation in the modulus of elasticity among mixtures

Source: Authors (2023).

The literature review carried out for this article included studies on the application of hardened concrete waste as a substitute for natural coarse aggregate in concrete production. The tabulation of the collected data allowed the analysis of the main properties of the recycled aggregates, as well as the resulting concretes.

The maximum size and apparent density of recycled aggregates are similar to those of natural coarse aggregates. However, the high water absorption rate of this type of aggregate, up to 7.35% higher than natural coarse aggregates, is a limiting factor for its application in concrete production. Therefore, a more careful dosage is necessary in order to correct the amount of water added to the mixture, while paying attention to the limit values of the water/cement ratio.

In general, the values referring to the durability parameters (water absorption, porosity and sorptivity) of recycled concretes showed a drop when compared to those exhibited by reference concretes, produced without replacing natural aggregates. However, among the studies in which the water absorption rate was tested, the majority showed results below the maximum normative value (10%) for concrete blocks with or without structural function, indicating a possible use for this type of concrete.

Likewise, the mechanical strength of recycled concretes also decreased compared to reference concretes, but still, in all selected studies, recycled concretes exhibited compressive strength values higher than the minimum normative value (20 MPa), which also points to the technical feasibility of using recycled concrete.

It is observed that changes in the properties of concretes and mortars using recycled aggregates are related to the lower density of the materials and the greater absorption of water, resulting from the surface of the aggregates, which may contain adhered old mortar. In this sense, the application of this material brings about a tendency for changes in plasticity, water absorption and, finally, particle packaging, taking into account the material's resistance.

Since the incorporation of concrete waste as a substitute for natural coarse aggregates appears, in principle, to be a viable alternative for reducing environmental liabilities caused by civil construction, the gap that still exists in the literature regarding the properties of this type of recycled aggregate is highlighted and the appreciable potential for it's use indicates a real possibility of a more responsible, clean and sustainable development.

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RECTANGULAR CONCRETE BLOCKS FOR INTERLOCKING PAVING: USE OF SPENT FOUNDRY SAND AS A SUBSTITUTE FOR NATURAL SAND

BLOCOS DE CONCRETO RETANGULARES PARA PAVIMENTAÇÃO INTERTRAVADA: USO DE AREIA DESCARTADA DE FUNDIÇÃO COMO SUBSTITUTO DA AREIA NATURAL

BLOQUES RECTANGULARES DE HORMIGÓN PARA PAVIMENTOS ENTRELAZADOS: UTILIZACIÓN DE ARENA DE FUNDICIÓN USADA COMO SUSTITUTO DE LA ARENANATURAL

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ABSTRACT

The foundry industry generates large quantities of spent foundry sand (SFS), a solid waste. The use of SFS as a substitute for natural sand is a more sustainable solution to address disposal issues. In this study, rectangular concrete blocks were developed for use in paving with total replacement of natural sand by SFS contaminated with phenolic resins. This allowed for an analysis of the influence of SFS on concrete properties. The SFS was characterized using X-ray diffraction, X-ray fluorescence, thermal analysis, and scanning electron microscopy. The blocks' mechanical and chemical properties demonstrate their technical feasibility and compliance with Brazilian pavement application regulations (compression strength > 50 MPa and water absorption < 6%). Therefore, this study suggests that producing rectangular concrete blocks with total sand replacement with SFS is a more sustainable, technically and economically feasible alternative.

KEYWORDS

Spent Foundry Sand; Concrete Blocks; Phenolic Resin; Waste Foundry Sand; Interlocked Pavement

RESUMO

A indústria de fundição gera grandes quantidades de resíduo de areia descartada de fundição (ADF). O uso de ADF como substituto da areia natural é uma solução mais sustentável para resolver problemas de descarte. Neste estudo, blocos retangulares de concreto foram desenvolvidos para uso em pavimentação com substituição total de areia natural por ADF contaminada com resinas fenólicas. Isso permitiu uma análise da influência do ADF nas propriedades do concreto. O ADF foi caracterizado usando difração de raios X, fluorescência de raios X, análise térmica e microscopia eletrônica de varredura. As propriedades mecânicas e químicas dos blocos demonstram sua viabilidade técnica e conformidade com as regulamentações brasileiras de aplicação de pavimentos (resistência à compressão > 50 MPa e absorção de água < 6%). Portanto, este estudo sugere que a produção de blocos retangulares de concreto com substituição total de areia por ADF é uma alternativa mais sustentável, técnica e economicamente viável.

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PALAVRAS-CHAVE

Areia descartada de fundição; Blocos de concreto; Resina fenólica; Areia de fundição residual; Pavimento intertravado

RESUMEN

La arena de fundición gastada (AFG) es un residuo sólido generado en grandes cantidades por la industria de fundición. El uso de AFG como sustituto de la arena natural representa una solución más sostenible para abordar los problemas de disposición. En este estudio, se desarrollaron bloques de concreto rectangulares para su uso en pavimentación, reemplazando totalmente la arena natural por AFG contaminada con resinas fenólicas. Esto permitió analizar la influencia de la AFG en las propiedades del concreto. La AFG fue caracterizada mediante Difracción de Rayos X y Fluorescencia de Rayos X, análisis térmico y Microscopía Electrónica de Barrido. Las propiedades mecánicas y químicas de los bloques obtenidos demuestran su viabilidad técnica y conformidad con las normas reglamentarias brasileñas para aplicaciones en pavimentos (resistencia a la compresión > 50 MPa y absorción de agua < 6%). Por lo tanto, este estudio sugiere que la producción de bloques de concreto rectangulares con reemplazo total de arena por AFG es una alternativa más sostenible, técnica y económicamente viable.

PALABRAS CLAVE

Arena de fundición gastada; Bloques de hormigón; Resina fenólica; Arena residual de fundición; Pavimento entrelazado

1. INTRODUCTION

A country's industrial development closely links the steel industry and melting processes, which involve activities in the automotive, domestic, military, and agro-industrial sectors (CHEGATTI, 2016; MURARI; SIDDIQUE; JAIN, 2015). Smelters, in particular, are significant contributors to gas emissions and solid waste generation, including spent foundry sand (SFS) and slag. The production of molten metal generates approximately 0.8 to 1.0 kilograms of waste foundry sand (WFS). This indicates a direct correlation between production volumes and waste generation. In 2020, the global production of solid foundry waste was approximately 105.5 million metric tons, highlighting the extensive scale of waste associated with these industrial processes (SRD, 2022).

This work aims to establish a methodology in accordance with the Brazilian Association of Technical Standards (ABNT) — Standard NBR 9781 (NBR 9781, 2013) – to determine the technical feasibility of reusing SFS contaminated with phenolic resin as a replacement for natural sand in the production of rectangular concrete blocks for paving. Furthermore, only a small number of papers have investigated the use of SFS as a recyclable component in paving block production. This area is of significant interest to both materials researchers and environmental engineers due to the potential for interdisciplinary collaboration focused on sustainable practices.

2. LITERATURE REVIEW

Waste foundry sand that contains physical binders exhibits a significant variation in its silicon dioxide (SiO_2) content, ranging from 78.4% to 94.1%. This variability in composition can result in different properties, which makes it challenging to use in various applications (PAIVA *et al.*, 2021). On the other hand, the use of phenolic resin as a chemical binder in the preparation of sand molds to produce metallic components results in WFS with high SiO_2 concentrations, up to 99%. While this high concentration of SiO_2 makes results more predictable and makes WFS better for mixing with cementitious materials, it opens up a wider range of possible uses (MAVROULIDOU; LAWRENCE, 2019; SANTOS *et al.*, 2021).

Guerino *et al.* (GUERINO, K.B; VICENZI, J; BRAGANÇA, S.R; BERGMANN, 2010) (NBR 10004, 2004; NBR 10005:2004, 2004; NBR 10006:2004, 2004) evaluated and classified the specimens as inert materials. Due to their high concentration of silicon dioxide (SiO_2), these SFS reuses can also serve as raw materials for the production of glasses and glass-ceramic materials. Silva *et al.* (SILVA *et al.*, 2020) were able to replace 100% of the silica by SFS for the production of this type of material.

Paiva *et al.* (DE PAIVA *et al.*, 2023) produced mortars with up to 50% waste foundry phenolic sand (WFPS), which has a high concentration of phenolic resin on its surface. The study found that high concentrations of resin significantly increase the void index, reducing the mechanical strength of cementitious composites. The authors (DE PAIVA *et al.*, 2023) attribute this low interfacial interaction to the WFPS and the cement matrix. Mastella *et al.* (MASTELLA *et al.*, 2014) investigated the impact of substituting traditional sand with resin-contaminated waste foundry sand in the composition of concrete blocks. The WFS underwent thermogravimetric analysis, which revealed a minimal mass loss of 0.9% within the temperature range of 400 to 450 °C, attributed to the presence of resin. The study found that replacing up to 25% of conventional sand by WFS does not negatively impact the mechanical strength of concrete. This was observed at hydration intervals of 28, 56, and 91 days. Also, Fourier-transform infrared (FTIR) spectroscopy of the WFS revealed an aliphatic structure, which is different from what is usually seen for phenols, which have a carboxylic acid structure. This suggests that formaldehyde is present. The compound's low water solubility suggests minimal environmental impact, as it results in negligible leaching (MASTELLA *et al.*, 2014).

Under Brazilian law, smelters must dispose of their SFS in licensed landfills. However, due to the limited number of available landfills, service providers charge high fees for transporting residues from industries to the final destination. This results in many companies resorting to unauthorized disposal methods, which are illegal and harmful to the environment (ABIFA, 2008).

Generally, the molds used in the foundry industries are formed by silica sand mixed with a binder (phenolic resin, bentonite clay, coal powder, and carbonaceous material) and water. In a previous publication, SANTOS *et al.* (2021) presented the characterization of spent foundry sand mixtures (SFS-M), incorporating several different binders, and explored their novel application in the production of concrete blocks for interlocking pavements.

In 2021, Santos *et al.* carefully collected WFS from five different industrial sources. They divided the samples into two groups based on the type of binder they were: chemical and physical. Two of the chemical binder samples were mixed with three of the physical binder samples and then used in interlocking concrete blocks (SANTOS *et*

al., 2021). A scanning electron microscope (SEM) analysis showed that the surface of WFS had small particles. These particles were made up of compounds like bentonite, coal dust, and phenolic resin. Concrete samples containing 100% WFS in place of sand showed a reduction in mechanical strength of up to 50%. The presence of surface impurities correlated this reduction with impaired interfacial adhesion between WFS and the cement matrix. This observation, documented by Santos *et al.* (2021), underscores the critical impact of surface cleanliness on the mechanical performance of concrete composites containing WFS.

3. MATERIALS AND METHODS

3.1 Natural Sand and Spent Foundry Sand

The physical and chemical properties of Natural Sand and SFS were compared through characterization. Natural sand is commonly used in the construction and building industry for concrete production. SFS, contaminated with phenolic resins, was collected from a smelter in Presidente Prudente, São Paulo, Brazil, that produces white, gray, and nodular cast iron.

3.2 Sand Caracterization

Approximate values for the most stable oxide percentages of Natural Sand and SFS were obtained using an energy dispersive X-Ray Fluorescence spectrometer (EDX7000, Shimadzu) with Rh atoms as the primary radiation. We analyzed the scanning from Na to U in the qualitative--quantitative mode, keeping the temperature and pressure at normal. We used a biaxially-oriented polyethylene terephthalate (boPET, Mylar®) sample holder. We found the crystalline phases of all the synthesized samples using X-ray diffractometry (XRD) on an X-ray diffractometer (XRD-6000, Shimadzu) with Cu K±1 (λ = 1.5406 Å) and Cu K±2 (λ = 1.5444 ô) radiation. The divergence and reception slits were set to 1º in continuous scan mode, with a 40 kV voltage, 30 mA current, 2º/min scan speed, and 2θ angular range from 10º to 80º. The diffraction spectra were identified using the crystallographic records from the Powder Diffraction Files (PDF) of the Joint Committee on Powder Diffraction Standards—International Center for Diffraction Data (JCPDS-ICDD) database.

Thermal analysis was performed using a SDT Q600 instrument from TA Instruments to identify thermal degradation and phase transformations. We analyzed the sands in alumina crucibles, maintaining a heating rate of 10 oC/min, an equilibrium temperature of 30 oC, and a synthetic air atmosphere with a flow rate of 100 mL/min. The maximum temperature was 1000 ºC. We evaluated the SFS morphology using Scanning Electron Microscopy (SEM) with an EVO LS 15 instrument from Zeiss. A Q150TE instrument from Quorum used an evaporation process to coat the sample with gold.

The natural sand and SFS were tested for bulk specific gravity using ABNT Standard NBR 9781 (NBR 9781, 2013). Granulometric analysis was conducted following ABNT Standard NBR (NBR 248, 2003). The classification of the samples within the recommended granulometric range (optimal and usable zones) was determined through visual analysis, in accordance with ABNT Standard NBR 7211 (NBR 7211, 2022).

3.3 Production of Rectangular Concrete Blocks

Two traces were prepared: one for reference (natural sand) and the other for SFS. The only difference between them is the total replacement of the natural thin aggregate with SFS, as shown in **Table 1**. The composition of the Reference trace was performed in accordance with the trace used in the industrial sector (SIDDIQUE *et al.*, 2015).

Constituents	Reference Trace	SFS Trace
Cement (kg/m³)	288.0	288.0
Natural Sand (kg/m³)	330.0	-
SFS* (kg/m³)	-	326.7
Fine Gravel (kg/m³)	565.3	565.3
Water (kg/m³)	94.2	94.2
Additive (kg/m³) – 0.05% Cement	1.44	1.44
Slump Test	0	0

SFS* - SFS with phenolic resins

Table 1: Concrete mix proportions.

Source: authors.

In this work, we used High Initial Strength (HIS) cement, with a water/cement ratio of 94.2 kg/m³ for both mixes.

Following ABNT Standard NBR 9781 (NBR 9781, 2013), we produced ten rectangular concrete blocks (8 x 15 x 25 cm—**Figure 1**) using both the reference and SFS traces. The concrete mixer in use had a capacity of 100 liters. The order of placement in the mixer is crucial: begin with the addition of fine gravel (coarse aggregate), followed by half the volume of water, HIS cement, natural sand (or SFS), the remaining volume of water, and finally the additive.

The concrete compositions were mixed for 5 minutes and then subjected to the trunk abatement test,

according to ABNT – Standard NBR NM 67 (NM 67, 1998). Next, the rectangular concrete blocks were shaped into

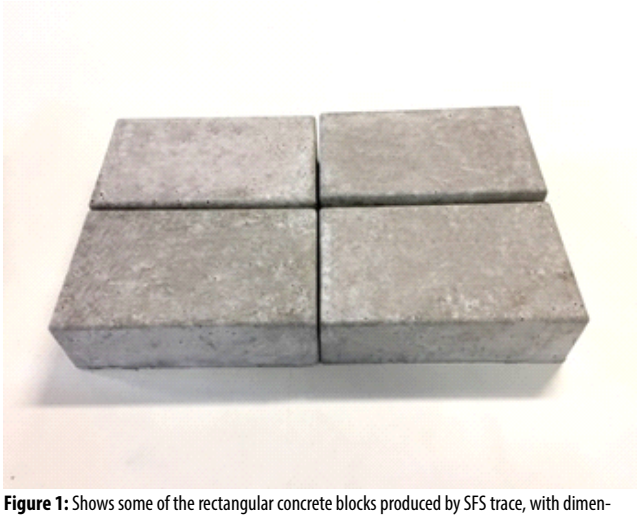

Figure 1: Shows some of the rectangular concrete blocks produced by SFS trace, with dimensions of 8 x 15 x 25 cm.
Source: authors.

molds containing lubricating oil to facilitate immediate deformation, as per ABNT – Standard NBR 5739 (NBR 5739, 2018). Next, we vibrated the molds on a vibrating table for approximately 15 seconds before unmolding them onto a clean, flat surface.

The curing process was carried out in a moist chamber. We maintained the healing period until the rupture ages, which were 7 and 28 days. To conduct the compressive strength tests, it was necessary to flatten the concrete blocks' surfaces to ensure homogeneous distribution of the applied force during the test. We performed the flattening procedure for the rectangular concrete blocks using a cement paste in accordance with ABNT-Standard NBR 9781. The rectangular concrete blocks were subjected to tests for compressive strength and water absorption through immersion, in accordance with ABNT Standard NBR 9781.

The water absorption test results were calculated using the arithmetic mean value of five specimens (blocks made with natural sand and SFS) and Equation 1 from ABNT - Standard NBR 9778 (NBR 9778, 2009).

In which A is the total water absorption (%), m^1 is the dried block (110 ± 5 °C) mass (g) and m^2 is the saturated block mass (g).

Compressive strength tests were conducted using

$$A = \left(\frac{m_2 - m_1}{m_1}\right) x100 \qquad \text{Equation 1}$$

a 20T universal testing machine (UTM). The results were calculated as the arithmetic mean of five rectangular concrete blocks made with natural sand and SFS).

The cross-section of rectangular concrete blocks (28 days) was analyzed using an optical microscope (V12 Stereo Discovery, Zeiss) coupled with a digital camera (SSC-DC54A, Sony).

4. RESULTS AND DISCUSSION

Table 2 shows the chemical composition of natural sand and SFS as determined by XRF spectroscopy. The casting process, which uses sand as a refractory material to prepare molds to produce metallic pieces, is characterized by the high content of silicon dioxide (SiO2). It is worth noting that the SFS sample has a higher concentration of SiO2 (98.311 wt%) than the commercial Natural Sand sample (91.462 wt%). During the casting process, small amounts of other metals present in the natural sand diffuse into the metal cast. Both samples contain SO3, which is related to the phenolic resins used in the molding process for SFS and to a common and small contamination present in natural sand. The minor concentration elements originate from scrap and refractory furnaces, as well as other mineralogical components (VARGAS *et al.*, 2015).

Constituents	Natural Sand	SFS
SiO_2	91.462	98.311
Al_2O_3	3.954	-
Fe_2O_3	1.082	0.562
TiO_2	0.927	-
SO_3	0.718	0.533
CaO	0.708	0.366
K2O	1.055	0.108
CuO	0.012	0.079
ZrO_2	-	0.033
ZnO	0.006	0.008
Other	0.076	-

Table 2: Chemical composition of Natural Sand and SFS by XRF spectroscopy.
Source: authors.

Figure 2 (a) and **Figure 2 (b)** show the XRD patterns for natural sand and SFS, respectively. The test showed that alpha quartz (α-SiO_2) was the only crystalline phase (PDF 5–490) in both samples, which matches the results of the XRF analysis. The darker color of SFS (inset (b) in Figure 2) compared to Natural Sand (inset (a) in Figure 2) might be because it has phenolic resins in it, since neither bentonite nor coal powder were added to this SFS.

Figure 3 (a) and **(b)** display the thermal analyses for natural sand and SFS, respectively. The analysis for natural sand reveals a single endothermic reaction at approximately 572 ºC, which corresponds to the polymorphic transition of quartz (α-SiO_2 to β-SiO_2) (PEREIRA *et al.*, 2014). The weight fluctuations observed in this sample's thermogravimetric curve are likely due to background noise rather than real reactions. The weight values only vary slightly, from 30.20 to 30.25 mg, which is close to the equipment limit.

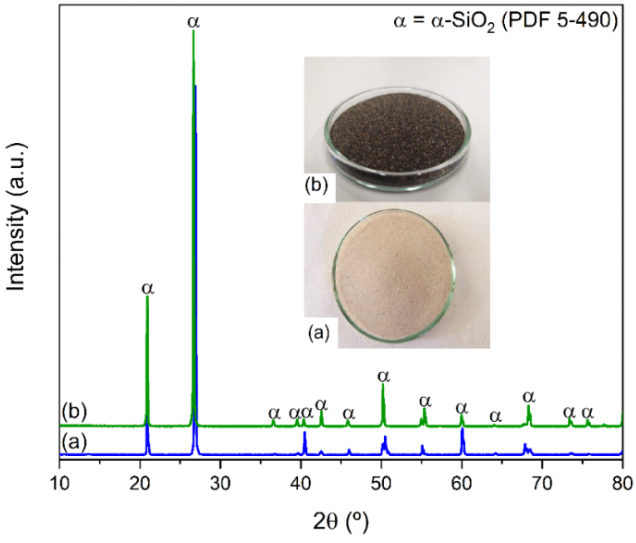

Figure 2: DRX patterns of (a) Natural Sand and (b) SFS. Inset: digital image of (a) Natural Sand and (b) SFS.

Source: authors.

The thermogravimetry analysis data from SFS shows that the first thermal event occurs in a range from ambient temperature to approximately 100°C and is related to the loss of adsorbed water (moisture). The second thermal event starts after 200°C (calibration temperature of the DSC equipment) and extends up to 850°C. The loss of about 0.30 mg of mass from the phenolic resins that formed around the grains of SFS is due to the raw materials used in the molding process and/or Macharia (CARNIN *et al.*, 2012). The differential scanning calorimetry data shows an endothermic peak at 572 ºC. This is because α-SiO_2 changes to β-SiO_2, which we already talked about.

Figure 4 presents SEM micrographs of the SFS, magnified at 100x, 300x, and 350x. The images show that the heterogeneous grains of the SFS have irregular surfaces and varying sizes. Additionally, layers of phenolic resins can be observed surrounding the SFS grains (ZHANG *et al.*, 2013).

The analysis of bulk specific gravity yielded a value of 2.85 g/cm^3 for natural sand and 2.65 g/cm2 for SFS. The production processes involving high temperatures and phenolic resins are responsible for the lower specific mass value of SFS. This reduction, however, has a positive impact on the final product, as blocks made with SFS are 7% lighter than those made with natural sand (reference blocks).

There was a problem with the granulometric curves of natural sand and SFS not fitting into the Usable Zone Optimum (UZO) set by ABNT-Standard NBR 7211. This can be seen in **Figure 5**. However, all grain sizes fall within the

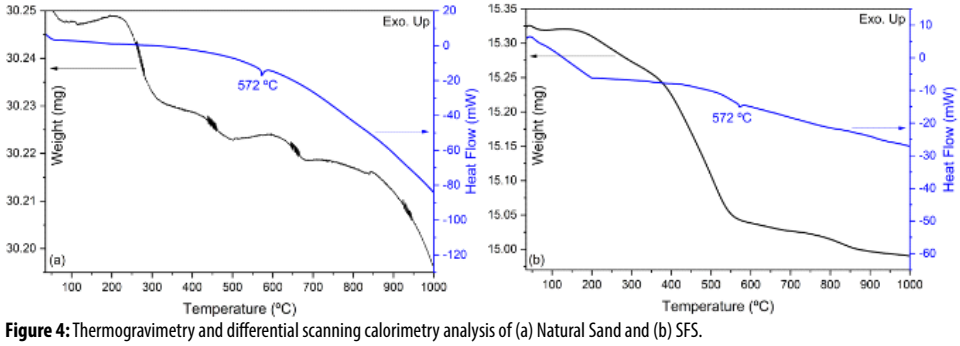

Figure 4: Thermogravimetry and differential scanning calorimetry analysis of (a) Natural Sand and (b) SFS.

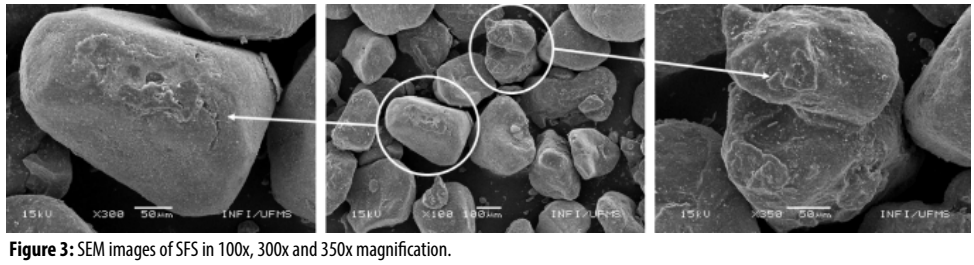

Figure 3: SEM images of SFS in 100x, 300x and 350x magnification.

Source: authors.

Usable Zone Limits (UZL) set by the same standard. Based on this analysis, we classified SFS as a usable and suitable fine aggregate for the concrete mix. We observed a reduction in grain diameters in the SFS compared to natural sand. The SFS has a higher percentage of smaller-diameter grains.

Figure 6 displays the individual and average results for the compressive strength of rectangular concrete blocks at 7 and 28 days of age for both reference and SFS traces. The axial compression strength of the rectangular concrete blocks after 7 days of curing in the wet chamber was 54.96 MPa for the reference trace and 53.30 MPa for the SFS trace. After 28 days of curing, the concrete blocks showed an increase in resistance. The reference trace had a mean value of 66.92 MPa, which represents a 21.76% increase, while the SFS trace had a mean value of 62.81 MPa, representing a 17.84% increase. According to ABNT - Standard NBR 9781 (NBR 9781, 2013), concrete blocks used for interlocked paving must have a minimum compressive strength of 35 MPa (for light trucks) and 50 MPa (for heavy trucks) (FORTES *et al.*, 2017). Therefore, the results obtained meet the standardized requirements satisfactorily. The blocks under study achieved high compressive strength on the 7th and 28th day due to the use of HIS cement in their production.

It was observed that the rectangular concrete blocks had a 6.14% reduction in compressive strength at 28 days of cure compared to the concrete blocks molded from the Reference trace, when the same proportion of materials in

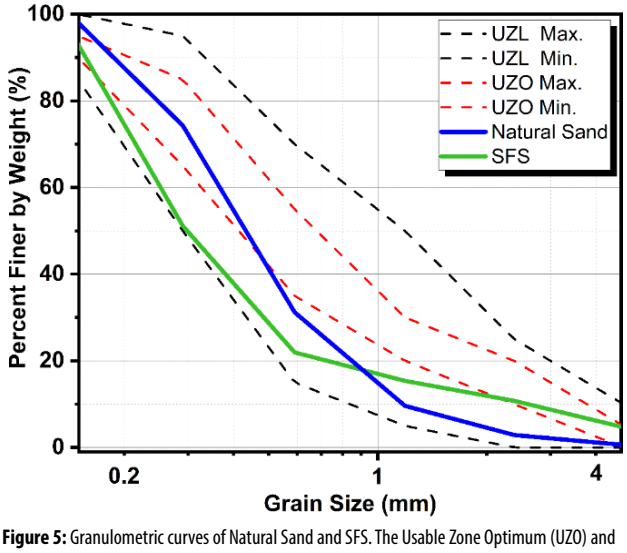

Figure 5: Granulometric curves of Natural Sand and SFS. The Usable Zone Optimum (UZO) and Usable Zone Limits (UZL) are shown.
Source: authors.

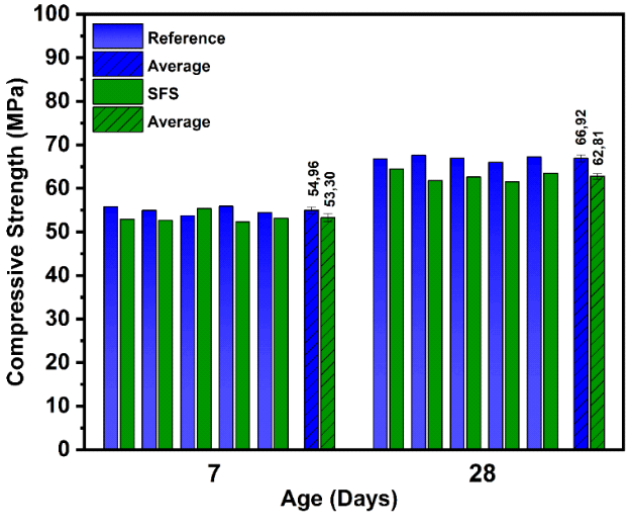

Figure 6: Individual and average values for the compressive strength of the rectangular concrete blocks.
Source: authors.

the trace (water, large aggregates, cement, and additive) were used, except for the small aggregate. The justification for this result is based on the fact that the SFS grains were coated with a phenolic resin, which resulted in a smaller particle size compared to the Natural Sand used in the Reference trace. These effects ultimately led to a reduction in compressive strength (AMITH; SABEEL, 2018).

Water absorption is influenced by sample compaction and curing conditions. **Figure 7** displays the individual and mean absorbance values of rectangular concrete blocks molded from the reference trace and the SFS trace. We obtained these values by conducting immersion absorption tests after 28 days. The immersion water absorption test results for the rectangular concrete blocks were 3.06% and 3.98% for the reference block and SFS trace, respectively. Both values are in accordance with the Brazilian standard (ABNT-Standard NBR 9781), which establishes a maximum average absorption of 6% for concrete pieces used in interlocking pavements. It is important to note that the amount of SFS used in this study for the concrete composition was 326.7 kg/m^3. If a higher amount of SFS is used, it may result in increased water absorption due to the presence of phenolic resins adhered to the SFS grains.

Optical microscopy aims to observe the surface and internal area of rectangular concrete blocks to understand the interaction between SFS, coarse aggregate, and cement. **Figure 8** shows an image of the internal area of

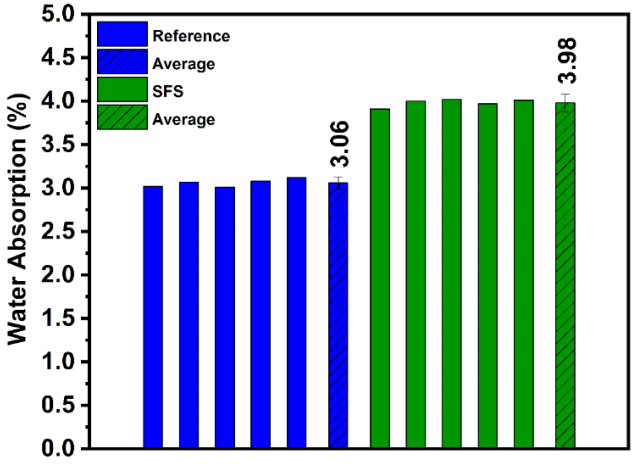

Figure 7: Individual and average values for the water absorpton of the rectangular concrete blocks.
Source: authors.

the rectangular concrete block (80x). The micrograph of the internal sand of the rectangular concrete block shows homogeneity between the grains of SFS, which is an important feature for increasing compressive strength (DUERAMAE *et al.*, 2019). The sand contains large aggregates and cement. The SFS grains have rounded shapes, while other grains have a sub-angular format.

5. CONCLUSIONS

This study concludes that rectangular concrete blocks composed of SFS with phenolic resins exhibit a high concentration of silicon oxide (SiO_2), with quartz serving as the main phase. Scanning electron microscope (SEM) images of the blocks show layers of phenolic resins around the grains of silicon oxide, which has little effect on the blocks' properties. Additionally, the mechanical behavior of the blocks with SFS showed compression resistance above 50 MPa after 28 days, classifying them as concrete blocks suitable for heavy vehicles. The results show that it is possible to completely replace natural sand with SFS that has been contaminated with phenolic resins. This would produce a material with a compression strength of over 50 MPa and a water absorption rate of less than 6%, which is in line with Brazilian standards. The use of contaminated SFS with phenolic resins in concrete blocks offers technical, economic, and environmental advantages, considering the expenses associated with disposing of this solid residue in landfills.

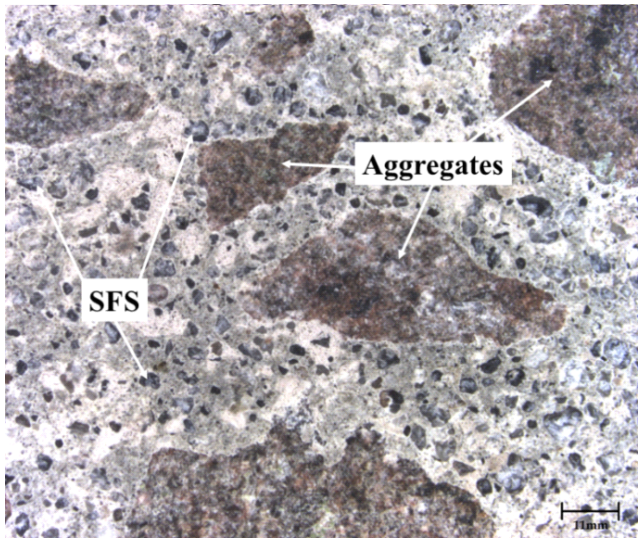

Figure 8: Photomicrograph of the rectangular concrete block (SFS trace). Nominal magnification at 80x.
Source: authors.

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URBAN AND PERI-URBAN AGRICULTURE IN BRAZILIAN CAPITALS: WHAT DOES RECENT ACADEMIC PRODUCTION REVEAL?

AGRICULTURA URBANA E PERIURBANA NAS CAPITAIS BRASILEIRAS: O QUE A PRODUÇÃO ACADÊMICA RECENTE REVELA?

AGRICULTURA URBANA Y PERIURBANA EN LAS CAPITALES BRASILEÑAS: ¿QUÉ REVELA LA PRODUCCIÓN ACADÉMICA RECIENTE?

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ABSTRACT

Urban and peri-urban Agriculture (UPA) is intertwined with a comprehensive sustainability agenda, being a key element of a robust and resilient food system, while promoting greener cities. However, UPA is not fully understood by researchers, governments and general population, partly due to the heterogeneity of its forms. This article seeks to contribute to the understanding of the debate on UPA initiatives in Brazil by presenting the results of a systematic literature review of UPA's article, published from 2018 to 2022, that intended to outline: a quantitative overview of recent academic production on UPA in Brazil; a qualitative analysis of recent academic production on UPA in Brazilian capitals states and the Federal District. The results indicate a quantitative increase in the number of articles published on the subject. Additionally, the spatial distribution of cited cases in the articles shows that they are concentrated in cities located in the south and southeast Brazil. Also, the frequency of keywords found in the papers highlights the social character and environmental aspects of the discussion about UPA. Qualitatively, the overview indicates that UPA initiatives are primarily located intra-urban, often in common/public places rather than private ones. The majority of initiatives operate within a community system, focusing on the production of vegetables for self-consumption.

KEYWORDS

Urban and peri-urban Agriculture; Literature review; City; Urban planning; Brazil

RESUMO

A Agricultura Urbana e Periurbana (AUP) está ligada a uma ampla agenda de sustentabilidade, sendo chave para um sistema alimentar robusto, resiliente e para cidades mais verdes. As ocorrências da AUP, todavia, não são plenamente compreendidas por pesquisadores, governos e população em geral, em parte devido à heterogeneidade de formas que ela tem adotado. Buscando contribuir com a compreensão sobre as iniciativas de AUP no país, o presente artigo apresenta os resultados de uma revisão sistemática da literatura em artigos sobre AUP publicados entre 2018 a 2022, com objetivo de traçar: um panorama quantitativo da produção acadêmica recente sobre a AUP no Brasil; e uma análise qualitativa da produção acadêmica recente sobre AUP nas capitais dos estados da federação e no Distrito Federal. Como resultados, percebe-se, quantitativamente, um crescimento no número de trabalhos publicados sobre a temática. Adicionalmente, a

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distribuição espacial dos casos citados nos textos mostra que eles estão concentrados em cidades das regiões sul e sudeste do Brasil. Além disso, as palavras-chave destacam o caráter social e ambiental da discussão sobre a AUP. Qualitativamente, o retrato formado pela amostra aponta que as iniciativas de AUP têm localização intraurbana, realizada em espaços comuns/públicos. A maioria das iniciativas opera em sistema comunitário, focando na produção de vegetais destinados ao autoconsumo.

PALAVRAS-CHAVE

Agricultura Urbana e Periurbana; Revisão da Literatura; Cidade; Planejamento Urbano; Brasil

RESUMEN

La Agricultura Urbana y Periurbana (AUP) está vinculada a una amplia agenda de sostenibilidad, siendo clave para un sistema alimentario robusto, resiliente y para ciudades más verdes. Las ocurrencias de la AUP, sin embargo, no son completamente comprendidas por investigadores, gobiernos y la población en general, en parte debido a la heterogeneidad de formas que ha adoptado. Buscando contribuir a la comprensión de las iniciativas de AUP en el país, el presente artículo presenta los resultados de una revisión sistemática de la literatura en artículos sobre AUP publicados entre 2018 y 2022, con el objetivo de trazar: un panorama cuantitativo de la producción académica reciente sobre la AUP en Brasil; y un análisis cualitativo de la producción académica reciente sobre AUP en las capitales de los estados de la federación y en el Distrito Federal. Como resultados, se percibe, cuantitativamente, un crecimiento en el número de trabajos publicados sobre el tema. Además, la distribución espacial de los casos citados en los textos muestra que están concentrados en ciudades de las regiones sur y sudeste de Brasil. Asimismo, las palabras clave destacan el carácter social y ambiental de la discusión sobre la AUP. Cualitativamente, el retrato formado por la muestra apunta a que las iniciativas de AUP tienen una ubicación intraurbana, realizadas en espacios comunes/públicos. La mayoría de las iniciativas opera en un sistema comunitario, enfocándose en la producción de vegetales destinados al autoconsumo.

PALABRAS CLAVE

Agricultura Urbana y Periurbana; Revisión de la Literatura; Ciudad; Planificación Urbana; Brasil

1. INTRODUCTION

Urban and peri-urban agriculture (UPA) has garnered increasing attention in discussions concerning sustainable urban development both in Brazil and globally (KUHN et al., 2023; SARKER et al., 2019). UPA exhibits various positive attributes, including the reduction of greenhouse gas emissions, mitigation of heat island effects, and the potential management of urban compostable waste. Additionally, urban agriculture contributes to the aesthetic enhancement of areas and facilitates opportunities for community engagement, recreational activities, and therapeutic practices (MELLO et al., 2002). Furthermore, it serves as a local alternative to food produced in distant areas from the point of consumption. As a result, there is growing concern about the environmental and territorial impact of mass food production and its impact on human health. (HEARN, 2018).

According to the Food and Agriculture Organization of the United Nations (FAO), UPA is linked to a broader sustainability agenda, being key to a robust and resilient food system while promoting greener and more sustainable cities (FAO, 2014).

International academic literature, in turn, suggests that UPA is a diverse phenomenon, which manifests itself in particular ways in each country and even within a single city or region. The practices of UPA are still not fully understood by researchers, governments, and the general population, in part due to the heterogeneity of forms it has adopted (ZAAR, 2017).

Therefore, understanding how UPA initiatives are characterized in Brazilian capitals is relevant. One of the most comprehensive studies on the subject in the country (SANTANDREU, LOVO, 2007) indicates that 75% of the researched UPA experiences were located in the capitals of metropolitan regions. Consequently, as capitals concentrate a considerable portion of the population and exhibit a high degree of urbanization, conflicts between urban, peri-urban, and rural areas are more explicit.

Seeking to contribute to a broader understanding of the debate on UPA initiatives in the country, this article presents the results of a systematic literature review aimed at: a) providing a quantitative overview of recent academic production on UPA in Brazil; b) offering a qualitative analysis of recent academic production on UPA in the capitals of the states and in the Federal District.

The systematic literature review examined Brazilian academic articles on UPA published from 2018 to 2022. The literature review followed four key stages: a) surveying the following digital repositories: Scielo, Scopus, DOAJ, and Web of Science; b) filtering based on predefined criteria; c) classifying according to frameworks by Mougeot (2000) and Cabannes (2021); and d) conducting quantitative and qualitative analysis of the results.

This article is organized into three parts, besides the introduction and conclusion. The first part presents a theoretical discussion on the concept of UPA that will be used in the classification of results. The second part outlines the methodology used to collect data for the systematic literature review. The third part presents the main quantitative and qualitative findings, with a brief discussion at the end of each subtopic.

2. CHARACTERIZING UPA

Although UPA remains a polysemic concept to this day, referring to diverse practices, there is one constant in its definition: UPA seeks to differentiate itself from agriculture practiced in rural areas (ZAAR, 2017).

Mougeot (2000) conceptualizes UPA as an activity present in urban or peri-urban areas, encompassing cities of different sizes, which involves the production, processing, and distribution of food and non-food products. This practice is intrinsically linked to urban dynamics, making extensive use of human resources, materials, products, and urban services. Additionally, it contributes by providing human resources, materials, products, and services back to urban areas. According to Mougeot (2000), the fundamental characteristic of UPA is its greater or lesser integration with the urban economic and ecological system.

Furthermore, Mougeot (2000) suggests that to understand the different forms of UPA manifestation, it can be broken down into the following categories of analysis:

- Location: intra-urban or peri-urban;
- Types of areas where it is practiced;
- Scale and production system;
- Destination of products;
- Categories and subcategories of products;
- Types of economic activity.

Location is the most common element in delineating UPA. It is also the criterion that generally problematizes the definition of concepts such as intra-urban and peri-urban, urban, and rural spaces. The category of types of areas where it is practiced relates to modes of ownership or enjoyment of lots: residential areas, shared spaces, etc. Scale and production system refer to individual, family, or business initiatives of micro, small, and medium scales, generally opposed to initiatives by large producers

and companies. The criterion of product destination is attentive to the purpose for which production is reserved: self-consumption, trade, barter, gift, among others. Categories and subcategories of products encompass various agricultural productions, whether food or non-food. Lastly, types of economic activity refer to various phases of agricultural production such as processing, trade, among others.

Another form of characterization, used by the FAO (CABANNES, 2012), relates to the objectives of different UPA initiatives and recognizes the existence of three main typologies:

- Social dimension;
- Economic dimension;
- Ecological dimension.

The social dimension encompasses initiatives aimed at the subsistence of urban poor and the middle class during crises. They include domestic, community, and institutional gardens and other small-scale plantings with minimal investments. The objective is to generate positive impacts such as social inclusion, poverty reduction and community development. Generally demonstrate low direct profitability (CABANNES, 2012).

The economic dimension refers to UPA initiatives oriented towards the market aiming to generate economic impact and profitability. They are mainly carried out by small-scale family businesses or cooperatives and producer associations but may also include farms managed by private investors. They generally involve the entire food chain, from production to processing and marketing (CABANNES, 2012).

The ecological dimension encompasses initiatives directed towards leisure, recreation, and environmental management. Its primary aim is to foster connections between urban inhabitants and nature, while also promoting awareness of environmental concerns. Additionally, it endeavors to provide essential environmental services, including but not limited to composting, wastewater treatment, and landscape management within multifunctional green areas. This typology of UPA typically employs agroecological production methods and is observed to be more prevalent in developed countries compared to developing ones (CABANNES, 2012).

Identifying the specific characteristics of each initiative is crucial for advancing understanding of the UPA phenomenon, as well as in its theoretical debate.

3. METHOD

This research centered on the examination of Brazilian academic articles concerning Urban and Peri-Urban Agriculture (UPA) published within the timeframe of the last five years (2018 to 2022). The choice of this specific temporal scope is substantiated by the study's objective, which aims to delineate and assess the ongoing academic discourse surrounding UPA initiatives in Brazil. In essence, the methodological approach adopted for this literature review comprised four principal stages, as illustrated in Figure 01: surveying, filtering, classifying, and analyzing the outcomes. Subsequently, each stage will be expounded upon in detail.

3.1. Step 1: Survey

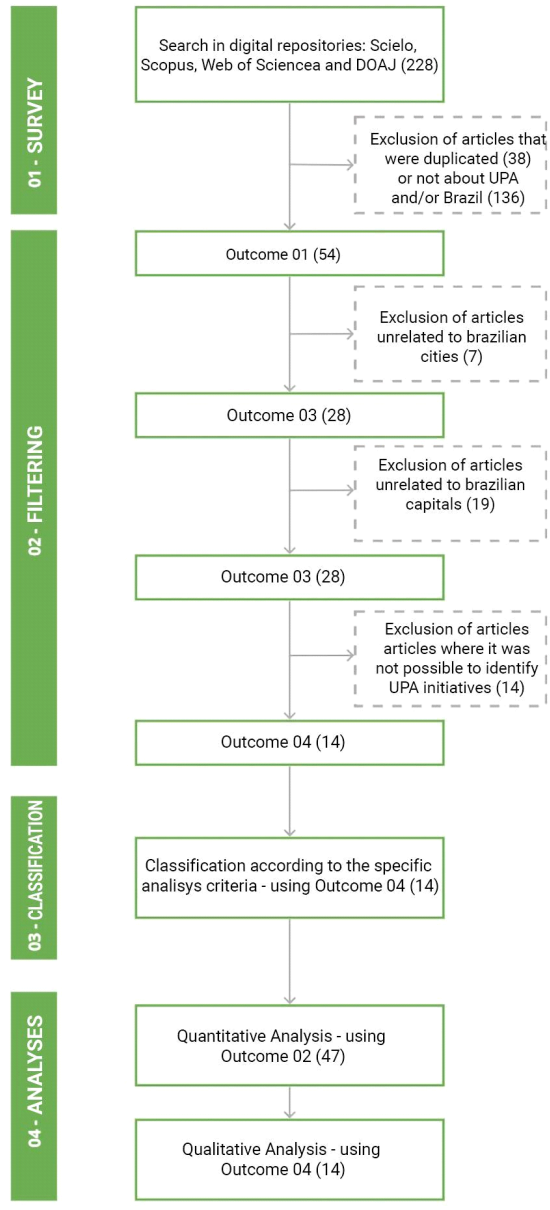

Figure 01: Literature review method.

The survey phase consisted of searching for articles conducted between November 9th, 2022, and December 4th, 2022, in Scielo, Scopus, DOAJ (Directory of Open Access Journals), and Web of Science, which are digital open access databases repositories. Search terms were adapted to the search logic of each platform to ensure comprehensive coverage. The objective was to identify articles produced between 2018 and 2022 on Urban and Peri-Urban Agriculture (UPA) in Brazil, as previously mentioned. The data retrieved were exported in .xml or .csv format and aggregated into a single spreadsheet. Subsequently, articles were selected for inclusion in the research corpus. In total, 228 articles were found. First, 38 duplicates (studies indexed on more than one platform) were excluded. Next, 136 articles that, despite being indexed in research repositories with keywords related to urban agriculture, were clearly unrelated to the UPA theme, were excluded.

For details on the search terms and Boolean operators used in searching for articles, refer to Figure 02.

3.2. Step 2: Filtering

Repositories	Search terms
Web of Science	Urban agriculture OR urban farm* OR peri-urban agriculture OR peri-urban farm* OR urban garden* OR peri-urban garden* OR periurban garden* OR commun* garden AND case* OR experi* OR essay OR review OR study* OR case study* AND brasil OR brazil
	Urban agriculture* OR agricultura periurbana OR horta urbana OR horta periurbana OR horta* comunitária* OR quinta* urbano*
Scopus	"Urban agriculture" OR "urban farm*" OR "peri-urban agriculture" OR "peri-urban farm*" OR "urban garden*" OR "peri-urban garden*" OR "periurban garden*" OR "commun* garden" AND case* OR experi* OR essay OR review OR study* OR "case study*" AND brasil OR brazil
	"Urban agriculture*" OR "agricultura periurbana" OR "horta urbana" OR "horta periurbana" OR "horta* comunitária*" OR "quinta* urbano*" AND brasil OR brazil
DOAJ	“Urban agriculture” OR “urban farm*” OR “peri-urban agriculture” OR “peri-urban farm*” OR “urban garden*” OR “periurban garden*” OR “commun* garden” AND brasil OR brazil
	“Urban agriculture” OR “agricultura periurbana” OR “horta urbana” OR “horta periurbana” OR “horta comunitária” OR “quintal urbano” AND brasil OR brazil
Scielo	"Urban agriculture" OR "agricultura periurbana" OR "horta comunitária" OR "horta urbana" OR "horta periurbana" AND "brasil"
	"Urban agriculture" OR "agricultura periurbana" OR "horta comunitária" OR "horta urbana" OR "horta periurbana" AND "brazil"
	"Urban agriculture" OR "agricultura periurbana" OR "horta comunitária" OR "horta urbana" OR "horta periurbana" AND "brasil" OR "brazil"
	“urban agriculture” OR “urban farm” OR “peri-urban agriculture” OR “peri-urban farm*” OR “urban garden” OR “periurban garden” OR “commun garden” AND case OR study OR “case study” AND brasil OR brazil

Figure 02: Repositories and search terms

During the survey phase, 174 articles were preliminarily excluded based on predefined criteria. This left 54 publications (Outcome 1). Subsequently, publications without a direct relation to Brazilian cities were removed, totaling 7 articles. These mainly comprised articles with a more theoretical bias providing a comprehensive overview of UPA in Brazil. The pool of articles was reduced to 47 publications (Outcome 2). Following this, articles unrelated to the capitals of the 26 states of the federation and the Federal District, where UPA initiatives were identifiable, were filtered, resulting in 28 publications (Outcome 3). Finally, articles where it was not possible to identify urban and peri-urban agriculture initiatives were removed, leaving 14 publications (Outcome 4).

3.3. Step 3: Classification

The third part of the method involved classifying the 14 publications according to specific criteria characterizing the UPA initiatives they described. These criteria were based on Mougeot (2000) and Cabannes (2012) and included: a) dimension; b) intra-urban or peri-urban location; c) type of area where it is practiced (typology); d) scale and system; e) product destination; f) product category; g) type of economic activity.

3.4. Step 4: Analyses

Two types of data analysis were conducted: quantitative and qualitative. For the quantitative analysis, publications from Outcome 02 (47 studies on UPA in Brazilian cities) were considered. Here, descriptions of the temporal and spatial distribution of the studies found were performed, as well as the occurrence of keywords.

The analysis of temporal distribution consisted of counting the studies by their year of publication. Spatial analysis, on the other hand, involved analyzing the studies according to the Brazilian city where the described

initiative was located. The examination of keyword occurrence involved extracting these terms from each publication, followed by translation into English when they were only available in Portuguese. Additionally, similar terms were grouped and counted for analysis purposes.

For the qualitative analysis, publications from Outcome 4 were considered. The discussions were organized based on categories described in section 3.3 and the research results were compared with the outcomes of the previous literature review.

It is necessary to underline that, for qualitative classification, only the information present in the selected articles was analyzed, without seeking additional information about the initiatives from other sources. Therefore, it was not possible to evaluate all studies based on all categories. Additionally, in one of the articles (REC01), only the information present in the abstract was used because it was not an open access article. A more detailed description of these qualitative evaluation criteria is indicated in section 4.2.

4. RESULTS

The results of the quantitative and qualitative analyses are presented in sections 4.1 e 4.2, respectively.

4.1. Quantitative and Descriptive Analysis of the Literature on UPA

In the following subsections, quantitative analyses are subdivided into articles' temporal and spatial occurrence

4.1.1. Temporal Distribution

The temporal distribution of articles by year (Figure 03) reveals an increase in publications related to UPA from 2019, with a peak in the year 2021. This data demonstrates a growing academic interest in the topic.

4.1.2. Spatial analysis

The spatial distribution of the cases mentioned in the articles shows that publications more frequently mention cities in the South and Southeast regions, while there is a low frequency of citations of cities in the Midwest, Northeast, and North regions of the country. The most cited cities in the articles are those that are more urbanized - São Paulo (9 articles) and Rio de Janeiro (3 articles), followed by other state capitals (Figures 04 and 05). It can

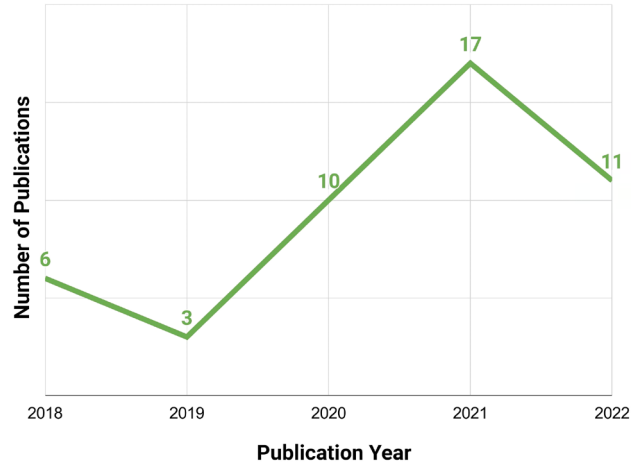

Figure 03: Temporal distribution of articles: number of publications per year of publication.

be inferred, therefore, that the most urbanized regions have been the predominant, but not exclusive, locus of studies on UPA in Brazil.

Out of the 47 articles selected in Outcome 2, 19 (40%) mention cities that are not state capitals, totaling 23 municipalities: Planaltina (GO); Campos dos Goytacazes and São João da Barra (RJ); Lavras and Muzambinho (MG); Campina Grande (PB); Herval D'Oeste, Rio do Sul, Lages, Chapecó, and Ibirama (SC); Araras, Vale Histórico, Uchoa, and Araraquara (SP); Maringá and Campo Magro (PR); Alta Floresta (MT); Castanhal and Santarém (PA); Arapiraca (AL); Porto Nacional (TO); Pelotas (RS). On the other hand, 28 articles (60%) mention 14 state capitals (São Paulo, Rio de Janeiro, Curitiba, Florianópolis, Manaus, Natal, Recife, Teresina, Belém, Belo Horizonte, Fortaleza, Macapá, Porto Alegre and Salvador). No articles were found that mentioned the capitals of the other 12 states and the Federal District (Vitória, Campo Grande, Goiânia, Cuiabá, Aracaju, Maceió, João Pessoa, São Luís, Porto Velho, Rio Branco, Boa Vista, Macapá, Palmas, and Brasília).

The analysis of keyword occurrence (Figures 06 and 07) demonstrates that, in addition to obvious terms like "Urban Agriculture" (24 occurrences) and "Brazil" (9), terms such as "Community Gardens" (9) and "Sustainability" (8) stand out. The emphasis on the term "Community Gardens," in turn, suggests a particular interest from the academic community in the community dimension of UPA, which is typically familial and lacks an entrepreneurial or mass-commercial production aspect. It's worth noting that the community perspective of the initiatives may be linked to municipal

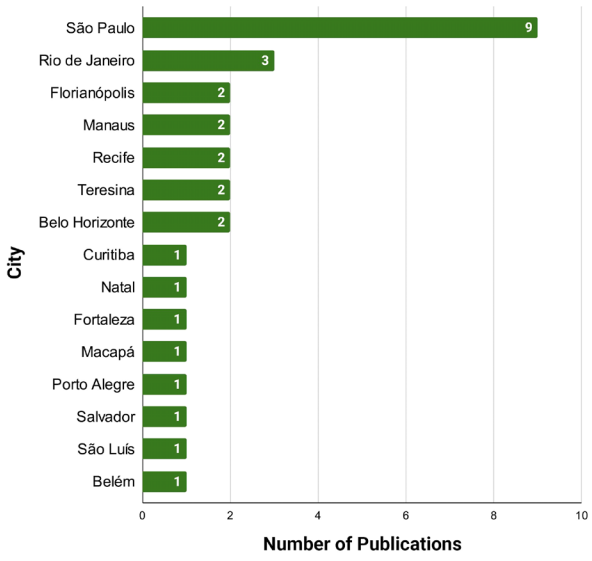

Figure 04: Occurrences of publications about each capital..

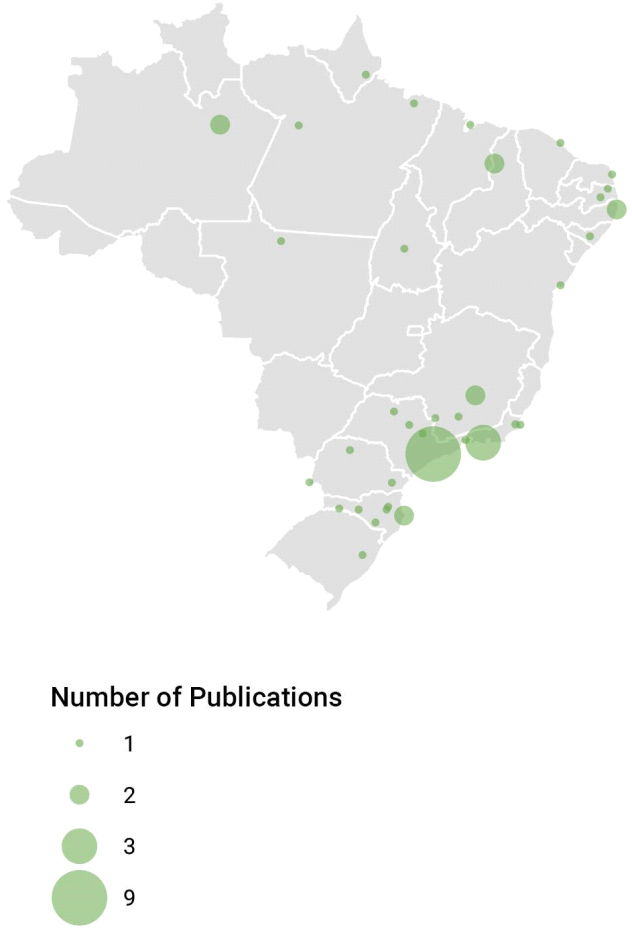

Figure 05: Map illustrating the number of publications in each city.

programs that value this dimension.

The keywords mentioned above highlight a dual perspective of the discussion on UPA in Brazilian capitals: on one hand, they reinforce its environmental character and positive ecological impact; on the other hand, they corroborate its social/community dimension. Both aspects align with findings by RAO et al (2022), who conducted a systematic literature review globally and found, among six thematic outcomes of UPA, themes of environmental sustainability and subjective/relational well-being.

Despite the term UPA being widely disseminated in Brazil, it is still common for urban agriculture practices to be referred to in various ways by practitioners, social media, academic literature, and legal instruments. There is an abundance of terms used in academic, political, and community debate spaces, such as urban gardens, community gardens, urban farms, productive gardens, among others. This mention is necessary, as it may explain the presence of other terms beyond urban agriculture.

Figure 06: Keyword cloud (excluding the most obvious terms: "Urban Agriculture" and "Brazil").

4.2. Qualitative analysis

For the qualitative analysis, the categories mentioned in section 3.3 were adopted. To facilitate reading, the articles were cataloged by a code referring to the capital to which the initiative refers. The code, city, and article reference can be found in Attachment A.

The sample includes reports from 9 capitals: Belo Horizonte (1), Florianópolis (2), Natal (1), Porto Alegre (1), Recife (1), Rio de Janeiro (2), Salvador (1), São Paulo (3), and

N°	Keyword	Quantity
1	Urban Agriculture	24
2	Community Gardens	11
3	Brazil	9
4	Sustainability	8
5	Enviroment* (Awareness/Contamination/Ethics/Health/Psycology/Se	7
6	Food (Markets/Production/Supply Chains/Systems)	6
7	Agroecology	6
8	Public Policies	5
9	Urban Gardens	4
10	Sustainable (Agriculture/Cities/Development/Development Goals)	4
11	Food/Nutrition Security	4
12	São Paulo	3
13	Organic (Agriculture/Farming/Production System)	3
14	Family (Agriculture/Farming)	3
15	Covid-19/Pandemic	3
16	(Urban) Soil	3
17	Vegetables	2
18	Urban Planning	2
19	Urban And Periurban Agriculture	2
20	Subsidence	2
21	Socio-Spatial (Development/Transformations)	2
22	Slum	2
23	Marketing	2
24	Land Use	2
25	Knowledge (Dissipation/Transmission)	2
26	Informal Settlement	2
27	Inclusive Urbanism	2
28	Histosols	2
29	Genetic (Heritage/Resources)	2
30	Food-Energy-Water Nexus	2
31	Ecosystem Services	2
32	Contamination/Pollution	2
33	Community Of Practices	2
34	Acid Sulfate Soils	2
35	Watershed Management	1

Figure 07: The 35 most frequently occurring keywords.

Teresina (2).

The analyzed publications total 74 cases. Most publications report only one case, except for article BHZ01, which mentions 2 gardens, SSA01, which mapped 17 gardens, and THE01 which mentions 45 gardens. The two articles from Florianópolis (FLN01 and 02) address the same case, counted only once. In articles SAO02 and SAO03, which compare gardens in São Paulo with experiences in other cities, only initiatives in São Paulo were considered.

The selected articles use UPA initiatives as the subject of study through different approaches. In two articles, community gardens are used to understand social dynamics: Zambrano-Gutierrez et al (2018) - FLN01 analyzes collaborative management learnings, and Bonatti et al (2022) - FLN02 seeks to understand the "Social Learning" process occurring in the Revolution of the Buckets Project.

Three focus on the educational process: in Carvalho et al (2021) - POA01, the UPA practice is exposed as an approach to sustainability issues, Mota et al (2021) - NAT01 exposes the "Horticulture-Based Learning (HBL)" methodology applied in higher education context, and finally, Santos et al (2019) - SAO01, reports the experience of changing sustainability views in students from a school where a vertical garden was implemented.

Two articles compare production processes: Michelon et al (2020) - THE02 compares the yield between Simplified soilless cultivation system and conventional bean production system; David et al (2022) - SAO03 compares the energy synthesis of hydroponic gardens to assess their sustainability.

Two articles discuss public policies: Fernandez and Filho (2019) - RIO02 study the application of public policy for family farming in urban areas and Hearn (2018) - RO01 studies UPA programs to understand the creation of trust between producers, consumers, and governments.

There are also three articles focused on natural sciences: two evaluate gardens from a chemical perspective, discussing water quality (DO ESPÍRITO SANTO SILVA et al, 2020 - THE01) or the presence of heavy metals in crops and soil (DALA-PAULO et al, 2018 - BHZ01); and Cunha et al (2020) - SSA01, identifies the species produced, especially "Neglected and Underutilized Species (NUS)", from a botanical perspective.

Nagib and Giacche (2021) - SAO02 expose ideas and practices of urban farmers in São Paulo and Rennes. Santos Silva et al. (2018) - REC01 reports changes implemented in the CEASA/PE garden with technical assistance from the local university.

Therefore, it is noticeable that the approaches, issues, and themes of the articles are quite diverse. Below, we present the classification of existing initiatives in the capitals of Brazilian states in the already listed categories.

4.2.1. Characterization of existing initiatives in the capitals of Brazilian states

In general, initiatives characterized as community practices (THE01, REC01, SSA01, POA01, and SAO01) are more closely associated with the social dimension (THE01, REC01, and SSA01), promoting food security and nutritional safety among participants, and/or the ecological dimension (POA01 and SAO01) by facilitating environmental education at the site. SAO03 is the only initiative related to the social dimension that is not a community practice. The initiative is managed by an organization with the aim of reintegrating individuals in situations of social vulnerability.

The private practices described in the articles (SSA01 and RIO02) are all related to the economic dimension as their production objective is profitability and/or serving as a supplementary source of income for those who

engage in them.

Educational initiatives (NAT01 and SAO01), on the other hand, are more related to the ecological dimension, as their primary objective is environmental education and studies of natural flows. However, there is also an interface with the social dimension by promoting healthy eating, thereby promoting food security and nutritional safety.

The "Revolução dos Baldinhos" (FLN01 and FLN02) is a case that deviates from the typical community initiatives linked to urban poverty, which are usually associated with the social dimension. The initiative primarily focuses on environmental management of solid waste through composting, thus linked to the ecological dimension. However, it is also not a classic case of the ecological dimension because it is not inherently related to the environmental agenda. Environmental management was a necessity to find a local solution to public health issues (leptospirosis contamination). Today, the project is more closely linked to the environmental agenda, with a strong role in environmental education for its participants (BONATTI et al., 2022 - FLN02).

Another noteworthy case is the Manguinhos Garden (RIO01). The social dimension is common in community initiatives, with the program's objective being to "promote social inclusion and improve nutritional health indicators" (HEARN, 2018). However, the distinctive feature of this project lies in addressing the economic dimension as well. The project presents a "business model" structured by the municipality, organized as follows: while the garden depends on subsidies, it must donate part of its production; after becoming self-sustainable, it may sell this portion. Additionally, the article reports that part of the population's engagement with the program was obtained through the payment of a monthly salary to some key participants who work in the garden's daily maintenance, as the need for alternative income sources was a concern for the population.

(b) Intraurban or peri-urban Location:

For this analysis, the authors primarily considered the description of the location. For example, the article that mentions a "community garden on the outskirts of Teresina" (DO ESPÍRITO SANTO SILVA et al., 2020 - THE01) was classified as peri-urban, while the one referring to "located in downtown São Paulo" (SAO03, DAVID et al., 2022), was classified as intraurban. There is a greater volume of articles reporting initiatives in intraurban areas (FLN01, FLN02, NAT01, SSA01, SAO01, SAO02, SAO03, RIO01), totaling 25 initiatives. Initiatives in peri-urban areas were reported in 5 articles (BHZ01, POA01, REC01, THE01, and THE02) and total the highest value, with 48 initiatives. It was not possible to classify the location of the case considered in RIO02, described as "quite urbanized." The article also describes the agriculture practiced in the Maciço da Pedra Branca as "an expression of agriculture in the city" that "even though located in the city, preserves strong traits of rural landscapes and ways of life" (FERNANDEZ and FILHO, 2019), a description close to the idea of peri-urban. The article presents an important debate regarding the location, exposing the views of Almeida (2016) and Mougeot (2000) that the classification of urban agriculture is not related to the location of the phenomenon but its incorporation into urban dynamics (FERNANDEZ and FILHO, 2019). This perspective complicates and challenges the concept of peri-urban since if the classification does not depend on location, the classification of peri-urban agriculture would be based on its lesser interaction with the urban environment rather than its location away from the urban center.

(c) Types of Areas Where it is Practiced (Typology):

It was possible to identify mention of typology in 25 initiatives, divided as follows: 10 in private spaces (nine in SSA01 and one in RIO02); and 15 in common/public spaces (nine in SSA01, RIO02, SAO02, POA01, NAT01, SAO01, FLN02, RIO01, and REC01), with two clearly classified as green areas with some level of environmental preservation as they are close to bodies of water (SAO02 and POA01) and five in institutional areas, with two in universities (NAT01 and SAO01), 1 in a school (FLN02), one in a non-buildable area (RIO01), and REC01 that occurs in federal areas and under high-voltage lines.

Regarding land ownership, SSA01, with a sample of 17 gardens, reports that most initiatives do not operate in a legalized manner (13), implemented in public areas without land ownership. The report is similar to SAO02, which describes the garden occupying an area under the "guerrilla gardening" tactic and which later secured ownership for the initiative.

In BHZ01 (DALA-PAULO et al., 2018), the studied gardens were described as abandoned areas used as waste dumps, without explaining how these spaces turned into gardens. However, the study shows that the soil presented acceptable values for the studied metals (cadmium, copper, and lead) and indicated that atmospheric deposition is likely an important route for lead to pollute plant leaves.

Five initiatives had their area described, ranging from

162 m² (RIO02), a small producer's backyard, to 33 hectares (REC01), unused spaces in the road system. There was a certain pattern in community gardens, with sizes ranging from 800 (SAO02) to 1200m² (NAT01), in addition to the Manguinhos Garden, the largest in Latin America, with 2km in length.

(d) Scale and System:

Community production (FLN01 and FLN02, SAO01, POA01, THE01, SSA01, RIO01) overlaps among the types of systems, with few reports (SSA01 and RIO02) of individual production. Within the community production system, it is difficult to classify institutional initiatives, as they are related to the surrounding community. However, the impact of the initiative on the community and participation in educational spaces is collective. There is only one report of a garden (SAO03) belonging to an NGO.

Regarding production systems, some initiatives identify as a type of "non-traditional/conventional" production, such as hydroponic (SAO03) or agroecological and organic (NAT01 and POA01).

(e) Product Destination:

There are reports of products destined for commercialization (RIO01, RIO02, SSA01, and FLN01), totaling 15 initiatives, self-consumption (SSA01 and THE01) with 59, and consumption for the community/donation (SSA01, POA01, RIO01, and FLN01) with 11.

Although not directly associated with economic value like commercialization, self-consumption or donation to the community are always seen as positive aspects of the experiences, often linked to an economic gain, as beneficiaries "buy less food and learn to produce it themselves," as exposed in BONATTI et al (2022) (FLN02).

In initiatives aimed at the learning process, in SAO01, the production is donated for preparations in the institutional kitchen for the students, and in NAT01, the food is directed to the test kitchen of the Nutrition Department.

(f) Product Category:

The most recurring production is vegetables (SSA01, THE02, POA01, NAT01, RIO01, and RIO02). Only two experiences (POA01 and RIO02) process the production. Fruits are mentioned only in the gardens of Salvador (SSA01) and herbs in the Vertical Garden Project (SAO01). Two reports (THE01 and FLN02) mention food production, citing self-consumption as a benefit of production, but without specifying the type of food. And the report SAO03 mentions hydroponic production without specifying if it's fruits, vegetables, or herbs. Among food items, it is important to highlight the production of Neglected and Underutilized Species (NUS) in SSA01.

None of the reports mention animal production.

There are some mentions of "Non-food" production of inputs such as seeds (POA01) and fertilizer in NAT01, FLN01, and FLN02). The Revolution of the Buckets (FLN01) includes soap production.

(g) Type of Economic Activity:

Almost all publications (FLN02, NAT01, POA01, RIO01, RIO02, SSA01, SAO01, SAO03, and THE01), where it was possible to identify the type of economic activity, report the production of some food. Few (FLN01, FLN02, NAT01, and RIO02) report transformation processes, such as composting or processing. Four initiatives develop service activities, such as promoting courses and workshops (POA01), agritourism/visitation (SAO03), and research activity (NAT01 and SAO01). Commercialization activity is mentioned in two initiatives (RIO02 and REC01). One initiative (SAO02) prohibited the commercialization of produced food.

There are initiatives where food production is not the focus. The Revolution of the Buckets (FLN01 and FLN02) stands out as an initiative for composting organic solid waste, with the garden not playing a prominent role in the project reports. However, it can be verified that the project has a garden installed in the community school (FLN02). Also notable are the Vertical Garden Project (SAO01) and LabNutrir (NAT01), which use gardens as learning methods. LabNutrir also has academic production with what is produced in the garden.

5. CONCLUSION

The present article aimed to present the results of a systematic literature review that intended to outline: a) a quantitative overview of recent academic production on Urban and Peri-urban Agriculture (UPA) in Brazil; b) a qualitative analysis of recent academic production on UPAin the capitals of the states and the Federal District.

Regarding the quantitative overview, the data demonstrate that between 2019 and 2021, there was a growth in the number of publications on UPA, indicating an increasing

interest from the academic community in the topic. It was also observed that the spatial distribution of the cases mentioned in the articles shows a concentration of cities in the southern and southeastern regions, while there is a low frequency of citations from cities in the central-western, northeastern, and northern regions of the country. The most cited cities in the articles are the most urbanized ones: São Paulo and Rio de Janeiro. The analysis of the occurrence of keywords indicates that, in addition to obvious terms like "Urban Agriculture" and "Brazil," terms such as "Community Gardens," "Sustainability," and "Environment" stand out, highlighting the social and environmental nature of the discussion on UPA in Brazilian capitals.

Regarding the qualitative analysis, the sample reinforces that UPA is a heterogeneous phenomenon. The sample presented initiatives in all dimensions pre-established by the analysis methodology. It is also worth noting the intersection of various dimensions, with a higher occurrence of the ecological dimension over the others. Concerning the characteristics of the initiatives, it can be said that the portrait formed from the sample regarding UPA practiced in Brazilian capitals is as follows: they are predominantly located intraurban, usually carried out in public/common spaces rather than private ones, most initiatives are carried out in a community system, with the production of vegetables intended for self-consumption.

Finally, it is noticed that UPA is an emerging phenomenon that has mobilized society to carry out initiatives with a wide variety of formats and approaches. The academic environment is also attentive to this fact, given the growth in the number of publications on the topic. However, it seems necessary to conduct more comprehensive analyses that seek to synthesize the characteristics of these initiatives. A look in this direction could contribute to public policies that create rules, stimulate, and reinforce UPA in Brazil.

ATTACHMENT A – QUALITATIVE ANALYSES ARTICLES

ID	CAPITAL	TITLE	INITIATIVES	REF
BHZ01	Belo Horizonte (MG)	Cadmium, copper and lead levels in different cultivars of lettuce and soil from urban agriculture	Horta Comunitária do Cafezal (Cafezal) e Jardim Produtivo (Jardim)	DALA-PAULO et al, 2018
FLN01		Individuals in	Revolução dos Baldinho	ZAMBRANO-GUTIERREZ et al, 2018
FLN02		Social learning as an underlying mechanism for sustainability in neglected communities: The Brazilian case of the Bucket Revolution project	Revolução dos Baldinho	BONATTI et al, 2022
NAT01	Natal (RN)	A Laboratory without walls: biodiversity education in nutrition training using a garden-based learning method	LabNutrir	MOTA et al, 2021
POA01	Porto Alegre (RS)	Education and sustainability: learning in an urban garden	Horta Comunitária da Lomba do Pinheiro	CARVALHO et al, 2021
REC01	Recife (PE)	Peri-urban allotment gardens: A successful experience in Recife/ Pernambuco, Brazil	Alças Comunitárias	SANTOS SILVA et al, 2018
RIO01	Rio de Janeiro (RJ)	Beanstalks and Trust in Chinese and Brazilian Food Systems	Hortas Cariocas - Manguinhos	HEARN, 2018
RIO02	Rio de Janeiro (RJ)	Agricultura familiar urbana	Quintal da Andreia	FERNANDEZ e FILHO, 2019
SAO01	São Paulo (SP)	Vertical Gardens:	Vertical Garden Project	SANTOS et al, 2019
SAO02	São Paulo (SP)	A vida cotidiana das hortas comunitárias: casos de Rennes (França) e São Paulo (Brasil)	Horta das Corujas	NAGIB e GIACCHE, 2021

ID	CAPITAL	TITLE	INITIATIVES	REF
SAO03	São Paulo (SP)		Farm B	DAVID et al, 2022
SSA01	Salvador (BA)	Urban gardening and neglected and underutilized species in Salvador, Bahia, Brazil	17 hortas não nomeadas/ identificadas no artigo	CUNHA et al, 2020
THE01	Teresina (PI)	Irrigation Water Quality of a Community Garden Complex in the State of Piauí,	45 hortas comunitárias em 10 bairros pobres de Teresina não nomeadas/ identificadas no artigo	DO ESPÍRITO SANTO SILVA et al, 2020
THE02	Teresina (PI)	Strategies for Improved Yield and Water Use Efficiency of Lettuce (Lactuca sativa L.) through Simplified Soilless Cultivation under Semi-Arid Climate	Fazenda Nova Esperança	MICHELON et al, 2020

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CEMENTITIOUS MATRICES WITH LIGHT AGGREGATE BASED ON POLYESTER WASTE AND LAMINATED PVC EXTRUDED WITH POLYSTYRENE

USO DE AGREGADO LEVE À BASE DE RESÍDUOS DE POLIÉSTER E LAMINADO DE PVC EXTRUSADOS COM POLIESTIRENO EM MATRIZES CIMENTÍCIAS

USO DE AGREGADO LIGERO A BASE DE RESIDUOS DE POLIÉSTER Y LAMINADO DE PVC EXTRUSADOS CON POLIESTIRENO EN MATRICES CEMENTICIAS

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ABSTRACT

Waste generation from diverse sectors of the economy has given rise to studies related to consumption and disposal of several associated products. The traditional shoe making sector in the state of Rio Grande do Sul (Brazil) is no exception and has a need to implement sustainable actions for the re-use of raw material waste. The objective of this study was to develop a light aggregate based on polyester waste and laminated PVC extruded with recycled polystyrene for use in cementitious matrices. A reference mortar was prepared with a mix ratio of 1:3 (cement: quartz sand) and water/cement ratio (w/c) of 0.48. Additionally, 4 mortars were prepared with light aggregate replacement contents of 25 %, 50 %, 75 % and 100 % in volume with respect to quartz sand. Properties evaluated were consistency in the fresh state and compressive strength, density, water absorption and porosity in the hardened state. It was determined that consistency decreased as light aggregate substitution content increased. Similarly, decreases in compressive strength and density were noted with increasing light aggregate substitution content. On the other hand, water absorption, porosity and void index increased in conjunction with the decrease in density as substitution content increased.

KEYWORDS

Shoe making industry; waste; light aggregate

RESUMO

A geração de resíduos provenientes dos diversos setores da economia tem gerado estudos e pesquisas relacionados ao consumo e descarte dos mais variados produtos. Neste contexto, inserem-se as indústrias do setor calçadista, tradicionais no Estado do Rio Grande do Sul (Brasil), as quais têm a necessidade de buscar ações sustentáveis no reaproveitamento das sobras de matérias-primas da produção de calçados. Este trabalho teve como objetivo produzir um agregado leve à base de resíduos de poliéster e laminado de PVC extrusados com poliestireno reciclado e utilizá-lo em matrizes cimentícias. Foram preparadas argamassas referência com traço, em massa, de 1:3 (cimento: areia quartzosa) e relação água/cimento (a/c) de 0,48. Outras quatro argamassas foram preparadas com teores de substituição da areia quartzosa, em volume, pelo agregado leve, em 25%, 50%, 75% e 100%. No estado fresco, foi determinado o índice de consistência das argamassas. No

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estado endurecido, as amostras foram submetidas a ensaios de resistência à compressão, densidade, absorção de água e porosidade. A consistência das argamassas reduziu com o aumento do percentual do agregado leve nas argamassas. Da mesma forma, o aumento do percentual do agregado leve conduziu a uma diminuição da resistência à compressão e da massa específica das amostras. Por outro lado, o aumento do percentual do agregado leve conduziu a aumentos da absorção de água, da porosidade e do índice de vazios, indicando que a densidade da argamassa diminuiu com o aumento da substituição de areia quartzosa pelo agregado leve.

PALAVRAS-CHAVE
Indústria calçadista; resíduo; agregado leve

RESUMEN
La generación de residuos provenientes de diversos sectores de la economía ha impulsado estudios e investigaciones relacionados con el consumo y la eliminación de una amplia variedad de productos. En este contexto, se encuentran las industrias del sector del calzado, tradicionales en el estado de Rio Grande do Sul (Brasil), las cuales enfrentan la necesidad de implementar acciones sostenibles para reutilizar los desechos de materias primas provenientes de la producción de calzado. Este trabajo tuvo como objetivo producir un agregado ligero a base de residuos de poliéster y lámina de PVC extruidos con poliestireno reciclado y utilizarlo en matrices cementicias. Se prepararon morteros de referencia con una proporción, en masa, de 1:3 (cemento: arena cuarzosa) y una relación agua/cemento (a/c) de 0,48. Además, se elaboraron otros cuatro morteros con diferentes niveles de sustitución de la arena cuarzosa, en volumen, por el agregado ligero, en proporciones de 25%, 50%, 75% y 100%. En estado fresco, se determinó el índice de consistencia de los morteros. En estado endurecido, las muestras fueron sometidas a ensayos de resistencia a la compresión, densidad, absorción de agua y porosidad. Los resultados mostraron que la consistencia de los morteros disminuyó a medida que aumentó el porcentaje de agregado ligero. De manera similar, el incremento del agregado ligero condujo a una reducción de la resistencia a la compresión y de la densidad de las muestras. Por otro lado, el aumento en el porcentaje de agregado ligero provocó un incremento en la absorción de agua, la porosidad y el índice de vacíos, lo que indica que la densidad del mortero disminuyó con el incremento de la sustitución de la arena cuarzosa por el agregado ligero.

PALABRAS CLAVE
Industria del calzado; residuo; agregado ligero

1. INTRODUCTION

Waste generated by diverse sectors of the economy has given rise to studies related to the consumption and disposal of several associated products. The traditional shoe making sector in the state of Rio Grande do Sul (Brazil) is no exception and has a need to implement sustainable actions for the re-use of raw material waste.

The environmental impact of economic activity occurs from the generated amount of polluting waste and limited re-use of excess raw materials during both manufacture and post-use. These materials tend to be disposed in sanitary or industrial landfills (Alves and Barbosa, 2013; Soares and Araújo, 2016; Albanio and Tatsch, 2016) and present a contamination risk to soil and groundwater (FLACH *et al.*, 2017). Trein (2015) also noted another environmental problem in industrial centers: often waste incineration is not a recommended option due to the release of toxic gases so excess waste has to be disposed in sanitary landfills.

According to Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais (ABRELPE), only 4 % of waste is recycled in Brazil (ABRELPE, 2020). Studies have determined that recyclable wastes were mostly plastic (16.8 % amounting to 13.8 million t/year), paper and cardboard (10.4 % amounting to 8.57 million t/year), glass (2.7 %), metals (2.3 %) and multilayered packaging (1.4 %). The remaining 5.6 % comprised textile, leather and rubberized recyclable waste (ABRELPE, 2020; AGÊNCIA BRASIL, 2022).

According to the 2019 yearly activity report from Associação Brasileira das Indústrias de Calçados (ABICALÇADOS, 2019), there were over 6 thousand shoe making businesses in Brazil. The shoe making sector represented 4 % of gross national product (GNP) with gross revenue of R$21 billion in 2018 for a production of 944 million pairs of shoes. This placed Brazil as the 4th largest shoe maker in the world and Rio Grande do Sul as the 2nd major shoe making state in the country accounting for 20.1 % of the total in 2018. Within Rio Grande do Sul, the Vale do Rio dos Sinos region produced 78.6 million pairs of shoes in 2022 (ABICALÇADOS, 2022). Soares and Araújo (2016) noted that the most common solid waste from shoe making production originated in the steps of cutting, assembly and finishing for a total of approximately 300 t/day.

In parallel, the construction sector has several initiatives related to the management of plastic waste, with re-use being considered the ideal disposal method (ALMESHAN *et al.*, 2020). Hita *et al.* (2018) considered plastic recycling equivalent to a product life cycle extension and adding environmental worth to its use.

The objective of many sustainability studies in civil construction has been the development of alternative materials with lower environmental impact. These were produced from recycled solid waste and used as total or partial replacement of conventional materials. One such material is recycled polymer used in substitution to aggregates in cementitious matrices (Saikia and Brito, 2012; Trein, 2015; Gu and Ozbakkaloglu, 2016; Babafemi *et al.*, 2018; Badache *et al.*, 2018; Bahij *et al.*, 2020). However, the variety of recycling processes affected the characteristics of these substitute aggregates and induced subsequent changes to the properties of cementitious matrices both in the fresh and hardened state.

Schneider *et al.* (2021) evaluated mortars with sand partially replaced with aggregate produced from the non-metallic portion of PCI boards. Results showed decreases in flow table and compressive strength as replacement content increased. Silveira *et al.* (2022) partially replaced quartz sand with wet blue leather waste encapsulated in recycled polypropylene (PP). Results showed a decrease in compressive strength as substitution content increased, peaking at a 93 % decrease in strength with 100 % substitution at 28 days. Similarly, Lansing (2018) tested light extruded PP aggregate recycled from textile waste and observed a decrease in strength and specific mass as well as an increase in porosity and water absorption with increasing substitution content.

On the other hand, Tutikian *et al.* (2017) replaced sand with light aggregate from ethylene-vinyl acetate (EVA) copolymer waste in substitution contents of 20 %, 40 %, 60 %, 80 % and 100 % in floor mortar beds. Results showed good improvement in sound insulation for all substitution ratios. Similarly, Trein (2015) evaluated the re-use of EVA waste and polyurethane-covered (PU) textile waste as light aggregate in alkali-activated mortars. Chart 01 presents a summary of reference studies that made use of polymer light aggregates and their results.

Results of **Chart 1** denoted that, regardless of the light aggregate used, increased substitution content produced a decrease in cementitious matrix mechanical properties and loss of workability. However, some advantages gained were lower density and increased thermal-acoustic insulation. Thus, the focus of this study was the use of shoe making industry waste as light aggregate. The shoe making process involved several steps that generated several types of wastes which have not been fully

considered as substitution material despite being technically and environmentally viable. The light aggregates used in this study were from polyester and laminated PVC extruded with recycled polystyrene. Resulting cementitious matrices properties were evaluated both in the fresh and hardened states for future feasible applications in civil construction projects.

REF.	TITLE.	LIGHT AGGREGATE FROM WASTE (LAW)	SAND SUBST. CONTENT	MAIN RESULTS
TREIN, 2015	Effect of using shoe making industry waste in alkali-activated mortars	EVA and polyurethane-covered (PU) textile waste	10 %, 20 %, 30 % and 40 % by volume	Compressive strength above 1.5 MPa for 40 % LAW content at 28 days. Water absorption and porosity increased as LAW content increased.
KROEFF, 2016	Evaluation of shoe making industry waste use in Portland cement-based cementitious matrices	EVA and polyurethane-covered (PU) textile waste	25 % and 50 % by volume	50 % LAW content deemed ideal for a minimum strength of 1.5 MPa.
TUTIKIAN *et al.*, 2017	Use of light aggregate from recycled shoe making industry waste in mortar bed for sound proofing in residential buildings	Shoe making industry EVA waste	20 %, 40 %, 60 %, 80 % and 100 % by volume	Decrease in compressive and flexural tensile strengths as LAW replacement content increased. But all LAW content mortars had positive increases in sound proofing.
LANSING, 2018	Evaluation of light aggregates from recycled shoe making industry waste incorporated in cementitious matrix	Extruded textile waste (polyester and cotton) with polypropylene (PP)	25 %, 50 % and 75 % by volume	Decrease in compressive strength and specific mass as LAW substitution content increased. Increase in porosity and water absorption as LAW substitution content increased.
BADACHE *et al.*, 2018	Thermo-physical and mechanical characteristics of sand-based lightweight composite mortars with recycled high-density polyethylene (HDPE)	Plastic waste from HDPE tubes	15 %, 30 % 45 % and 60 % by volume	Composite mortars had lower mechanical performance than reference mortar. A 60 % LAW substitution content decreased compressive strength by 38 % with respect to reference mortar.
SILVEIRA *et al.*, 2022	Light aggregate produced from recycled shoe making industry waste for use as partial replacement of river quartz sand in cementitious matrix	Wet-blue leather waste encapsulated in recycled polypropylene (PP)	25 %, 50 %, 75 % and 100 % by volume	Decrease in compressive strength as LAW substitution content increased. Decrease of 93 % in compressive strength for 100 % replacement content at 28 days.

Chart 01: Summary of reference studies on the use of polymer light aggregate in cementitious matrices.

LAW: light aggregate from waste.

Source: Authors.

2. MATERIALS AND METHODOLOGY

The binder used in this study was CPV ARI – RS, a sulfate-resistant, high initial strength Portland cement equivalent to type III Portland cement (ASTM C150, 2021). The chemical oxide composition of CPV ARI – RS is shown in Table 01. The main oxides contained in CPV ARI – RS were CaO (67.97 wt.%) and SiO_2 (15.54 wt.%).

Sand used in the cementitious matrices was natural quartz sand from the Vacacaí river in the state of Rio Grande do Sul, Brazil. Sand was dried in an oven at 105 ºC ± 5 ºC for 24 h and sifted with standardized sieves recommended by standard NBR 17054 (ABNT, 2022). After this preparation, sand was separated into parts matching the granulomety of light aggregate shown in **Table 01**. This sand preparation methodology was applied to minimize the effects of distinct granulometries of sand and light aggregate in the cementitious matrices.

Oxide	wt. %
MgO	1.51
Al2O3	3.73
SiO2	15.54
SO3	3.33
Cl	0.07
K2O	1.16
CaO	67.97
TiO2	0.26
V2O5	0.01
MnO	0.04
Fe2O3	2.77
SrO	0.26
ZrO2	0.01
BaO	0.02

Table 01: Chemical oxide composition of Portland cement CP V ARI - RS determined from X-ray fluorescence (XRF) (in wt.%). L.O.I (Loss on ignition) determined as 3.30 wt.%.
Source: Authors.

Quartz sand density was 2.62 g/cm^3 and water absorption was 0.87 % as determined from the procedures of standard NBR 16916 (ABNT, 2021). Hardness in the 0 to 100 Shore D scale was determined as 92.11 in 10 s from the procedures of standard ASTM D2240 (ASTM, 2021) averaged over 9 pressure points. It should be noted that the Shore D methodology of ASTM D2240 (ASTM, 2021) was to determine the hardness of thermoplastics and hard rubbers. Despite not being recommended for ceramic materials, it was used nonetheless in order to offer a direct comparison to the light aggregate.

2.1 Production of light aggregate from polyester and laminated PVC extruded with polystyrene waste.

Light aggregate was produced from polyester and laminated PVC waste. Both wastes were extruded with recycled polystyrene (PS). Polyester and laminated PVC waste were collected from a shoe and hand bag maker located in the state of Rio Grande do Sul, Brazil. Both wastes were generated from cutting processes in the manufacture of these products. Polystyrene used for the extrusion process were sourced from plastic cups and wastes from an injection mold business, namely soles, wedge clogs, insoles and heels. The latter were 50 wt.% polystyrene.

Light aggregate was produced with 20 % shredded polyester and laminated PVC waste and 80 % recycled polystyrene by mass. These proportions were based on Lansing (2018) in order to obtain an aggregate with non-fibrous texture since excessive fiber content would require more water and cause deleterious effects on the mechanical properties of the matrices.

Light aggregate material was homogenized in a mixer and fed to a SEIBT model 25 extruder with 4 kg/h capacity at 22 m/min and 4 heating exit levels (140 ºC, 155 ºC, 170 ºC and 180 ºC). The mixed material was extruded layered at a speed related to mixture homogeneity based on previous studies (Trein, 2015; Kroeff, 2016; Lansing, 2018; Silveira *et al.*, 2022).

Extruded material was cooled by passing through a 4 m long tub with water and compressed air kept at 10 ºC, fed to a granulator machine with a 6 mm sieve and collected in a metal bin with maximum carrying capacity of 500 kg. Granules were aspirated into a USIFER tower dryer model ES 100 with a processing capacity of 100 kg/h. Drying was conducted at 60 °C for 10 min.

Finer granulometries were obtained with a micronizer machine with sieves ranging from 2 mm to 4 mm as in reference studies (Lansing, 2018; Silveira *et al.*, 2022). The final light aggregate contained 75 % of passing material from the 6 mm granulator sieve (**Figure 01a**) and 25 % of passing material from the 2 mm micronizer sieve (**Figure 01b**).

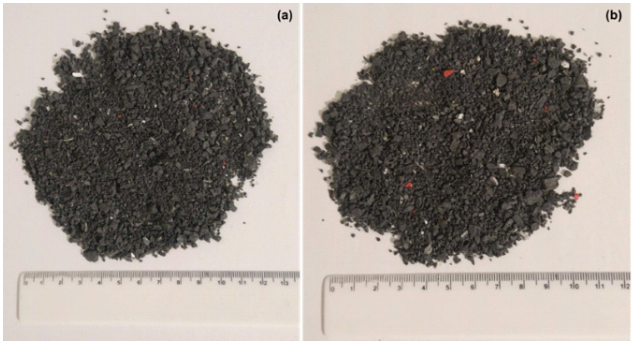

Figure 01: Materials of the light aggregate of this study: (a) granules produced by the granulator; (b) granules produced by the micronizer.
Source: Authors.

Table 02 presents the granulometry of the light aggregate of this study. Based on the composition and the criteria of standard NBR 17054 (ABNT, 2022), the fineness modulus of the light aggregate was determined as 4.18.

Sieve size (Normal series, in mm)	% retained	accumulated % retained
2.36	36	36
1.18	51	88
0.60	8	96
0.30	3	98
0.15	1	100
< 0.15	0	100

Table 02: Granulometry of light aggregate used in this study processed with granulator and micronizer.
Source: Authors.

Besides granulometry, light aggregate real density was determined as 0.87 g/cm³ and water absorption as 5.08 % with procedures of standard NBR 16916 (2021). The procedure used to determine water absorption was adjusted to a drying temperature of 70 °C instead of 105 °C. This was needed to avoid softening of the thermoplastic in the aggregate. Hardness in the 0 to 100 scale Shore D was determined as 54.22 Shore D with 10 s over 9 pressure points as per standard ASTM D2240 (ASTM, 2021).

2.2 Mixing and preparation of cementitious matrices

The reference matrix (M0) contained 0 % light aggregate content and was prepared with a mix ratio of 1:3 (cement: sand) and a water/cement (w/c) ratio of 0.48 based on standard NBR 7215 (ABNT, 2019). In order to keep most factors constant, only sand substitution content by volume was considered while mix ratio and w/c ratio were kept the same for all matrices. The substitution matrices and their respective substitution contents were: M25 (25 %), M50 (50 %), M75 (75 %) and M100 (100 %) by volume. Considering that the densities of quartz sand and light aggregate were 2.62 g/cm³ and 0.87 g/cm³, respectively, the mass of light aggregate for each matrix was determined from equation (1):

(1)

Where:

$$M_{ag} = \frac{M_{sand}}{\gamma_{sand}} \times (\%\ substitution\ content) \times \gamma_{ag}$$

M_{ag} = mass of light aggregate;
M_{sand} = mass of quartz sand;
= density of quartz sand;
= density of light aggregate.

Standard NBR 7215 (ABNT, 2019) prescribed standardized sand with 4 granulometries to be used, each corresponding to a proportion of 25 %. For this study, this standard was adapted to use sand with 6 granulometries (2.36 mm; 1.18 mm; 0.6 mm; 0.3 mm; 0.15 mm and < 0.15 mm) in the same proportions found for the light aggregate so that both would match. A visual comparison of the granulometries of both aggregates is shown in **Figure 02**.

Matrix preparation started with cement and water being homogenized in an EMIC model AG-5 mechanical mixer with 5 L capacity for 1 min at high speed. Aggregates (quartz sand and light aggregate) were added and further mixed for 1 min at low speed. The axle was scraped to remove any adhered material and the matrix further mixed for 3 min at high speed. Mixing times were adapted from previous studies (KROEFF, 2016; LANSING, 2018 and SILVEIRA *et al.*, 2022).

Mortars were poured in prismatic cubic molds measuring 50 mm x 50 mm x 50 mm in 2 layers. Each layer was consolidated by applying 30 impacts over 30 s with a flow table apparatus in a similar fashion as the flow table test of standard NBR 13276 (ABNT, 2016). After consolidation of the second layer, the mortar top surface was smoothed out. Samples were covered with a plastic film and allowed to rest for 48 h prior to demolding. Demolded samples, shown in **Figure 03**, were stored in a saturated solution of calcium hydroxide in accordance with standard NBR 5738 (ABNT, 2015) until evaluated for compressive strength, density, water absorption and porosity.

Table 03 presents the materials and composition of the cementitious matrices of this study, namely M0, M25, M50, M75 and M100.

Figures 02 and **03** are shown respectively in the next page.

2.3 Cementitious matrix consistency analysis

Cementitious matrix	% LAW	Cement	Sievesize (Normal series, inmm)	Quartz sand	LAW	Water (mL)	w/c ratio	Cement consumption (kg/m³)
		Mass (g)		Mass (g)	Mass (g)			
M0	0	500	2.36	545.70	0.00	240	0.48	510.63
			1.18	770.25	0.00			
			0.6	121.20	0.00			
			0.3	39.00	0.00			
			0.15	18.00	0.00			
			<0.15	5.85	0.00			
M25	25	500	2.36	409.28	45.30	240	0.48	510.63
			1.18	577.69	63.94			
			0.6	90.90	10.06			
			0.3	29.25	3.24			
			0.15	13.50	1.49			
			<0.15	4.39	0.49			
M50	50	500	2.36	272.85	90.60	240	0.48	510.63
			1.18	385.13	127.89			
			0.6	60.60	20.12			
			0.3	19.50	6.48			
			0.15	9.00	2.99			
			<0.15	2.93	0.97			
M75	75	500	2.36	136.43	135.90	240	0.48	510.63
			1.18	192.56	191.83			
			0.6	30.30	30.18			
			0.3	9.75	9.71			
			0.15	4.50	4.48			
			<0.15	1.46	1.46			
M100	100	500	2.36	0.00	181.90	240	0.48	510.63
			1.18	0.00	256.75			
			0.6	0.00	40.40			
			0.3	0.00	13.00			
			0.15	0.00	6.00			
			<0.15	0.00	1.95			

Table 03: Materials and composition of cementitious matrices containing distinct light aggregate substitution contents.

LAW: light aggregate from waste.

Source: Authors.

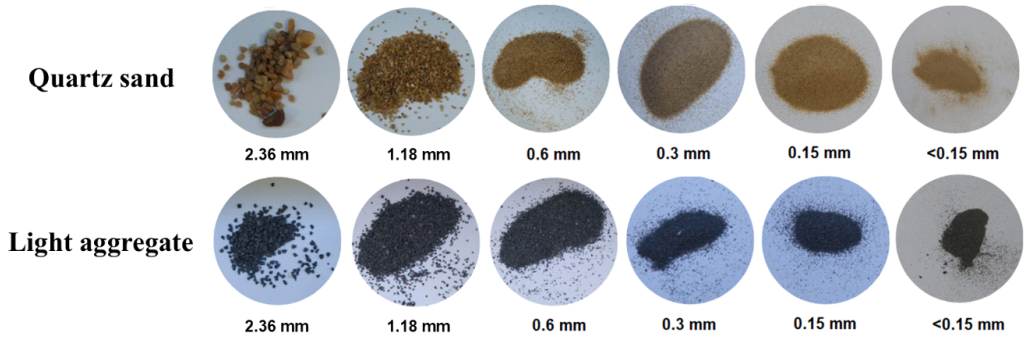

Figure 02: Visual granulometric comparison between quartz sand and light aggregate.
Source: Authors.

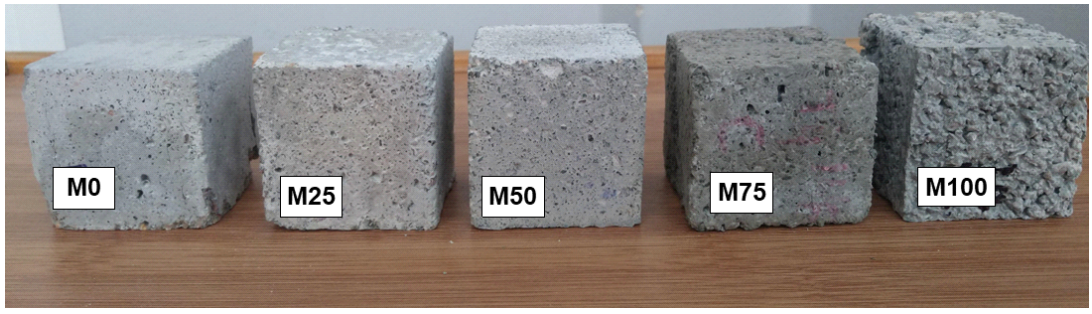

Figure 03: Cubic samples (50 mm x50 mm x50 mm) of each cementitious matrix tested.
Source: Authors.

Workability of all mortars was evaluated with a flow table test in accordance with the procedures of standard NBR 13276 (ABNT, 2016). The truncated conic mold was filled with 3 layers of mortar of approximately same height. The first, second and third layers were tamped 15 times, 10 times and 5 times with a tamping rod, respectively, for consolidation. The mold was lifted vertically and the table raised and dropped freely 30 times in 30 s in accordance to the procedures of standard NBR 13276 (ABNT, 2016). The consistency index was then calculated as the average of 3 measured diameters.

2.4 Mechanical characteristics

Axial compressive strength was evaluated at 7 days and 28 days of age. Testing was conducted with an Instrom universal testing machine, model1500 HDX at Laboratório de Materiais de Construção Civil (LMCC-UFSM). Testing was conducted with a load of 1 kN/s and, at each age, 4 test bodies were used for each matrix.

2.5 Physical characteristics

Water absorption, void index and real density of all mortars were evaluated af 28 days with equations (2), (3) and (4) based on the procedures of standard NBR 9778 (ABNT, 2009):

where:

msat: mass of water-saturated sample after immersion and boiling;

ms: mass sample dried in an oven at (105 ± 5) °C;

Water absorption (%):

$$Ab = \frac{m_{sat} - m_s}{m_s} \times 100 \qquad (2)$$

Void index (%):

$$Vi = \frac{m_{sat} - m_s}{m_{sat} - m_i} \times 100 \qquad (3)$$

Real density (g/cm³):

$$\rho_r = \frac{m_s}{m_s - m_i} \times 100 \qquad (4)$$

mi: mass of saturated sample immersed in water after boiling.

3. RESULTS AND DISCUSSION

Consistency index and compressive strength results are presented in **Table 04**. The M0 reference matrix, with no substitution, yielded a higher consistency index than all other matrices with light aggregate content. These results were attributed to higher absorption and angular shape of the light aggregate when compared to quartz sand. The effects of these characteristics were noted in several studies that made use of polymer-based materials in cementitious matrices. For example, Lansing (2018) observed that light aggregate from polyester and cotton waste extruded with polypropylene had a negative effect in the workability of cements. Silveira (2020) also observed decreased workability attributed to the hygroscopic characteristics of the light aggregate over quartz sand. Finally, Hartmann (2019) noted that the laminated shape of light aggregate grains produced greater interlocking between them.

Cementitious matrix	% LAW	Average consistency index (mm)	Average compressive strength and standard deviation (MPa)	
			7 days	28 days
M0	0	254	36.04 ± 2.34	43.35 ± 1.63
M25	25	221	17.10 ± 2.72	20.89 ± 1.69
M50	50	184	11.32 ± 0.52	14.14 ± 0.49
M75	75	169	8.03 ± 0.62	8.82 ± 0.31
M100	100	156	6.29 ± 0.36	6.03 ± 0.14

Table 04: Average consistency index and compressive strength of cementitious matrices of this study with different light aggregate substitution content.
Source: Authors.

On the other hand, Zhang *et al.* (2021) observed substantial increases in the workability of a cementitious matrix with added polymers due to greater water retention and entrained air. Aattache, Soltani and Mahi (2017) noted that mortars with polymer content tended to be more porous, requiring more mixing water to maintain workability and, consequently, changed the characteristics of the mixture.
Average compressive strength results of matrices with respect to light aggregate substitution content are also shown in the graph of **Figure 04** alongside standard deviation bars. Strength at 7 days varied between 36.04 MPa (M0) and 6.29 MPa (M100) while at 28 days varied between 43.35 MPa (M0) and 6.03 MPa (M100).

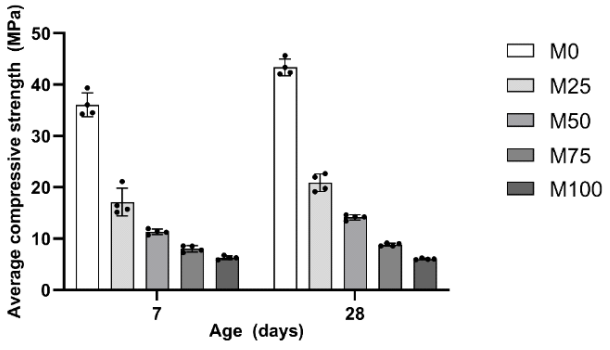

Figure 04: Average compressive strength and standard deviation bars for cementitious matrices with different light aggregate substitution content.
Source: Authors.

A statistical ANOVA (analysis of variance) was conducted to determine the effect of light aggregate substitution content (0 % 25 %, 50 %, 75 % and 100 %) and age (7 days and 28 days) on the compressive strength of the cementitious matrices. The ANOVA had a double factor for compressive strength due to the substitution contents with a 95 % confidence level. Data were evaluated for normality with a Shapiro-Wilk test and found to follow a normal distribution ($\propto << 0.05$). The subsequent ANOVA and its results are shown in **Table 05**.

ANOVA results indicated significant statistical difference between all 3 factors: age, substitution content and age x substitution content. Therefore, a post hoc Tukey test was conducted to identify factors with significant differences and the results are shown in **Table 06**.

Comparing the results of **Table 06**, non-significant differences in compressive strength were observed between contents of 50 %, 75 % at 7 days and 75 % and 100 % at both 7 days and 28 days. Similar results were obtained in other reference studies. Lansing (2018) did not identify significant differences in compressive strength for cementitious matrices with 50 % and 75 % light aggregate content in all ages of the study (7 days, 28 days, 63 days and 91 days). Similarly, Silveira (2020) obtained no significant differences between the ages of 7 days and 28 days for matrices with light aggregate substitution contents of 25 %, 50 %, 75 % and 100 %.

	SUM OF SQUARES	DEGREES OF FREEDOM	AVERAGE OF SQUARES	CRITICAL F	CALCULATED p-VALUE
AGE	83.45	1	83.45	F(1,30) = 42.82	P < 0.0001***
CONTENT	5827	4	1457	F(4,30) = 747.6	P < 0.0001***
AGE X CONTENT	69.33	4	17.33	F(4,30) = 8.893	P < 0.0001***
RESIDUAL	58.46	30	1.949		

Table 05: ANOVA (analysis of variance) of the effects of light aggregate content (0 % 25 %, 50 %, 75 % and 100 %) and age (7 days and 28 days) on the compressive strength of cementitious matrices.
Critical F = tabulated F value for p = 0.05
Calculated p-value = reference value
*** significant values
Source: Authors.

Age (days)	LAW content comparision (%)									
	0 - 25	0 - 50	0 - 75	0 - 100	25 - 50	25 - 75	25 - 100	50 - 75	50 - 100	75 - 100
7	SD	SD	SD	SD	SD	SD	SD	ND	SD	ND
28	SD	SD	SD	SD	SD	SD	SD	SD	SD	ND

Table 06: Tukey test significance analysis of light aggregate content with respect to age for compressive strength of cementitious matrices.
Source: Authors.

Calixto *et al.* (2017) observed that axial compressive strength was not significantly affected when up to 15 % of sand was replaced with expanded polystyrene (EPS). However, substantial decreases in strength were noted for a substitution content of 40 %, attributed to the hydrophobic characteristic of EPS. Bahij *et al.* (2020) also observed decreases in strength of cementitious matrices incorporating polymer aggregates. This was attributed to a lack of adhesion between polymer aggregate and Portland cement paste, characteristic lower rigidity strength of polymer when compared to natural aggregates and increased entrained air content. Zhou and Brooks (2019) also pointed out that another factor contributing to the decrease in compressive strength was the lower density of substitute light aggregates when compared to conventional ones such as gravel and sand.

Overall, it could be concluded that higher light aggregate content led to decreases in compressive strength which affected other mechanical properties of the cementitious matrix. According to Záleská *et al.* (2018) and Bahij *et al.* (2020), the decrease in strength was related to factors such as lower density of light aggregate when compared to quartz sand and low adhesiveness between the surface of light aggregate and cement paste. Polymer-based light aggregates also presented a trend of decreased compressive strength with increasing replacement content. In the case of replacing sand with vermiculite (a light conventional mineral aggregate), Sinhorelli (2019) obtained decreases in mortar compressive strength between 56 % and 63 % for replacement contents between 60 % and 80 %. Similarly, results of this study also pointed to 52 % and 67 % decreases in compressive strength for matrices M25 and M50, respectively.

Physical characteristics of water absorption, void index (porosity) and real density were evaluated at 28 days. Real density results are shown in **Figure 05(a)** with respect to substitution content while the relation between compressive strength and density is shown in **Figure 05(b)**.

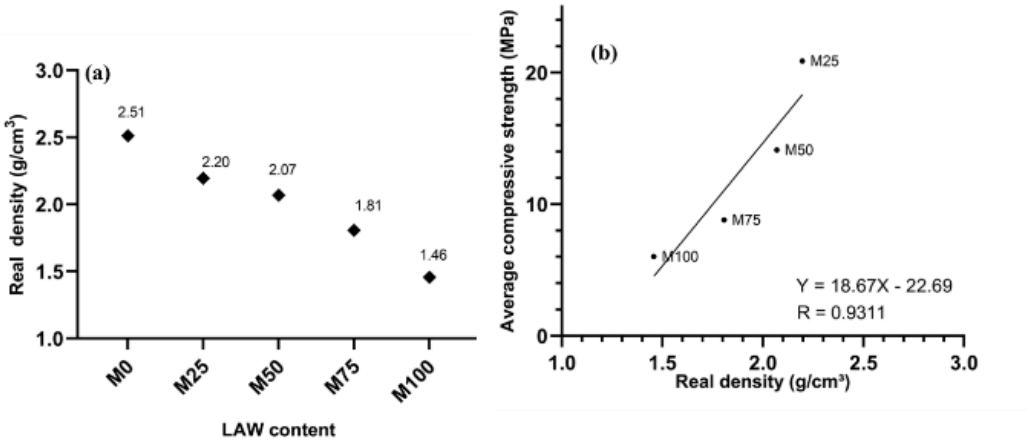

Figure 05: (a) Real density (g/cm^3) of cementitious matrices with respect to light aggregate replacement content at 28 days and (b) relation between compressive strength and real density at 28 days.
Source: Authors.

Figure 05a shows that real density of the cementitious matrix decreased with increasing light aggregate substitution content. This was related to the lower density of light aggregate (0.87 g/cm^3) when compared to quartz sand (2.62 g/cm^3). The same results were obtained by Soares (2016), Lansing (2018) and Bahij *et al.* (2020). Silveira (2020) noted that density had the opposite behavior as water absorption and porosity of the matrices as light aggregate substitution content increased. Lv *et al.* (2015), Gupta, Chaudhary and Sharma (2016) and Angelin *et al.* (2019) reported the same behavior with the use of ground tire rubber and deemed it to be a result of the characteristics of the recycled aggregate. In the case of rubber, its hydrophobic properties were combined with surface air entrainment to increase void spaces. Finally, Záleská *et al.* (2018) also observed a reduction in density with the use of polypropylene (PP) waste.

Figure 05b shows that replacing sand with light aggregate decreased both real density and compressive strength. Matrix M50 had an 18 % decrease in real density and 67 % in compressive strength when compared to the reference M0 matrix. Furthermore, matrix M100 had a 42 % decrease in real density and 86 % in compressive strength when compared to the reference M0 matrix. The decrease in compressive strength with respect to real density is non-linear as demonstrated by the trend line and correlation coefficient of $R^2 = 0.9311$. It should be noted that the trend line calculation did not include the reference M0 matrix due to its outlier behavior. Sharper decreases in strength were observed between matrices M0 and M25 (52 %) than M25 and M50 (32 %), M50 and M75 (38%) and M75 and M100 (32 %). This indicated that, in addition to aggregate type, aggregate real density was also a contributing factor to the decrease in strength.

Average water absorption and porosity for the cementitious matrices of this study at 28 days are shown in **Figure 06.**

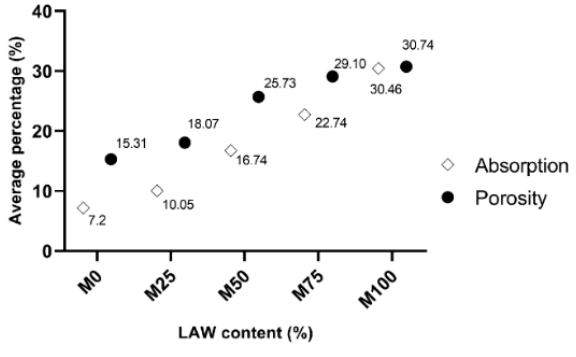

Figure 06: Average water absorption (%) and porosity (%) of the cementitious matrices with light aggregate substitution content at 28 days.
Source: Authors.

Figure 06 shows a direct relation between increased substitution content and increases both water absorption and porosity in the cementitious matrices. It should be noted that water absorption was related not only to porosity but also to pore size and connectivity. At 25 % substitution content, a 40 % increase in water absorption was noted with respect to the reference M0 matrix. Subsequent substitution content increases of matrices M50, M75 and M100 resulted in water absorption increases of 133 %, 216 % and 323 %, respectively, with respect to reference matrix M0. Silveira (2020) related this behavior to the higher water absorptivity of light aggregate compared to quartz sand. That was indeed confirmed as the light aggregate of this study had an absorptivity of 5.08 % while quartz sand was 0.87 %. Silveira (2020) also detected the presence of entrained air in the cement paste-aggregate interface. Mello (2011) also observed increased water absorption in cementitious matrices with recycled high-density polyethylene (HDPE) due to higher entrained air with respect to a reference matrix. In this case the increased water absorption was attributed to increased porosity in the cement paste. Moayeri, Ashrafi and Beiranvand (2016) determined that light aggregates absorbed 5 % to 25 % of water with respect to its dry mass depending on pore characteristics. Liu, Chia and Zhang (2011) proposed a workaround for the increased absorption of light aggregates in building construction that involved pre-wetting based on the specific water absorptivity of the aggregate.

Regarding average values of porosity, Figure 06 shows a similar increase as light aggregate substitution content increased. Matrix M25 presented an increase in porosity of 18 % with respect to reference matrix M0. Similarly, matrices M50, M75 and M100 had increases of 68 %, 90 % and 101 %, respectively, with respect to reference matrix M0. These results matched Hwang, Kim and Ann (2015), Blazy and Blazy (2021) and Miah *et al.* (2023) which observed similar increases in porosity with the use of recycled industrial materials such as steel, polypropylene and Asian areca palm nut fibers as light aggregate substitutes for sand.

Soares (2016) reported a porosity of 17 % for a cementitious matrix that replaced 50 % of treated commercial river sand with light aggregate by volume. This value was close to the 18 % of the M25 matrix of this study and demonstrated the effect of the type of aggregate on porosity. Soares (2016) also verified that increased porosity and decreased density from light aggregate substitution produced an increase in water absorption. This indicated that the increase in porosity was not the single main contributor to the decrease in compressive strength and the type of aggregate should also be considered. In the case of this study, the polymer-based light aggregate had less rigidity than quartz sand as confirmed by the hardness test results of 92.11 Shore D and 54.22 Shore D for quartz sand and light aggregate, respectively.

Figures 06 and **07** show water absorption increases of 23 % and 30 % for matrices M75 and M100, respectively. This was due to the higher waster absorption of the light aggregate (5.08 %) when compared to quartz sand (0.87 %). This result was related to compressive strength values of matrices M75 and M100 which had no significant variation at 7 days and 28 days. Similar results were obtained by Lansing (2018) for matrices with 50 % and 75 % light aggregate content and porosity around 25 %.

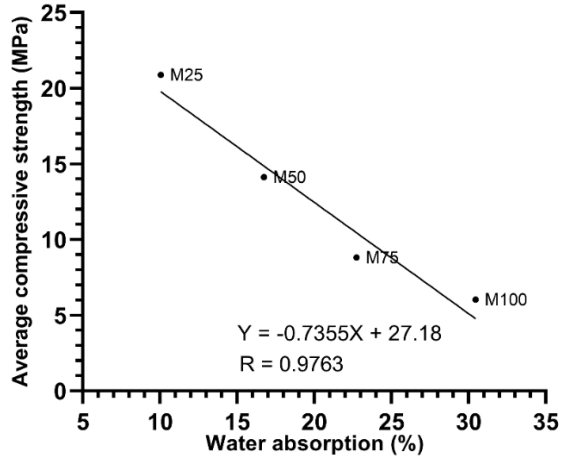

Figure 07: Relationship between average compressive strength and water absorption ot the cementitious matrices with light aggregate substitution content at 28 days.
Source: Authors.

Figure 07 shows that increases light aggregate substitution content increased water absorption and decreased compressive strength in the cementitious matrix. The decrease in strength was approximately linear with respect to water absorption as shown by the trend line and correlation coefficient of $R^2 = 0.98$. Once again the trend line did not include the outlier reference M0 matrix data point. These results indicated that porosity and, by extension, water absorption were predominant factors in the decrease of strength as substitution content increased. Koksal, Gencel and Kaya (2015) pointed to a strong correlation between porosity, water absorption and density in that, as porosity increased, density decreased and water absorption increased with carryover effects of decreasing mechanical properties.

4. CONCLUSIONS

Results of this study confirmed that light aggregate from polyester and laminated PVC extruded with polystyrene affected fresh and hardened state properties of cementitious matrices based on Portland cement. The following conclusions were drawn:

- In the fresh state, increased substitution of quartz sand with light aggregate markedly decreased workability, as confirmed through flow table tests. The 100 % substitution content of matrix M100 produced a decrease of around 61 % in mortar consistency index with respect to the reference M0 matrix.
- In the hardened state and through statistical analysis, it was determined that increased substitution of quartz sand with polymer-based light aggregates decreased compressive strength of the cementitious matrices.
- Increased substitution of quartz sand with light aggregate increased water absorption and void index and decreased real density of the cementitious matrices.

Results of this study demonstrated that light aggregates produced from polyester and laminated PVC extruded with polystyrene could be used to replace quartz sand in civil construction as long as the replacement content was not too high. For example, matrix M50 at 28 days had a compressive strength above 14 MPa, real density 18 % lower and water absorption of over 100 % higher than the reference mortar. Consequently, the use of such matrix would be adequate only for situations in which the mortar was not responsible for the integrity of the system such as filling cavities or normalizing surfaces

Future extensions to this study would continue the analysis of the use of this cementitious matrix as acoustic and thermal insulation as well as economic viability.

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DESIGN FOR REVERSE LOGISTICS GUIDELINES: A LITERATURE REVIEW

DIRETRIZES DE PROJETO PARA LOGÍSTICA REVERSA: UMA REVISÃO DA LITERATURA

DIRECTRICES DE DISEÑO PARA LA LOGÍSTICA INVERSA: UNA REVISIÓN DE LA LITERATURA

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ABSTRACT

Environmental challenges related to solid waste generation and disordered consumption are becoming increasingly prominent. The Circular Economy (CE) has emerged as a strategy for generating value through effective waste management, and *Reverse Logistics* (RL) plays an important role in the transition to CE. Sustainable Design (SD) and *Design for Reverse Logistics* (DfRL) have emerged as approaches to integrating RL into product design. This research aimed to explore the context of Design Guidelines (DG) for RL under the concept of DfRL. To this end, a Systematic Literature Review (SLR) approach was used. The research covered aspects of DG, such as related Design for Excellence (DfX), product design context, relationship with RL, sustainability and the Sustainable Development Goals (SDGs). In addition, the research identified research gaps, such as the definition of the term and hierarchy around DG and the need for integration between research and technique to share design information. Potential areas were identified for DfRL and for integrating RL into the product process, promoting the transition to a more sustainable and circular production model, in line with the SDGs and the needs of future generations.

KEYWORDS

Circular Economy; Sustainable Design; Reverse Logistics; *Design for Reverse* Logistics; Design Guidelines.

RESUMO

Desafios ambientais relacionados à geração de resíduos sólidos e ao consumo desordenado ganham cada vez mais destaque. A Economia Circular (EC) surgiu como estratégia de geração de valor, por meio de uma gestão eficaz dos resíduos, e a Logística Reversa (LR) desempenha um papel importante na transição para a EC. O Design Sustentável (DS) e o Design for Reverse Logistics (DfRL) surgem como abordagens para integrar a LR ao projeto de produtos. Esta pesquisa objetivou explorar o contexto das diretrizes de projeto para LR sob o conceito de DfRL. Para isso, utilizou-se uma abordagem de Revisão Sistemática da Literatura (RSL). A pesquisa abrangeu aspectos acerca de diretrizes de projeto, como Design for Excellence (DfX) relacionados, contexto de projeto de produto, relação com a LR, a sustentabilidade e os Objetivos de Desenvolvimento Sustentável (ODS). Além disso, a pesquisa identificou lacunas de pesquisa, como a definição do termo e hierarquia acerca de diretrizes de projeto e a necessidade de integração entre pesquisa e técnica para compartilhamento de informações de projeto. Foram identificadas áreas potenciais para o DfRL e para integrar a LR ao processo do produto, promovendo a transição para um modelo de produção mais sustentável e circular, alinhado aos ODS e às necessidades das gerações futuras.

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PALAVRAS-CHAVE

Economia Circular; Design Sustentável; Logística Reversa; Design para Logística Reversa; Diretrizes de Projeto

RESUMEN

Los desafíos ambientales relacionados con la generación de residuos sólidos y el consumo desordenado están ganando cada vez más relevancia. La Economía Circular (EC) surgió como una estrategia para generar valor a través de una gestión eficaz de los residuos, y la Logística Inversa (LI) desempeña un papel importante en la transición hacia la EC. El Diseño Sostenible (DS) y el Diseño para la Logística Inversa (DfLI) emergen como enfoques para integrar la LI en el diseño de productos. Esta investigación tuvo como objetivo explorar el contexto de las directrices de diseño para la LI bajo el concepto de DfLI. Para ello, se utilizó un enfoque de Revisión Sistemática de la Literatura (RSL). La investigación abarcó aspectos sobre las directrices de diseño, como el Diseño para la Excelencia (DfX) relacionado, el contexto del diseño de productos, la relación con la LI, la sostenibilidad y los Objetivos de Desarrollo Sostenible (ODS). Además, la investigación identificó brechas en la literatura, como la definición del término y la jerarquía sobre las directrices de diseño, así como la necesidad de integración entre investigación y técnica para el intercambio de información de diseño. Se identificaron áreas potenciales para el DfLI y para integrar la LI en el proceso del producto, promoviendo la transición hacia un modelo de producción más sostenible y circular, alineado con los ODS y las necesidades de las generaciones futuras.

PALABRAS CLAVE

Economía Circular; Diseño Sostenible; Logística Inversa; Diseño para Logística Inversa; Directrices de Diseño

1. INTRODUCTION

In recent years, the world has faced significant challenges related to environmental problems associated mainly with the generation of solid waste and the disorderly consumption of natural resources. In 2010, Brazil approved the National Solid Waste Policy - PNRS (established by Law 12.305 of August 2010), which emphasizes the need to find integrated solutions to solve the problems arising from the generation of waste that can affect the quality of life of Brazilians. The PNRS presents *Reverse Logistics* (RL) as an instrument of economic and social development characterized by a set of actions, procedures and means designed to enable the collection and return of solid waste to the business sector, for reuse, in its cycle or other production cycles, or another environmentally appropriate final destination" (Brasil, 2010).

The depletion of resources is considered a problem for the economic sustainability of the current production and consumption model, which needs to be reviewed to transition to a social and productive model that does not jeopardize the survival opportunities and well-being of future generations (Manzini; Vezzoli, 2016).

The culture of unbridled and disposable consumption plays a fundamental role in the excessive generation of waste. In addition to this, it is important to address sustainable strategies that promote economic and social development while reducing negative environmental impacts.

One of these strategies is the Circular Economy (CE) a model that aims to produce value without destroying nature, but rather restoring and protecting it (Sehnem; Pereira, 2019). The CE is an environmental management policy that aims to improve the management of resources used in production chains (Su, Heshmati, & Geng, 2013), preventing the deterioration of the environment and promoting the conservation of scarce resources through effective waste management, especially solid waste management (Sehnem and Pereira, 2019). The CE model, according to the Ellen MacArthur Foundation (2017) has four technical cycles consisting of product maintenance; reuse/ redistribution - used product; product updating/ remanufacturing; and product recycling.

When dealing with these propositions concerning the process and the product from the CE, RL are seen in the encounter between the items returned in the chain and the possible activities for recovering value and the final destination of the waste (Melo *et al.*, 2022). Rogers and Tibben-Lembke (1998) defined RL as the process of efficiently planning, implementing and controlling the economic flow of raw materials, in-process inventory, finished products and information related to the point of consumption and origin, to recover value or dispose of it properly. Thus, RL plays an important role in the transition to CE, as it involves returning products, materials and packaging to the production cycle to recover value, instead of sending them directly to landfills.

Melo *et al.* (2021) also cite *Reverse Logistics* as an efficient set of resources and actions that can play an important role in promoting Sustainable Design (SD), considering DfX (*Design for X or Design for Excellence*) approaches, more specifically *Design for Reverse Logistics* (DfRL). SD is understood to be a wide range of design activities on the product system, which tend to address the issues posed by the environmental issue by linking the technically possible with the ecologically necessary, resulting in new socially and culturally appreciable proposals whose acceptance depends on a change in the culture and behaviour of consumers (Manzini; Vezzoli, 2016).

Following this logic and aiming to find applicability to the set of actions from CE, RL and DS, the most objective approaches concerning different sets of actions and products are DfX, which, according to Melo, Merino and Merino (2017), aims to design products with a focus on optimized characteristics, and the "X" that accompanies the term *"Design for"* can be any desired characteristic/ skill for such products.

The waste issue in Brazil is complex and multifaceted and the adoption of strategies such as CE, RL and SD can play a key role in mitigating the environmental problems associated with waste generation (Geng *et al.*, 2020; Aguiar *et al.*, 2022; Braga Jr *et al.*, 2023). This is expected not only to reduce the negative environmental impact but also to contribute to achieving the SDGs - Sustainable Development Goals (United Nations, 2015), promoting a more sustainable and equitable future.

To better specify the approaches of this research, *Design for Reverse Logistics* (DfRL) emerges as a branch of DfX that considers, even at the product design stage, aspects associated with the processes and activities that make up Reverse Logistics, as well as their direct positive impacts to promote sustainable competitive advantage. This proposed concept allows sustainability to be more robust, as it considers factors that are little addressed by researchers and designers (Melo *et al.*, 2021).

To achieve and enable DfRL, more specific and assertive information such as Design Guidelines (DG) is needed to enable designers to consider RL demands at an early stage of the PDP, facilitating the execution of RL processes

at the end-of-life stages of products and increasing the chances of these materials being identified, separated, collected and recovered or disposed of in environmentally suitable locations, making them more sustainable. The inclusion of sustainable guidelines in the management of RL activities is a topic of growing interest among researchers (Martins *et al*., 2019).

DG are sets of recommendations on how to apply design principles to provide a positive user experience (*Interaction Design Foundation*, 2016). They provide the direction to be followed, general principles and concepts that serve as a basis for design decisions, a direction and a set of ideas that should be followed during the design phases; this helps to ensure that the design process remains consistent and focused.

The aim of applying DG to product development is to make the results of designers' activities more predictable and supposedly improve results by aiding decisions during the design process, allowing new functionalities to be adapted later without changing the entire concept (Bischof and Blessing, 2008).

Despite their relevance, most information on DG is scattered throughout the literature, in various forms and levels of abstraction and often with an emphasis on products, industry sectors or specific life cycle stages, making it difficult to access and use (Telenko *et al*., 2008) or presented only in text, which increases the difficulty of locating and understanding (Bischof and Blessing, 2008). In addition, there is an opportunity for a solution through new DfX to aid the design process (Sassanelli *et al.* 2020). Thus, by considering DG for RL, it is possible to use the DfRL approach as another alternative (instrument or means) for transitioning towards more circular and sustainable product, process and artefact designs.

Against this backdrop, this research aims to characterize the context of the literature regarding publications on DG for *Design for Reverse Logistics* (DfRL).

2. METHODOLOGY

In order to carry out this research, a Systematic Literature Review (SLR) will be carried out, which is generally used to identify, in the publications considered, evidence of research trends, the evolution of research topics, as well as research *gaps*, helping to provide an overview of current knowledge on the theory, assess the progression of knowledge on the subject and propose potential paths for advancing knowledge (Kraus *et al*., 2022). In particular, this work used the RSL proposed by Tranfield *et al.* (2003), to find a set of DG that meet the DfRL and make it possible to analyse and characterize them from the current context of the literature, in line with the aim of this research. The approach consists of the stages described below, divided according to the objective:

Pilot Review: A search was carried out considering the terms "design guidelines" and "*design for reverse* logistics", as well as some possible synonymous terms, in the *Science Direct, Web of Science* and *Scopus* databases, to survey the literature for DG already proposed for DfRL, as well as to define inclusion and exclusion criteria to be considered in this research.

Research Proposal and Protocol Creation: Based on the information acquired in the previous stage, the search *strings* and scientific bases to be researched were confirmed. It was then possible to define the research protocol which brought together all the information relevant to the article search and selection process, as well as the information to be collected.

Obtaining and Selecting Publications: With the *strings* and databases defined in the protocol, searches were carried out, eliminating duplicate articles and those that could not be accessed. At this stage, five databases were considered: *Science Direct, Web of Science, Scopus*. *Emerald and Springer*. Next, the titles and abstracts of the selected articles were read to check that they were in line with the focus of the research, using inclusion and exclusion criteria.

Data Extraction: In this stage, a full scan of the texts of the selected articles was carried out, to identify and extract the data considered in the research protocol. To this end, a set of research questions (RQ) was considered, with objectives converging with the general objective of this work, as shown in **Table 1**.

Presentation of results: The information extracted from the articles has been synthesized and the results generated were organized in tables, figures and statistics. The parameters considered in this research are those already considered in other research on the subject and aimed at characterizing the current context in the literature, as presented in Appendix A.

Analysis of Results: The results presented in the previous stage were discussed, considering a parallel between information collected and results obtained by other authors involved in studies related to the central theme of this research, to answer the questions initially proposed, as well as present contributions to theory and practice relating to the central theme and the achievement of

the general research objective. The contributions of this stage regarding DG for DfRL were a current overview of research, the current state of research in the area, contributions to achieving the SDGs and sustainability. Finally, the aim is to present the relationship between design and CE and RL, a definition of the associated terms, and the gaps and prospects in the area.

Code	Question	Objective
RQ1	Is the article talking about design guidelines?	Understand whether what is mentioned are design guidelines or some other similar approach;
RQ2	Does the article provide design guidelines?	Understand whether the term is included in the research or just in the title of the papers.
RQ3	Do the identified design guidelines present the form in which they were defined and/or proposed?	Identify methods in the literature for proposing and validating design guidelines.
RQ4	Are the design guidelines identified related to Reverse Logistics (through its activities)?	Understand the current context of the literature on design guidelines that could potentially be correlated to Reverse Logistics.
RQ5	Does the research address design guidelines focused on process, product or artefact?	Understand the context that is considered within the aspects of Product Development Process in research.
RQ6	Are the design guidelines studies related to sustainability?	Understand whether the design guidelines studies are converging towards a scenario that contributes to sustainable development.
RQ7	In studies on sustainability, what is the main aspect (social, economic and/or environmental) considered?	Understand how sustainability is considered in research related to design guidelines.
RQ8	Are the design guidelines studies related to achieving the Sustainable Development Goals?	Understand whether the design guidelines studies are converging towards a scenario that contributes to sustainable development.

Table 1: Research questions
Source: Authors

3. RESULTS AND DISCUSSION

Following the methodology presented, specifically in the Pilot Review stage, a preliminary survey was defined (**Table 2**) and then the initial quantitative surveys were carried out, considering the *Science Direct, Web of Science* and *Scopus* databases. These surveys aimed to confirm signs of convergence with the initial research proposal or, if not, to define new directions and parameters.

Search terms	Design Guideline, Guideline, Checklist, Method, Methodology, Design for Reverse Logistics.
Boolean operator	OR, AND
Research base	Science Direct (SD), *Scopus* and Web of Science (*WoS*)
Inclusion Criteria	Talk about any aspect related to design guidelines for reverse logistics.
Exclusion Criteria	Do not address design guidelines for reverse logistics in any way.
Language	No restrictions
Document types	No restrictions
Research period	No restrictions

Table 2: Pilot Review Protocol
Source: Authors

In these research, it was started with an initial *string*, considering the terms presented in the protocol (table 2) and possible substitutions for the term "guidelines", according to Mantese *et al.* (2018), evaluating the number found in the databases considered, as shown in Table 3. For the pilot review, limiting parameters such as language, type of document and period of research were not considered, as this is still an emerging topic in the literature, as reported by Melo *et al.* (2022) and Braga Jr. *et al.* (2023). As can be seen in **Table 3**, the research databases used in this stage did not provide any results when searching with the two *strings*, based on the parameters defined in the protocol, so it was necessary to develop another search strategy capable of confirming an assertive research proposal about the objective of this work.

No.	*String* Uses	Word or Term Search Extracted	Research Bases			
			Scopus	*WoS*	SD	Total
1	("Design Guideline" OR Checklist) AND (Method OR Methodology) AND (Environmental OR Sustainable) AND "Design for Reverse Logistics"	-	0	0	0	0
2	("Design Guideline" OR Checklist) AND "Design for Reverse Logistics"	("Design Guideline" OR Checklist) **AND (Method OR Methodology) AND (Environmental OR Sustainable)** AND "Design for Reverse Logistics"	0	0	0	0

Table 3: *String* Tests for Pilot Review
Source: Authors

To search for related content to obtain an overview of the topic discussed in this research and achieve a strategy aligned with it, the base *string* ("design guidelines") AND ("product design" OR "sustainable design" OR "eco design" OR "design for x") was considered which groups together the themes and areas of study that this work addressed in its introduction. This search once again considered the 3 previous search bases, and the results are shown in **Table 4**.

No.	*String* Used	Database			
		Scopus	*WoS*	SD	Total
1	"design guidelines" AND ("product design" OR "sustainable design" OR "eco design" OR "design for x")	709	160	52	921

Table 4: Pilot Review *String* Test
Source: Authors

The metadata was imported from the research databases and uploaded to the Rayyan platform (www.rayyan.ai), where 216 articles were excluded for being duplicates and the rest were merged into a single file. To make it possible to understand patterns and trends related to this specific topic, considering the remaining 705 articles, the VOSviewer *software* was used, which also allowed, through a bibliometric analysis, the presentation of maps for visualization in networks (van Eck and Waltman, 2010). The visualization of keyword co-occurrence from VOSviewer is shown in **Figure 1**.

As shown in **Figure 1**, the term product design appears prominently, indicating that the results are consistent with the field of product development and interconnected with all other terms, reflecting the unique aspects of this process. Concerning the blue *cluster*, there is a grouping with design guidelines, design process, computer-aided design, optimization and structural design, referring to a set belonging to research that considers aspects of PDP. The other *clusters* do not differ from each other in terms of predominance.

Related to the blue *cluster*, it is possible to see the green *cluster* with the terms design, manufacture, 3D printers, design for x and product development, another grouping that refers to PDP and highlights a relevant term for this research, DfX, confirming alignment and relationship with the trend of analysis on PDP.

Also close by is the red *cluster*, which brings a group of more unique terms related to sustainability, with the presence of ecodesign, life cycle, circular economy, sustainable development, sustainable design, sustainability and decision making. As initially presented in this research and especially concerning the approaches of Telenko *et al.* (2016), there is a potential relationship in the alignment between product design, DG and DfX, considering the terms highlighted and related on the map.

Finally, there is the yellow *cluster*, dealing with aspects related to the terms ergonomics, humans, human engineering, human-computer interaction and user interfaces, which seems to point out that research based on the *string* raised for the creation of these maps also touches on more technological aspects focused on usability and computer data.

In **Figure 2** you can see the time frame of the documents surveyed, where it is relevant to mention the aspects of sustainability, DfX and 3D printing involved in more recent research, dating back to the average year of 2018 and the relationship between the terms product design and design guidelines permeate the average time between the years 2012-2014.

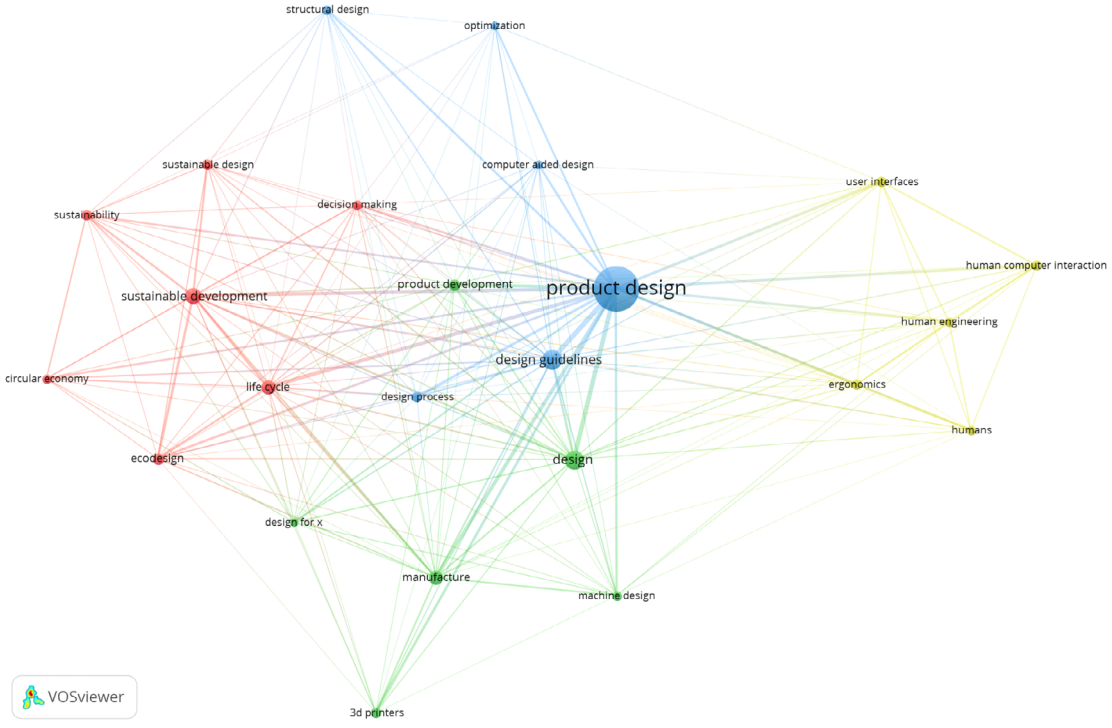

Figure 1: Cooccurrence network Keywords
Source: Data generated by VOSViewer (2023).

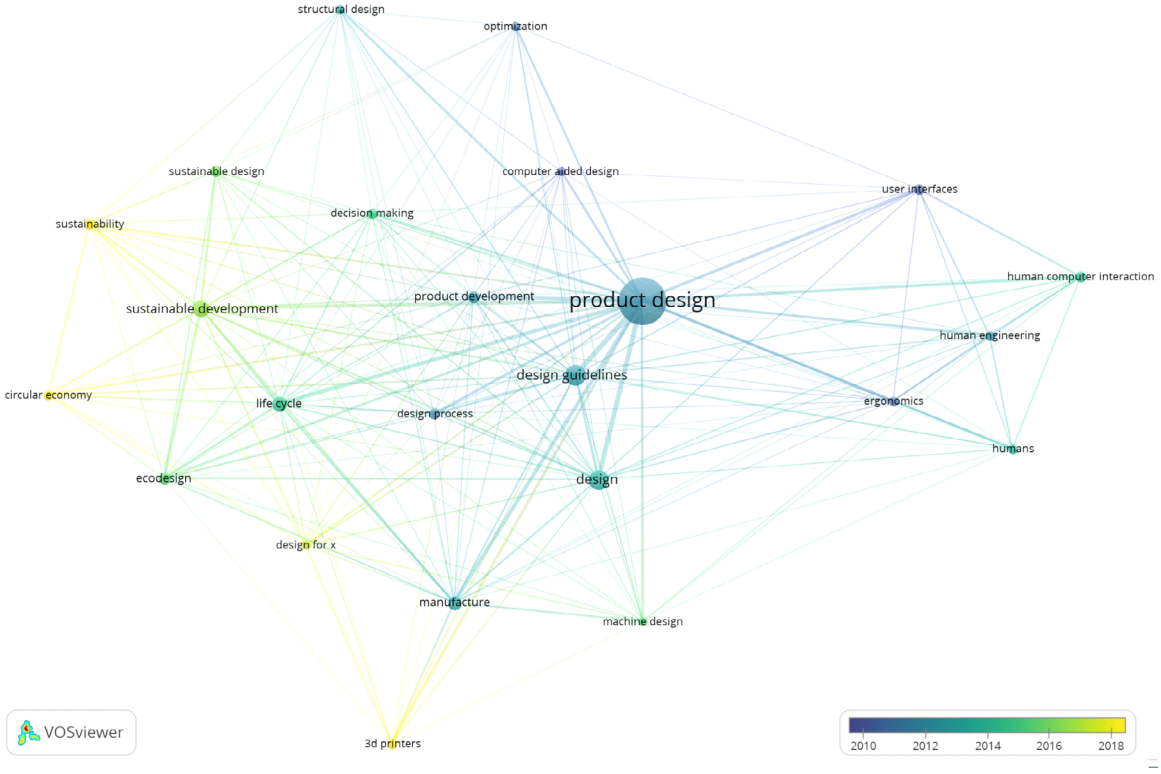

Figure 2: Keyword Cooccurrence Network (Average Date of Terms)
Source: Data generated by VOSViewer (2023).

It is therefore possible to conclude that this group of terms involves recent research and that they are in the average time of ten years to date. At the end of the visualization, analysis and interpretation of the scientific mapping generated by the VOSviewer *software*, new parameters were obtained for the definition of keywords capable of guiding a new search strategy aimed at results in line with the objective of this research.

Understanding that, to achieve the objective of this research, three themes must be analyzed: Reverse Logistics, DfX and DG, we sought a research path that presented some correlation between them, considering the results obtained in the bibliometric analysis carried out in previous stages, to guide the search in the literature for DG for DfRL that could be analyzed and characterized after identification.

As presented by Melo *et al.* (2022), RL is made up of ten activities that enable the process, as follows: integration, acquisition, inbound sorting, collection, transportation, inspection/testing, storage, disassembly, classification and redistribution. Given that these activities constitute RL, the research focused not only on these processes but also on addressing topics related to DfX, DfRL, or DG. Braga Jr. *et al.* (2023) proposed a set of 15 DfX potentially related to RL activities based on the association of definitions of these activities with the definitions of DfX identified in the literature. They are Design for Procurement, Design for Supply Chain, Design for Disassembly, Design for End of Life, Design for Remanufacture, Design for Testability, Design for Storage and Distribution, Design for Logistics, Design for Supportability, Design for Modularity, Design for Mass Customization, Design for Reuse, Design for Materials Conservation, Design for Maintainability/ Maintenance and Design for Industrial Symbiosis. These authors also suggested that further research should investigate DG for DfRL, followed by a comparative analysis of these with the guidelines of other DfX approaches associated with DfRL in this study. For these authors, this will allow a more consistent assessment of the level of contribution of each design guideline, since the definitions of DfRL and DfX will be at the same level of detail.

Therefore, the term Design for X (DfX) was considered instead of Design for Reverse Logistics (DfRL), where "X" was replaced by the 15 characteristics/skills "X" potentially associated with RL activities, according to Braga Jr. *et al.* (2023).

Through this strategy, it is believed that it is possible to identify DG that meet the RSL since they consider the demands of the activities needed to make it possible. In this way, two different possible *strings* were tested, considering two new bases to add more documents and give more scope to the RSL, and the quantities obtained were evaluated, as described in **Table 5**, also considering the result generated in the scientific maps.

No.	*String* Base	Word or Search Term Extracted	Database					
			Scopus	*WoS*	SD	*Emerald*	Springer	Total
1	("Design Guideline") AND ("product design") AND ("Design for X*")	-	13	0	0	42	354	409
2	("Design Guideline") AND ("Design for X*")	("Design Guideline") AND ("product design") AND ("Design for X*")	52	1	9	53	497	612
*15 characteristics/skills X associated with RL activities, according to Braga Jr. *et al.* (2023)								

Table 5: *String* Test and Quantitative Result per Database

Source: Authors.

Based on the obtained result, to develop the second stage of this research, the quantity found was evaluated to ensure the research objective was met. The second *string* was chosen because it yielded a broader search result for potential publications identified in the initial survey of the considered databases. As part of this stage, a new research protocol was elaborated and defined based on the parameters as follow.

- **Search Terms:** Design Guideline, Design for End of Life, Design for Industrial Symbiosis, Design for Logistics, Design for Maintainability/Maintenance, Design for Mass Customization, Design for Modularity, Design for Procurement, Design for Remanufacturing, Design for Reuse, Design for Supply Chain, Design for Supportability, Design for Testability, Design for Disassembly, Design for Storage and Distribution, Design for Materials Conservation;
- **Boolean Operator:** OR, AND;
- **Research Database:** Science Direct (SD), *Scopus*, Web of Science (*WoS*), Springer, *Emerald*;
- **Inclusion Criteria:** Discuss any aspect related to DG for DfX related to RL activities;
- **Exclusion Criteria:** Do not address, in any form, DG for DfX related to RL activities;
- **Parameters:** Authors; country; product; process; artifact; cited guidelines; defined guidelines; DG associated with RL; DG associated with sustainability;
- **Language:** English;
- **Document Types:** Research Articles and Reviews;
- **Period:** No restrictions.

By applying the limiting parameters of format and language, as outlined in the previous paragraph, the final search result, based on the defined *string*, is shown in **Table 6.**

In the Obtaining and Selecting Publications stage, searches were carried out based on the results shown in **Table 6**. After applying the inclusion and exclusion criteria, only five articles were considered suitable for the next stages of the research method, where only one was identified as duplicated and excluded, and one was inaccessible. **Table 7** shows the list of selected articles.

String Base	Database					
	Scopus	*WoS*	SD	*Emerald*	Springer	Total
("Design Guideline") AND ("Design for X*")	25	0	5	48	76	**154**
*15 characteristics/skills X associated with RL activities, according to Braga Jr. *et al.* (2023)						

Table 6: String Results and Number of Articles per Database

Source: Authors.

Code	Title	Authors	Year	Search DfX
A1	Design for circularity and durability an integrated approach from DFX guidelines	Jaime A. Mesa	2023	Modularity
A2	Inventive solutions for remanufacturing using additive manufacturing - ETRIZ	Srujana Kandukuri, Elif Elçin Günay, Omar Al-Araidah, Gül E. Okudan Kremer.	2021	Remanufacturing
A3	Multiple generation life cycles for product sustainability	T.F. Go, D.A. Wahab, H. Hishamuddin.	2015	Modularity Disassembly
A4	Inventive Guidelines for a TRIZ-based Eco-Design matrix	D. Russo, C. Rizzi, G. Montelisciani.	2014	Disassembly
A5	Development of integrated design for disassembly and recycling in concurrent engineering	Ke-Zhang Chen	1999	Disassembly

Table 7: Selected articles

Source: Authors.

Given the low number of surveys, it was decided on a new strategy to try to expand the number of surveys obtained by carrying out a snowball search, a survey technique used in qualitative research that allows us to reach populations that are little known or difficult to access, proving to be useful for investigating samples that are still little known or explored, helping with a general understanding of factors associated with the topic (Bockorni; Gomes, 2021).

Therefore, in the full scan of the references cited in the five results initially obtained, an analysis was carried out to look for other references that corroborated the theme of this work.

Eight new references were identified with potential contributions and conformity with the first five articles selected. One article was also excluded due to duplication (A2A-A3B), effectively adding up to seven new articles which now make up a new total of twelve results for extraction, presentation and analysis, as shown in **Table 8**.

Code	Title	Authors	Years
A1	**Design for circularity and durability an integrated approach from DFX guidelines**	Jaime A. Mesa	**2023**
A1A	Design for sustainability (DFS): the intersection of supply chain and environment	Andrew N. Arnette, Barry L. Brewer, Tyler Choal.	2014
A1B	A methodological approach to design products for multiple lifecycles in the context of circular manufacturing systems	Farazee M.A. Asif, Malvina Roci, Michael Lieder, Amir Rashid, Aleš Mihelič, Simon Kotnik.	2021
A1C	Design for Circularity Guidelines for the EEE Sector	Anton Berwald, Gergana Dimitrova, Thijs Feenstra ,Joop Onnekink, Harm Peters, Gianni Vyncke, Kim Ragaert.	2021
A1D	Addressing circular economy through design for X approaches: A systematic literature review	Claudio Sassanelli, Andrea Urbinati, Paolo Rosa, Davide Chiaroni, Sergio Terzi.	2020
A1E	EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development	Conrad Luttropp, Jessica Lagerstedt.	2006
A2	**Inventive solutions for remanufacturing using additive manufacturing: ETRIZ**	Srujana Kandukuri, Elif Elçin Günay, Omar Al-Araidah, Gül E. Okudan Kremer.	**2021**
A2A (A3B)	A tool to implement sustainable end-of-life strategies in the product development phase	A. Gehin, P. Zwolinski, D. Brissaud.	2008
A3	**Multiple generation life cycles for product sustainability**	T.F. Go, D.A. Wahab, H. Hishamuddin.	**2015**
A3A	Design for environment (DfE): strategies, practices, guidelines, methods, and tools	DP Fitzgerald, JW Herrmann, PA Sandborn, LC Schmidt, TH Gogoll.	2007
A4	**Inventive Guidelines for a TRIZ-based Eco-Design matrix**	D. Russo, C. Rizzi, G. Montelisciani.	**2014**
A5	**Development of integrated design for disassembly and recycling in concurrent engineering**	Ke-Zhang Chen	**1999**

Table 8: Final results of the selected articles

Source: Authors.

Finally, after investigating all of these options, it was possible to deduce, based on Khatcherian *et al.* (2022), that the low number of articles on this topic may be similar to the condition exposed by the authors, where no results or few results were obtained, which qualifies this situation as an occurrence resulting from a recent topic, still controversial among the scientific community and/or a concept not yet recognized or vague by professionals in the areas involved, or, finally, because it covers different areas of knowledge, it is complex to study the whole set and form an overall conclusion. These authors also contribute to the fact that an RSL does not return results, emphasizing the importance of more research to verify the subject and that possibly only part of the complexity surrounding it has been identified.

Based on these results, it was possible to begin the Data Extraction and Presentation of Results stages by scanning the full texts of the twelve classified articles in search of answers to the research questions initially defined. From the new articles collected, it was possible to discover new DfX associated with this research that can be added to the contributions to the initial fifteen DfX, considered by Braga Jr. *et al.* (2023), namely:

- A1: Design for Circularity and Durability;
- A1A: Design for Sustainability;
- A1B: Design for Multiple Lifecycles;
- A1C: Design for Circularity;
- A1D: Design for Supply Chain, Design for Circular/ Sustainable SC, Design for System Change, Design for Resource Efficiency and Conservation, Design for Slowing Lifecycle, Design for Long life Use of Products, Design for Maintenance, Design for Product-life Extension, Design for Reliability, Design for Safety, Design for Multiple Life Cycles, Design for Disassembly and Reassembly, Design for Remanufacturing, Design for Remake, Design for Recovery, Design for Recycling, Design for End-of-Life, Design for Adaptability, Design for Standardization, Design for Compatibility, Design for Modularity, Design for Upgradability, Design for Sustainability, Design for Environment and Design for Social Responsibility;
- A1E: Design for Environment;
- A2A (A3B): Design for Environment;
- A3: Design for Multiple Life-Cycles;
- A3A: Design for environment.

As for the debate based on the research questions, following the protocol, the Results Analysis stage can begin. For RQ1 and RQ2, which investigate whether the articles address and present DG, all twelve articles address DG, but four do not present them in their text, a result that still allows us to understand that the term DG is pertinent and corresponds to what was presented in the introduction of this research, but it is still pending to explore and present its contrasts concerning other terms that were also identified in the text, such as requirements, considerations, rules, recommendations, principles, propositions and tools.

The four articles that did not present DG (A1A, A1B, A1D, A2A-A3B) raise important discussions about the relevance and characterization of DG related to their respective DfX, in line with the theme of this research.

Article A1A discusses the fact that the DFX literature is extensive, covering many topics in various disciplines and this complexity makes it difficult for researchers and practitioners to keep up with developments in DFX, considering that some research covers similar ideas but under different names, and even techniques with the same name often take on different meanings, approaches and DG. A1B doesn't present any DG either, for example, but it does present the need to understand why and how products reach their end of life. The authors also state that in the linear approach, it is not a designer's priority to think about the value recovery phase, so they should be given the possibility to synchronize the objectives of the intended project with the planning of a product's multiple life cycles.

Accordingly, article A2A (A3B) reports that the overall recovery process should be foreseen as soon as possible, especially during the design phase, taking into account the different stages from the collection to the use of the recycled materials, the assembly of restored or reused components into new products and the sale of remanufactured products. After all, product recovery is not just a question of reprocessing a used product, but also of transporting it to a place where recycling is feasible, for example. Designers need simple and efficient methods that can be adapted to their daily tasks and skills, considering aspects according to the DfX approaches considered. The A3A article adds that there is a need for a simple DfE tool that forces designers to consider environmental issues when designing products, so integrating a DG/checklist document into a new DfE process is a simple and effective way of highlighting environmental concerns. However, this document needs to be company-specific and systematically integrated into the product development process. All these works address an opportune scenario for discussing DG and their contextualization.

About RQ3, which asks whether the DG identified present how they were defined and/or proposed, it can be concluded that the articles that present DG also present propositions through associations with other concepts and DfX, in which they demonstrate how DG were proposed based on some already existing ones, thus configuring a result of proposing new ones based on this adaptation and/or adaptation. This group of articles clarified how DG should be presented, from their writing to their visual configuration. Specifically, A4 states that project guidelines should be structured with a clear and complete goal, with a description containing tools, strategies, best practices and examples. Article A1E confirms these aspects by gathering and presenting a compilation of documents and references as a basis for understanding and visualizing project guidelines.

Still, concerning RQ3, one article presents a case study (A1), another an example (A4), and a third (A2) defines a route for implementing the DG for the design process. Only in these three cases was there any validation of the proposition of DG, but all of them are still insufficient. This is reinforced by article A1, which suggests that future research efforts should consolidate and analyze the implementation of these DG. This is reinforced by article A1E which points out that there is a lot of interest in sustainable product development and many design tools and guidelines have been suggested, but it is not clear whether these tools are being used and whether they have any real effect on the development of product systems.

About RQ4, "Are the identified DG related to RL (through their activities)?", it can be concluded that the current context of the literature on DG is potentially correlated to RL from the disassembly activity, cited in seven articles. The activities of integration, acquisition, inbound sorting, collection, transportation, inspection/testing, storage, classification and redistribution, mentioned by Melo *et al.* (2022), are discussed in articles A1A, A1D, A2A (A3B), A3 and A5.

The A1A article reports that many works focus on narrow aspects of product design considerations and do not consider many other facets of product design, production, delivery, use and end-of-life. From a broader perspective, it was previously understood that post-production was a matter of infrastructure rather than product design. However, it is now clear that design decisions have a direct impact on the maintainability and reliability of the product, interfering with the frequency of service and product support. After all, product design affects the amount of service required and the mode of delivery and the concept of Design for Logistics (DFL) shows that product design impacts the packaging and transportation of a product and incorporating these considerations into the design can make distribution more efficient and reduce costs. The authors state that business processes seem to be seen as independent of the design process, but it should be recognized that product design affects supply chain activities.

This article also discusses the role of RL, which is increasingly being recognized as important for dealing with product service and support, returns and their recovery at the end-of-life stage, to support remanufacturing, recycling and disposal, facilitating the achievement of goals from an environmental, sustainability and economic point of view. Within this article, the authors mention Rogers and Tibben-Lembke (2001) regarding the differences between RL and green logistics and report that barriers to RL include a lack of importance and attention from management and a lack of policies, systems and resources to implement it, but it needs to be considered in the design process. Also, according to the A1A article, RL is becoming increasingly important for implementing returns and moving products that will be remanufactured or recycled at the end of their useful life, and DfRL raises questions about how product design relates to RL, going beyond the choice of channels and methods for accepting returns and recovery. Therefore, making DfRL a design technique has the potential to reduce costs by planning and developing the infrastructure and activities that the supply chain must carry out.

Next, the A1D article states that methods and tools that support the systematic integration of products and services from a circular perspective are still under development, and are in an under-researched research context, even if they deserve more attention from both researchers and practitioners. The article concludes by presenting the promotion of RL and the definition of the useful life of products as a strategy, converging with the need for new DfX methods and tools to satisfy the very heterogeneous issues present in the design process. Strategies mentioned to support the design decision-making process or to find a balance between the various existing DfX skills or reveal their unique limitations.

Article A2A (A3B) presents the possibility of considering RL channels, product and component disassembly processes or material recycling, moving towards product recovery carried out by the manufacturer itself or through partnerships with independent stakeholders specialized in various activities so that it is possible to maintain control over its products. As an obstacle, the article points

out that RL and disassembly are especially sensitive, as they often do not belong to the core business, and that the recovery process must be foreseen as soon as possible, especially during the design phase.

Article A3 cites RL and Reverse Engineering (RE) as contributors to considering the use of existing direct supply chain facilities and transportation systems as much as possible for the reverse supply chain, sorting used products as early as possible in the recovery chain and reducing the volume and quantity of materials going to landfill, as well as considerations for alternative uses of used products or waste. He also states that designing for the return of a product and establishing a single system for this to happen increases its chances of being reused, remanufactured or recycled, confirming his proposition and the relevance of designing for Multiple Life Cycles (MLC).

Article A5 states that although the costs of collecting and transporting waste are beyond the control of product designers, it is a factor that is related to the value of the materials recovered and consequently to their responsibilities. Therefore, products should be designed with these two aspects in mind, plus the possibility of separating or disassembling the parts, to reduce disassembly costs and expand the possibilities for reuse and recycling.

Still, to RQ4, article A1 presents guidelines for circular and durable designs and points out that it may be interesting for future work to consider and develop a framework for software, services and product-service systems since the rules relating to the incorporation of design are still mainly focused on the architecture and geometry of the product and the definition of materials.

Moving on to the data extraction activity for RQ5, which asks whether the research addresses DG for processes, products or artefacts, the results showed some articles that deal with products and processes, but not artefacts. It is important to mention that there is a contradiction between the articles analyzed, where some point out the need to define DG specific to a product context and others believe that the way forward is to develop a more comprehensive DG. It is believed that this lack of convergence is because there is no standardization in the literature of the hierarchy of categorization of information used in PDP, namely: rules, guidelines, checklists, checklists and others, reinforcing the need to understand how DG are currently characterized by researchers.

As for RQ6 and RQ7, which investigate issues associated with understanding the panorama of project guidelines concerning sustainability and which aspects of sustainability, the articles present content in line with sustainable development, with priority given to the environmental aspect and a total of six articles discussing the economic aspect. Only article A1A also presents the social aspect of sustainability, according to Elkington (1994) concerning the Triple Bottom Line.

Within this theme of RQ 6 and 7, some articles have interesting content to highlight. A2A (A3B), for example, it presents that designers are often not environmental experts and don't have the knowledge to design products that are more environmentally friendly and adapted to recovery strategies such as reuse, remanufacturing and recycling. The authors report that although the DfE has added environmental awareness to the company, it is still a long way from the work of a designer, as most methods are limited to measuring environmental impacts which can only be explored by specialists.

Article A3A points out that most product development organizations should treat environmental objectives in the same way as they treat safety issues. In addition, the A1E article states that designers hold the key to sustainable product development through EcoDesign, where many tools have been built for this purpose. They also state that most are rarely used, mainly due to the lack of sustainability-oriented requirements in product specifications. They report that there are many tools and DG suggested, but it is unclear whether these tools are being used and whether they have any real effect on the development of product systems.

Concluding the debate on RQ 6 and 7, the A1A article points out that the information dealt with and related to various DfX has provided an exchange of sustainability and the environment, but only focuses on one pillar of sustainability, ignoring the other two (social and economic) which can lead to projects that are not economically viable or involve negative social impacts. According to the authors, as the role of sustainability in business has grown, the recognition that product design plays a key role in helping to achieve sustainability is indisputable. They also conclude that the DfX literature on the three pillars of sustainability is lacking in its approach to this topic. Therefore, as the importance of supply chain activities has grown, DfX techniques have expanded to assess the impact of product design on these activities.

Also discussed in A1A, the concept of disposal, in which a product is discarded at the end of its life cycle, should be given more attention by researchers, first considering whether the materials to be discarded are those that cannot be revalued and represent the "leftovers" of this process, or having the correct vision and

understanding, according to the literature, that a product that does not fit into the first case should be disposed of safely. Complementing the analysis of sustainability, the authors noted that the need to recognize social equity has increased in recent years, but still lags behind economic and environmental design issues. Regarding a DfX for social equity, the authors state that its development goes beyond the scope of a more traditional DFX, aiming to change opportunities and responsibilities and eliminate restrictions or negative social aspects.

Finally, in RQ8, which aims to identify whether the DG are related to the achievement of the SDGs, a contribution to the achievement of the SDGs was identified in all the articles that discuss DG, since the interventions proposed to product designs induce improvements that reduce the negative impact of the occurrence of solid waste. However, the authors of these articles do not directly mention the achievement of the SDGs in their texts. It should be noted that in the case of articles A1E, A2A (A3B), A3, A3A, A4 and A5, these publications date from before the SDGs were discussed by the UN.

In addition to the above information, the articles analyzed presented other important considerations for this work, which were not foreseen in the research protocol. According to article A1, an obvious challenge is the integration of geometry and materials rules for more circular products, especially for complex products made up of several sub-assemblies. Similarly, design rules must be generated for non-tangible products, such as software and services, to cover CE issues related to resource consumption and sustainability performance.

According to the A1A article, the current literature is deficient in addressing social equity and RL, and these areas should be further developed, including the need for alignment with theory and empirical testing, as well as exploring the relationships between DfX techniques and sustainability dimensions. According to the authors, the original DfX approaches emerged as a means of making the operations and production aspects of product creation more efficient, while reducing time, costs and errors, and should now move towards addressing and addressing sustainability issues. The authors point out that one of the major findings is that DfX is still very much focused on professional practice, and further research is needed, perhaps confirming why there were few results selected in this research.

Although some new approaches may look beyond the product to the supply chain, such as Design for Supply Chain (DfSC), they are not as prominent in the literature as a DfX topic as Design for Logistics (DfL). Finally, the authors mention that even more neglected in the literature, in addition to DfSC and DfL, is DfRL, because although DfL can affect the RL process, there are many scenarios in which used components, recyclable materials or remanufactured end items must return through the supply chain, and this movement, to comply with regulations, capture remaining value or to remove hazards from the community, is essential to the functioning of the closed-loop supply chain.

In article A1B, the research identified that there is a strong synergy between the concepts of product design strategies, product obsolescence and product end-of-life options. Designing a product that can be used in multiple life cycles is not an established practice in PDP and there is a lack of methodological approaches capable of supporting designers in designing products for multiple life cycles. The authors conclude that designers should seek a balance between design strategies and end-of-life options, to improve value recovery in each product life cycle (PLC).

Also confirming and adding to the previous articles and the subject of this research, article A1D states that, in the context of the Product-Service System, DfX has rarely been considered by experts, and new design knowledge related to new technologies is needed to guide the joint search towards CE and Industry 4.0.

The A1E article then points out that DG, checklists and other tools have been used in product design for a long time and many other purposes besides eco-design. These are tools that differ in complexity and structure, sometimes being very simple, like a few practical rules, and sometimes constituting a complete, comprehensive and complex system, during this, engineers and designers have also created their checklists and tools to document experiences and facilitate cooperation in product development teams. Therefore, the need to develop clear solutions for DG was realized.

Still on DG, article A2A (A3B) reports that, according to DfE guidelines, designers must integrate the environmental variable into all their tasks, going through guidelines that do not indicate how to design the product itself, but rather recommendations on what the product should look like and how to check the guarantee in respect of the envisaged policy. Given these considerations, documents that record all this, such as the research object of the authors in question, should be a "living document".

In conclusion, it was possible to extract, present and analyze the data under the protocol and the use of the snowball technique brought greater scope and reach to the results of the work, proving to be a fruitful alternative. After

presenting the discussion and considerations on the articles researched, it was possible to reach some conclusions about achieving the objectives set out in the RQ. **Table 9** summarizes the information presented in order to better visualize the consolidation of the results of this research.

Code	Question	Objective	Results achieved
RQ1	Is the article talking about design guidelines?	Understand whether what is mentioned are design guidelines or some other similar approach;	Design guidelines are presented in the literature as well as other associated terms.
RQ2	Does the article provide design guidelines?	Understand whether the term is contemplated in the research or only makes up the title of the papers.	Not all the articles discuss design guidelines, associating this term with other information outside the scope of this research.
RQ3	Do the identified design guidelines present the form in which they were defined and/or proposed?	Identify methods for proposing and validating design guidelines in the literature.	The information obtained is not sufficient, reliable or valid to identify a method already established in the literature.
RQ4	Are the design guidelines identified related to Reverse Logistics (through its activities)?	Understand the current context of the literature on design guidelines that could potentially be correlated to Reverse Logistics.	The current literature does not sufficiently cover potential design guidelines for Reverse Logistics activities.
RQ5	Does the research address design guidelines focused on process, product or artefact?	Understand the context that is considered within the aspects of Product Development Process in research.	The literature surveyed covers products and processes but is divided into approaches for specific products and more general approaches.
RQ6	Are the design guidelines studies related to sustainability?	Understand whether the design guidelines studies are converging towards a scenario that contributes to sustainable development.	The literature presented an already present and opportune scenario for stimulating sustainable development.
RQ7	In studies on sustainability, what is the main aspect (social, economic and/or environmental) considered?	Understand how sustainability is considered in research related to design guidelines.	It was possible to understand that sustainability is dealt with primarily in its environmental and economic aspects, and there is a gap in the social aspect.
RQ8	Are the design guidelines studies related to achieving the Sustainable Development Goals?	Understand whether the design guidelines studies are converging towards a scenario that contributes to sustainable development.	The results converge towards sustainable development and there is a potential relationship with the achievement of the Sustainable Development Goals.

Table 9: Consolidation of Research Results

Source: Authors.

It is also interesting as a contribution to present the terms associated with the term "design guidelines" identified in the literature surveyed. It was noted that the word "guideline" is still closely associated with other terms in the literature. As previously mentioned, this is possibly due to the dispersion and lack of clarity about the hierarchy of project-related information. Understanding the need to establish the use of the term "design guidelines" for recommendations for the application of design principles and decisions, avoiding distorting the research and making it difficult to identify in the vast literature, it is important to understand that terms such as rules, principles, strategies, checklist, method, etc., take on meanings in this context that do not characterize the intended recommendations.

Still, based on the themes that run through and contribute to the development of this research, it was possible to see opportunities for research into the relationships between design, CE and RL. Considering the results obtained in the literature investigated, there is little relationship between the themes when it comes to DG. The quantitative analysis shows that designers do not discuss CE when it comes to DG. The professionals who carry out this scientific and technical discussion are engineers. Understanding the transformations and results possible through CE and RL in the PDP, we can see the

potential and need for these topics to be addressed more frequently and in greater depth when proposing DG, to maximize the scope of a scenario in which designers dialogue more closely with aspects of sustainable development. According to Farazee *et al.* (2021), many research contributions are rapidly emerging that describe the role of design in the context of SD, but existing design paradigms are still developed to support designers in product design for a single life cycle. Furthermore, for these authors, paradigms such as SD and Ecodesign still approach the design process for linear systems, thus lacking the perspective of maintaining value over time, which is a fundamental principle in CE.

However, it is also possible to conclude that this gap exists given the perception that there is no satisfactory exchange of information between designers and researchers. It is assumed that some information about product development is retained in the industrial/company environment and does not reach researchers who can disseminate this information in scientific circles, thus boosting the capitalization of knowledge on the subject. Some DG for DfRL, for example, may exist, and even be used and validated. However, designers and/or businesspeople don't consider this information relevant, don't see the contributions that sharing it can make, or don't even record it, so it can't be recognized or identified. This understanding also stems from market observation, where interesting design solutions are seen that are potentially related to RL activities, such as disassembly, but no scientific information is found on these products.

The discussion about the relationship between CE, RL and the exchange of information in technical and scientific circles can lead to another reflection on the professional training and responsibilities of designers. There is a need for adjustments in the pedagogical projects of courses that develop competencies, skills and attitudes associated with the training of product designers so that it is possible to reduce the knowledge gaps between their technical activity and the understanding of their responsibilities and contributions to strengthening the relationship between PDP and sustainable development. Suitable interventions can reduce the knowledge gaps between designers and researchers.

Moving on to the results, it is possible to conclude that studies aimed at proposing DG for DfRL are still in their infancy since there is a lack of duly formalized means in the literature related to a safe proposition method and subsequent tested validation. However, in addition to characterizing the current context of the literature on the subject, it was also possible to learn about other potential DfX related to RL activities. Future research could look into this new relationship, according to the research model developed by Braga Jr. *et al.* (2023). Finally, the results generated contributions to theory and practice related to the research theme. As a contribution to theory, there is a need to properly develop terms and hierarchize DG and other methods, mainly as a way of facilitating the development of and access to design instructions and recommendations aimed at specific objectives. It is understood that DG have been in the literature for some time, and it is important to develop them through new DfX, with objectives that contribute to the development of circular products and the achievement of the SDGs, covering environmental, economic and social aspects of sustainability. As a contribution to practice, in line with the discussion presented above, there is a significant opportunity and need for the training of designers to include subjects aligned with sustainable development and, at a professional level, for companies and designers to be motivated to share more information about PDP so that there is greater collaboration between the technical and scientific world, strengthening a useful contribution that is aligned with the reality of sustainable product design.

4. CONCLUSIONS

The research in question brought to light important considerations about the intersection of product design, Reverse Logistics (RL) and Circular Economy (CE), especially in the context of DG for RL, under the concept of Design for Reverse Logistics (DfRL). By analyzing the literature and conducting a Systematic Literature Review (SLR), gaps, trends and potential contributions to theory and practice of Sustainable Design (SD) and the development of more circular and sustainable products were identified.

One of the main conclusions of the research is that there are few studies on specific guidelines for DfRL and, although there are mentions and related approaches, no formalized methods have been identified in the literature for proposing and validating these guidelines. This is an aspect that deserves attention and future development, considering the growing importance of RL and CE in solid waste management and in promoting sustainability. The need and relevance of designing a product that can be used in several life cycles was perceived, as a practice that is not yet established in the PDP and lacks methodological approaches capable of supporting designers in the

design of these products. Designers must seek to improve the recovery of value in each PLC.

In terms of contributions to theory, the need for the appropriate development and hierarchization of terms and methods related to DG is highlighted, to facilitate access to and application of these guidelines by designers. In addition, the research highlighted the importance of exploring new DfX approaches aligned with and potentially contributing to DfRL, with a focus on circularity and achieving the Sustainable Development Goals (SDGs), considering the environmental, economic and social aspects of sustainability.

In practice, there is an urgent need to promote greater collaboration between companies, designers and the academic community, encouraging the sharing of information and experiences related to the product design process. This collaboration can strengthen useful input aligned with the real needs of product design, driving the transition to a more sustainable and circular production model.

In summary, the study has provided insights into the guidelines for DfRL, highlighting areas for improvement and opportunities for future research. By promoting a critical reflection on current practices and the challenges faced, this work can contribute to significant advances in the integration of RL in the early stages of the design process, driving the adoption of more sustainable and circular practices in industry and society. As a research limitation, other future work could reproduce the research path presented in this paper, exercising the use of other terms that have been identified here, seeking to achieve more information about guidelines for DfRL.

As a proposal for future work, it is relevant to group the DG identified, compile them and apply them in a case study to gather the necessary information for the proposition and safe validation of guidelines for the DfRL. It is also possible to further investigate the relationship between the newly identified DfX and DfRL.

In addition, it was possible to identify other research opportunities in terms of alignment with aspects of sustainability, especially the social aspect and contributions to achieving the SDGs and exploring new relationships between design, CE and RL, as well as the need for greater integration between designers and researchers to share knowledge and experiences.

The professional training of designers is also a key issue, highlighting the importance of adjusting educational curricula to enable future designers to deal with the challenges and responsibilities associated with sustainable development. A common practice is for designers to work alongside specialists and users, seeking to achieve more integrated and efficient solutions within the context of the project, and at times the literature points to this as a weakness in the designer's professional practice, but it constitutes a necessary method and practice.

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CHALLENGES AND SOLUTIONS FOR SUSTAINABLE URBAN MOBILITY: LESSONS FROM AMSTERDAM AND CURITIBA

DESAFIOS E SOLUÇÕES PARA A MOBILIDADE URBANA SUSTENTÁVEL: LIÇÕES DE AMSTERDÃ E CURITIBA

DESAFÍOS Y SOLUCIONES PARA LA MOVILIDAD URBANA SOSTENIBLE: LECCIONES DE ÁMSTERDAM Y CURITIBA

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ABSTRACT

The significance of sustainable urban mobility has become increasingly apparent, emerging as a priority in addressing contemporary environmental challenges. Frequent congestion in major urban centers, coupled with pollution from combustion-based transportation, exacerbates global warming. These challenges necessitate a reevaluation of urban transport systems and the implementation of measures that foster more sustainable and equitable mobility. Such measures include the development of dedicated cycling infrastructure and the enhancement of public transportation to increase its appeal and efficacy. This study examines sustainable urban mobility solutions in Curitiba and Amsterdam through bibliographic and descriptive research. The findings indicate that a well-planned road system can significantly reduce travel time, enhance quality of life, and alleviate the stress associated with daily transportation. Moreover, public policies that promote the use of bicycles and electric vehicles are essential in advancing sustainable mobility. The study concludes that planning measures aligned with sustainability have positive impacts on traffic flow, population well-being, and the environment.

KEYWORDS

sustainable urban mobility; cycle path; public transport; urban sustainability.

RESUMO

A importância da mobilidade urbana sustentável tem se tornado cada vez mais aparente, emergindo como uma prioridade no enfrentamento dos desafios ambientais contemporâneos. O congestionamento frequente nos principais centros urbanos, juntamente com a poluição do transporte baseado em combustão, agrava o aquecimento global. Esses desafios exigem uma reavaliação dos sistemas de transporte urbano e a implementação de medidas que promovam uma mobilidade mais sustentável e equitativa. Essas medidas incluem o desenvolvimento de infraestrutura dedicada ao ciclismo e o aprimoramento do transporte público para aumentar seu apelo e eficácia. Este estudo examina soluções de mobilidade urbana sustentável em Curitiba e Amsterdã por meio de pesquisa bibliográfica e descritiva. As descobertas indicam que um sistema viário bem planejado pode reduzir significativamente o tempo de viagem, melhorar a qualidade de vida e aliviar o estresse associado ao transporte diário. Além disso, políticas públicas que promovam o uso de bicicletas e

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veículos elétricos são essenciais para o avanço da mobilidade sustentável. O estudo conclui que medidas de planejamento alinhadas à sustentabilidade têm impactos positivos no fluxo de tráfego, no bem-estar da população e no meio ambiente.

PALAVRAS-CHAVE
Mobilidade urbana sustentável; ciclovia; transporte público; sustentabilidade urbana.

RESUMEN
La importancia de la movilidad urbana sostenible se ha vuelto cada vez más evidente, emergiendo como una prioridad en la lucha contra los desafíos ambientales contemporáneos. La congestión frecuente en los principales centros urbanos, junto con la contaminación generada por el transporte basado en combustión, agrava el calentamiento global. Estos desafíos exigen una reevaluación de los sistemas de transporte urbano y la implementación de medidas que promuevan una movilidad más sostenible y equitativa. Estas medidas incluyen el desarrollo de infraestructuras dedicadas al ciclismo y la mejora del transporte público para aumentar su atractivo y eficacia. Este estudio examina soluciones de movilidad urbana sostenible en Curitiba y Ámsterdam a través de una investigación bibliográfica y descriptiva. Los hallazgos indican que un sistema viario bien planificado puede reducir significativamente el tiempo de desplazamiento, mejorar la calidad de vida y aliviar el estrés asociado al transporte diario. Además, las políticas públicas que promueven el uso de bicicletas y vehículos eléctricos son esenciales para el avance de la movilidad sostenible. El estudio concluye que las medidas de planificación alineadas con la sostenibilidad tienen impactos positivos en el flujo del tráfico, el bienestar de la población y el medio ambiente.

PALABRAS CLAVE
Movilidad urbana sostenible; carril bici; transporte público; sostenibilidad urbana.

1. INTRODUCTION

Sustainability in transportation entails meeting mobility needs while considering environmental impacts and maintaining human quality of life. According to Carvalho (2011), the transportation of people and goods in urban centers is invariably linked to pollution—whether atmospheric, noise, or visual—regardless of the mode used. Sustainable mobility encompasses travel methods that minimize negative impacts on the environment, society, and the economy. This includes promoting the use of efficient public transportation, electric vehicles, active mobility, and smart urban planning, alongside technologies designed to reduce congestion and pollution.

The growing demand for electric vehicles (EVs) has sparked discussions about their actual sustainability, primarily due to the use of lithium batteries. Overall, recent global literature reviews conclude that EVs contribute to reducing greenhouse gas emissions and offer lower operational costs (Das; Bhat; Sajith, 2024; Verma; Dwivedi; Verma, 2022). However, other environmental aspects, such as resource extraction and human toxicity levels, must be considered. Battery production requires the extraction of manganese, cobalt, nickel, and graphite, which poses significant environmental harm (Das, Bhat; Sajith, 2024). Furthermore, the increased use of metals, chemicals, and energy in lithium batteries heightens human toxicity risks (Verma, Dwivedi; Verma, 2022). Therefore, further research is necessary to assess these long-term environmental impacts. Additionally, the recyclability of batteries remains a limiting factor in developing countries, as there is a limited number of companies worldwide capable of recycling these materials effectively.

Despite significant advances over the last few decades, the quest for sustainable urban mobility continues to face persistent challenges. According to Carvalho (2016), the increase in the use of individual transportation presents considerable difficulties for public managers concerning urban planning and the efficient management of mobility in cities. Ferreira (2015) points out that large cities, under past administrations, should have emphasized urban planning. By focusing solely on economic development, these administrations inadvertently caused a series of urban infrastructure problems, such as flooding due to soil impermeabilization and the removal of native vegetation. Therefore, it becomes a challenge for public managers and leaders to plan and mitigate these negative consequences. It is incumbent upon them to incorporate the concept of sustainable development into their planning efforts.

At the international level, it is recognized that excessive dependence on individual vehicles, over-occupation of territories, and a large ecological footprint significantly impact sustainable urban mobility (Ortúzar, 2019). Consequently, Lam and Head (2012) discuss several strategies, including integrated urban planning and design, the expansion of ecological vehicles, the promotion of changes in habits, and the implementation of low CO_2 emission policies.

According to Ortúzar (2019), the rise in congestion is a consequence of the increasing use of individual vehicles, which adversely affects public transportation. This situation is further exacerbated by population growth in segregated urban peripheral areas. These combined factors lead to a decrease in the efficiency of public transport services, rendering cars a more attractive option.

In Europe, public measures have been considered to reduce the use of individual transport by incentivizing employees to adopt more sustainable means of transportation. In Belgium, a study conducted by Van Malderen et al. (2012) examined the role of organizations in promoting sustainable mobility by implementing policies aimed at encouraging the use of bicycles, public transport, and carpooling. To motivate employees to adopt sustainable modes of transport, organizations must offer additional financial incentives, provide facilities such as bike racks and showers, and disseminate information on cycling routes and public transport timetables.

Through a case study of Curitiba and Amsterdam, this article aims to provide valuable insights into the aspects of sustainable urban mobility in these cities, which serve as benchmarks in Brazil and globally. The study will address the benefits and challenges encountered in implementing sustainable mobility plans. Moreover, it will serve as a foundation for reflections on the future of large cities in their pursuit of sustainability.

2. METHODOLOGY

This research was structured based on methodological procedures designed to align and discuss sustainable urban mobility interventions, with a focus on their application in Curitiba, Brazil, a city of national significance in this regard, and Amsterdam, a global benchmark in sustainable mobility.

This study is exploratory and descriptive, involving the understanding and interpretation of bibliographic information sourced from articles, books, dissertations, and government documents (Gil, 2010). Consequently, it is characterized as a case study due to its specific focus on Curitiba, Brazil, and Amsterdam.

Based on the literature reviewed, this study aims to evaluate the guidelines adopted by the management of these municipalities to pursuit sustainable urban mobility. It compares the strategies employed in two cities with distinct technical, economic and structural realities.

3. RESULTS AND DISCUSSION

3.1 Curitiba

Curitiba gained prominence for its urban solutions, albeit in a distinct manner. Rather than pursuing artificial transformation, the city adapted its growth to the rationalization of public space, utilizing planning as a catalyst for development (Gnoato, 2006). The major transformation in Curitiba was driven by the Preliminary Urban Planning Plan of 1965 (Gnoato, 2006). This plan sought to deviate from the extensive urban reforms applied in cities like São Paulo, exemplified by the Prestes Maia Plan, which introduced bridges and viaducts, or the cold and inhumane model proposed by the modernist precepts of the Athens Charter, as seen in Brasília. The principal architect behind this plan was Jorge Wilheim, who collaborated with a group of young technicians who would later become significant figures in the Brazilian urban scene, such as Luiz Forte Netto, Jaime Lerner, José Maria Gandolfi, Alfred Willer, among others. These individuals were also instrumental in founding the Architecture and Urban Planning course at the Federal University of Paraná. According to Miranda (2010), Curitiba transformed the preliminary version of this plan into law in 1966 with the approval of Municipal Law No. 2,828, just one year after its conception. Additionally, the city established an important urban planning and design body: the Curitiba Urban Research and Project Institute (IPPUC).

The significant urban transformations in Curitiba began with the inauguration of Jaime Lerner as mayor in 1971 (IPPUC, 2009). This period marked a departure from the mistakes of modernist urbanism, such as the segregation of the urban fabric based on activities, as recommended by the concept of functional spaces by Le Corbusier (Choay, 2007). The influence of Jane Jacobs' urban theories was clearly evident in the urbanism concepts adopted in Curitiba. According to Jacobs' perspective, the safety of an area is directly linked to the variety of functions it supports, as the constant presence of users and observers on active streets fosters natural community surveillance (Jacobs, 2007). This suggests that diverse functions should coexist, attracting people throughout the day. Consequently, the city's urban planners concentrated their efforts on revitalizing existing streets, ensuring they remained vibrant all day long (Gnoato, 2006).

Wilheim's initial plan, continued by Lerner, was based on a crucial tripod: land use, public transport, and circulation (IPPUC, 2009). Following this model, new zoning legislation enacted in 1975 considered land use and its implications (use coefficient and building height), in conjunction with the concepts of Structural Axes and the public transport system (Gnoato, 2006). This approach enabled Curitiba to achieve significant political success and, with the continuity of the same team of urban planners at IPPUC, ensured the successful implementation of its plan across multiple administrations (Miranda, 2010).

The Structural Axes (Figure 1) led to the development of the trinary system, which consists of a set of three roads. The central road is designated for slow traffic, accommodating the public transport corridor and local commerce, while the outer roads are intended for fast traffic and are known as "Fast Lanes" (Miranda, 2010).

Figure 1: Structural Axes.
Source: PlanMob Curitiba, IPPUC, 2008. Adapted.

According to Miranda (2010), the Structural Axes represent the classic urban design developed in Curitiba. The city's zoning was established based on the distance different regions maintain from these key growth and population density references. Consequently, building heights are staggered, being taller along the axes and decreasing as one moves away from them. In addition to the changes introduced by land use and occupation laws, Curitiba designated a significant portion of its central area exclusively for pedestrian circulation through the implementation of sidewalks (Figure 2).

The Street XV Promenade became the symbol of this new urban planning, with the preferential pedestrian routes marking a milestone in the transformation experienced by the city in the early 1970s (IPPUC, 2008). The intense pedestrian circulation revitalized these spaces, attracting entertainment activities for the population, such as fairs and open-air cultural events.

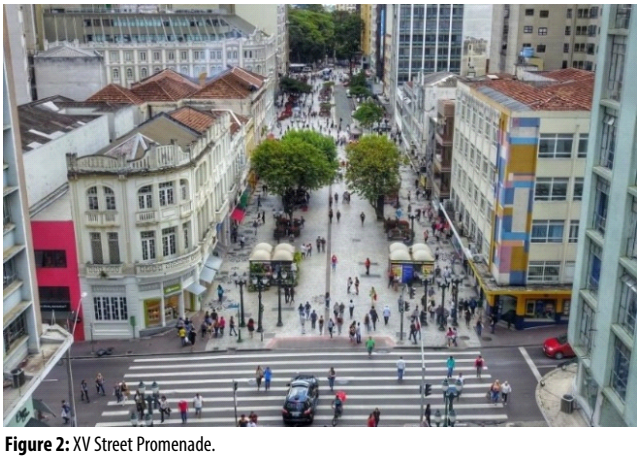

Figure 2: XV Street Promenade.
Source: CNB Curitiba, 2022.

Another crucial aspect of Curitiba's mobility plan is the evolution of the public transport system between 1970 and 2009, which exhibited significant variations in operational aspects and demand. The length of the network increased from 53 km to 81.4 km, representing a 54% expansion. This growth enhanced the system's capillarity, improving accessibility for urban travel. Concurrently, the bus fleet expanded from 826 to 1,911 vehicles, with a substantial increase in passenger capacity due to the introduction of larger vehicles. Initially, passenger demand increased, peaking at 2.4 million daily passengers in 2008, but then began to decline, falling to 2.3 million within the same year—a reduction of 9%—and continuing a downward trend to 2.2 million by 2014 (Vasconcellos, 2019). The latest data released by Urbanization of Curitiba (URBS, 2022) indicates that daily public transportation usage stands at approximately 1.1 million, reflecting a sharp 50% decline over just eight years.

The population increased significantly during this period. Therefore, it is crucial to estimate the general demand per inhabitant of the metropolitan area to reflect the transport system's attractiveness to the population. In 2004, the rate of daily trips per inhabitant on the metropolitan bus network was 0.77, but this rate began to decline, reaching 0.64 in 2014, a drop of 17%. The value recorded in 2016, 0.43, can be considered extraordinary due to the economic crisis that affected the country, significantly impacting the use of public transport (IPPUC, 2010; Vasconcellos, 2019). The latest 2022 data shows a daily trip rate of only 0.29 (URBS, 2022).

According to Vasconcellos (2019), several hypotheses can explain the decrease in public transport use. In a city with a relatively high income by Brazilian standards, the first hypothesis considers the increase in the fleet of individual cars. Indeed, the rate of cars per hundred inhabitants increased from 22 to 60 (172%) between 1970 and 2009, reaching 77 in 2023, according to DETRAN-PR (2023). A second factor may be related to low-income individuals who struggle to afford the fare. The burden of the fare on the minimum wage, which is received by most low-income people, increased from 6.4% in the first decade to 23.7% in the last decade.

Despite the decline in the use of public transport, these means of transport still have several significant advantages. According to Miranda (2010), several characteristics were adopted to improve the efficiency and quality of public transport. These characteristics include metropolitan coverage, which allows public transport to cover a wide area of the city and its surroundings. Furthermore, a single-fee payment system was implemented, which facilitates user access and simplifies the payment process. The buses were differentiated through a typology of services with different colors, which helps users to easily identify the different lines and their routes. The public transport system also has 72 km of dedicated channels, roads and lanes, which allow buses to circulate more quickly and efficiently, avoiding congestion typical of roads shared with private vehicles.

Regarding bus terminals, they are classified into different types according to their location and function within the road system. These types include tip terminals, which are the endpoints of certain lines; intermediate terminals, which serve as transfer points between different lines; neighborhood terminals, which serve specific areas within neighborhoods; central area terminals, which

facilitate access to the city center; and metropolitan terminals, which connect the city with peripheral areas and other nearby cities. This classification, as illustrated in Figure 3, is fundamental for the proper functioning and organization of the public transport system.

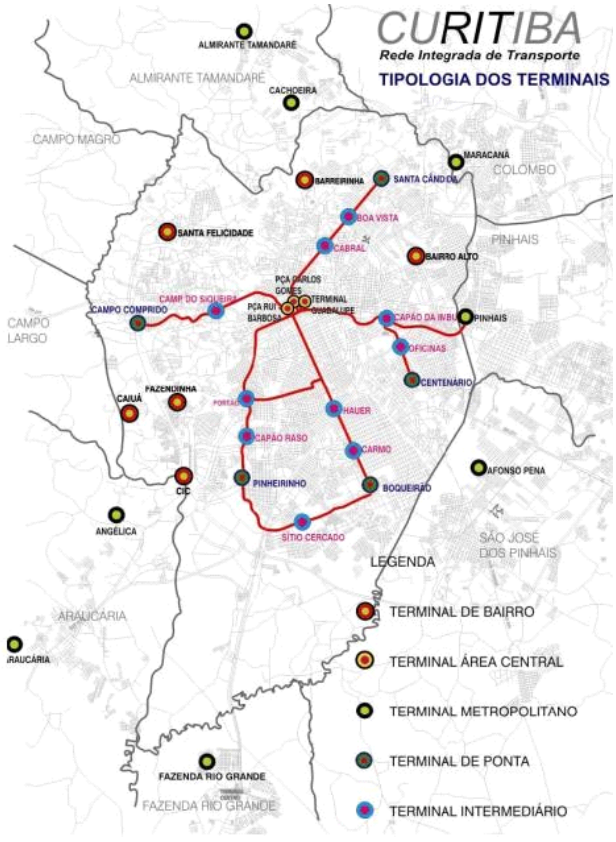

Figure 3: Terminal typology
Source: Miranda, 2010.

The Green Line is also notable (Fig 4), developed based on Law 13,909/2011. This initiative establishes guidelines in the area influenced by BR-116, which traverses Curitiba in the northeast-southeast direction. It encompasses a series of interventions by municipal public authorities, funded by the sale of certificates of additional construction potential (Locatelli, Bernardinis, & Moraes, 2020).

Figure 4: Green Line, Curitiba.
Source: Miranda, 2010.

Another notable implementation is the concession of electric public transport. According to the City of Curitiba, the first tests with electric buses and taxis were conducted in 2023, involving 70 vehicles that will become part of the 2024 fleet. This marks the beginning of the decarbonization of the public transport fleet, establishing one of the pillars of sustainability for the municipality. These measures align with Curitiba's commitment to consolidating public policies aimed at climate change, with transformative and inclusive actions to enhance climate resilience, in accordance with the objectives of the Paris Agreement and the 2030 Agenda for Sustainable Development (SDGs) (City of Curitiba, 2023).

The city of Curitiba was the first in the country to conduct tests of electric buses from brands such as BYD, Volvo, Eletra, and Marcopolo. The results indicated zero emissions, quiet operation, and air-conditioned comfort, which were well-received by users who participated in quality tests (Prefeitura de Curitiba, 2023). Thus, it can be concluded that Curitiba's urban mobility planning was comprehensively designed to prioritize public transport. This involved promoting exclusive routes throughout the city, aiming to enhance efficiency and consequently encourage the population to utilize public transport.

3.2 Amsterdam

Over the last century, the primary mobility planning challenge in the Netherlands has been to develop an adequate railway system connecting the country's secondary centers to the "mother city" of Amsterdam, followed by establishing road connections. Years later, with the expansion of activities in intermediate zones, the challenge shifted to developing a regional transit system through road hierarchization. This approach allows different cities to function as complementary centers, as illustrated in Figure 5 (Bertolini & Le Clercq, 2003).

According to Bersan (2023), in 1978, the government

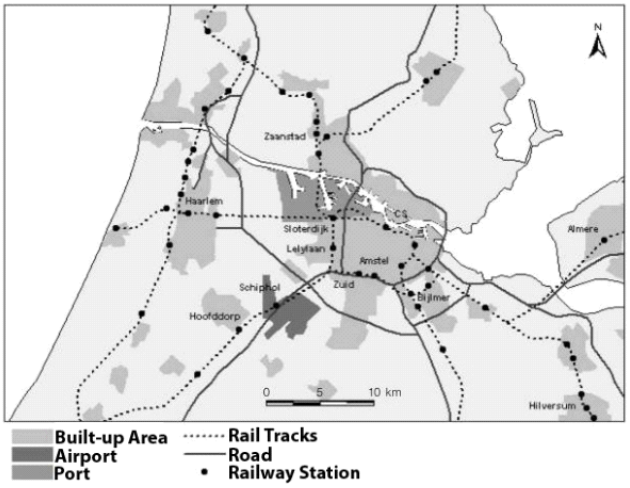

Figure 5: Amsterdam Road System and Subcenters.
Source: Bertolini; Le Clercq, 2003. Adapted.

implemented the Traffic Circulation Plan, an initiative that transformed Amsterdam into a more welcoming city for cyclists. Space allocated to large vehicles was reduced and reallocated to create cycle paths and common areas for pedestrians, as illustrated in Figures 6 and 7, showing the before and after. This initiative significantly improved the infrastructure for bicycle traffic throughout the city.

In the 1980s, the Netherlands implemented significant traffic measures aimed at promoting safer and more sustainable urban mobility. These measures included introducing new signage, expanding the cycle path network, imposing strict speed limits, installing speed bumps, increasing parking prices in city centers, and reducing road sizes to discourage high-speed driving and the use of individual vehicles. Cities such as The Hague and Tilburg were pioneers in adopting red-painted cycle paths to ensure high visibility, an innovative approach at the time (Bersan, 2023).

Figure 6: Damrak Avenue in the 1970s and 2010s.
Source: ArchDaily, 2023.

Figure 7: Currently preferred street for cyclists.
Source: Tarantino, 2023.

In addition to these measures, the most effective approach has been the creation of extensive networks of cycle paths, totaling approximately 35,000 kilometers in the Netherlands, reaching 815 km in Amsterdam (Government of the Netherlands, 2024; European Union's Horizon, 2024). The habit of cycling was already ingrained in local culture long before congestion problems arose, leading around 40% of the population to choose this mode of transport for their daily commute. The country's flat topography further favors the use of bicycles. Moreover, there is a licensing system for cyclists, available to individuals over 12 years of age, which imposes fines on those who disregard traffic rules (Denardi et al., 2011).

In the central region of Amsterdam, trams are the primary means of public transport. They operate on rails and are powered by electricity through overhead cables along the streets. Despite their effectiveness, trams pose challenges for the city's numerous cyclists, who must be cautious to prevent their wheels from getting caught on the tracks that cross many streets (Denardi et al., 2011).

A policy implemented not only in Amsterdam but throughout the Netherlands is the introduction of a Corporate Mobility Management (CMM) system. This system, aimed at companies with more than fifty employees, seeks to effectively improve employee mobility by offering measures to reduce the use of private vehicles. In 1989, when concerns about urban mobility began to emerge in the Netherlands, Novem, a Dutch company specializing in energy and the environment, conducted a survey involving 16,000 companies regarding the CMM. The survey revealed that 30% of these companies had some knowledge about the system, and only 6% had implemented it. Among the companies that adopted the CMM, there was an 8% reduction in the use of private vehicles by employees (Denardi et al., 2011).

Recently, a new law in the Netherlands mandates that, starting July 1, 2024, companies with more than 100 employees must report annually on business travel and employee commuting. The law requires companies to restrict parking access to employees commuting more

than 15 km, provide public transportation passes without payroll tax deductions, encourage train use for business travel, offer incentives for purchasing or leasing company bicycles, and promote remote work (KVK & RVO, 2024). Thus, the law aims to strengthen corporate engagement with sustainable urban mobility policies.

The authors further explain that, in addition to the previously mentioned strategies, the Dutch Ministry of Transport announced in 2012 the implementation of a fee per kilometer driven as a means to combat urban congestion. From that year onwards, all cars circulating in the country were charged three euro cents per kilometer, with adjustments continuing until 2017. In areas and during times of heavy traffic, the tariff would be higher. Highly efficient vehicles, such as hybrids, would receive a reduced rate. To compensate for this new tariff, vehicle taxes would be reduced. By 2012, all cars were required to be equipped with GPS devices, under penalty of fine, to transmit movement information to the Fare Collection Center. The receptivity of Dutch culture to change was crucial for the government's implementation of these measures, facilitating their acceptance (Denardi et al., 2011).

According to Knorek (2019), cycle paths and lanes dedicated to bicycles are prominent features of Amsterdam. Due to its geographical configuration, the city has many canals that facilitate urban mobility, used by both tourists and local residents. Amsterdam also has numerous ferries and boats that transport people and products around the city, integrating into the logistics of urban mobility. Consequently, it is concluded that urban mobility in Amsterdam is primarily due to the various modes of transport supported by public policies that were introduced to further encourage the population to utilize more sustainable forms of transport, especially bicycles, which are already an integral part of daily life. This, in turn, reduces the emission of polluting gases into the atmosphere.

3.3 Challenges

The comparison between Curitiba and Amsterdam in sustainable urban mobility reveals significant differences shaped by their contexts as a developing and developed country, as well as their topography and climate.

In Curitiba, the focus has been on developing an innovative public transportation system, highlighted by bi-articulated buses operating on exclusive corridors. However, increased use of private vehicles, fare pressures on low-income users, and declining public transportation demand pose significant challenges. Recent fleet electrification initiatives demonstrate a commitment to sustainability, but overcoming cultural resistance to abandoning individual transportation and securing continuous funding remain critical challenges for the future.

Amsterdam has pursued an integrated approach, establishing the bicycle as the primary mode of urban transportation, complemented by trains, trams, and boats. Its extensive cycling infrastructure, along with policies restricting car use, has fostered a low-carbon environment. Furthermore, favorable topography and relatively mild annual temperatures have been key factors in the successful consolidation of bicycle use in both Amsterdam and the Netherlands.

Thus, public policies play a fundamental role in implementing sustainable urban mobility practices, but the consolidation of certain modes, such as cycling, is often constrained by physical and climatic conditions, posing a barrier in many cities and countries—not exclusively in Brazil.

4. CONCLUSION

Sustainable urban mobility is an increasing priority for cities worldwide, with Curitiba and Amsterdam serving as illustrative cases of distinct yet effective strategies. Curitiba's focus on an innovative public transportation system—exemplified by bi-articulated buses on exclusive corridors—demonstrates how infrastructure tailored to local needs can optimize mobility. In contrast, Amsterdam's emphasis on integrating cycling with public transport, supported by an extensive network of paths and complementary trams, trains, and buses, showcases how multimodal systems can drive sustainable mobility and significantly reduce car dependency.

Both cities exemplify that there is no universal formula for sustainable urban mobility; rather, success depends on aligning policies with the social, geographic, and climatic realities of each location. Their experiences highlight the importance of flexibility in policy-making, where investments in public transportation, incentives for active mobility, and car-use restrictions work in tandem to foster sustainable environments.

Ultimately, Curitiba and Amsterdam provide transferable insights that can inspire other cities, adapting solutions to their unique contexts. These examples underscore that sustainable urban mobility is not merely about reducing emissions but about creating efficient, livable cities that prioritize accessibility, environmental responsibility, and the well-being of their citizens.

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IDENTIFICATION OF MATERIALS IN COFFEE PACKAGING:VISUAL SYMBOLS OF SUSTAINABILITY AND CONSUMER CO-RESPONSIBILITY

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1. INTRODUCTION

This study aims to analyze pedestrian and cyclist crossing conditions on the BR-364 highway, which bisects the city of Vilhena, in Rondônia. Although the Brazilian Traffic Code (CTB) provides guidance on road safety in the country, conflicts between pedestrians, cyclists and motorized vehicles are a reality in the locality, aggravated by inadequate urban planning. These conflicts reflect the lack of adapted infrastructure, with pedestrians being the most affected party, as they are vulnerable, since they expose their own lives in an attempt to cross these routes (PESSOA, 2019).

For Bartolomeos et al. () the exposure of pedestrians along the road and their consequent vulnerability can be solved with the implementation of traffic engineering measures. These measures can lead to a reduction in the volume of vehicle traffic or the separation of pedestrians from cars.

In the context of Vilhena, pedestrians and cyclists are subject to traffic risks, given the demand for heavy vehicles crossing the city and the lack of road safety equipment at the traffic circles that cross the urban stretch of the BR-364 highway.

The research aims to identify the challenges related to this crossing and propose solutions based on the community's point of view as well as road safety regulations. With this, the aim is to subsidize public bodies for future interventions and promote sustainability in the city, since it will meet social demand.

2. METHODOLOGY

We carried out bibliographic studies and on-site data collection at the 5 traffic circles located in the city (Figure 1), taking photographs and counting users at specific times of the day (from 11:00-12:00). An online questionnaire was administered to pedestrians and cyclists who use the road.

Figure 1: Location of the traffic circles analyzed.
Source: Authors.

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3. RESULTS

According to the survey carried out, the lack of safe and accessible crossing conditions at the traffic circles studied is notorious. The number of users, especially cyclists, who take their chances in the midst of vehicles is high, according to the photographic survey. It can also be inferred, extrapolating the user count for all business hours, that interventions at the crossings to ensure user safety would serve a significant portion of the municipality's population.

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IDENTIFICATION OF MATERIALS IN COFFEE PACKAGING: VISUAL SYMBOLS OF SUSTAINABILITY AND CONSUMER CO-RESPONSIBILITY

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1. INTRODUCTION

The variety of materials used without proper identification, along with the presence of visual elements that imply sustainability in coffee packaging that cannot be recycled, prompted the proposal of alternatives to enhance consumer choice (UNEP, 2017) by considering processes with positive impacts for producers, consumers, and the environment.

As a product of economic, historical, and cultural significance, coffee is embedded in Brazilian daily life and is reflected in various design projects, whether in packaging, preparation and consumption products, brand identity, or the interiors of coffee shops. As a result of various territorial factors, coffee is also a symbolic product, whose study can resonate in other markets, making it a suitable focus for analysis.

2. METHODOLOGY

The main objective of this work was to propose consumer empowerment processes that make consumers an integral and active part of selecting materials for coffee packaging.

The development began with the contextualization of the Brazilian coffee market, establishing the research problem and hypothesis, objectives, justification, and methodological aspects.

The theoretical foundation drew upon concepts of design and packaging design (SOUSA; CARVALHO; PEREIRA, 2020); visual symbols and sustainability (FORMIGA, 2011); materials (TEIXEIRA; ITO, 2017) and consumer perception (VELASCO; SPENCE, 2018); economic, social, and environmental factors (RØPKE, 2015); information and consumption; as well as laws and regulations.

The coffee production and consumption chains were delineated, allowing the identification of quantitative and qualitative factors in material management that influence the selection of materials used in packaging. Packaging analysis was conducted, and a questionnaire was administered to consumers, professionals, and researchers in the Brazilian coffee market.

3. RESULTS

Along with the case study on consumer co-responsibility initiatives, the work was able to propose consumer empowerment processes such as: expanding the perception of consumer rights regarding packaging information; proposing guidelines on information about the materials used; predicting visual solutions that correctly communicate material information; developing technological solutions for sustainability evaluation; reviewing standards and creating specific legislation on material indication; and adopting sustainability verifiers that account for the packaging.

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